Work Proficiency in the Space Cabin Simulator

SIEGFRIED J. GERATHEWOHL, PH.D.

IF manned space flight capabilities are to be exploited effectively, an appropriate set of requirements must be established. Methods for the assessment of the conditions of space flight, task performances, and stresses must be designed which can be employed for the development of operating procedures in space vehicles. Several means are available to achieve this goal. One is extrapolation from experience with high performance aircraft, submarines, and balloons. Another is to experimentally simulate the chain of events which connects environmental conditions with their effects upon human performance. From such studies we can then determine not only what kind of conditions must be established, but also the tolerance limits within which they must be maintained.

At present, neither the limits of human performance nor the limits of stress are known. The effects of long confinement in an artificial and closed environment are not fully understood. This lack of information requires the investigation of human parameters under simulated space conditions, particularly those which keep man functioning efficiently as a link in a closed and self-sustaining system.

The experiments described in this report attempt to assess work proficiency in the hermetically sealed cabin. They were made at the U. S. Air Force School of Aviation Medicine, then at Randolph Air Force Base, Texas, as part of an extended study of human requirements in space cabin simulators. The first one was conducted by scientists of the Department of Space Medicine, with Airman First Class D. G. Farrell as the subject in a well-publicized seven-day test in February 1958.[2,3,8] The second study was performed by Dr. Bruno Balke and Master Sergeant S. M. Karst, Department of Physiology and Biophysics, who were sealed in a cabin on September 12, 1958. The characteristics of the environment and their physiologic effects have been previously described.

PROCEDURE

The space flight simulator used in the Farrell experiment measured about 96 cubic feet. Almost half of this space was filled with instruments necessary for maintaining a balanced cabin atmosphere of about 380 mm. Hg. pressure and 40 per cent O_2. The larger pieces of equipment included the O_2 analyzer, the food preparation and storage shelf, the CO_2 absorber system which kept CO_2 below 0.3 per cent, filters, blowers, ducts for cleaning and circulating the air, and a perceptual test apparatus. The subject occupied a modified pilot seat with a writing board directly in front of him which was used for performing a simple mathematics test.

From the U. S. Air Force School of Aviation Medicine, Brooks Air Force Base, Texas. Dr. Gerathewohl is now chief of the Bioastronautics Research Office, U. S. Army Medical Research and Development Command, Redstone Arsenal, Alabama.

Presented on April 29, 1959, at the 30th annual meeting of the Aero Medical Association, Los Angeles, California.

Numerical operations of various kinds requiring arithmetic reasoning and perceptual speed have long been used to assess human behavior variables. In this country, for instance, McFarland[5] and Russell[7] employed the addition of digits as an "attention test." Of all the psychologic functions studied in the low pressure chamber by Tanaka, computation ability was the most significantly affected by hypoxia.

NAME: DATE: HOUR:

9	8	7	4	9	9	5	2	3	5	6	5	2	8	7
4	6	6	3	2	4	8	4	7	4	9	6	2	3	4
5	3	9	6	3	8	9	6	4	8	7	7	8	7	8
5	9	3	2	8	6	5	8	2	4	6	8	6	9	5
3	7	3	7	7	7	5	7	9	6	4	8	9	9	3
8	5	7	7	2	9	3	7	3	1	3	3	9	5	9
2	7	8	3	2	3	8	5	6	5	9	6	3	7	6
7	9	2	9	6	2	7	5	4	3	4	4	8	8	6
6	2	7	6	5	7	6	4	4	8	6	7	4	2	3
9	8	5	8	9	2	4	7	7	8	8	3	5	2	5
9	5	8	7	3	8	4	9	8	9	5	5	5	6	2
5	4	5	2	3	3	9	3	3	2	9	4	8	4	8
8	6	9	6	5	7	8	8	2	7	5	8	2	4	7
3	5	4	6	8	0	2	4	2	3	6	9	7	9	1
3	3	5	4	8	3	7	4	7	4	3	6	9	2	5
6	2	6	7	9	9	4	2	5	2	4	8	4	3	3
4	4	6	5	4	7	3	9	5	2	7	5	6	6	8
2	3	3	8	2	3	5	6	9	9	2	7	6	5	8
9	1	9	3	5	3	2	7	4	9	8	4	8	5	9

Fig. 1. Work sheet employed for the work performance test.

The task used in our experiment was Kraepelin's work performance test.[4] It requires continuous adding of single digits which are arranged in 80 vertical columns of 51 digits each (Fig. 1). The columns are so composed that the numbers from 2 to 9 and their possible combinations occur in a regular but arbitrary sequence in order to secure the uniformity of the task during the course of the work. The task consists of adding only two digits at a time. Each figure is first added to the preceding figure and then added to the following figure; in each case the result is written in the space at the right side of the column. If the result has two digits, the 1 in front (indicating the ten) is to be spared. Every three minutes, the subject is told to underline the last result. This enables the experimenter to display graphically the subject's performance and to evaluate his proficiency over the one-hour period. Because of the known effects of stress, the test was taken daily in the capsule before the usual noon rest period. It was preceded and followed by base line studies under normal conditions.

Although the basic mental requirements of this test are extremely simple, it can be very demanding with regard to certain psychologic variables, such as motivation and attitude. Before the test, the subject is instructed to attempt to achieve his peak performance while simultaneously avoiding all errors and corrections. In order to reach this goal and to maintain maximum proficiency during a relatively long period of monotonous work, the subject must be highly motivated and retain his mental, emotional, and physical capabilities. If we are justified in assuming that the motivational conditions are fulfilled, changes in performance may indicate changes of the subject's ability. Decrements of task proficiency may then be indicative of undesired alterations of the set of external conditions. On the other hand, our method also yields information concerning attitude and motivational factors which are of crucial importance for prolonged periods of space exposure.

Although the work performance test has a long history of application and validation, its use within the sealed cabin research program posed several problems. Because nothing was known about the effects of practice due to repeated performance, Farrell was furnished only seven work sheets before he entered the capsule. On the sixth day of his journey he remarked in his diary:

1402: Math test finished. Completed it with 3 minutes to spare in addition to doing the complete test. Gerathewohl said: "Even a genius couldn't do the entire thing in one hour." Pardon me, all to hell.

1405: Sharpened the pencils for tomorrow's test (last one). Getting a little anxious to get the hell out of this box.

The entry on his last day reads:

1400: Finish math test. Did the entire test again today, and had 5 minutes to spare. Wait 'till Gerathewohl sees that. I'll have him calling me "genius"! Ha!

Farrell took the test very seriously. He stated later that he had looked forward to taking the test as a recurring challenge. It was one of the few real challenges with which he was faced except, of course, for terminating the experiment after seven days. It helped to keep up the morale of this highly motivated subject even during the gradual onset of irritability. Under the conditions of isolation and his daily routine, he was trying to do better in this test every day, thus competing with himself in the struggle against boredom and fatigue.

Balke and Karst, who made the experiment later, worked under rather different conditions. Four weeks after returning from Mt. Evans, they began their ten-day experiment in a 212 cubic feet sealed cabin to study the effects of various physiologic stress situations on men conditioned and acclimatized to high altitudes. The temperatures in the chamber varied between 26° and 36° C. with an average of 29.5°. Standing outside the laboratory, the chamber was protected against the direct radiation from the sun by a large canvas. During the hottest hours of the day it was cooled by a sprinkler system. The effective altitude ranged from 13,000 to 17,000 feet during the test (Fig. 2). The CO_2 concentration of the inspired air was usually between .4 and .8 per cent; the relative humidity varied from

70 to 90 per cent. The following details are cited from Dr. Balke's report:

On the first day in the chamber we overdid it and went up relatively high, to about 15,000 feet during the test. The temperature was high, 32° C, and the cramped position, holding the board on our knees, and the sweat made the test a severe physical exercise. This was true for all the following days, especially since the competitive spirit became more outspoken.

The environmental conditions encountered in the capsule hit the two space men with different severity. Dr. Balke maintained his efficiency quite satisfactorily; but Sgt. Karst was very tired and kept falling asleep during the first day. He felt much better on the second day, but the next day he again remarked on his work sheet: "Sleepy during the test." However, from the fourth day on, after getting fully acclimatized, the two subjects began competing against each other. They remained highly motivated throughout the entire experiment but did not take the test on their last day in the capsule because of a special experiment on temperature, CO_2 and humidity accumulation. Unfortunately, no ground level tests were taken after the termination of the cabin run. However, the results obtained in the sealed environment are complete enough to warrant an objective evaluation. A picture of the two test subjects is given in Figure 3.

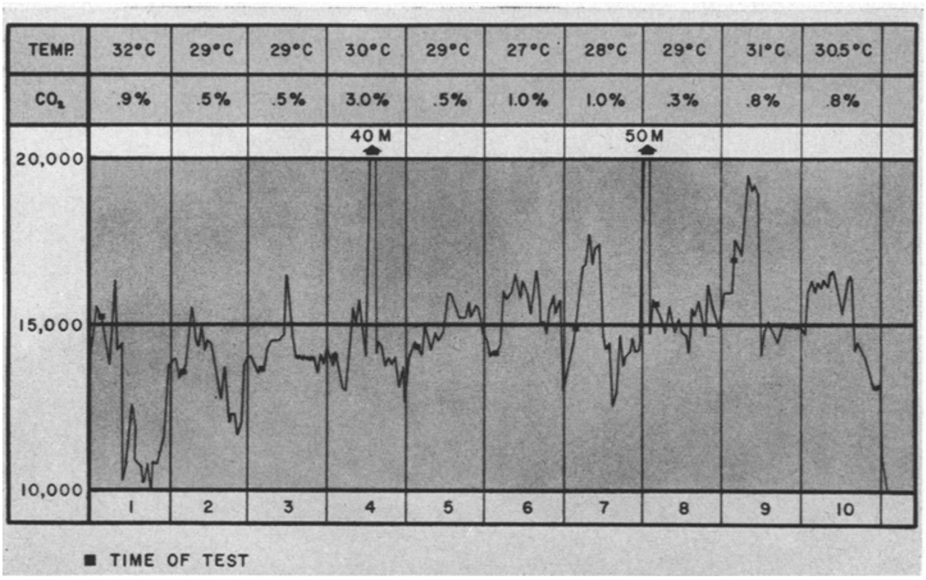

Fig. 2. "Effective" altitude during Balke's and Karst's sealed cabin tests.

RESULTS

Kraepelin, a German psychiatrist and inventor of the method, suggested several indexes more than 50 years ago to determine the "essential characteristics of the working proficiency of the subject, his ability to learn, and the effects of fatigue."[4,6] Of the various types of indexes which since have been used for numerical and statistical analyses, the following criteria proved to be reliable and therefore will be used in our evaluation: (1) the volume of performance (number of problems worked); (2) the quality of performance as expressed by the percentage of errors and corrections; (3) the steadiness and tendency of the performance. Steadiness of performance is measured by the standard deviation of the scores obtained during each three-minute period, but it is also found by an inspection of the individual curves. This is equally true for assessing tendency; that is, whether the performance is quantitatively increasing or decreasing in time, which can be mathematically expressed by the angle of the regression line of the scores with the time axis.

Fig. 3. Dr. Balke and Sgt. Karst in the sealed chamber.

Figure 4 contains the scores of the three subjects, which were obtained before the chamber runs, plotted over the one-hour period. The horizontal line in the center indicates 150 additions per three-minute period. This is an average score for persons of this age group and educational background. Dr. Balke is an eminent scientist, Sgt. Karst is supervisor of physiologic training at the School of Aviation Medicine, and Airman Farrell was trained as an accountant clerk. The test was taken in the laboratory February 6 and September 11, 1958, at temperatures of 20° and 22° C (about 70°F), respectively. Balke, who finished a total of 3,248 problems, corrected 24 times (.74%), and made 7 errors (.22%). The standard deviation from the mean is 9.21. He starts with a relatively high score (170 during the first three minutes), drops off during the first quarter of the test, and gradually steps up his performance, working very steadily and reaching his maximum in an end spurt. The tendency of the curve is positive (i.e., it shows an over-all increase in the course of time, and it reaches it's maximum at the finish line). By and large, this curve depicts the performance of a healthy, stable, and well-motivated subject under standard conditions.

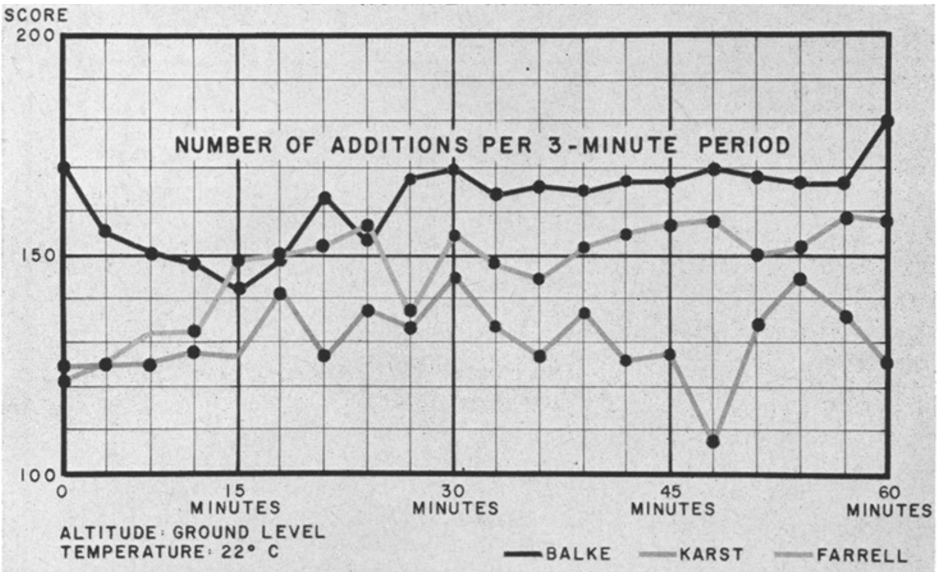

Fig. 4. Performance curve of three subjects obtained under normal conditions.

Farrell's curve shows a somewhat slower start, but otherwise it has very similar characteristics: A total of 2,945 additions, 38 corrections, 13 errors, a standard deviation of 10.98, and a positive tendency, reaching the maximum at the 19th period.

Karst's curve, on the other hand, differs rather markedly from the others. Starting at about the same point as Farrell's, it reaches its maximum in the tenth period. From there on it drops off very unsteadily, rises sharply during the seventeenth and eighteenth period, and falls again with its end-point not much higher than its starting score. The standard deviation of 8.66 does not really reflect the lack of constancy of the performance. However, Karst worked very carefully making only 16 corrections and 3 errors, yielding percentages of .61 and .11, respectively.

Because space does not permit a detailed analysis of the results, only the most striking features of the curves will be discussed. Actually, the results contain a wealth of information concerning the working behavior, proficiency and personality variables of the three subjects which can be exploited by a thorough analysis of the measurements available.

The first day in the cabin shows a

picture rather different from that obtained on ground level. As can be seen in Figure 5, the effects of the space cabin conditions are as obvious as they struggle of the individual just to stay awake.

The curves in Figure 6 illustrate the similarity and differences among the

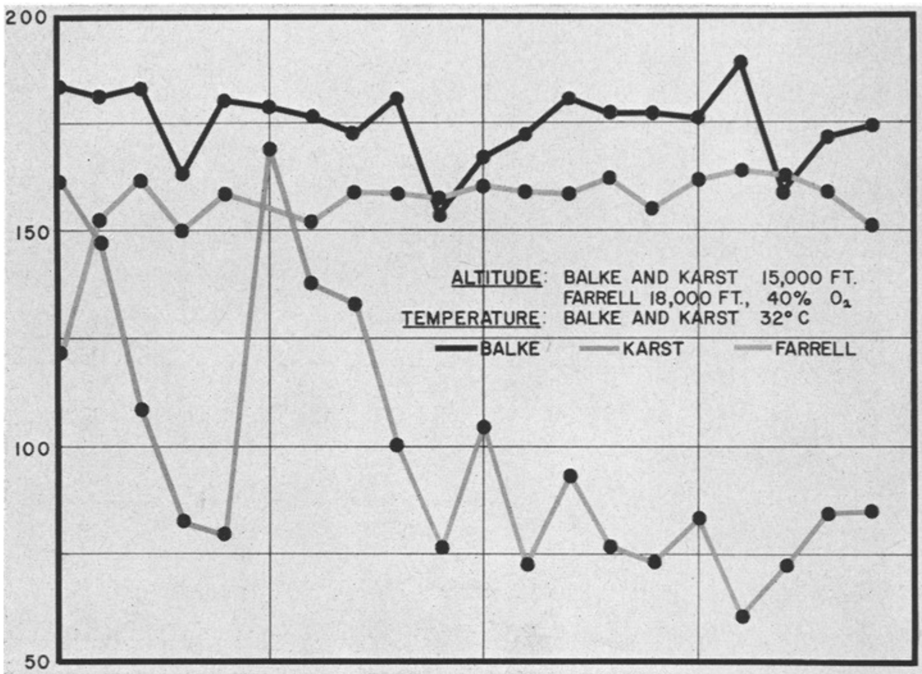

Fig. 5. Performance curves obtained on the first day of the experiments.

are different for our three subjects. Farrell, having the more favorable environment, maintains his performance in almost every respect. Balke now reaches a higher total score, but his performance becomes less steady and shows no increasing trend. Karst's curve distinguishes itself by great variations. He starts out higher than before, drops to a mere 80 in the fifth period, pulls himself together and reaches his maximum in the sixth. The curve again declines and falls to the minimum of 62 in the seventeenth period. The standard deviation is 30.93. His performance clearly reflects the three subjects. They were plotted after the results of the third cabin test. With a few exceptions, Balke's and Farrell's curves show the same characteristics: Increase in total scores, similar standard deviations, correction and error percentages, and almost identical shape during the last third of the test. Karst's curve, on the other hand, deviates from the others, showing a rather steep decline during the first half of the test and his effort to step up his performance toward the end.

The curves obtained on the fourth day are given in Figure 7. Balke and

Karst are now ahead of Farrell. Both curves show a positive tendency, but Balke still beats his companion at the finish. The relatively high CO_2 concentration, which reached 3 per cent during the test, seems to exert a rather stimulating effect, if any. Farrell's curve, on the other hand, remains substantially unchanged.

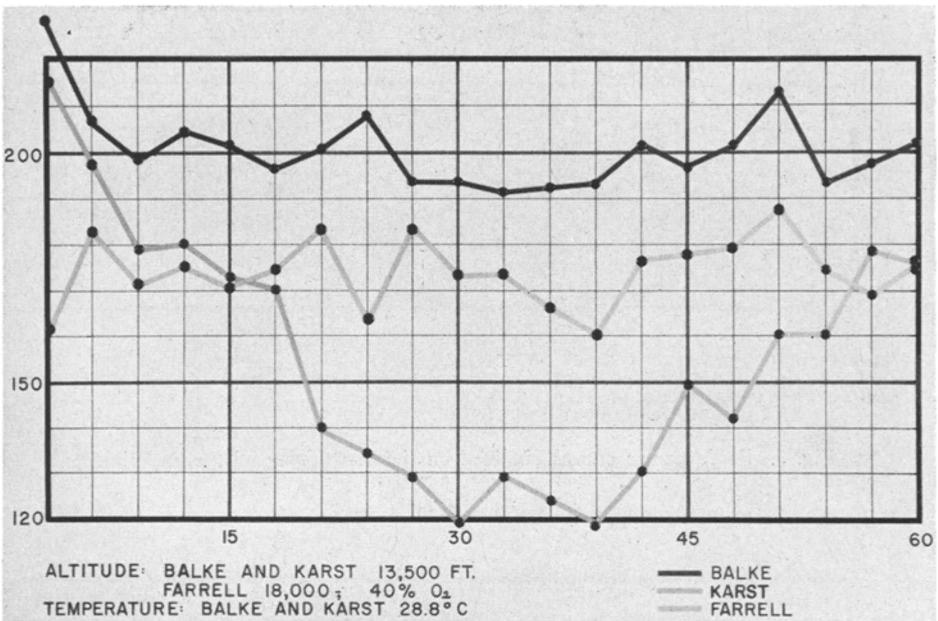

Fig. 6. Performance curves obtained on the third day of the experiments.

The sixth day shows all three curves close together with Farrell stopping at the 4,000 digit mark (Fig. 8). It should be noticed that all three have about the same main characteristics, scores, deviations, and tendencies. As for Balke and Karst, their performances gradually decline after a relatively high and energetic start.

If the subjects themselves would not have stated it explicitly, the curves in the next two figures illustrate beyond any doubt the competitive spirit of the two remaining space men. In Figure 9, Karst seems to have the lead; on the last day, as shown in Figure 10, Balke reaches the higher score. However, the most surprising feature now is the remarkable similarity of the curves and their characteristics. During the last two days in the cabin, the task performance of the two subjects is almost identical.

In Figure 11 we plotted the total scores, percentages of corrections and errors, and the standard deviations for Farrell. While his quantitative performance shows a steady increase over the entire experiment, the qualitative indexes vary in a peculiar way. Psychologically, a correction means a controlled error. From the graph it can be seen that the subject carefully controlled his performance until the fourth day, that the accuracy of his work

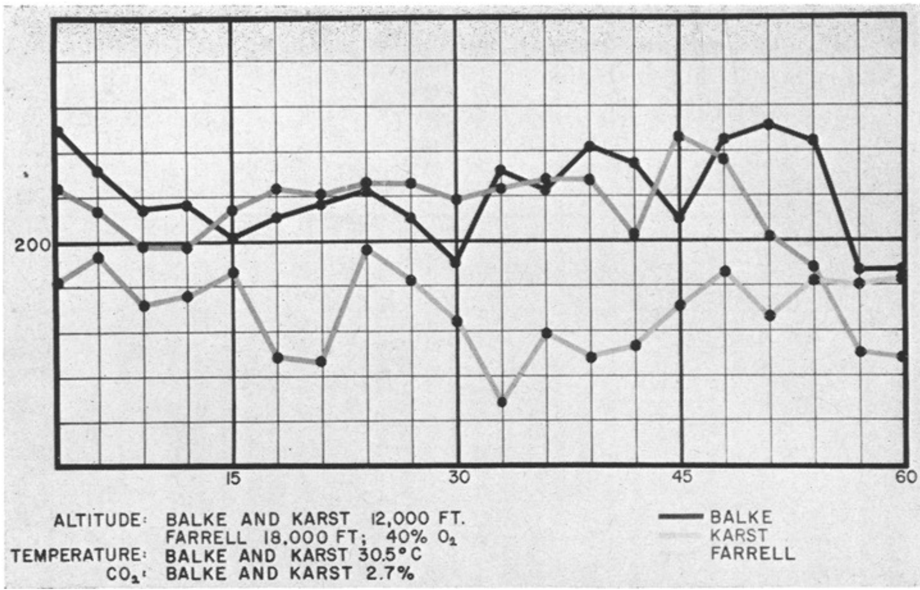

Fig. 7. Performance curves obtained on the fourth day of the experiments.

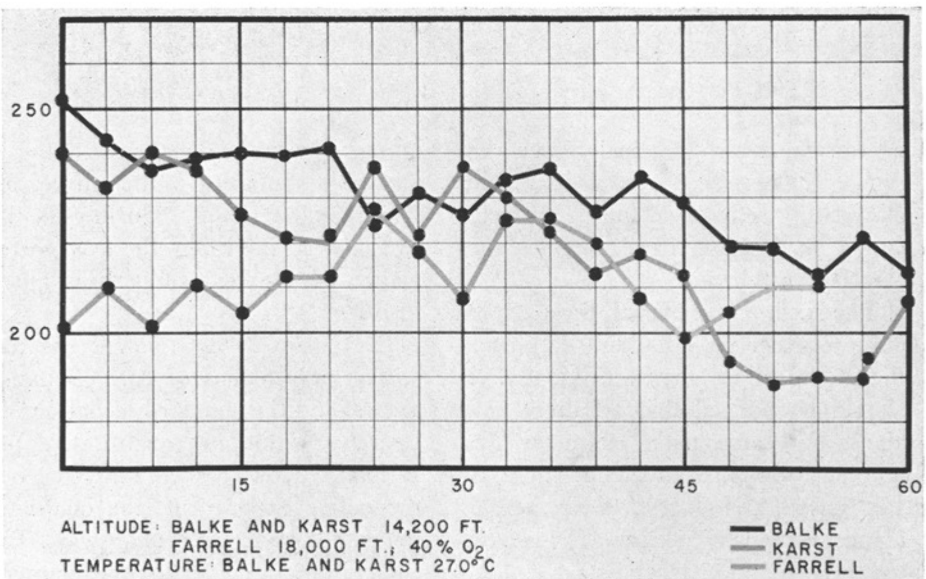

Fig. 8. Performance curves obtained on the sixth day of the experiments.

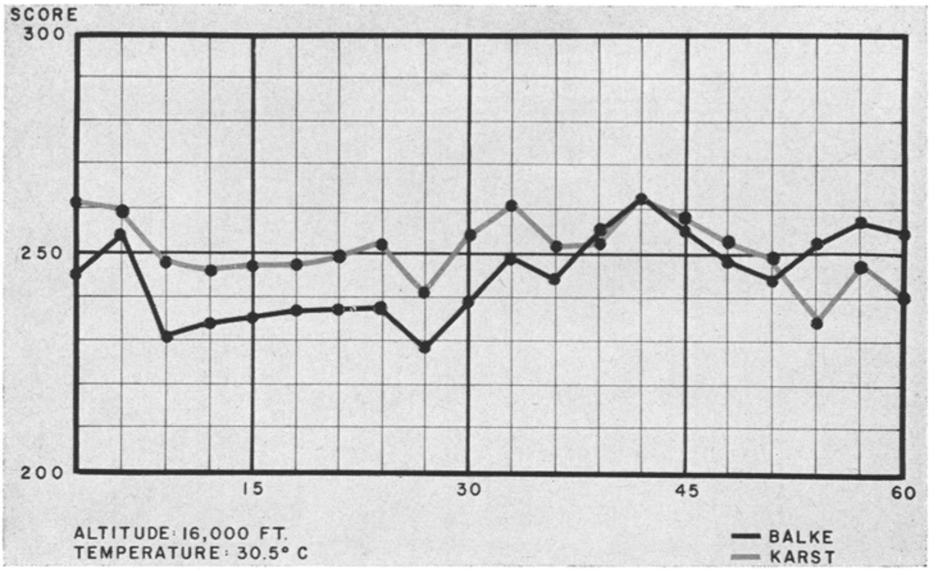

Fig. 9. Performance curves obtained on the eighth day of the experiments.

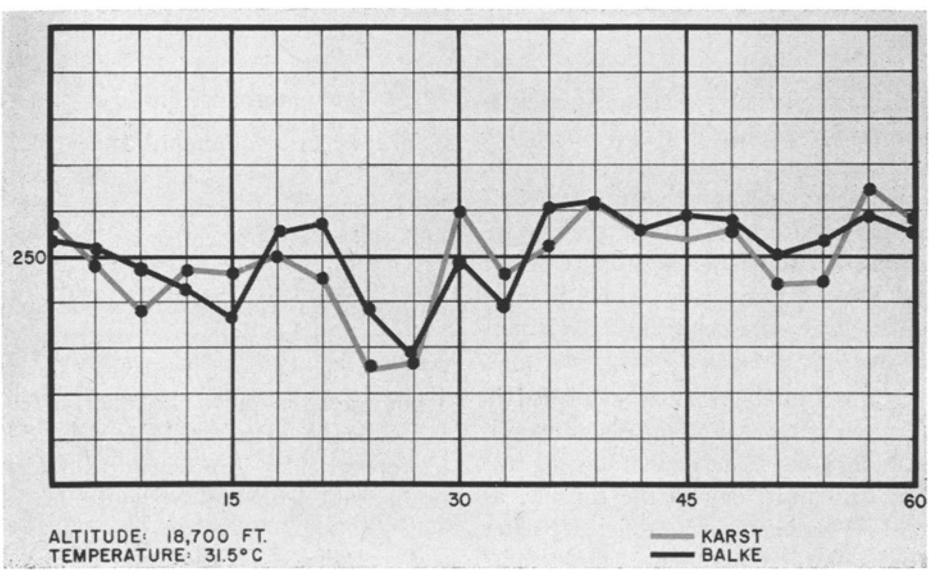

Fig. 10. Performance curves obtained on the ninth day of the experiments.

sharply declined during the next two tests, and that it increased again during the last day in the cabin.

toward the end of the test series, which may well be considered as the efficiency plateau of the individuals.

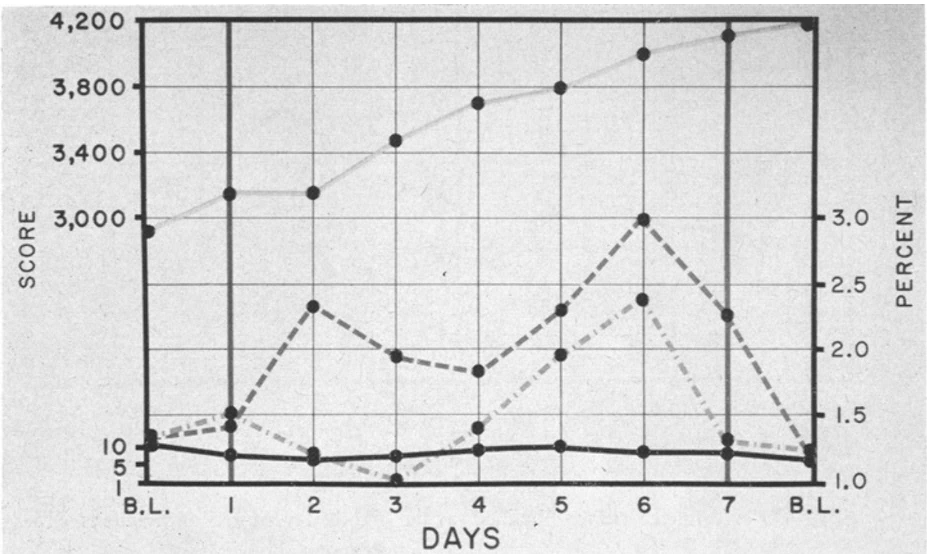

Fig. 11. Total scores, percentages of corrections and errors, and standard deviations for Subject Farrell. The light solid line shows the totals; the dark broken line, the per cent of corrections; the light broken line, the per cent of errors; and the dark solid line, the standard deviation.

Figure 12 shows the same measurements for Balke. By and large, the picture is very similar. Correction and error scores drop during the first half of the experiment but rise sharply toward the end. The "incentive kick" of the last day, so clearly visible in Farrell's curve, is lacking in Balke's performance.

Karst's final graph as displayed in Figure 13 reveals again his unsteadiness and work decrement during the first and third day in the capsule, as well as his increasing proficiency after acclimatization. Although no definite plateau was reached by any one of the subjects, the results indicate that a certain degree of saturation occurred

CONCLUSIONS

The experiment described above is believed to clarify some of the problems concerning human performance under simulated space conditions. Naturally, conditions in a simulator will always differ from those encountered in actual flight. However, assuming a certain degree of transfer validity from one situation to the other, a few generalizations on proficiency and behavior variables in hermetically sealed cabins and space ships can be made.

Perception.—The addition of 5,000 digits in one hour requires the continuous discrimination, recognition and reading of at least three single digits per second. During the concentration on the column of figures, perception narrows considerably. However, no

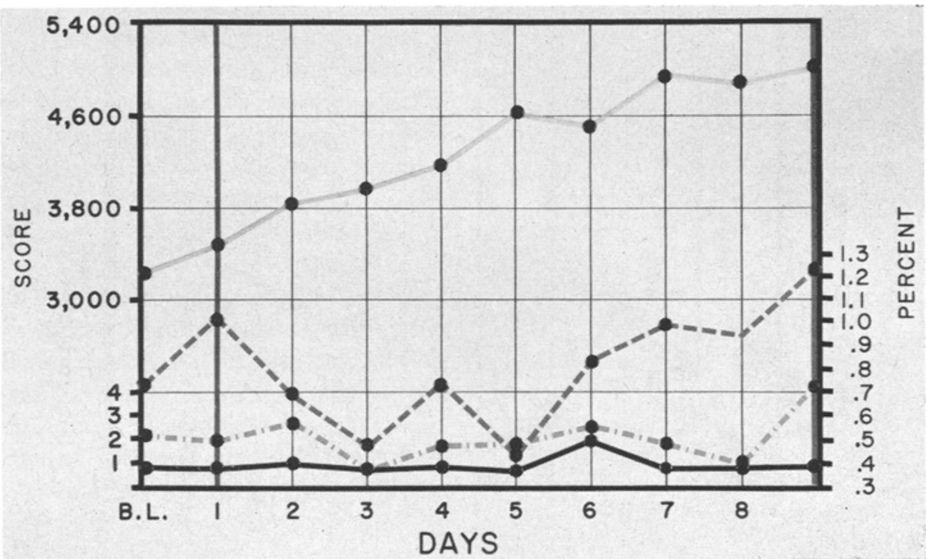

Fig. 12. Total scores, percentages of corrections and errors, and standard deviations for Subject Balke. The light solid line shows the totals; the dark broken line, the per cent of corrections; the light broken line, the per cent of errors; and the dark solid line, the standard deviation.

visual illusions, hallucinations or perceptual detachment were observed by the individuals. There is some reason to assume that under space conditions the individual can perform perceptual tasks fast and accurately, if he is engaged in purposeful activities and well informed about his situation.

Learning.—The ability tested was a simple mental activity which was very well established and performed almost automatically. There is evidence that the ability to learn through practice is not impaired if the physiologic minima are secured.

Proficiency.—Daily performance increased quantitatively despite considerable changes in the composition of the cabin atmosphere, temperature, and relative humidity. Likewise, lack of appetite, extensive sweating, insomnia, irritability, and loss of weight did not markedly impair the individual's mental efficiency. It is well known that an individual can regain his normal level of proficiency in a state of fatigue, if his routine performance is interrupted by unusual or motivating stimuli. This means, for instance, that a space crewman may very well participate in the re-entry operation although his proficiency during the routine orbital activities was dangerously poor.

Control.—Mental control functions were more affected by unfavorable environmental conditions than quantitative performance. However, the subject's never lost control of the activity during their seven and ten days stay. There is some reason to believe that they also would have been able to control the passage of their vehicles in space.

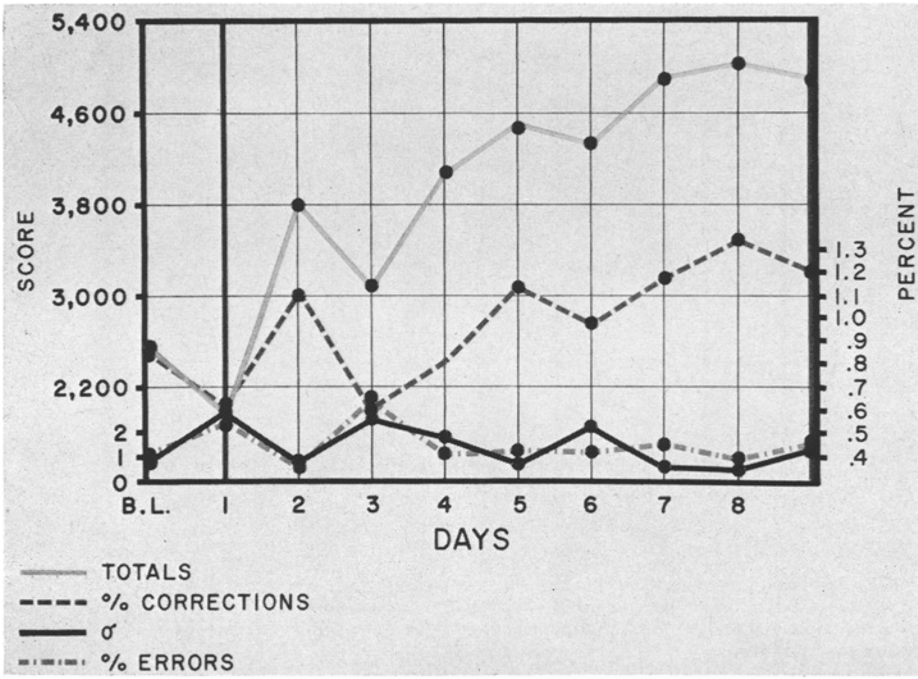

Fig. 13. Total scores, percentages of corrections and errors, and standard deviations for Subject Karst.

Motivation.—The motivation for taking the test was maintained and even increased during the course of the experiments. Although the highly efficient system of work and rest that Farrell developed during the first two days was gradually reduced to the minimum essentials, he maintained his interest in the "Math Test" during the entire period of confinement. The task became a real challenge for all three subjects that stimulated their minds and boosted their morale. The considerable stresses involved and the apparent uselessness for their immediate needs did not adversely affect motivation.

Individual Differences. — Tolerance to physiologic and psychologic stress naturally varies among individuals and seems to depend upon a variety of factors, primarily upon physical stamina, emotional stability, state of acclimatization and conditioning, interest, and motivation. On the other hand, we found a high degree of similarity of performance characteristics and work proficiency, which developed during the confinement to the very primitive and odd chamber environment and reflects the adaptation of the two individuals to the severe stress situation. We thus have reason to suppose that capable, well trained and highly motivated crew members can adjust psychologically to form a successful working team in a space vehicle.

SUMMARY

Three test subjects performed a simple mental task during experiments lasting seven and ten days, respectively, in a Space Cabin Flight Simulator.

The number of additions made in the arithmetic test taken daily increased almost steadily during the stay in the hermetically sealed cabins, but so did the error and correction scores obtained. The individual subjects became more irritable as time progressed; but they retained learned and useful behavior. The results suggest that capable, well trained and highly motivated subjects can adjust successfully to the severe stresses associated with the exposure to an engineered environment.

ACKNOWLEDGMENT

The author is indebted to Dr. Bruno Balke, Master Sergeant S. M. Karst, and Airman First Class D. G. Farrell for their co-operation and participation in the experiments, and to J. L. Johnson, Bill Snoddy, and D. Cochran, Research Projects Laboratory, ABMA, Redstone Arsenal, Alabama, for programming and performing the E-102 computer analysis of the data.

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Spontaneous Pneumothorax

The "average" patient who has a spontaneous pneumothorax at ground level usually has a moderate amount of chest discomfort, some dyspnea on effort, and perhaps a cough. He is usually physically able to seek medical advice on his own, and to receive proper care without too much difficulty. In flying personnel, first, there may be an increased frequency of initial pneumothorax due to recurrent exposure to altitude. Second, if the spontaneous pneumothorax should occur at altitude, the already existing problem of hypoxia is greatly magnified. It may be severe enough to result in the abortion of a mission or in an aircraft accident.—George Dermksian and Lawrence E. Lamb: Spontaneous Pneumothorax in Apparently Healthy Flying Personnel. *Annals of Internal Medicine,* July, 1959.