A Physiologic Study of Human Subjects Confined In a Simulated Space Vehicle

THOMAS D. HANNA

THE PRESENT STUDY is the second in a series concerned with the habitability aspects of extended confinement. The particular purpose here was to gather information about the physiologic response patterns of men in future orbital satellites, space vehicles, or nuclear powered aircraft. The first study concerned six men confined in a small chamber of approximately 75 cubic feet per man for seven days at a simulated altitude of 10,000 feet while breathing an oxygen concentration of 55 per cent sea level equivalent.[13] The second study, a part of which is reported here, concerned six men confined in a similar chamber for eight days at sea level while rebreathing their own expired air by means of a closed cycle oxygen regenerating system. This report presents the findings of of certain physiological measures recorded during the confinement period. Other reports in this second study cover biochemical findings,[26] psychologic findings,[7,8] and descriptions of the chamber, its equipment, and systems.[6]

MATERIAL AND METHODS

The six subjects participating in this study were selected from a much larger group on the basis of physical health and a battery of psychometric tests. Each man's medical history was carefully evaluated to ensure the absence of chronic disease processes and included x-rays of the chest, urinalysis, serologic studies, and various other procedures when indicated. The six men ranged from eighteen to twenty-nine years of age with a mean of twenty-two years, varied from 135 to 177 pounds with a mean of 156 pounds, and a height from 66 to 70 inches with a mean of 67.6 inches. Thus, the group was composed of healthy young men possessing physical characteristics similar to those one might expect to find in an operational setting of this nature. A description of the psychometric data and the selection methods employed in choosing the subjects for this study is found elsewhere.[6]

Certain measurements were recorded from each subject while on duty at the Vigilance work station. This station was selected because it was the most stressful of the four work stations, i.e., the subject was led to believe that he was, among other things, controlling the oxygen supply both for himself and the other members of the crew. Each crew member maintained a watch at this station for two hours (W_1), was off duty four hours, and then returned for two hours (W_2) during each twenty-four-hour period.

Two closed circuit television cameras and two receivers allowed continuous observation of the men at all times. In addition, emergency communication facilities were available. The subjects were continuously exposed to a sound level of approximately 80 decibels throughout the study. The oxygen concentration was accurately held at 20 $\pm$ 1 per cent.

Records were obtained continuously from the subject on duty at the Vigilance work station for plantar electrical skin conductance. Measures of heart rate, respiration rate, and forehead skin temperature were also recorded every twenty minutes. The latter measures commenced ten minutes before and ten minutes after the change of watches in order to allow sufficient time for the change to occur and for a state of equilibrium to be reached. The operator of this station

From the Environmental Stress Branch, Air Crew Equipment Laboratory, Naval Air Material Center, Philadelphia, Pennsylvania.

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donned a bioelectric harness containing the electrodes shortly before relieving his predecessor at the station. Three harness sets were available and care was exercised to insure that any particular subject used the same harness throughout the experiment. Connection of bioelectric harness leads was facilitated by means of a Cannon plug which connected the harness and its electrodes with the recording equipment outside the chamber. In addition, an oxygen mask which contained the respiration sensing device was also worn. Each subject was thoroughly indoctrinated prior to the study in the proper procedure of donning the electrodes and in locating them in a consistent manner.

Due to the collection of certain psychometric data, it was not possible to obtain the bioelectric measures on the last day of this study. Therefore, the results presented and their discussion apply only to the first seven days of the eight day session.

Heart Rate.—Three stainless steel electrodes, one inch in diameter, were fitted into a bioelectric harness to facilitate donning. Areas of electrode attachment were delineated previous to the experiment by staining a small area of the skin with crystal violet. A dipolar lead was attached high on the upper chest and upper back, i.e., an electrode was placed over the fourth intercostal space and just to the left of the sternum (standard lead V_2). The electrodes were held in place by a flexible ECG rubber strap around the chest. All straps were covered by a cloth sleeve to prevent irritation due to direct and prolonged contact of the rubber strap with the skin. The ground electrode was attached to the lower right leg.

Pen deflections up to 3 cm. were obtained without the use of electrode paste using a moderate sensitivity setting on a Model 150 Sanborn recorder. A paper speed of 5 mm./sec. permitted an accuracy of $\pm$ ¼ heart beat per minute. The majority of calculations involving heart rate were based on a minimum of thirty seconds. Faster paper speeds were used for the study and analysis of ECG recordings.

Respiration Rate.—A resistance type transducer mounted in the oxygen mask formed one arm of a Wheatstone bridge. Two equal precision resistors and a heliopot for balancing the ambient temperature in the mask completed the bridge. The output of the bridge was fed into the DC amplifier of the Sanborn recorder allowing continuous recording of the respiration. In most cases a minimum of thirty seconds was used to calculate this rate.

Forehead Skin Temperature.—A thermistor calibrated from 30.0 to 37.0 degrees C. was attached to the forehead for recording the forehead skin temperature. Using the thermistor as an arm of a modified Wheatstone bridge, a change of 1 degree C. was represented on the Sanborn recorder as approximately 1 cm. of pen deflection and allowed accurate readings to 0.1 degree C.

Electrical Skin Conductance.—A fine wire mesh electrode of Monel metal approximately ½ inch square was attached to the sole of each foot for measuring the plantar electrical skin conductance. The lead from each foot was brought up the leg and incorporated into the harness described earlier. An elastic band held the electrode firmly in place without undue pressure. A loop approximately five inches in diameter at the distal end of the electrode wire provided slack to insure that limb movements did not displace the electrode. Electrode paste consisted of clay, glycerin, and an electrolyte, with the mixture adjusted to the desired plasticity and characterized by its resistance to drying. Excess paste was carefully removed after the electrode was located, since Blank and Finesinger[5] have demonstrated that the effective electrode area is that total skin area wet with electrolyte, i.e., the size or area of the electrode itself is not a relevant factor in resistance (conductance) measurements.

A portable, fully transistorized Tissue Resistance Monitor (Model 152A, Airborne Instruments Laboratory, Mineola, N. Y.) was connected to a low impedance oscillograph (Esterline Angus milliammeter recorder) for these measures. This instrument provides an unambiguous measurement of tissue conductance while permitting a simultaneous independent 11,000 ohms, i.e., the 4.5 inch paper width would represent a change of 5,000 ohms (200 micromhos).

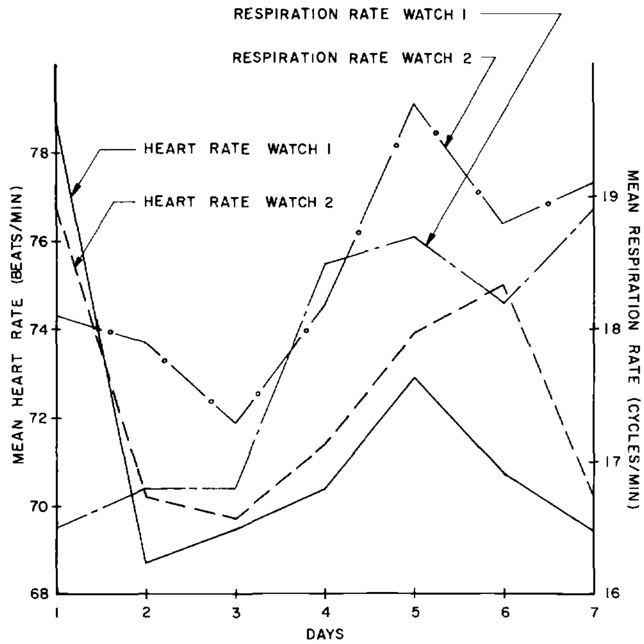

Fig. 1. Mean variation in heart and respiration rates for the two watches.

measurement of tissue potential. By using an operating frequency of eight cycles per second $\pm$ ten per cent square wave, the error producing effects of electrode polarization were greatly diminished. The apparatus was calibrated with a decade resistance box connected in place of the subject.

The micromho was selected as the unit of measurement as suggested by Lacy and Siegel.[15] Using the normal range, full scale deflection on the recorder could be obtained with 500, 200, 100, 50, and 20 x 10^3 ohms (2, 5, 10, 20, and 50 x 10^3 micromhos). In addition, an expanded range control permitted a 4:1 expansion of the record. For example, by setting the sensitivity selector at a resistance of 20 x 10^3 ohms (conductance of 50 microomhos) and the expanded range control at 30 to 55 per cent, the scale would represent a resistance from 6,000 to

RESULTS

All data were subjected to an analysis of variance.

The two Watches (W_1 and W_2) were each two hours in duration and separated by four hours during each twenty-four-hour period. For purposes of analysis, each Watch was divided into six Periods representing twenty-minute intervals.

The analysis of the heart rate data indicated that one second order interaction, two first order interactions, and three main effects were significant at the 0.01 probability level. Subjects and many interactions involving Subjects were significant, making generalizations difficult. The Day x Subject x Watch, Day x Subject, and Subject x Watch interaction effects contributed significant variance; however, the heart rate was higher on Watch 2 than on Watch 1 for all days except Day 1, but the difference for the two watches was greater on Days 1, 2, and 6 than on Days 3, 4, 5, and 7 (Fig. 1).

Analysis of the respiration rate was made. Values for each Watch were calculated from the arithmetic mean of the six Periods within the Watch. Two interactions and one main

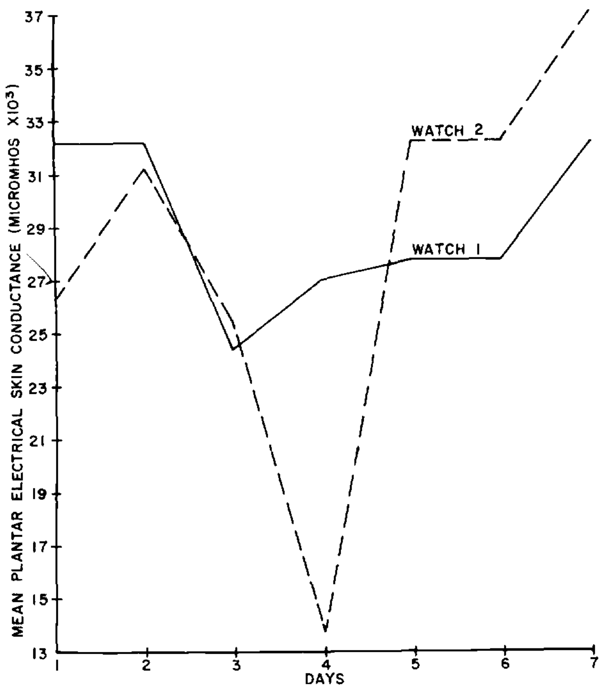

Fig. 2. Mean variation in electrical skin conductance for the two watches.

effect were significant. Here again, Subjects and all interactions involving Subjects were significant, making generalizations difficult. The Day x Subject and Subject x Watch interaction effects contributed significant variance at the .01 probability level while Subjects displayed significant variance at the .05 level. As with heart rate, the respiration rate was higher on Watch 2 than on Watch 1 for all days except one (Day 4), but the difference for the two Watches was greater on Days 1, 2, 5, and 6 than on Days 3, 4, and 7 (Fig. 1).

Heart rate was highest on Days 1, 5, and 6; moderate for Day 4; and low on Days 2, 3, and 7. This was true for both Watches. Thus, there was a relatively large drop in heart rate from Day 1 to Day 2, a positively accelerated rise from Day 2 to Days 5 and 6, reaching a peak during the emergency* on Day 5, followed by a drop on Day 7.

Respiration rate was highest on the last four days and lowest on the first three days of confinement. While not as marked, the general pattern seemed to follow that of heart rate. Thus, the respiration rate was initially steady, dropped slightly, rose from Day 3 to Day 5, and was

*Part 2 of the second study[7] describes an emergency which was introduced into the chamber on Day 5 and which is reflected in the physiological measures that follow. As a result, the crew became disorganized and confused in their behavior and failed to function as a team. Various members forgot the instructions they had received before the experiment concerning the correct procedures to be followed. After the emergency, the crew tended to blame the experimenters outside the chamber for their confusion and displayed great hostility by cursing and other aggressive behavior which lasted the remaining three days of the study.

followed by a drop on Day 6. The highest values which occurred on Day 5 were probably due to the experimentally introduced emergency. One major difference between the two variance. Thus, Subjects were significant at the 0.01 probability level while Days x Watches and Subjects x Watches were significant at the 0.05 level of confidence. The plantar electrical

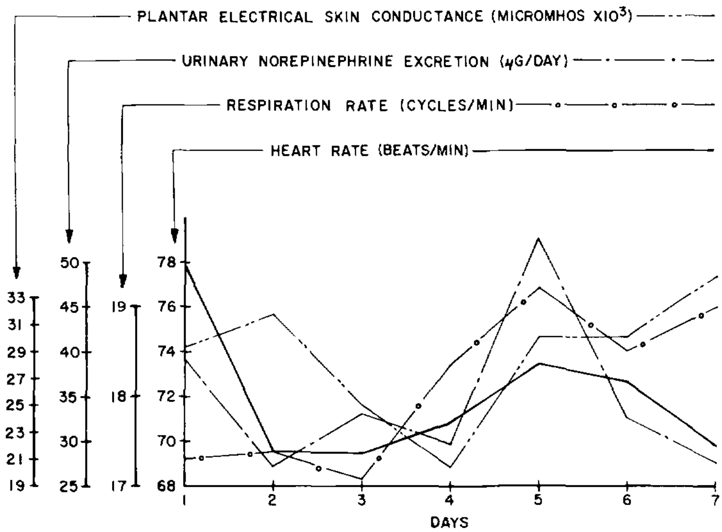

Fig. 3. Comparison of mean values for all physiologic indices. (Scales have been readjusted for ease of comparison.)

measures is the slight rise in respiration rate on Day 7 which could be interpreted as an interest by the subjects in the termination of the experiment. This increase in respiration rate toward the end of the confinement period was in contrast to the results obtained for heart rate; however, it agrees with those findings recorded during the first confinement study which were previously reported.[13]

The calibrated thermistor used for recording forehead skin temperature failed to function properly after the second day. However, this temperature varied from a low of 30.1 to a high of 34.5°C with a standard deviation of 1.0°C during the first two days of the experiment. It is of interest that the mean value for Watch 2 was 0.25°C lower than for Watch 1.

Analysis of the plantar electrical skin conductance was made. Values for each watch were calculated from the arithmetic mean of the six periods within the watch. One main effect and two interactions displayed significant skin conductance for Watch 1, however, was greater than for Watch 2 on the first two days, slightly lower for Day 3, much higher for Day 4, and moderately lower the last three days (Figure 2). Again, the greatest difference occurred on Day 4 and represented a reversal of the preceding trend while the least difference occurred on Days 2 and 3.

The plantar electrical skin conductance was highest on the first two and last three days of the study reaching its peak on Day 7. A marked drop occurred on Day 4 with a moderate value for Day 3. This trend was followed by both watches. Thus, there was a slight increase from Day 1 to Day 2, a marked decrease during Days 3 and 4, a marked increase on Day 5 to the preceding level, a stable value for Day 6, and an increase to its highest value for Day 7. The sharp rise on Day 5 followed by a further increase on Day 7 probably reflects the effects of the emergency introduced on Day 5 and the hostility, aggression, and desire on the part of the subjects to terminate the experiment which was manifested the remainder of the study. In a general way this pattern resembles those obtained for heart rate and respiration rate reported herein and for urinary epinephrine-norepinephrine excretions and psychological data reported in the other parts of this study.[8,26]

Finally, changes in body weight were varied from man to man. Thus, one man gained one pound during the eight days of confinement while two of the men each lost four pounds. The mean net change in weight of the six men was a loss of two pounds over the eight days.

DISCUSSION

An overall indication of the major trends can be seen in Figure 3. In addition to the data on heart rate, respiration rate, and electrical skin conductance, the mean urinary norepinephrine excretion[26] has also been included. The scales in the figure have been adjusted to facilitate comparisons. It may be seen that in general all these indices have a high initial value. This would be expected in a new and unfamiliar situation. By Day 2, 3, or 4 all values have decreased from Day 1 as adjustments to the new milieu occur. The introduction of the emergency on Day 5 resulted in a sharp increase in the values of every variable. This would indicate a certain degree of anxiety and a marked arousal pattern. All values fell on Day 6 (except electrical skin conductance which remained steady) indicating some degree of adjustment to the emergency of the preceding day and an attenuation of the anxiety. However, all values on Day 6 remained above their values on Days 3 and 4 (except norepinephrine excretion which was very slightly lower than on Day 3). Heart rate and norepinephrine excretion continued to drop on Day 7. Respiration rate and electrical skin conductance exhibited slight rises.

These findings of Day 7 could indicate that the crew was alert (high electrical skin conductance) and looking forward to the termination of the experiment but physically relaxed (decreased heart rate and norepinephrine excretion). This physiologic state was probably facilitated by a projection of hostilities or aggressions without a great amount of internalization. Unfortunately, physiologic measures could not be obtained for Day 8 due to certain psychometric testing.

The internal environment of a manned space capsule will ultimately become a compromise between the psychophysiologic needs of the crew and the structural specifications and engineering requirements for launching and recovery of the capsule. The present study was an attempt to simulate certain aspects of the environment which one might expect to find in such a capsule. Some studies in this area have structured the environment but, in general, have used a man gratification approach in which life necessities such as food and water are plentiful, e.g., prisons, submarines, ships, et cetera.[1,25,31] Other studies have isolated the individual(s) and more severely structured and controlled the sensory environment, e.g., sealed cabins, flight simulators, "brain washing" and/or "concentration" camps, et cetera.[4,10,13,14,16,21,22] Still other studies have greatly restricted the sensory input or attempted complete sensory deprivation.[2,3,11,17,19,27,28,29,30] Many review articles have recently appeared in this field.[18,23,24,32,33] In any event, most authors appear to agree that man will be exposed to a far greater number of stresses when in space than he has ever experienced before. This interaction of stresses may act both in an additive and in a cumulative manner to the detriment of the crew.

Human limitations are often expressed in terms of only one variable at a time such as man's tolerance to vibration, noise, temperature, decompression, or acceleration forces.[9,12,20] The effects of simultaneous interaction are often not explored. Even when the interaction of several variables is investigated, all pertinent variables have unfortunately not been included. Some, of course, are not readily investigated such as the effects of prolonged zero gravity, cosmic radiations, penetration by microscopic meteorites, or real conditions wherein the subject knows he is facing actual danger and can-not stop the experiment by merely pushing a "panic" button.

There are many uncontrolled sources of "error" in this type of experimentation. The present study was concerned with many phases, i.e., the continuous oxygen regenerating system, temperature, CO_2, and humidity control, the design, functioning and monitoring of the four work stations, emergency communication equipment, leisure activities, and the selection of the "crew" in addition to provisions for food, sleeping, toilet and bathing facilities. Detailed emergency procedures and safety facilities were of great importance. Apparatus and techniques for monitoring the physiologic and psychologic variables had to be worked out. Personnel assigned to develop these various areas must of necessity often work independently of other areas. Under the pressure of time limitations the final integration of all phases is not always compatible.

As a result it was not always possible to adequately control all those external variables that may influence human behavior, performance, and physiologic state. It must be kept clearly in mind that we are reporting data which represents both internal (motivation, affect, skill, experience, practice effect, et cetera) and external factors (temperature, humidity, oxygen concentration, food, chance happenings and the like) which are either beyond control or subject to limited control. Changes and variations in any or all of these conditions could functionally alter the physiologic state and well-being of the crew.

It is considered that only by a broad approach, which includes the sum total and the interactions of its parts, that certain significant problems related to future travel in space will be satisfactorily resolved. This would dictate the need for better control of intervening variables and a more rigid structuring of the immediate environment in future studies.

SUMMARY

The effect of eight days confinement on four bioelectric measures of six men while monitoring a Vigilance Work Station in a simulated space capsule was presented and discussed. Under the conditions of the experiment, it was concluded that the significant differences which occurred in the four physiologic functions (heart rate, respiration rate, forehead skin temperature, and plantar electrical skin conductance) recorded were due to anxiety-provoking stimuli, rather than the confinement *per se*. The interpretation of physiologic measures is discussed.

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