

ADA 087272

Report SAM-TR-80-16

LEVEL

II

(2)

A REVIEW OF USAFSAM STUDIES EMPLOYING MULTIPLE-TASK PERFORMANCE DEVICES

Bryce O. Hartman, Ph.D.

Russell A. Benel, Ph.D.

William F. Storm, Ph.D.

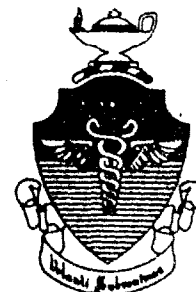
DTIC
ELECTE
S JUL 30 1980 **D**
E

June 1980

Final Report for Period October 1979 - December 1979

Approved for public release; distribution unlimited.

USAF SCHOOL OF AEROSPACE MEDICINE
Aerospace Medical Division (AFSC)
Brooks Air Force Base, Texas 78235



DDC FILE COPY

80

7

28

149

NOTICES

This final report was submitted by personnel of the Crew Performance Branch, Crew Technology Division, USAF School of Aerospace Medicine, Aerospace Medical Division, AFSC, Brooks Air Force Base, Texas, under job order 7930-10-28.

When U.S. Government drawings, specifications, or other data are used for any purpose other than a definitely related Government procurement operation, the Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data is not to be regarded by implication or otherwise, as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.


BRYCE O. HARTMAN, Ph.D.
Project Scientist


ROY L. DEHART
Colonel, USAF, MC
Commander

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM	
1. REPORT NUMBER 14 SAM-TR-80-16	2. GOVT ACCESSION NO. AD-A087272	3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle) 6 A REVIEW OF USAESAM STUDIES EMPLOYING MULTIPLE-TASK PERFORMANCE DEVICES.		5. TYPE OF REPORT & PERIOD COVERED 9 Final rept. Oct 1979 - Dec 1979.	
7. AUTHOR(s) 10 Bryce O. Hartman Ph.D. Russell A. Benel Ph.D. William F. Storm Ph.D.		8. PERFORMING ORG. REPORT NUMBER	
9. PERFORMING ORGANIZATION NAME AND ADDRESS USAF School of Aerospace Medicine (VNE) Aerospace Medical Division (AFSC) Brooks Air Force Base, Texas 78235		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 62202F 16 7930-10-28 17 10	
11. CONTROLLING OFFICE NAME AND ADDRESS USAF School of Aerospace Medicine (VNE) Aerospace Medical Division (AFSC) Brooks Air Force Base, Texas 78235		12. REPORT DATE 11 Jun 1980 12 19	
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		13. NUMBER OF PAGES 16	
		15. SECURITY CLASS. (of this report) UNCLASSIFIED	
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE	
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited.			
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)			
18. SUPPLEMENTARY NOTES			
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Psychomotor apparatus Man-machine system Task battery Work-rest schedules Performance Sleep deprivation Pilot performance Long-duration missions			
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Apparatus development at the USAF School of Aerospace Medicine to measure the performance and proficiency of systems operators is reviewed. The devices reviewed are all classified as multiple-task performance batteries that were designed to measure efficiency in the general sense. Simulators of specific systems were not included. The bulk of this paper consists of summaries of studies. K			

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

A REVIEW OF USAFSAM STUDIES EMPLOYING MULTIPLE-TASK PERFORMANCE DEVICES

INTRODUCTION

Apparatus development in the Air Force program of applied behavioral research has been firmly anchored in the jobs held by aircrewmembers. This emphasis arose from equally firm recognition by operational commanders that understanding aircrew jobs was vital. Missile and space systems technology brought about vastly increased emphasis on problems of systems-operator proficiency. The increased automation of many flight functions, navigation, and weapons delivery systems brought increased emphasis to the need for appropriate laboratory tasks. We faced a multitude of human factors problems. Our research laboratories had a crying need for apparatus and tests appropriate for the analysis of the "operator-pilot." The responses to their needs are described in this report. The Air Force-developed devices described here represent efforts to study efficiency in a general sense. We have not included simulators for specific systems, because the concern of this review is with devices which provide simulation of more general systems-operator functions.

The bulk of this paper consists of summaries of studies using multiple task devices, most studies being conducted at the USAF School of Aerospace Medicine (USAFSAM). Table 1 is an overview of the material to be presented.

THE SAM ONE-MAN SIMULATOR

The SAM one-man simulator was a small altitude chamber just large enough for one occupant, his life-support equipment, and the psychomotor test apparatus. The approximately 50 ft³ (1.415 m³) of space available to the subject limited him to his seat. Additionally, the subject was without visual access to the outside and possible noise transmission through pipes or airborne sources was effectively masked by a constant internal noise level of approximately 84 dB. The atmosphere during flights was maintained at one-half normal atmosphere with twice the normal oxygen concentration. Chamber environmental parameters were maintained automatically (with the exception of PCO₂, requiring a simple change of absorbent canisters), allowing the subject to devote his entire attention to the operator task. The subject was presented with tasks involving the functions of spatial discrimination, perceptual judgment, vigilance, and problem solving, with performance recorded electrically (3). Figures depicting the cabin and work panels are available in Hauty (14, 15) and Steinkamp et al. (24). The operator task and television screen upon which part of the task was displayed completely filled the front part of the chamber. A second closed-circuit television system continuously monitored the subject.

Actual flights in the one-man simulator were of two types: a 30-hour mission during which continuous performance was required, and a 7-day mission. During the latter, two different work/rest schedules were followed; some of the subjects were on a schedule of 4 hr on duty and 4 hr off duty, while the remainder were on a schedule of 5 hr on duty and 3 hr off duty. Work with the

ALLS G. 10-1 DDC TAB Unannounced Justification	By Distribution/ Availability Con- Avail and/c special	Dist. A
---	--	------------

TABLE 1. SUMMARY OF USAFSAM STUDIES USING MULTIPLE-TASK BATTERIES

Experiment	Environment	Performance task	Work schedule	Subjects	Psychomotor effects
Steinkamp et al. (1959)	1/2 Atm 2x PO ₂	1-man simulator	4/4, 7 days	4 pilots, 1 nonpilot	For pilots, no difference. Nonpilots, within period decrement and additional day-night variation.
Hauty (1960)	18,000 ft (5,486 m)	1-man simulator	30 hr continuous	4 pilots, 4 nonpilots	Proficiency decrement beyond 22 hr greatest in vigilance task.
McKenzie et al. (1961)	18,000 ft (5,486 m) 40% O ₂ , 60% N ₂	2-man simulator	39 days, varied work/rest with minimum 5 hr sleep	2 pilots	No effect due to duration of work period or signal rate.
Hartman et al. (1962)	33,500 ft (10,211 m) 100% O ₂	2-man simulator	17 days scheduled as above	2 pilots (same as above)	Gradual decrement during flight.
	33,500 ft (10,211 m) 96% O ₂	2-man simulator	17 days	8	Decrement at low signal rate.
Morgan et al. (1963)	258 mm Hg total 96% O ₂	2-man simulator	14 days, 2/2 with 5 hr sleep	4 pilots	No decrement.
Hartman & McKenzie (unpublished)	Ground level	CBS	130 min, varying signal rates	20 pilots	No decrement due to base signal rate.
Hartman & McKenzie (1961)	Ground level	CBS	3 - 125 min periods, varying signal rates	6 pilots	No decrement due to base signal rate; decrement increases during overload period.
Langdon & Hartman (1961)	Ground level	CBS	Sudden awakening	5 basic airmen	Decrement upon sudden awakening with gradual recovery.
Hartman & Langdon (1965)	Ground level	CBS	Sudden awakening	2 basic airmen	Similar to above.

TABLE 1 (Continued)

Experiment	Environment	Performance task	Work schedule	Subjects	Psychomotor effects
Hartman et al. (1960)	Hypodynamic (water immersion) environment	CBS & Special task battery	7 days, 4 hr/day pre and post immersion	1 nonpilot	Decrement over days. Major decrement post immersion.
Cutler et al. (1964)	3% CO ₂ @ 700 & 200 mm Hg total pressure	Neptune	4 days, 2 hr twice/day	4 pilots	No decrement.
Rodgin & Hartman (1966)	O ₂ -He at 258 mm Hg	Neptune	56 days, 25 min three times/day	4 aircrewmembers	No systematic decrement; day-night variation on vigilance task.
Hartman (1967)	70% O ₂ , 30% He	Neptune	30 days	4 airmen	No decrement.
Hartman & Cantrell (1967)	Ground level	Neptune	12 days, 4/4, 4/1, 16/8	13 basic airmen	Decrement on all schedules, greatest on 4/4 and 4/2.
Glatte et al. (1967)	3% CO ₂	Neptune	5 days, 6-30 min sessions/day	5 airmen	No decrement.
G'Donnell et al. (1971)	CO at 0, 75, 150 ppm	Neptune	Overnight exposure, testing following	4 enlisted men	No CO decrement. Performance decrement with increased workload.
Storm et al. (1973)	Low humidity, 8,000 ft (2,438 m)	Neptune	36 hr 2/2	4 basic airmen	No decrement; minor day-night variation.
Pepelko et al. (1974)	25,000 ft (7,620 m) with O ₂ mask	Neptune	3 hr near continuous	6 enlisted men	No decrement within sessions.
Storm & Benel (unpublished)	0, 8,000, 15,000 ft (0, 2,438, 4,572 m)	Neptune	1 hr	14 basic airmen	Decrement on tracking at 15,000 ft, no decrement 0 and 8,000 ft.
	Ground level	Neptune	Sudden awakening vs. sleep deprivation	11 basic airmen	No significant differences.

5/3 schedule was cited by Flinn and Hartman (3) but remained unpublished, and details are not available for inclusion. Steinkamp et al. (24) provide a detailed description of the chamber arrangement and scheduling of practice flights prior to commencing flights on the 4/4 schedule. Subjects received 1 hr of practice on the operator task the first day and 4 hr the second day. The first 4-hr work period on the third day (the beginning of the actual 7-day flight) commenced at 0900 following ascent at 0800. The remainder of the flight was a continuation of the 4/4 cycle. Of the 5 subjects in this study, 4 were pilots. The nonpilot subject showed the predictable effects of work on this schedule: decrement within work periods. However, this was not the case for the pilot subjects. The proficiency of the 4 pilots was initially higher and was sustained throughout the course of the experiment near ceiling levels. The pilot subjects appeared to Steinkamp et al. to have conducted themselves as if in actual flight and were purposeful and disciplined in adherence to the schedule. However, the nonpilot appeared aimless and restless during the off-duty periods. None of the expected sensory deprivation effects were seen; presumably the scheduling of work and rest and the ambient sensory experiences had a mitigating effect.

Hauty (15) reported the results of "maximum effort" flights by 8 subjects encompassing 6 hr of simulated pad time followed by a 30-hr flight. The subjects were equally divided between pilots and nonpilots. Entry into the chamber for the pad time was either 0800 or 2400 with most of the time devoted to sleep, reading, or rest. Immediately following the pad time, ascent was made to 18,000 ft (5,486 m), and subjects commenced operating the system. Performance was to be continuous and the subject was exclusively responsible for remaining awake. At 90-min intervals timed by the subjects, a verbal report of the chamber conditions was required. This contact was 10 min or less. For the nonpilots, one flight was aborted after 7 hr because of claustrophobia and another after 27 hr because of panic induced by a hallucination. When flights exceeded 20-22 hr in duration, proficiency deteriorated in the vigilance task. For the pilots who started at 1400 the proficiency curve approximates roughly the normal circadian rhythm, showing a decrement during the normal sleep period followed by recovery to the previous level. For the 0600 starting time, subjects maintained proficiency throughout the period normally devoted to sleep, but following 20 to 25 hr of flight they fell asleep for appreciable periods of time. Individual task proficiency curves indicate the extent to which different tasks were executed. Hauty noted one subject, who did quite poorly on the vigilance task, had performed extremely well on another task. That subject reported he had really "gotten with" that task. This apparently reflected a disproportionate time-sharing at the expense of the vigilance task.

THE SAM TWO-MAN SPACE CABIN SIMULATOR

This simulator was a hermetically sealed cabin containing all the necessary environmental control and life support equipment on-board, with the exception of the heat exchanger and power supply. The cabin was an elliptically shaped steel cylinder, 12 x 8 x 5 ft (3.7 x 2.4 x 1.5 m), divided into two separate areas--the rest area and the work area. The rest area was used for water purification, oxygen, food and water storage, and contained a work table, as well as sleeping facilities. The work area was utilized as the

control center of the vehicle. The right side of the work area panel (the operator station) contained the environmental system controls, transfer switches, indicator lights, and analyzer calibration equipment. The left side contained the psychomotor performance equipment. A more thorough description of the system with several illustrative figures is available in Welch et al. (26).

The two-man simulator imposed three broad categories of requirements on the subjects: (1) management of the logistical aspects of the simulated space flight (disposal of wastes, recycling of fluids, preparation of foods, etc.); (2) management of the internal environment (control of atmosphere contaminants, etc.) achieved through an environmental control panel in parallel with a similar system external to the cabin; and (3) management of the operator (psychomotor test) system. No attempt was made to evaluate operator effectiveness for the logistical and environmental functions. The operator system had no direct effect upon the overall efficiency of the system. It was an independent subsystem whose sole purpose was the evaluation of the functional effectiveness of the man in the system during the flight.

The operator system consisted of six units: the master programmer, which programed and selected signals in the several tasks which the operator performed; an assembly of subprogramers which operated these tasks; two parallel display units (one inside and one outside for monitoring); the control assembly inside the cabin for performing the tasks; and a recording unit giving a time history of performance and measurement of response time. Only the displays and controls within the cabin were relevant to the subjects. The displays were predominantly visual and were scattered across three panels. Only one task (Morse code) used an auditory signal. In addition to different types of meters and lights, one task presented pairs of block designs on a CRT TV. All tasks were given space-age names to increase the realism. Controls were located on both sides of the bottom panel and were either lever-type or push-button switches. Location, physical arrangement, color coding, and variations in operation and appearance for each task increased compatibility of displays and controls. All but the block design task had one mode of operation, "on" until the operator turned them "off." The assembly of 14 tasks into the system produced a simulated systems task described as multivariate by McKenzie et al. (18). Like the apparatus in the one-man cabin, the tasks measured vigilance, perceptual judgment, problem solving, and decision making, but at a more complex level with greater demands on the subject.

Signal rate is a basic variable within system tasks. As the system was originally configured, signal rate could be varied from 175 to 350 signals per hour. This was later modified to use a paper tape reader programming system found effective with the Complex Behavior Simulator (10) yielding signal rates of 3600, 1200, 400, and 40 per hr. Two separate simulated flights were reported by McKenzie et al. (18). The first (30-day) used the original signal rate, and the second (17-day) used the later modification.

Both simulated flights attempted to add to the realism by adopting a mission with 90-min orbits (16 each day). Two pilots served as subjects for both flights. Within a 2-day block on the 30-day mission, each operator manned the system 10 hr on one day and 12 hr on the alternate day. Two 1-hour periods of ground control completed the 24-hr cycle. Longer work periods at night allowed each subject to sleep as long as 6 to 7 hr continuously each day.

During the ground control periods the system was set to a new signal rate. The chamber atmosphere during this flight was 40% O₂, 60% N₂ at 18,000 ft (5,486 m). The study investigated three major variables: (1) the effect of prolonged commitment to the task; (2) the duration of work period; and (3) the effect of differing signal rates. Results from this study indicated a scattering of differences. No systematic effects for any of these variables were obtained (18). The most general finding was that performance, for the most part, remained at a stable level throughout the flight.

For the 17-day flight, data were obtained in the same manner as for the longer flight. However, one task malfunctioned early in the flight and error scores were not available. The cabin atmosphere for this flight differed from the longer flight with 100% O₂ at a simulated altitude of 33,500 ft (10,211 m). The change of programming procedures for this flight imposed periods of both overload (3600 signals per hr) and underload (40 signals per hr) on the subjects with the maximum effective rate set at 1200 signals per hr (based on 10). This system had several distinct advantages over the earlier system. First, it avoided regular bursts of tasks every 72 sec and, secondly, permitted time-sharing of the more difficult tasks. Results indicated a steadily increasing average response time during the flight. This gradual decrement in proficiency might have been due only to a reduced motivational state, perhaps aggravated by the fact that this was the second extended flight for these subjects. Alternatively, this may have reflected the altered environment. Differential decrements for task variables by time of day or periods of flight did not occur. Although procedural events made it difficult to analyze the data for signal rate effects, McKenzie et al. (18) concluded that signal rate contributed considerably to differences in performance. One problem noted in analyzing these effects is the instability of the mean with a small number of responses. Despite these difficulties, it appeared that signal rate might be a way of manipulating both the duty time and diurnal variables.

In a related investigation Hartman et al. (13) reported the results of varying signal rate for four pairs of subjects in the two-man simulator during 17-day flights. The operator system of 14 subtasks was again used with the punched tape reading system. Four different overall signal rates were used: 40, 300, 500, and 1200 signals per hr. Two flights had low signal rates at night and high rates during the day, while the other two were reversed. Similar tasks were again pooled for analysis. The atmosphere was equivalent to that of the previous 17-day flight. The schedule for subjects' performance and the environmental conditions were similar to that of previous 17-day flights. Results indicated no systematic clear-cut task differences. Hartman et al. (13) gave the example of discrimination times which were very low for one flight, but very high for another. Likewise, they reported low ("good") vigilance times for two flights and high vigilance times for a third. It was concluded that each subject's approach to the system as a whole affected the response time more than any subtask itself, and this occurred despite attempts to standardize the subjects' task orientation. Marked performance decrement at low signal rates was clearly demonstrated. The magnitude of the signal rate effect was attenuated by the day/night, 2- to 5-hr schedule. Specifically, the decrement from low signal rates during the day was not as great as at night. The possibility of an interaction between signal rate and task schedule was also entertained as an alternative, but additional information

from other experiments favored the designation of the day-night cycle as a secondary, attenuating factor.

A further study in the two-man simulator consisted of two 14-day experiments directed at investigating possible pulmonary atelectasis (20). Psychomotor performance was included to determine the gross effect of atelectasis (if present) on the functional capability of test subjects. The 4 subjects (all pilots) followed a schedule similar to that in previous studies of 2 hours on duty and 2 hours off duty, with 5 hours on duty at night. This schedule allowed 5 hours of uninterrupted sleep. Performance data for 2 subjects were reported to be unsatisfactory because of lack of data, or data falling into no systematic pattern. Technical problems were related to the chamber and a failure of the subjects to follow the schedule. The available data indicated performance decrements did not occur during the experiment. In fact, indications were of significant improvement. In this study, signal rate and the work-rest schedule were held constant. Presumably this procedure led to the improvement in performance. It was also noted that this constant-rate group handled more signals more efficiently than the variable rate groups of previous experiments.

THE COMPLEX BEHAVIOR SIMULATOR (CBS)

The CBS (9) consisted of two major elements: the subject's console and the programmer system. The subject's console contained an assembly of tasks that, for the most part, had discrete inputs and simple discrete responses. The inputs were simple signals such as a light coming on or the needle on a dial making a simple, invariant deflection. Associated response units were simple controls such as spring-loaded switches, selector switches, or isometric control handles. When operated, they restored input units to their original state. The subtask stimulus displays varied considerably in size, color, configuration, and location of indicators. The response units varied in control design and in types of movement required. Some subtasks involved multiple signals and required multiple responses.

Two models were built. The first had 14 subtasks mounted on a vertical panel in a rack-type configuration. The second had 29 subtasks mounted in a desk-type console. For both models, subtasks were given "space-age" names to stimulate interest on the part of subjects and to reinforce the concept that the simulator represents a "control station" in a complex system. The programming system operated these subtasks in a variable sequence; its only function was delivery of the signal to the operator. Its major components were a tape reader, timers, and relay tree. Activation of a holding loop was initiated by a tape signal. The signal remained on until the operator responded. Use of punch tape allowed an infinite variety of programs at varying speeds. Performance measurement was accomplished by recording on a 20-pen event recorder with the experimenter selecting the tasks to be recorded. Measurements were made of the time of event onset and of response time by distance equivalents on the paper. Difficulties in scoring were inherent with this system. The total number of responses at the medium tape speed in 1 hr was approximately 1200, providing a formidable obstacle to hand scoring.

In use, the CBS was described to subjects as the operator's console of a complex, semiautomatic, man-machine system. Their job was to correct malfunctions in subsections of the system as they occurred. Operation of the proper control corrected the malfunction which had been indicated on the panel, resetting the display. Depending on the nature of the investigation, practice times of 30 min to 1 hr had been found satisfactory.

Many of the subtasks were quite similar conceptually and were found to have highly similar frequency distributions. In an effort to eliminate some of the scoring difficulties mentioned earlier, similar tasks were combined for a composite score. The scheme adopted for combination was for discrete signal/discrete control (DD) tasks to be pooled. The response times for DD tasks differed by stimulus properties and were further divided into normally-off tasks (DD-) with shorter response times than the normally-on tasks (DD+). The tasks with multiple signals and responses had even longer response times and were designated M. The CBS was predominant DD- with fewer DD+ and even fewer M tasks.

Performance data reported by Hartman and McKenzie (9) indicated very similar responses for both pilot and nonpilot populations, although pilots were consistently more proficient and more resistant to decrement. Nonpilots appeared to have a greater variability of responses than pilots. Data from 1 (pilot) subject on signal rate effects showed a major increase in response time at signal rates greater than 2000 per hr. Hartman and McKenzie label this the "maximum effective operator capacity" and it was used as an anchor point in all studies where high signal rates were part of the design. A similar point for the low end of the continuum was not identified.

In an unpublished study by Hartman and McKenzie (11), 20 pilots performed on the CBS at varying rates well below their capacity, with short bursts simulating an overload. The base rates were 1000, 400, 200, or 100 signals per hr. Bursts were at 4000 signals per hr lasting 50 sec, followed by a 10-sec interval with no signals, after which the signal rate returned to the base rate. Periods between bursts were varied from 5 to 21 min. Finally, there were three 5-min periods at 2000 signals per hr (the maximum effective operator capacity). These periods served two purposes: to provide a measure for comparing subjects, and to study overload when the operator was already performing at maximum capacity. In an attempt to obtain matched groups, a paper and pencil pretest formed the basis for assignment to one of the four base rates. Subjects were not informed of experimental details other than duration of their participation. Despite these attempts to match groups, systematic differences in proficiency existed among groups. An analysis of covariance did not reveal reliable differences between base rates, but the performance curve for 1000 signals per hr suggested a fatigue effect not present with the other base rates. When the initial burst signals for all groups were compared with the proficiency for the entire burst period, in all cases the early signals were handled more effectively. Caution in rejecting base rate as an important variable was noted. Because of contamination by intra- and interindividual differences, definite rejection of this variable was not possible.

A second experiment was conducted by Hartman and McKenzie (10) on the effects of signal rate on operator performance. The CBS was again used and 6 pilots served as subjects. All subjects received 1 hour of practice prior

to the three experimental sessions of 125 min each. Subjects generally worked at a level well below capacity, with occasional bursts of overload (4000 signals per hr) for 40 sec followed by a 10-sec period with no signals. Periods between bursts were 5, 15, or 25 min, and there were two periods (5 min) of 2000 signals per hr. One of the 2000 signal periods occurred at the beginning of the run and the other at the end. These periods allowed comparison among subjects and investigation of overload following maximum effective work level. Results comparing initial burst responses to the entire burst period were similar to the unpublished study; initial signals were handled more efficiently (lower response times). It appeared that high signal rates (2000 per hr), when manageable, had no effect on overload performance. Speed stress effects were concluded to be dependent upon immediate operator load and were, for the most part, independent of preceding task-load levels. It appeared that the significant factor in overload performance may be the number of overlapping signals which, in turn, may cause the systems operator to utilize certain adaptive strategies to maintain effective performance.

Two studies of performance upon sudden awakening were conducted with the CBS. Langdon and Hartman (16) trained 5 volunteer airmen for three 1-hr periods on the CBS. During the experiment they worked their regular duty day and then reported to a special dormitory. The dormitory provided individual air-conditioned rooms with comfortable beds. The M tasks on the CBS were not used. Signal rate for the remaining CBS tasks were set at 2000 per hr. Response times for 15 representative tasks were taken on the event recorder with the 10-min record divided into 1-min segments. This facilitated a minute-by-minute account of scores for each run. Subjects had a 10-min pre-sleep run on the task prior to retiring at 2230. Subjects were suddenly awakened individually twice during the night and at the regular time in the morning. The elapsed time between sudden awakening and start of CBS performance was under 2 min. Following 10 min of performance subjects returned to bed. For the DD- tasks, proficiency improved minute-by-minute during each 10-min run. However, the subjects' performance did not reach their normal presleep level. Total performance for both awakenings was worse than presleep levels and the postsleep response times were nearly as good as the presleep values. For DD+ tasks, results were very similar, but increased variability attenuated the significance of differences. Conclusions included the significantly poorer proficiency when suddenly awakened and the gradual recovery over 10 min, not quite reaching presleep levels.

In the second study on performance upon sudden awakening, Hartman and Langdon (8) followed approximately the same procedure as the previous study. The M tasks were included in this study and the signal rate was once again set to 2000 per hr. Two subjects worked on the CBS while an additional 3 subjects were assigned to the SAM Multidimensional Pursuit Test (MDP; a compensatory tracking task). Results for the CBS paralleled the previous study with a gradual improvement over time following awakening. The absolute value for the mean response time was greater in this study with the more complex tasks included. The comparisons between MDP and CBS were only favorable for the overall mean for each time of performance. Explanation for the lack of correspondence between MDP and CBS on the minute-by-minute comparisons centered on the differences in response characteristics. It was concluded that recovery functions differ for different classes of tasks.

An additional study with the CBS was conducted to determine the effects of weightlessness simulated by the hypodynamic (water immersion) environment (12). Changes in psychomotor proficiency were assessed in two ways: (a) three 1-hr sessions on the CBS; and (b) simpler perceptual-motor tasks performed during immersion. The apparatus built for performance testing during immersion was a small task battery with a binary matching subtask, a simple vigilance subtask, and a multiple vigilance subtask. Programming of the subtasks was done through a motor-driven cam-system and stepping switch. The subject performed this task for 4 hours continuously during two work periods each day. Pretraining occurred during an earlier trial immersion. During immersion, performance changed significantly over days. This decrement was represented by a consistent but small increase in response time on each successive day. The preimmersion CBS run was a training session and did not provide an adequate baseline for the postimmersion CBS data. The postrecovery CBS data were used as the baseline. Comparisons show consistent decrement resulting from a period of exposure to the hypodynamic environment. A verbal description of the subjects' performance indicated a marked disorganization of the psychomotor response pattern with each response clearly fractionated into three segments: signal detection, response selection, and response execution. Exaggerated startle response to signals and gross spatial errors in reaching for controls were also noted.

McKenzie (17) described possible use of the CBS for selection of special mission personnel. In this investigation the CBS was used in conjunction with an additional task, AUDIT. The letters AUDIT are an acronym for Auditory Interface Task. This task provided a continuous auditory monitoring and processing task by presenting from two to five single-letter Morse code signals at a rate of one code letter every 5 sec. The operator's task was to monitor the code letters. When he heard a specified number of letters, he responded by pushing the corresponding button. Subjects were instructed to do as well as possible on both tasks and were allowed practice on both tasks separately and combined. All training and testing was completed within 1 hr. Testing consisted of three distinct 15-min periods of signal rates on the CBS--20, 40, and 60 signals per min. The AUDIT was maintained at 12 signals per min throughout the hour. Performance was compared to an "ideal" subject using a difference score method. For the "ideal" subject, rate changes resulted in a 10% drop in efficiency from the low to high speeds. Overall, the special mission subjects showed an average decline of 23%, but 6 of the 32 subjects showed a 7% average increase in efficiency. An inspection of the data indicated the CBS M tasks were largely ignored as signal rate increased; therefore, the M scores were eliminated from analysis. The scores of the individuals actually selected for the special mission differed from the group as a whole. They had significantly lower response times on the CBS and a smaller variance on the AUDIT, indicating greater adaptability to competing tasks, although the AUDIT scores did not differ between selectees and nonselectees.

THE NEUROPSYCHIATRIC TEST UNIT: NEPTUNE

NASA asked for recommendation of a psychomotor device which could be used in a standardized way in several laboratories engaged in studying the psychologic and physiologic effects of subclinical atelectasis and related Apollo

spacecrew problems. The experience gained from the work with the CBS and the space cabin systems indicated that a different kind of psychomotor device was needed. The problem posed was that of how to use psychomotor testing devices as part of the assessment of the biomedical status of the operator. The orientation taken was to identify those aspects of behavior likely to be degraded as a result of central nervous system (CNS) insult, e.g., of interest to the neurologist.

It seemed that the important psychologic dimensions were those of neuromuscular efficiency, intellectual efficiency, information storage and retrieval (memory), alertness, and problem solving ability. We saw this as a device which would also have an input for our own programs, especially those concerned with effects of drugs upon aircrew performance. We had two basic concepts in mind: (1) the unit would have to measure a fairly wide range of both simple and complex neuromuscular and intellectual behavior of the type relevant to CNS status; (2) these behaviors should simulate some of the tasks that the operator of a complex aerospace system might be expected to perform.

As indicated earlier, the conceptual approach to developing tasks for NEPTUNE was to identify performance dimensions which were neurologically meaningful and which would be expected to show decrement following CNS insult. A system report prepared by McKenzie et al. (19) is the primary reference source for information, schematic diagrams, and representative data on the NEPTUNE. A brief description is presented here. The tasks incorporated into NEPTUNE involve the functions of vigilance, arithmetic and encoding, compensatory tracking, visual monitoring with short-term memory, problem solving, and an auditory code identification task (AUDIT). The vigilance task (Roll, Pitch, Yaw) provided a measure of alertness with minimal requirements for intellectual and neuromuscular function. The arithmetic task (Solar Radiation) was a measure of intellectual function at an intermediate level of complexity, with neuromuscular functions minimal. The compensatory tracking task (Satellite Tracking) was a measure of high-level neuromuscular function which also involved intellectual functioning at a level of moderate complexity. The short-term memory task (Meteorite Monitoring) was a memory and intellectual function task with a complexity level which was variable from moderate to intensely demanding. The problem solving task (Reactor Control) involved a measure of intellectual function at a relatively more difficult level with minimal neuromuscular requirements. Early models provided only a semirandom program via stepping switch programming systems. Later models were programmed with a punched tape/reader system, offering an infinite variety of programs in terms of length, signal rate, and time-sharing requirements. Task presentation could be experimenter- or subject-paced. Performance readout was presented on three electronic counters for each task. An event counter recorded the number of times a task was activated by the programmer and completed by the operator. A second counter served as either a time clock or an error counter. The third counter determined the total number of times the task was presented.

Cutler et al. (2) sequentially exposed 4 pilots to elevated carbon dioxide environments (partial pressure of 21 mm Hg, equivalent to 3% at sea level) at both ground level and simulated altitude (200 mm Hg total pressure). The total duration of carbon dioxide exposure was 4 days in each case. Each of the 4 subjects worked for 2 hours twice each day with the signal rate held constant. The physiological response to carbon dioxide was nearly the same at the two different pressures as measured by the degree of hyperventilation and

hypercapnia produced. Subject-paced performance on the NEPTUNE tasks (excluding AUDIT) was not affected by the experimental treatments. Operator efficiency, defined as the number of signals processed per hour, showed no significant deviations across days, between 700 mm Hg and 200 mm Hg, across periods, or between the two treatments as a result of increased inspired carbon dioxide.

In another study (4) on the effects of elevated carbon dioxide (3%), 7 volunteer airmen were exposed continuously for 5 days. All subjects tolerated the experimental atmosphere with no undue physiological or medical problems. One-hour exercise periods were tolerated very well. Testing on all six NEPTUNE tasks occurred three times daily for 30-min periods. No significant changes occurred in any of the NEPTUNE scores nor was performance affected on a paper and pencil performance test.

Using an early version of NEPTUNE, Rodgin and Hartman (23) studied the performance of 4 aircrewmembers during a 56-day exposure to an oxygen-helium atmosphere at 258 mm Hg total pressure. The five NEPTUNE tasks already described were used, plus three additional vigilance tasks. The tasks were programmed randomly, with the more complex tasks performed singularly. Performance was scored for total response time or errors. Subjects operated the test console for 25 min, 3 times each day, during the hour before sleep, during the hour after awakening, and midway around the clock. Equipment malfunctions resulted in lost data for weeks 5, 6, and 7.

Analysis of variance looked at day vs. night crews, time-of-day (adjusted to the sleep schedule), and duration (weeks). None of the tasks showed a significant difference for day vs. night crews. Subjects sleeping during the external day (1200-2000) did not perform differently than subjects in step with the normal schedule. There was a tendency for some of the vigilance data to show a time-of-day effect. Poorer performance on the Reactor Control task in later weeks was attributed to lowered subject motivation.

Hartman (5) analyzed the performance of four airmen on the NEPTUNE during a 30-day simulated Manned Orbiting Laboratory nutrition study. Two experimental subjects were confined in a small (300 ft³) (8.49 m³) altitude chamber at 27,000 ft (8,230 m) with an atmosphere of 70% oxygen and 30% helium. NEPTUNE testing was conducted in 4-hr sessions three times a day, every other day, alternating with 2 control subjects. All tasks were used, including AUDIT. Psychomotor changes associated with the experimental manipulations were fragmentary and largely unsystematic. Some tracking and problem-solving data were missing. The 30-day duration had no consistent effect, except for a suggested deterioration on the short-term memory task for the experimental subjects. The experimental subjects performed the arithmetic task better than the control subjects, and all improved as the run progressed. Short-term memory performance was poorer for the control subjects in the evening than in the morning and afternoon. Interpretation of changes in short-term memory were clouded by motivational factors. Correlations between the first half hour and the remainder of the test session were widely scattered. It was concluded that a daily half-hour psychomotor test of space crews was probably not sufficiently stable to meet biomedical monitoring requirements.

Hartman and Cantrell (7) studied the effects of demanding work/rest schedules (1/2, 4/4, or 16/8 hours) over continuous 12-day missions. On days

8, 9, and 10, the subjects (13 airmen) were deprived of sleep and worked continuously. Vigilance, short-term memory, arithmetic, and tracking were used from the NEPTUNE. Several other psychomotor test devices were used (complex coordinator, MDP, multiple reaction time task, and complex discrimination reaction time test).

The interaction of days x schedules provided the critical significance test. No significant work/rest effects were seen in NEPTUNE performance until the subjects were sleep deprived. All schedules showed progressive performance decrement during sleep deprivation, although, in general, subjects on the 16/8 schedule performed better during this period. During recovery days 11 and 12, subjects on the 16/8 schedule performed the vigilance, arithmetic, and tracking (and complex coordinator) tasks better than subjects on the other two schedules. It was generally concluded that unusual work/rest schedules do not compromise concurrent performance so much as they deplete the physical reserves required to meet additional challenges.

In a study of the effects of carbon monoxide on sleep and performance, various combinations of the NEPTUNE tasks were presented simultaneously to four enlisted subjects in order to test varying levels of workload (21). "Moderate work-load" required tracking and vigilance monitoring. "High work-level" additionally presented the short-term memory task. The arithmetic task was used independently of these tasks. Morning testing after overnight exposures (9 hours) to 75 or 150 ppm carbon monoxide yielded NEPTUNE performances equivalent to that seen in the control condition. Significant decrements in tracking and monitoring scores did occur under high workload as compared to moderate workload. Thus, the addition of one task caused a greater decrement in performance than the maximum carbon monoxide exposure experienced in this study. It should also be noted that the present study failed to find any effect of carbon monoxide on critical flicker fusion. Nevertheless, when sleeping under carbon monoxide, the subjects had more deep sleep and less light sleep than in the control condition.

In a chamber study investigating the effects of low humidity on performance, Storm et al. (25) employed the arithmetic, vigilance, tracking, and short-term memory tasks. Problems in data recording occurred for both the tracking and memory tasks. Four highly practiced subjects performed during 36-hour missions (2000-0900) following a 2/2 work/rest schedule. Tasks were presented randomly, one at a time. Neither low humidity, mild altitude (8,000 ft) (2,438 m), nor humidity x altitude had any significant effect on any of the NEPTUNE performance measures, nor on Link GAT-1 simulator and MDP performances. While not statistically significant, the NEPTUNE performances did tend to demonstrate typical circadian variation. Systematic day-night variations were found for MDP tracking skill and self-ratings of subjective fatigue.

The NEPTUNE was used by Pepelko et al. (22) in a general evaluation of the passenger oxygen mask for emergency use in the T-43 aircraft. The five basic NEPTUNE tasks were all used, with AUDIT excluded. Six enlisted subjects were tested for 3 hours at 25,000 ft (7,620 m) equivalent altitude (282 mm Hg) in an altitude chamber. During each 3-hour experiment, the subjects performed for five 25-minute sessions. The mask was well accepted with no evidence of hypoxia. No deterioration in performance could be detected on any of the tasks over the five work sessions.

Benel and Storm (1) modified the programing characteristics of the vigilance, arithmetic, and problem solving tasks. The original circuitry for these tasks permitted a signal or problem to be cancelled only by a correct response from the operator. If the operator failed to respond because of fatigue or some other experimental treatment, the experimenter lost control of any desired preprogramed schedule of events. Therefore, optional time-limiting circuitry was added to these tasks. Failure to respond in 15-30 sec (experimenter's choice) resulted in automatic cancellation of the signal or problem. Circuitry in the short-term memory task was improved using more sophisticated components for control of flash frequency and duration. The instructions and rules for the problem solving task were modified for clarity. Three programs, varying in workload and workload distribution, were developed for training and testing under various stress conditions. Learning data were acquired for each of the programs. Vigilance and tracking performance were most sensitive to the effects of increased workload.

In a pair of studies (unpublished), the sensitivity of the NEPTUNE tasks to known stressors was compared with the sensitivity of control theory parameters. In the first study, NEPTUNE tracking performance was poorer for 14 airmen after 1-hour exposure to 15,000 ft (4,572 m) simulated altitude (inspired gas mixture) than at ground level. None of the NEPTUNE measures were deteriorated at 8,000 ft (2,438 m) (simulated). A compensatory tracking task, designed to study control theory parameters, revealed numerous systematic changes in mean square error at 8,000 (2,438 m) and 15,000 ft (4,572 m). Similarly, in a study of performance upon sudden awakening, performance of 11 airmen on the NEPTUNE revealed no systematic changes when comparing sudden awakening to sleep deprivation. Performance on the tracking task was significantly decreased.

CONCLUSIONS

This review has emphasized that development and modification of multiple-task performance evaluation devices at SAM has been directed by medically oriented, applied problems from the operational environment. As summarized in Table 1, these problems have been concerned with a variety of environmental stressors. Frequently, the studies involved reasonably low intensities of the stressors being investigated, and, in some cases at least, this explains why little or no performance deficit was observed. When the stress was of considerable intensity, performance decrements did occur, although there was not always consistency in the subtasks affected. In general, the SAM multiple-task batteries provided a unique, although sometimes difficult to interpret, capability for performance evaluation.

REFERENCES

1. Benel, R. A., and W. F. Storm. Neptune: Modifications and current applications. SAM-TR-75-20, Aug 1975.
2. Cutler, R. G., et al. Human response to carbon dioxide in the low-pressure, oxygen-rich atmosphere. *Aerosp Med [Now Aviat Space Environ Med]* 35:317-323 (1964).
3. Flinn, D. E., and B. O. Hartman. Performance data in space cabin simulators. Paper presented at the SHAPE Medical Conference, Paris, France, May 3, 1961.
4. Glatte, M. A., G. J. Motsay, and B. E. Welch. Carbon dioxide tolerance studies. SAM-TR-67-77, Sep 1967.
5. Hartman, B. O. MOL: Predicting four-hour levels of psychomotor performance from the initial half-hour. SAM-TR-67-55, June 1967.
6. Hartman, B. O., and G. R. Cantrell. Psychomotor monitoring for general efficiency. SAM Special Report for MEND Symposium on Biomedical Monitoring. Nov 1964.
7. Hartman, B. O., and G. R. Cantrell. MOL: Crew performance on demanding work/rest schedules compounded by sleep deprivation. SAM-TR-67-99, Nov 1967.
8. Hartman, B. O., and D. E. Langdon. A second study on performance upon sudden awakening. SAM-TR-65-61, Aug 1965.
9. Hartman, B. O., and R. E. McKenzie. The Complex Behavior Simulator--a device for studying psychologic problems in modern weapons systems. SAM-TR-61-9, Dec 1960.
10. Hartman, B. O., and R. R. McKenzie. Systems operator proficiency: Effects of speed stress on overload performance. SAM-TR-61-40, June 1961.
11. Hartman, B. O., and R. E. McKenzie. An exploratory study of low work rates on performance during overload. Unpublished study, USAFSAM.
12. Hartman, B. O., R. E. McKenzie, and D. E. Graveline. An exploratory study of changes in proficiency in a hypodynamic environment. SAM-TR-60-72, July 1960.
13. Hartman, B. O., R. E. McKenzie, and B. E. Welch. Performance effects in 17-day simulated space flights. *Aerosp Med [Now Aviat Space Environ Med]* 33:1098-1102 (1962).
14. Hauty, G. T. Human performance in the space travel environment. *Air University Quarterly Review* 10(2):89-107 (1958).
15. Hauty, G. T. Maximum-effort-minimum-support simulated space flights. *Aero/Space Engineering* 19(4):44-47 (1960).

16. Langdon, D. E., and B. O. Hartman. Performance upon sudden awakening. SAM-TR-62-17, Nov 1961.
17. McKenzie, R. E. A systems task used in the stress testing of special mission personnel. Hum Factors 7:585-590 (1965).
18. McKenzie, R. E., B. O. Hartman, and B. E. Welch. Observations in the SAM two-man space cabin simulator. III. System operator performance factors. Aerosp Med [Now Aviat Space Environ Med] 32:603-609 (1961).
19. McKenzie, R. E., D. D. White, and B. O. Hartman. Neptune: A multi-element task system for evaluating human performance. SAM-TR-69-25, Oct 1969.
20. Morgan, T. E., et al. Physiologic effects of exposure to increased oxygen tension at 5 PSIA. Aerosp Med [Now Aviat Space Environ Med] 34:720-726 (1963).
21. O'Donnell, R. D., D. Chikos, and J. Theodore. Effect of carbon monoxide exposure on human sleep and psychomotor performance. J Appl Physiol 31:513-518 (1971).
22. Pepelko, W. E., et al. Physiologic testing of the T-43 passenger oxygen mask. SAM-TR-74-9, June 1974.
23. Rodgin, D. W., and B. O. Hartman. Study of man during a 56-day exposure to an oxygen-helium atmosphere at 258 mm Hg total pressure. XIII. Behavior factors. Aerosp Med [Now Aviat Space Environ Med] 37:605-608 (1966).
24. Steinkamp, G. R., et al. Human experimentation in the space cabin simulator: Development of life support systems and results of initial seven-day flights. SAM-TR-59-101, Aug 1959.
25. Storm, W. F., et al. Effect of low humidity on human performance. SAM-TR-73-3, Feb 1973.
26. Welch, B. E., T. E. Morgan, and F. Ulvedal. Observations in the SAM two-man space cabin simulator. I. Logistics Aspects. Aerosp Med [Now Aviat Space Environ Med] 32:583-590 (1961).

USAF SCHOOL OF AEROSPACE MEDICINE
AEROSPACE MEDICAL DIVISION (AFSC)
BROOKS AFB TX 78235

OFFICIAL BUSINESS

PENALTY FOR PRIVATE USE, \$300