Basic Research Problems in Space Medicine: A Review

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THE PHYSIOLOGIC and psychologic problems of weightlessness become increasingly more important as possible space travel for man becomes more real. This is true because a passenger in an orbiting space vehicle probably will experience weightlessness for practically the entire voyage. Before man can venture into a space vehicle with comparative safety, however, a "pre-explorer" must first prove that the feat is feasible. Since weight will demand high priority in initial space flights, the logical choice for an early passenger appears to be a small primate.

STUDIES OF THE SUBGRAVITY STATE DURING PARABOLIC FLIGHT

Orientation in space is established by means of the vestibular system, vision, and the mechano-receptors. They all react to external forces and inform man about the surrounding environment. Previous investigation on the effects of weightlessness on man has shown that vision and touch are very important for effective reaction.

Early weightless experimentation on man was limited to about twenty seconds. Ballinger[1] in 1952 flew subjects in an F-80 in a Keplerian trajectory. These subjects were able to maintain their sense of orientation by fixing a point of visual reference. Von Beckh[13] in 1954 noted some neuromuscular discoordination during the weightless stages of parabolic flight. Gerathewohl et al[7] in 1957 found that eye-hand coordination was moderately disturbed during the subgravity stage of parabolic flight. For the most part, the earlier experimentation does not indicate general autonomic nervous system disturbances for respiration and circulation. Henry et al[10] in 1952 found no significant cardiovascular or respiratory disturbances in the monkeys in V-2 or Aerobee flights of approximately three minutes of weightlessness. It is feasible that any blood pressure alteration, due to absence of vascular hydrostatic pressure, will be regulated by vascular baroreceptors. The previous investigation suggests that the main problem of weightlessness may be adaptation; that is, the problems of weightlessness appear to diminish if the subject can adapt to the new environment. This assumes that the subject has visual and tactile references.

In the current study, primates of approximately six and one-half pounds were used to study the effectiveness of response under subgravity conditions. Since the response to food, during

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weightlessness, could not be used to determine the motor coordination of the animal, a manual discrimination task with shock avoidance was utilized. The animals were restrained in a laboratory performance testing seat and trained to depress a lever mounted on a panel directly in front of them. The electronics of the system was designed to produce a shock stimulus to the animal if the lever was held down or remained up longer than three or four seconds. The number of avoidant responses in a five-minute period was recorded as well as the number of times the animal was shocked before making the appropriate response.

To obtain the subgravity conditions, the F-94 and T-33 aircraft were used. Approximately forty seconds of virtual weightlessness were achieved at the top of the parabola. Excellent pictorial recordings have been obtained during these flights. The resulting movie films have shown that the animals can perform effectively during these periods of weightlessness. To detect when and how long the animal was experiencing subgravity conditions, a sweep-second clock, a G-meter, and a tube containing a number of balls were placed in such a position that the camera recorded their movement as well as the animal's performance.

Future experimentation will involve a training program for the trained primate since it appears that one can adapt to subgravity conditions. Counting instrumentation has also been mounted on the performance testing seats used in the subgravity tests. This will aid in determining whether the effective performance of the primate does improve with experience. A higher speed aircraft (F-100) will also be utilized in place of the F-94. This should produce longer periods of virtual weightlessness.

The results of these tests should provide valuable information concerning the adaptability of small primates to weightlessness. High G-stress studies on primates are also being carried on. Therefore, if the animal can perform effectively under predicted high G-stress as well as under weightlessness, one should be able to determine the effectiveness of the animal in orbital flight at all times.

BIO-PACKS FOR SATELLITES

Life Cells.—Completely sealed, self-contained capsules for small animals may serve as experimental models for future development of sealed cabins designed to carry humans in space vehicles for extended lengths of time. Information obtained from such animal capsules not only will be of considerable aid from a physiological standpoint but will help in the design, development, and improvement of environmental engineering equipment.

Self-contained capsules less than 0.5 cubic feet have been developed to maintain several mice for at least five days. These capsules, including instrumentation, can withstand high acceleration and will function under gravity free conditions. Data and equipment have been provided to insure survival of mice specifically with respect to (1) a self-contained automatic oxygen supply, (2) proper carbon dioxide water vapor absorber, (3) adequate circulation of capsule air, (4) adequate combination of feeding and water device, (5) proper positioning and suspension of the mice to withstand high accelerations in any direction, and (6) monitoring of capsule oxygen tension as well as capsule pressure, temperature, and acceleration.

Parallel with the studies on the sealed capsule for mice, similar work has been conducted on primates. These studies have provided the information and data, along with the development of the equipment and instrumentation that are necessary to insure the survival of the completely isolated primate and at the same time to monitor from a distance the physical environment and physiological condition of the animal. So far, the experiments have been conducted on rhesus monkeys enclosed in self-contained capsules ranging from six cubic feet to less than two cubic feet in size. Physiological and psychological studies on the primates have been carried out so as to simulate missile launching, orbiting, reentry into the atmosphere, and pick-up.

Electrocardiographic, respiratory, and psychomotor data have been collected on both mice and primates under sub-orbital conditions.

Aspects of Respiratory-Metabolism Problems in Space Vehicles.—Whatever the type of animal selected for such space studies may be, the environmental conditions have to be as close to normal as possible. Also for any trip longer than a few hours, adequate food and water supply has to be provided. In order to exclude any side effects, which may be erroneously interpreted as effects caused by space factors, the respiratory-metabolic requirements of the selected animals have to be known.

While data on respiration and metabolism of most of the laboratory animals are available, almost no data can be obtained on monkeys. For this reason, studies on three types of monkeys, namely, squirrel monkeys, rhesus, and young chimpanzees were carried out. This required partially new techniques. Squirrel monkeys, for instance, require much water to drink and the male animals usually urinate outside an ordinary cage. This led to the construction of a special metabolic cage built from plastic material. This cage provided water supply which could not be splashed and also prevented loss of urine. For determination of oxygen consumption and the respiratory quotient, a closed system was used. This system consisted of a large metal cylinder (barrel) in which the animals could be enclosed and the cylinder was then sealed by a front cover lid. An air pump circulated the air in a loop which included a Beckman oxygen and carbon dioxide analyzer. These instruments measured the decrease in oxygen and increase in carbon dioxide up to such levels where the metabolic rate was not yet influenced. A special cage was necessary in order to transfer the chimpanzees from their usual cage to the barrel and to prevent damage of the barrel by this strong animal. The results of these studies are presented in Table I. The

TABLE I. OXYGEN CONSUMPTION PER 100 GRAM OF BODY WEIGHT OF THREE SPECIES OF MONKEYS

(A mixed diet was used resulting in a value for RQ between 0.75 to 0.85)

Species (Three Each)	Body Weight (Kilograms)	Oxygen Consumption in Liters/Day per 100 Grams of Body Weight
Squirrel monkey	0.460- 0.560	2.57-4.02
Rhesus (Macaca Mulatta)	2.270- 3.180	1.76-3.52
Chimpanzee	11.80 -14.10	1.12-1.65

fluctuation of the values of oxygen consumption is due to the difference in body weight and various degrees of muscular activity, as they occur even in a relatively small cage.

Besides assisting in providing sufficient supply of oxygen, food, absorbents for carbon dioxide and water vapor and other factors necessary in actual space vehicles, such metabolic respiratory values may assist to develop equipment under simulated space cabin conditions in the laboratory. The results obtained on primates may help to clarify some questions pertinent to man.

Recording of Nystagmic Electro-oculogram in the Monkey for the Detection of Motion Sickness During Space Flight.—The efficiency of a spaceman in a spaceship depends on his physical and mental integrity. Disturbances of this integrity would handicap his physical performance as well as his judgment, calculation, decision and other mental functions and may lead to disasters if they happened at a critical moment. The success of a space flight, therefore, depends on the evaluation and subsequent elimination or compensation of these disturbing factors. One of these factors is the change of angular acceleration which is known to cause motion sickness.

Since motion sickness is a subjective feeling, its evaluation is fairly difficult even in man. A man can verbally state the occurrence but can hardly describe accurately the degree of the motion sickness. It is even more difficult to evaluate this feeling in the animals since they cannot communicate with man. However, it is a necessity to test the safety of space flights with animals before a man can be put into orbit. This leads to the old problem of detecting subjective feelings in the animal with objective means. Fortunately, the nystagmic eye movements are closely associated with this type of motion sickness. Therefore, investigations were undertaken to develop a reliable technique of recording nystagmic eye movements.

The method of recording electro-oculograms was first tried on human subjects because of the ease of commanding human subjects to move their eyeballs at any given direction. The recording electrodes were made of silver discs used in conventional EEG recording. The discs were reduced to two-thirds of their original diameters. A half-inch segment of silver wire was soldered to the convex surface of each of the silver discs. A plastic electrode holder was made by molding a plexiglass ring around the left orbit of a manikin. A soft sponge rubber ring was glued to the under surface of the plastic mold. Four holes were drilled through the mold, and carefully positioned so that one pair was close to the right and left canthi to hold the electrodes for horizontal recording and another pair at the edge of the upper and lower eye socket for vertical recording. The silver discs were placed inside the rubber sponge ring and the silver wires were inserted through the holes in the electrode holder. As the silver wires were freely movable in the holes it was possible to attach the silver discs to the skin with a more or less constant pressure due to the elasticity of the rubber sponge ring. Each of the silver wires was soldered at the free end to a lead wire. The lead wires were fixed to the plastic holder in order not to pull on the electrodes. The lead wires were then bundled together into a metallic shielding sheath which was also connected through a fifth lead wire to a silver plated metallic ear clasp. The ear electrode was used as the common ground lead for all the ocular electrodes. The plastic electrode holder was held like one half of a goggle against the frame of the eye socket with fine plastic tubings looped around the ears. The pressure of the holder against the eye socket was adjustable by loosening or tightening the ear loops.

The eye movement potentials were led into the conventional Sanborn ECG oscillograph. The horizontal and the vertical movement potentials were recorded separately on two channels of the recorder. This set-up was found satisfactory for recording the gross voluntary eye movements. It was found that additional amplifiers were necessary to record the smaller nystagmic potentials.

The use of goggle type of electrode holder was found unsuitable for monkeys because of the extreme facial movements and also of the vestigial ear lobes. Moreover, the electrodes must be so attached to the monkey's head that the monkey is unable to remove them by hands if this type of recording should finally be used in space studies in which other lines of research require the freedom of the monkey's hands. A mask made of heavy fabrics was first made to fit to the monkey's head and silver disc electrodes were sewed to the inner surface of the mask. The positioning of the electrodes was modified. The position of the vertical electrodes was unchanged. The horizontal electrodes were placed so as to allow one at the left temporal and one at the right temporal canthi, and a middle one on the ridge of the nose between the two eyes. The central electrode was used as the common ground electrode. In the present arrangement, the potential obtained from horizontal eye movement was essentially double that obtained from electrodes placed at the two canthi of one eye. Besides this advantage, the replacement of the ear lobe electrode prevented the monkey from poking off the ground electrode. The leading wires from the electrodes were sewed to the inside lining of the mask and bundled into a common ground shield which was led to the back of the monkey's head. The monkey was placed and fastened into a specially designed seat. The seat was bolted to a spinning table. A cathode-follower amplifier was specially designed to relay the electric potential by way of the slip-rings of the spinning table to the amplifier-recording system. This method was proved to be very satisfactory. A number of nystagmic electro-oculograms were obtained. A typical record shows the electro-oculogram obtained before, during, and after the circular rotation of the monkey toward the left side at a rate of 11.5 rpm for twenty-six seconds. Immediately after the beginning of the rotation there were only three distinguishable nystagmic eye movements with the quick phase toward the left (same direction as the rotation). With continued rotation, the nystagmic eye movements disappeared. Immediately after cessation of rotation, a longer lasting series of nystagmic eye movements appeared. The rate was approximately .7 per second or one cycle per 1.5 seconds. The direction of the quick phase was toward right, or opposite to the direction of rotation. With rotation rate slower than 10 rpm we were unable to obtain consistent nystagmus. It thus appears that 10-11 rpm is the lowest rate that nystagmus can be obtained.

Another record shows the electro-oculogram obtained before, during, and after rotating the monkey toward the left at a rate of 20 rpm for 22.5 seconds. Immediately after the rotation had started, well defined nystagmic eye movements appeared for about thirteen seconds. The rate and amplitude were small at the beginning and the end. During the maximum amplitude period, the rate was approximately three per second with the quick phase towards the direction of rotation, that is, the left side. During continued rotation, the nystagmic eye movements gradually diminished in amplitude and finally disappeared completely. Immediately after the cessation of rotation, nystagmic eye movements appeared again for at least thirteen seconds. The amplitude appeared to be maximum at the beginning and diminished with time. The rate varied from five to two per second. The quick phase was towards the opposite direction of rotation, that is, towards right.

With higher rate of rotation (35 rpm and 40 rpm) the nystagmic eye movements lasted for a longer period than those just described. It is therefore concluded that the threshold rotation required to initiate nystagmus in the monkey is about 10-11 rpm. Rotation above this rate will invariably produce nystagmus.

For the preparation of the present method to be used in space flight studies, the leading wires from the electrodes were protected from the monkey's fingers by covering these wires with a foam rubber sheet of quarter inch thickness. Three pieces of the rubber sheet were cut to cover all of the five leading wires and were glued to the scalp of the monkey with a special adhesive. The durability of the electrodes as well as the fixation of the leading wires were tested by setting free the monkey in the cage after the experiments. It was found that the electrodes as well as the leading wire with the rubber sheet remained in position after the monkey had been free in the cage for forty-eight hours. It is concluded that this method would be suitable for use in detecting motion-sickness of the monkey during a space flight.

Physiologic Instrumentation of Man During Flight.—In spite of the rapid advance in aeronautical engineering, little has been done to develop medical instrumentation which would be suitable for unattended use in single-place, high-performance aircraft. Of the myriad of data which could be sampled, it was decided to concentrate on obtaining the most useful information for which adequate technics had been developed. Of major importance in evaluating the man's performance is the measurement of blood pressure (both systolic and diastolic) and his pulse rate. An automatic recording sphygmomanometer was developed which functions as follows: The arm is encircled with a conventional blood pressure cuff or a special thin cuff for use with a pressure suit. Below the cuff a sensitive microphone is mounted in a position where the Korotkov sounds are best heard by auscultation. The cuff is inflated rapidly to a predetermined pressure and then the pressure is allowed to bleed down linearly. Both of these functions are accomplished by a miniature cam actuate valve system. As the cuff deflates, the Korotkov sounds and the cuff pressure are recorded on an airborne oscillograph and/or telemetered. The sounds picked up by the microphone are passed through a filter which allows only those sounds in the Korotkov frequency range to be recorded. A ballast tank between the cuff and the pressure transducer reduces any spurious pressure fluctuations.

This system has the advantage in that it records the blood pressure in the same fashion as is used by the clinician, and thus the records are comparable to the normally accepted values for blood pressure. The use of the band pass filter successfully eliminates extraneous noise to the extent that excellent records have been obtained of a man running on a treadmill. The rapid inflation and deflation of the cuff serve to minimize any inconvenince caused the pilot.

To assess both the respiratory frequency and the minute volume, a standard three-wire thermopile has been modified. This unit is placed in the inspiratory circuit of the oxygen hose and faithfully senses both frequency and total flow. The heating of the wires is kept far below temperatures which would be hazardous with oxygen. The unit described fits standard Air Force oxygen hose connections. A unit has been fabricated which will fit the hose connection of a pressure suit. It would be valuable to know the subject's oxygen consumption and carbon dioxide output in each case. To measure these gases polarographic techniques are used.

To evaluate changes in regional blood flow under varying gravitational states, an electronic impedance plethysmograph has been developed. Currently the unit is being miniaturized for airborne use.

DISORIENTATION IN PILOTS

Disorientation in flight must be due to physical and psychological causes which lead to particular effects in predictable ways.[8] Theoretically at least, it should be possible to explain every occurrence in which the flyer is disoriented. Practically, this presents almost insuperable difficulties partly because of the paucity of information which can be obtained in relation to these occurrences and partly because of the complexity of the underlying psychophysiological mechanisms.[5]

Two basic causes of disorientation aloft are the linear and angular accelerations to which the flyer is subjected. The effects of these forces on the otolith organs and semicircular canals are of particular interest. Studies on the function of the otolith apparatus have been handicapped by the lack of a specific indicator. The oculogravic illusion as an indicator has been exploited and recently the phenomenon of counter-rolling of the eyes has been investigated utilizing a new method of measurement.[9,14] The amount of roll was determined in five subjects when tilted laterally in a tilt chair and exposed to a change in direction of resultant force on a centrifuge. By keeping the direction of force incident to the subject the same on tilt chair and centrifuge, it was possible to compare effects for similar directions but different magnitudes. When the amount of the roll was plotted as a function of the incident angle, the curves depicting these values were divergent. But when the amount of the roll was plotted against the magnitude of force acting laterally on the body (head), a single curve was obtained which was linear within the range of 1 g. These findings are in accord with current theories on the functioning of the otolith apparatus and emphasize the value of counter-rolling as an indicator.

The angular accelerations to which the flyer is subjected aloft may cause disorientation not because the accelerations are greater in magnitude than are ordinarily encountered but because their patterns are different. Thus the temporal separation of angular acceleration and deceleration may produce aftereffects when a flyer comes out of a prolonged turn. The underlying mechanism and the resulting symptoms are similar to those which may be experienced when a period of rotation at constant speed (zero angular acceleration) is allowed to intervene between angular acceleration (start) and angular deceleration (stop).

Another unusual pattern is the Coriolis acceleration which is generated by rotations simultaneously in two planes. Immediate interest is directed to problems which may arise in connection with space travel. The connection is indirect and requires explanation. In orbital flight the state of zero G will present such difficult problems for engineer and biologist that it may be decided to create an artificial field force by causing the satellite to spin. In this circumstance any movement of the head out of the plane of rotation will result in a Coriolis acceleration.

Coriolis accelerations cause disorientating effects not only because of the postural and visual illusions produced but also because of the unpleasant symptoms produced. The term "canal sickness" has been used in referring to these symptoms inasmuch as they are precipitated solely as a result of stimulation of the sensory endings in the semicircular canals.

The resulting symptomatology would depend on the angular velocities of the satellite and the movement of the head, and the susceptibility of the subject. Systematic studies employing Coriolis accelerations have not been numerous. One reason for this lack has been the difficulties involved in constructing a device in which a person could be subjected simultaneously to angular rotations in two planes. Such a device has been recently completed and installed at the U. S. Naval School of Aviation Medicine. With this device it will be possible to investigate the effects of carefully programmed patterns of Coriolis accelerations over a wide range.

PHOTOSYNTHETIC GAS EXCHANGERS AND RECYCLERS IN CLOSED ECOLOGICAL SYSTEM STUDIES

The long-range study of the closed ecologic system is in part directed to the trapping of solar energy and radiant energy for the needs of man and the complete and continuous recycling of biologic materials within a spatially restricted and closed environment. The ideal closed ecologic system should supply sufficient quantities of oxygen, food and water. It should also have provisions for the uptake and recycling of carbon dioxide and other waste products produced by man or crew in an extraterrestrial environment.

Studies are being conducted which involve the recycling of the atmosphere in a closed environment through exchange as that of the human being—that is, an evolution of oxygen and concurrent uptake of carbon dioxide. To date, all experiments involving biologic gas exchange have been centered on several species of simple, microscopic forms of plant life collectively called *algae*. The choice of algae as the photosynthetic gas-exchanging organisms, over higher forms of plant life, was made because the former groups are easier to manipulate from a mechanical standpoint and also exhibit the highest photosynthetic rates yet measured in any group of plants.

Several models of what we can call photosynthetic gas exchangers have been designed and successfully operated.[6] Succintly, each photosynthetic gas exchanger consists of a sealed animal cabin, a gas pump for recycling the atmosphere in the closed environment, and a suspension of algal cells growing in a fluid nutrient medium. Visible light for the photosynthetic process is provided by either fluorescent or tungsten lamps. The atmosphere is pumped from the sealed animal cabin into the algal suspension as a stream of relatively small bubbles; after the gas has passed through the algal cell suspension it is recycled back to the sealed animal cabin. Consequently the cyclic movement of gas not only provides the animals with oxygen, but also furnishes a source of carbon dioxide required by the algae for their photosynthetic activity.

Photosynthesis and growth of all species of algae are controlled by two important conditions of light intensity and carbon dioxide concentration. If a given species of alga in fluid suspension does not receive sufficient quantities of visible light, its rate of growth becomes severely limited. If, on the other hand, each cell in the algal suspension is saturated with light (that is, the light intensity is high enough to permit the maximum photosynthetic rate), light is no longer a limiting factor for growth and oxygen evolution. Studies performed on the green alga *Chlorella pyrenoidosa* at 250°C. show that light saturation is achieved at about 500 foot-candles. Studies performed with a high-temperature *Chlorella* (Strain 71105) and with the blue-green algae *Anacystes nidulans* and *Synechocystis* sp. grown at about 39° C. show that light saturation is achieved at higher intensities of about 900 foot-candles. Because of the very high light absorption by these plant cells and the relatively low intensity at which light saturation is reached, special problems arise, involving design of the photosynthetic gas exchanger; for example, a suspension of cells containing 10 gm./liter will absorb approximately 97 per cent of the incident light at a thickness of 0.4 cm. If this cell suspension is illuminated from both sides, a thickness of 1.0 cm. will become light saturated. Thus, with a culture of *Chlorella pyrenoidosa* growing at 25° C. at a concentration of 10 gm. of cells/liter, an illuminated surface of 23 eq. M. containing some 230 liters of algal suspension would be required to maintain one man in a sealed environment. However, other strains of algae grown under different conditions should be able to produce equivalent amounts of oxygen with considerable reduction in the quantity of cells and space in which they are grown.

The rate of growth of algal cells is also a direct function of the over-all concentration of carbon dioxide in equilibrium with the fluid phase of the photosynthetic gas exchanger. Concentrations of carbon dioxide ranging from 0.1 to 5.0 per cent will produce maximum growth and photosynthetic rates. Obviously, in order to permit maximum oxygen generation by a photosynthetic gas exchanger working as an integral part of a closed ecologic system the carbon dioxide content must be at a level of 0.1 per cent or somewhat higher.

The studies concerning the provision of atmospheric recycling by means of photosynthetic gas exchangers for small animals have been centered around two basic designs. The smaller of the two photosynthetic gas exchangers consists of an algal chamber in the form of a double condenser of glass. An inner annulus contains about 340 ml. of the working algal suspension. The algal chamber is illuminated with a total of sixteen 60-watt lamps. The animal chamber, which houses one mouse, consists of a 250 mm. desiccator provided with water from an external flask and food in the form of coarse pellets for the maintenance of the mouse for approximately one month in the closed state. More detailed description of this photosynthetic gas exchanger generates approximately 1200 ml. of oxygen which provides for the aerobic respiratory requirements of a small mouse and, through the photosynthetic process, takes up an equivalent amount of carbon dioxide from the sealed environment. This system has been operated in a closed state for periods of up to one month at which time the experiment was terminated by choice.

Another design of a considerably larger photosynthetic gas exchanger has been in operation over an extended period of time. This unit, described in greater detail elsewhere,[12] consists of a rectangular Plexiglas tank, which contains fifteen liters of a liquid algal suspension illuminated by one internal bank and two external banks of daylight fluorescent lamps. The atmosphere from a Plexiglas animal cage which contains from four to eight mice is circulated through the algal suspension by means of a gas manifold placed at the bottom of the algal tank. By constantly recycling the gas within this closed system it has been possible to provide adequate quantities of carbon dioxide for the photosynthetic process of the algae and oxygen for the respiratory requirements of the mice for periods of up to one month. The maximum quantity of oxygen produced by this photosynthetic gas exchanger when operated with the alga *Synechocystis* sp. at approximately 39° C. on the three banks of fluorescent lamps is ten liters of oxygen per day. More recently one of the external banks of fluorescent lamps was replaced by a battery of 100-watt tungsten lamps. The increased light intensity from the tungsten lamps increased the rate of photosynthesis twofold; that is, the rate of oxygen production was increased to approximately twenty liters per day.

Past models of photosynthetic gas exchangers are not considered adequate in design for efficient gas exchange at a high rate and on a large scale. Essentially, the relatively low yield of oxygen for the volume of algal suspension in the large photosynthetic gas exchanger can be accounted for by the failure to achieve light saturation as the algal culture approaches a density of 1 per cent cells by volume. Greater cell densities cause mutual shading of the algal cells to such a degree that the total amount of incident visible light reaching the average cell is far below the saturation level; consequently, the over-all photosynthetic rate is reduced.

Several alterations in photosynthetic gas exchanger design are now being undertaken and considered in order to overcome the effect of mutual cell shading in dense cultures. Since the photosynthetic mechanism is a two-phase phenomenon (that is, a very short light phase followed by a considerably longer dark phase), it is conceivable that dense fluid cultures of algae of up to 10 per cent or greater by volume can give peak photosynthetic rates if the cells can be maintained in a high state of turbulence or agitation. In theory, at least, thick fluid cultures of algal cells rapidly agitated by streams of gas, fluid pumping, or mechanical agitation should alter the position of the cells in a time cycle of such short duration that the constant repositioning of the cells in and out of the field of light will permit all of the cells to receive sufficient light saturation. Therefore, as a consequence of turbulence, it should be possible to grow thicker cultures of algae over extended periods of time. This method of growth should reduce the over-all bulk and weight of the photosynthetic gas exchanger required to recycle the atmosphere in a closed ecologic system.

Other provisions which are now being planned for future photosynthetic gas exchangers are: (1) maintenance of a relatively constant algal cell density in order to achieve a steady-state condition of cell synthesis and gas exchange, (2) development of geometric designs which will more readily permit the units to operate under extraterrestrial conditions, and (3) utilization of solar radiation for the energy requirements of photosynthesis.

Only a few species of algae have been studied in relation to their use for photosynthetic gas exchange in a closed ecologic system. New species of algae, which either have not been studied or isolated, might prove more desirable, as photosynthetic organisms, than those currently in use. Such new species should embody a number of characteristics—not all of which are found in present forms. Some of these essential characteristics are as follows: (1) grow cleanly to high cell concentrations without clumping or sticking to the walls of the algal chamber, (2) release a minimum amount of surface-active materials which cause foaming, (3) be able to use urea as a source of nitrogen, (4) exhibit a wide range of temperature tolerance, (5) exhibit tolerance to a wide range of salt and ion concentrations in the liquid medium, (6) be easily harvested from the algal tank by sedimentation or centrifugation, (7) be nontoxic and serve as a source of nutrition to the human, and (8) have high photosynthetic and growth rates.

A program involving the isolation of a large number of new strains of algae is now in progress. In particular a certain amount of stress is being placed on the isolation of thermophilic algae which in theory should exhibit very high rates of photosynthesis. Fourteen new strains of thermophilic algae have been isolated as unialgal cultures; each thermophilic strain isolated to date grows rapidly at 55° C. and possesses a number of the essential characteristics previously listed. A larger number of thermal tolerant algae have also been isolated but have not been screened for particular characteristics at this time.

Other studies involve the growth of algae, lichens, and mosses collected from arctic regions which may be used in photosynthetic gas exchangers operating at relatively low temperatures or as an integral part of a closed ecologic system in which such plants could grow with less need for water as compared with the algal system. A number of arctic lichens and mosses have been grown over an extended period of time in a refrigerated incubator held at 8.0° C. and illuminated by means of a fluorescent lamp. The ability to grow these plants successfully will soon lead to a series of experiments involving the photosynthetic gas-exchange efficiency of lichens and mosses at low temperatures.

If a completely closed ecologic system is to be developed and operated in the future, it will have the basic requirements of recycling not only the atmosphere but also liquid and semisolid waste materials. If such a complete recycling of all materials can be accomplished, then all of the essential materials required to maintain a human in a sealed system can be provided. Steps are now being undertaken to recycle semisolid waste in the form of feces and fluid wastes in the form of urine into the algal system. Present studies in this area involve the utilization of feces and urine by algae in small pilot tube studies. The blue-green alga *Synechocystis* sp. has been grown successfully on a combination of fecal salts (obtained by incinerating fresh feces at high temperature) and an added nitrogen and carbon source. It is therefore apparent that feces produced by a man or space crew can be recycled in part into the photosynthetic gas exchanger. Although utilizable nitrogen has not been obtained from feces treated in this manner, other experiments show promise that dilute raw urine or urine which has passed through ion exchangers can furnish a nitrogen source in the form of urea, for some species of algae. Since it is known that man excretes products of nitrogenous metabolism in the form of urea, this aspect of recycling waste materials in a closed ecologic system appears promising.

Future investigations are envisioned as centering on the utilization of algae as a possible source of food in a closed ecologic system. Because of the large and continuous harvest of algal cells produced in the photosynthetic gas exchanger, the cells must be recycled in the system or else they will represent an ever-increasing reservoir of unavailable carbon and nitrogen compounds. Although some have suggested the algae may be rapidly oxidized as a type of organic fuel and thus furnish a part of the kinetic energy required to operate a closed ecologic system, a more satisfactory utilization of the algae would appear to involve their use as food for man. The latter choice is the more inviting because of the high protein and carbohydrate content of the algal cells.

The long-range implementation of the closed ecologic system most likely will not only require algae and other plants as recycling agents but also require a multiplicity of other biologic, chemical, and physical processes in order to produce, on a limited scale, the balanced biologic conditions which have existed on our planet for millions of years.

SURVIVAL OF TERRESTRIAL ORGANISMS UNDER EXTREME ENVIRONMENTAL CONDITIONS

The prospect of extraterrestrial explorations has inspired a number of investigations dealing with the possibilities either of life on other planets or the effects on living organisms exposed to physical forces and physical agents in case of accident aloft.

Beischer[3,4] has reviewed some of the pertinent literature and presented theoretical speculations of his own. He points out that terrestrial life structured on the carbon atom and water molecule makes frequent use of a number of basic molecular structures as the tetrapyrrol ring, adenine, and desoxyribonucleic acid. He notes that a different assortment of basic structures formed during the biochemical period of evolution would lead to much different forms of life. He also suggests that the cell might survive hypoxia and even anoxia by conversion from respiration to fermentation with, however, a loss of higher structural identity of the cell. Currently, Dr. Beischer is studying the growth of yeast in magnetic fields of high intensity and has found that it produces a noticeable effect on the sprouting process.

In another study, Beischer and Born[2] exposed cold-blooded animals resistant to anoxia to ambient pressures equal and below the vapor pressure of their body fluid at room temperature. They concluded that the boiling phenomena under these conditions may be described as accelerated surface evaporation without bubble formation and denaturation of the colloidal structure of the plasma. The chief damage to tissues exposed to extremely low ambient pressure is caused by water loss with ensuing dehydration and freezing of the tissues. Morris and Beischer[11] have investigated the tolerance of invertebrates and small vertebrates exposed to high accelerations while immersed in water. They found that *euglena gracilis* survived exposure to 250,000 g for six hours. Small fishes survived 10,000 g for thirty seconds and mice 1300 g for sixty seconds.

In other studies, mixed populations of soil bacteria (including spore and vegetative forms, strict anaerobes and aerobes, and facultative anaerobes, and others) were exposed in modified Brewer anaerobic jars to certain environmental conditions hypothesized to be present on the planet Mars.

From the biologic aspects, the principal environmental conditions for consideration are temperature, pressure, moisture, gas composition, soil type, and radiation. Each of the aforementioned factors, with the exception of radiation, can be readily reproduced under laboratory conditions.

The following ranges of factors have been studied: (1) Atmospheric pressure: 65 mm. Hg, (2) Moisture content: 1 per cent (or less), (3) Atmospheric composition: commercial nitrogen gas, (4) Soil type: red sandstone, lava soil, (5) Temperature range: 25 to −25° C. (nocturnal-diurnal). It is realized that limits established for the experimental conditions are not precisely those ranges established by the specialists but we believe they approach the true conditions clearly enough to be valid.

The above listed conditions are produced on a small scale in modified Brewer anaerobic jars. The jars containing the specimens are evacuated and flushed with nitrogen gas several times to remove residual atmospheric oxygen. They are then filled to 65 mm. pressure with commercial nitrogen. To simulate the nocturnal-diurnal temperature fluctuation, the jars are held at room temperature (approx. 25° C.) during the daylight hours and are placed in a freezer (at -25° C.) during the night. No attempt has been made to simulate the factors of infrared and ultraviolet radiation. Soil types are simulated by employing red sandstone which is relatively high in the iron oxide, and red and black lava soil obtained from the Arizona Painted Desert. Moisture content of the soils is controlled by desiccating the soils under controlled conditions and adding water to the desired level. The results obtained in preliminary studies in which the soils were inoculated with a mixed population of soil microorganisms including spore and vegetative forms of anaerobic and aerobic bacteria, yeasts, fungi, and actinomycetes, have recently been reported. The inoculated soils were exposed to the simulated conditions in some experiments up to 10 months with periodic bacterial analyses accomplished on aliquots of the exposed soil.

As expected, the population reproportioned itself in time with a gradual loss of the obligate aerobic forms (both bacteria and fungi) with a proportional increase in the anaerobic and facultative anaerobic forms. The greater percentage of the survivors were found to be divisible into three rather specific morphologic forms as follows: (1) a highly pleomorphic, nonsporeforming organism tentatively identified as Corynebacteria, (2) a thin, short rod which as yet has not been classified, and (3) a spore forming organism showing the morphologic characteristics of the Clostridia. The first two forms are facultative anaerobes while the latter form is an obligate anaerobe. In addition to this, an increase in total numbers of these organisms was observed. This would indicate that these forms are not only capable of surviving but also capable of growing.

The results obtained in the initial studies have been confirmed and studies are being continued with other bacterial forms and with bacteria which have been isolated after surviving for ten months or longer in the initial exposure experiments. In addition, a screening and selection program for the purpose of obtaining higher forms of terrestrial life which may be capable of surviving under conditions simulating Martain atmosphere has been initiated. These studies are currently limited to algae, lichens, and mosses. These simple forms of terrestrial life are known to exist under relatively adverse environmental conditions and are found under all terrestrial conditions. It is highly probable that certain species of each will eventually be found which can tolerate the simulated Martian environmental conditions.

So far, the studies have been limited to the rather academic problems of determing the survival and multiplication of simple forms of terrestrial life under similated Martian atmospheric conditions. While the results obtained from these studies are not surprising to the biologist, they are important in that they show for the first time that terrestrial living forms can exist under a combination of certain of the conditions considered to be present on the planet Mars.

Parallel with these studies experiments are being conducted on mice in an attempt by the process of selection to obtain a colony that will grow and reproduce at extreme altitudes.

As for the practical aspects of such studies, the ultimate goal is to determine if various forms of terrestrial life can not only survive and multiply but also contribute some produce or perform some function required to support man in specific extraterrestrial environmental situations.

PHYSIOLOGICAL ASPECTS OF TRAINING AND SELECTION FOR MANNED EXTRATERRESTRIAL FLIGHTS

This selection is concerned with two phases of experimental research, designated as "Mt. Evans I" and "Mt. Evans II." The purpose of this research was to study the critical frontiers of a man's performance capacity before and after he had been well conditioned by physical and altitude training. The experimental volunteers were subjected to a variety of very demanding situations most likely to occur during space flights of the future, such as extreme altitude, heat, carbon dioxide accumulation, physical exhaustion, water loss and food deprivation, etc. In each of these situations the functional reserves and the physiologic limitations were evaluated. The results obtained in tests and retests, and the experiences made, can be basically applied to the eventual procedures of training and selecting crews for extraterrestrial flights.

During the Mt. Evans I phase of studies, the seven-man research team was first physically trained for the high metabolic requirements expected in the mountains. Work capacity tests were performed to pick up the improvements in functional and metabolis reserves. Then the team moved into Colorado's Rocky Mountains. A period of six weeks was spent at altitudes ranging from 10,000 to 14,000 feet. A mobile low pressure chamber and a mobile laboratory provided the hardware facilities for the experimental work.

The investigations included studies on five different brackets of interest:

1. Correlation between the partial denitrogenation at various altitudes and the occurrence of decompression sickness in a standardized chamber test at 38,000 feet of simulated altitude.
2. Effect of the altitude acclimatization achieved upon altitude tolerance and time of useful consciousness at critical levels of hypoxia.
3. Effect and usefulness of a special pressure breathing training during altitude acclimatization for raising the absolute ceiling, the subjects breathing oxygen under positive pressure but being unprotected by special garments.
4. Tolerance for increased levels of carbon dioxide before and during altitude aclimatization.
5. Increase of functional and metabolic reserves estimated from cardiovascular and respiratory measurements and from biochemical analysis.

In the Mt. Evans II phase of the studies, two members of the same research team spent a ten-day period in a sealed environment, simulating some of the conditions which, physiologically, might be encountered during travel in extraterrestrial vehicles. From the physiologic standpoint, it was hoped to learn how subjects, being four weeks off the mountains, would adapt to living at altitudes in excess of 14,000 feet, how they would tolerate heat, high humidity, and/or accumulation of carbon dioxide; what protection they would have against bends during acute ascents to altitudes in excess of 40,000 feet, or how fast they could put on a pressure suit in an emergency situation with relatively fast decompression. It was hoped to ascertain how subjects would get along with each other under the heavy strains encountered, and how they would tolerate the uncooked canned food and lukewarm drinks. The experiences to be gained with various types of water vapor and carbon dioxide asorbents were considered important.

Seven volunteer subjects participated in the Mt. Evans I phase of study. The ages ranged between twenty to fifty-one years with a mean of thirty-three and 3-tenths years.

Studies on Partial Denitrogenation as Prophylaxis of Decompression Sickness.—The susceptibility to bends and chokes was tested at a simulated altitude of 38,000 feet. The use of physical exercise (namely, five deep knee-bends performed at regular intervals) produced in all control experiments severe symptoms after relatively short time. Third-degree bends or chokes, forcing descent, occurred after an average time of eighteen minutes during the control tests at Randolph Air Force Base (barometric pressure of approximately 747 mm. Hg).

After three to four days of living at an altitude of 10,000 feet (B=525 mm. Hg) third-degree bends were not observed. Second-degree bends occurred after an average time of fifty minutes. The pains did not reach an intolerable level, forcing a descent.

By relocating the subjects to a lower level of altitude, averaging about 6,000 feet (B=625 mm. Hg), the partial renitrogenation again resulted in forced descent after an average time of fifty-three minutes. Two days at an altitude of 14,160 feet (B=455 mm. Hg), on the other hand, provided almost full protection against bends. During that test, only two subjects experienced very slight, easily tolerable pains which disappeared toward the end of the one-hour test.

The protective effect of the partial denitrogenation at an altitude of 14,000 feet was also confirmed in experiments in which the subjects were exposed to altitudes between 42,000 to 56,000 feet for a total time of thirty to forty minutes. The activity during this type of exposure was equivalent to the work involved in piloting a plane. There were no symptoms of decompression sickness. Comparative experiments at sea level had shown that four to six hours of breathing 100 per cent oxygen did not offer complete protection against decompression sickness.

Altitude Tolerance.—The highest level of simulated altitude at which the subjects became unconscious was determined before and during altitude acclimatization. In the control tests the critical altitude of the group was 24,000 feet; at the end of the acclimatization period the tolerable level was raised to 30,000 feet.

During the fifth week of the mountain episode, the time of useful consciousness was tested at simulated altitude levels of 25,000 and 30,000 feet. All subjects suddenly exposed to the oxygen pressure equivalent of 25,000 feet stayed alert for a period of thirty minutes. The decrement of neuromuscular coordination, tested on a coordination apparatus, was less than 10 per cent. From the two subjects suddenly exposed to the level of 30,000 feet, one stayed conscious for five minutes, the other subject for a total of thirty minutes. Normally, man will become unconscious within two to three minutes at this altitude.

Ceiling Tests.—The most critical testing procedure to evaluate the maximum of tolerable altitude included the breathing of oxygen under positive pressure without the use of protective garments. All subjects were conditioned by a special training of forced breathing as a part of the general physical training. The test was accomplished by lowering the chamber pressure to an equivalent of 44,000 feet within ten minutes, and holding it there for a period of five minutes during which time the coordination test was performed. Then the altitude was increased in steps of 2,000 feet, allowing two minutes for the ascent and three minutes for leveling off at each new altitude. From the start of the experiment, the subjects were breathing 100 per cent oxygen through a tightly fitted A-13 oxygen pressure demand mask from a D-II oxygen regulator. The experiments were not carried out to a critical level of hypoxia or to the maximum pressure breathing capacity but were terminated upon the individual's request. Thus, the individual's judgment was also tested under borderline conditions compatible with life.

Five subjects, not different from the "normal man" in the Air Force but well conditioned by extensive physical and altitude training, reached the average level of 55,000 feet, breathing against a positive pressure exceeding 15 mm. Hg for more than thirty minutes with a maximum of 35 to 40 mm. Hg pressure for about five minutes. The inadequacy of the A-13 pressure demand mask for pressures above 20 mm. Hg required great efforts to hold the mask tight to the face and, therefore, affected the coordination test. With more extensive training, proper altitude acclimatization, and adequate pressure breathing equipment the safely tolerable ceiling could be advanced to 58,000-60,000 feet (which had been experimentally proven before).

Sensitivity to Carbon Dioxide.—The objection was raised that acclimatization to high altitude, paralleled by a chronic hyperventilation, would alter the sensitivity of the respiratory center to carbon dioxide to such an extent that a slight accumulation of CO_2 in a sealed environment would interfere with the performance capacity of an acclimatized man more seriously than with that of a normal man.

It was found, in fact, that the pulmonary ventilation of the acclimatized man is more readily stimulated by carbon dioxide. The ventilatory response to a given increase of inspired CO_2 is greater by 10 to 30 per cent. But for the acclimatized man this additional ventilation does not mean a much greater effort because he has become used to larger ventilatory volumes and has increased his maximal breathing capacity. Increasing CO_2 concentrations in the inspired air stimulated the pulmonary ventilation during light steady-state work of the same intensity under normal conditions at normal atmospheric pressure and at an altitude of 14,000 feet in acclimatized men. The higher sensitivity of the acclimatized man to increased dosages of inspired carbon dioxide may lead to an earlier detection of unsatisfactory CO_2 absorption, leaving more time for countermeasures.

Functional and Metabolic Reserves.—The work capacity, a measure of "physical fitness" or of cardio-respiratory reserves, had improved during the course of the preparatory physical training by about 25 per cent. In general terms, the original performance level of the group, on the average was "fair," but this was considered as slightly substandard. The retest after the training period revealed an increase of performance capacity to a level which almost deserved a grading of "very good." Comparative studies had shown that during such a training the glucose reserves of the human body had increased by 50 per cent and that, in addition, the organism "had learned" to utilize its fat deposits more readily.

Unfortunately, during the mountain episode, biochemical research had to be dropped because of an accident involving the biochemist of the research team. Empirically, however, the progress made in increasing the metabolic reserves during the training at altitude could be assessed from the longer and longer periods of hard work sustained by the men without rest and food intake. Initially only one and one-half to two hours of continued hikes and climbs were tolerated. As time progressed, such workouts were extended to periods of six to nine hours before about the same degree of fatigue or exhaustion was experienced.

In addition to the physiologic data obtained in this study, many observations were made on variations in motivation, on psychologic stability and instability, on the individual reactions to unfamiliar and demanding environment, to relative isolation, and to some restrictions of normal living habits. The eagerness to meet the challenge of the mountains as natural obstacles, or the challenge provided by some heroic experiments or by physical exertion; the willingness to "serve" voluntarily despite depressing fatigue and hypoxia; the crew disicpline; the significance of habits as smoking, et cetera—all these and more qualities presented themselves within a few days of living and working at high altitude.

The Mt. Evans II phase of the study occurred four weeks after return from Mt. Evans. Two members of the research team began a ten-day experiment in a "sealed environment." This experimental study had a multiple purpose, namely, to study a variety of physiologic stress situations and their effects on well-conditioned and previously altitude-acclimatized men sealed off in a small cabin at simulated altitudes between 14,000 to 20,000 feet. For this experiment, the mobile low-pressure chamber was utilized. Standing outside the permanent laboratory in the open air, the chamber was protected against the direct radiation from the sun by a large tarpaulin cover. During the hottest hours of the day the chamber walls were cooled by tap water.

Effective Altitude.—As soon as the chamber door had been closed behind them the two men were completely on their own. One of their main tasks was to control the environmental conditions within the limits of tolerance. The oxygen and carbon dioxide content of the chamber air was measured by a Beckman oxygen analyzer and a Liston-Becker CO_2 analyzer, respectively. Because of the continuously changing pressure, the instruments had to be recalibrated for each measurement. The chamber pressure was read from a large aneroid barometer. The pressure changed continuously because of a slight leakage in the chamber seal, because of the amount of oxygen consumed and supplied, and because of temperature changes. The leakage, causing an increase in barometric pressure of 10 to 15 mm. Hg per hour, was of no concern to the effective level of altitude since the increase in pressure was more than compensated for by the decrease of the inspired oxygen tension due to the oxygen consumed by the two subjects. The effective altitude was regularly calculated as the product of the barometric pressure and the oxygen concentration. The barometric pressure was regulated at the desired level by a small laboratory vacuum pump which was installed on the outside of the chamber but activated from the inside by an electrical switch. Oxygen was fed from the oxygen supply lines of the chamber to a large rubber bag and from there it was passed through a dry gas meter into the cabin. Thus, the amount of oxygen supplied was measured periodically.

With the exception of the first two nights, the effective altitude was kept at a level above 14,000 feet. During the first night, the altitude was lowered to 11,000 feet because both subjects experienced severe headache and nausea. During the second night the adaptation to high altitude was much improved but the restlessness, so typical for hypoxia during night time, prevented the subjects having refreshing sleep. Lowering the effective altitude to 13,000 feet provided satisfactory comfort. On the following days and nights the altitude was maintained at levels above 14,000 feet. Gradually, it was increased up to 20,000 feet for several consecutive hours.

The entire procedure of checking and controlling the chamber environment required, routinely, twenty minutes out of every hour. Frequently, additional checks were made. The mental work involved in making the accurate measurements and the necessary calculations is comparable to that of a navigator. It therefore served as a test of mental alertness.

Absorption of Carbon Dioxide and Water Vapor.—The carbon dioxide and water vapor, given off by the two subjects in amounts varying with the type of work performed, were absorbed by lithium hydroxide. For comparison, a combination of granulated soda lime and Drierite ($CaSO_4$) was used during one twenty-four-hour period but it proved much less effective than LiOH. The absorbents were spread out in about ¾ inch layer on two window screens. Air circulation was provided by two electric fans.

On days when both subjects remained relatively quiet, ten pounds of

LiOH absorbed carbon dioxide and water vapor for a period of thirty-six hours with satisfactory efficiency. On days in which more physical work was performed the same amount of LiOH had to be replaced after a period of twenty to twenty-four hours. At that time the CO_2 concentration in the inspired air had increased to 1.5 to 2 per cent and the relative humidity was close to 90 per cent.

Exceptional care had to be taken in replacing the LiOH. Almost invisible dust clouds formed despite very careful handling of the material and these dust clouds were most irritating to the respiratory tract. The work of changing the absorbent and of cleaning up afterwards usually required forty-five to sixty minutes. For this work, long rubber gloves were worn. The amount of water pouring out from the gloves after the work was done reflected the work and heat stress during these manipulations.

The CO_2 concentrations of the inspired air were usually about 0.4 to 0.8 per cent. The relative humidity varied between 70 to 90 per cent. The cooling of the chamber walls from the inside caused considerable condensation of water on the outside and assisted in keeping the relative humidity at the level mentioned. The water was wiped off at regular intervals.

Chamber Temperatures.—The chamber temperature varied between the minimum of 26° C. and the maximum of 36° C. with an average of 29.5° C. for the entire ten-day period. Temperatures below 26.5° during the night were considered as "cool" by the resting individual. Temperatures up to 30° C. were "comfortable," between 30 to 32° C. a "slight discomfort" was noticeable, and a real strain, mostly due to the immense sweating rate, began at temperatures above 32° C.

General Physiologic Reactions to Altitude.—The beneficial effects of acclimatization to altitude on the tolerance for hypoxia usually recedes within four to eight weeks after return from the mountains. Daily one-hour exposures to simulated altitudes of 14,000 to 18,000 feet, however, can maintain the high level of altitude tolerance achieved in the mountains. That procedure was followed by the two subjects during the four weeks before entering the chamber for the ten-day experiment. As a result, a simulated altitude in excess of 15,000 feet was tolerated during the first day despite temperatures between 32° and 34° C. and a relative humidity up to 85 per cent. However, because of the combined stresses, both subjects suffered gradually increasing headaches and became slightly nauseated. To counteract the discomfort of these symptoms and to provide some recovery from the daytime stresses, more oxygen was added to the chamber air to such an extent that, by keeping the chamber pressure at 444 mm. Hg or equivalent to 14,000 feet, the effective altitude was lowered to 11,000 feet.

From the second day, altitude was maintained above the level of 14,000 feet. On the sixth day, a total time of twelve hours was spent at a simulated altitude of 16,000 feet, on the following day altitude was increased to 17,000 feet for several hours, and on the ninth day neither subject objected to being exposed to an average altitude of 20,000 feet for a period of eight hours. The subjective well-being as well as the performance tests indicated good altitude tolerance—as long as the subjects followed their routine activities. Respiration, of course, was slightly increased but regular. As soon as a man stretched out on the bunk bed, however, and began to doze, breathing became very irregular, and the periodic fighting for air interfered severely with rest and sleep. At these high altitudes slight to severe headache usually developed after a short period of resting in a supine position. Frequently the pains were lessened after sitting up and starting any type of a light activity. An increase of the oxygen content in the inspired air did not always help.

An observation was made which might be important in considering the optimal pressure within a sealed cabin. On the seventh day, several hours were spent at an effective altitude of about 18,000 feet, with the chamber pressure around 380 mm. Hg and the oxygen concentrations between 20 to 21.5 per cent. When in the evening hours subject B attempted to sleep, a severe headache occurred, accompanied by distressing periodic breathing pattern. Oxygen was added to the chamber air, reducing the effective altitude to a level of 14,000 feet but keeping the chamber pressure at an 18,000-foot equivalent. There was no relief from the pains. Subjectively, the subject felt that the air was stagnant and humid, despite the circulation of sufficient air by the two fans. Suspecting that the air density might play a role, he increased the chamber pressure from 380 to 430 mm. Hg but regulated the oxygen level so as to keep the effective altitude at the 14,000-foot level. The more effective air flow from the two fans was felt immediately, the headache disappeared after several minutes, and breathing resumed a more normal pattern.

The physical work in the chamber consisted of the following activities: (1) periodic checks of the chamber environment with the corrective actions, (2) changing the chemical absorbents for carbon dioxide and cleaning the chamber—including wiping the condensed water from the chamber walls; (3) neuromuscular coordination tests, (4) simple calculation tests in which speed was essential and which, therefore, were more of a physical than a mental strain; (5) practice of donning a pressure suit and helmet in the shortest possible time, (6) collecting physiologic data, and (7) occasional bicycle riding.

The metabolic gas exchange of a few of the routine activities was determined experimentally; the basal metabolic rate was in the range of normalcy with 1.2 cal./min. For the activity of instrumentation a value of 1.8 cal./min. was found, and the neuromuscular coordination test required 2.6 cal./min. Changing the chemical absorbents or donning the pressure suit under the crowded and hot chamber conditions was more work than expected, the latter requiring an oxygen intake of about 1,500 ml./min. or an equivalent of slightly more than 7 cal./min. That was almost as much work as the occasional work on the bicycle ergometer requiring an oxygen intake of about 1,700 ml./min. or an energy expenditure of 8 cal./min.

An estimation of the total expenditure of energy during the 10-day experiment averaged approximately 2,500 cal./day per subject.

The food supply was stocked according to each individual's taste and estimation of needs. Only about half of the supply was finally used. The occasional nausea, the almost total loss of appetite, and a change in taste as a consequence of hypoxia were the main factors for the reduced food intake. The experience of both subjects was that the best means to fight nausea and loss of appetite was to chew on salty dried beef. Surprisingly, there was a temporary aversion against sweet foods and drinks.

An estimation of the total energy supplies gave an average figure of 1,600 calories per day per person. The average daily deficit was approximately 900 cal./day, or a total of 9,000 calories within the ten-day experiment. The body weight loss of each subject averaged eight pounds, half of which can be explained by the compensating energy supply from the body tissue, the other half being a loss of body fluid.

The water loss was excessive on several days. Because of an aversion against lukewarm chlorinated water and, at altitude, against some of the canned juices, the fluid intake was far below the requirements. A mixture of two-thirds of water plus one-third of unsweetened red wine was found to be the best liked and tolerated beverage.

In addition to the shortcomings of the energy and water balance, there must have been a profound change in the electrolyte balance and, as an effect of the chronic hypoxia, a decrease of the buffer capacity of the blood. One subject frequently experienced spontaneous muscle cramps during the last two days in the chamber and also for a few days afterwards. During the first days of the experiment, both subjects observed edema around the ankle after many hours of sitting in a cramped position. All these experiences demand further biochemical investigations.

During daytime, both subjects were on an experimental schedule for twelve hours. The night hours were divided into shifts of two to three hours' duration. From the first day, the men did not get the amount of sleep they had hoped for. There were many reasons for this lack of sleep: heat, hypoxic restlessness, stiff and sore muscles caused by many hours of sitting, a narrow and uncomfortable bunk bed, increasing sensitivity to light, et cetera. Each subject averaged only three to four hours of sleep during each of the twenty-four hour periods. The best time for sleep was found to be in the morning hours after 0400 either because of the lower temperatures around that time or because of the eventually progressing neuro-vegetative relaxation. It might be mentioned that at no time were drugs used to stimulate alertness; not even the normal "coffee-break" was taken.

Headache and nausea on the third and fourth day were apparently provoked by the increasing unpleasantness of odors. During the first four days, all the urine was pooled in one big bottle, the cover of which was not tight enough to prevent odors from escaping. In addition, the odor of the feces, collected in plastic bags and stored away in a drum container, penetrated the plastic material. The use of commercial deodorant was found to make the situation worse.

After all the excretions had been removed from the chamber through a chamber lock on the fourth night, the urine, henceforth, was individually collected in tightly sealed bottles of plastic material, and two teaspoons of activated charcoal was added to each feces bag and also, everytime, to the storage drum. General spraying of deodorants was discontinued. From that time on, odors were practically absent. This was confirmed by "neutral" observers after the chamber experiment was terminated and the door reopened.

Subjectively, mental performance appeared to be sluggish during periods of more severe hypoxia to which adaptation was still inadequate. Also, the lack of sufficient sleep and the general stiffness and soreness caused by sitting for many hours in a cramped position on a very uncomfortable chair resulted in sensations of mental as well as of physical fatigue. Although the routine work of monitoring the chamber environment and since the daily calculation test were hardly affected, it was necessary to put forth extra effort when doing additional scientific reading or when planning and preparing metabolic experiments or other physiologic measurements not previously scheduled. As altitude acclimatization progressed, both subjects became more interested in collecting additional research data, and mental alertness, whenever required, was unimpaired.

Neuromuscular coordination increased slightly but steadily during the first days, reached a peak on the fourth and fifth day, and then sloped downward. It is questionable, however, if this impairment was caused by the individual's fatigue or by "apparatus fatigue" due to very high humidity: There was more resistance of the moving parts and some electrical contacts became very unreliable. For this reason, the test was practically invalid on the eighth day and had to be discontinued. Although repair measures on the apparatus were discussed, physical work involved in moving a few pieces of heavy equipment to provide for an access to the trouble spots was considered as too great a strain at this stage of experimentation. Similar work had been done on the third day and was still remembered as painfully hard labor. That withdrawal from a task considered possible and essential permits a better assessment of the state of physical fatigue than any of the other tests.

The most severe environmental conditions were encountered on the last day of the ten-day experiment when stress resistance of both subjects should have been hitting a low. At an effective altitude of 16,000 feet, carbon dioxide, humidity, and temperature were allowed to accumulate. When chamber temperature reached 36° C., relative humidity 92 per cent, and the inspired CO_2 concentration 4.5 per cent, the enormous sweating rate caused great discomfort but circulatory and respiratory reserves were only slightly affected. Unfortunately, a cold spell, unusual for that time of the year in Texas, terminated the heat stress experiment unexpectedly. Attempts to counteract the effect of drop in outside temperature by more rigorous exercise on the bicycle ergometer failed. Despite a high energy expenditure for a period of thirty minutes the inside temperature dropped to 34° C. The relative humidity, on the other hand, rose to almost 100 per cent and the carbon dioxide content to 5.5 per cent. Five hours later when the carbon dioxide level reached 8 per cent, the temperature had fallen to 31° C. and the subjects were in good physical and mental condition. When at this point a chamber clean-up was attempted, however, the increase in physical activity caused an unexpected respiratory and cardiovascular response. Within thirty minutes the pulmonary ventilation increased to maximum and the rise in pulse rate and blood pressure also indicated impending limitations in the CO_2 tolerance. Intense efforts were required for making the last physiologic and environmental measurements before putting on the oxygen masks.

Immediately after termination of the previous experiment the chamber pressure was lowered to a simulated altitude of 40,000 feet for a Bends Test. During a period of two hours at that altitude no symptoms of dysbarism were experienced, confirming the earlier findings that natural denitrogenation at altitude levels of 14,000 feet and above for a number of days results in satisfactory protection for decompression sickness.

The same experience was made during a fast decompression to an altitude equivalent of 50,000 feet with a consecutive stay there for a period of forty minutes. This test was performed mainly to test the usefulness of a normal pressure suit in an emergency situation during space travel. Under the given situation it took both subjects a time of eight minutes to complete the donning of their pressure suits while the decompression, starting at an altitude of 15,000 feet, progressed at a rate of 4,000 to 5,000 feet per minute. Since oxygen had to be supplied immediately, the helmet was put on first and slightly pressurized against fogging; the sealing of the garment's neck parts was thus made especially difficult and strenuous. As a consequence of the muscular efforts involved, one of the subjects noticed first- to second-degree bends pains in fingers, disappearing toward the end of the forty-minute exposure.

Psychologically, no definite observations were made. Subjectively, the two subjects felt that the confinement to the very primitive and odd chamber interior had no effects on their spirit. Boredom was not experienced. Any free minute was either utilized for "relaxation" or for technical or entertaining reading, especially during the night shifts. It was no problem for these two subjects to get along together for ten days in such a tiny compartment: The mutual respect and regard and the readiness to serve and help each other at any moment were rather accentuated under the more severe stress situations. Anxiety and fear, of course, did not enter into this type of earthbound experimentation. It is felt, however, that many *specific* situations causing anxiety and fear can be anticipated, and therefore, also be made a matter of training. Any experienced pilot, or deep sea diver, or mountaineer, et cetera, might agree with this hypothesis.

Experimental evidence exists that the human organism has a great capacity to adapt to "superhuman" requirements of biologic nature. With proper conditioning and training, each man can achieve his own maximum of adaptative capacity physically, mentally, and psychologically. Since the limitations of these capacities are not known before considerable efforts have been made to increase the psychosomatic reserves, the selection of an eventual space crew becomes possible only after such special efforts have been made. There are, certainly, numerous ways for proper conditioning and training. For the experimental research reported in this review, simple methods were utilized successfully. These methods also might be effective to increase G-tolerance. For a pre-adaptation to the state of weightlessness, exercises requiring highly developed neuromuscular coordination and spatial orientation might be considered helpful.

The ultimate in adaptive capacities of man still has to be sounded out. In the future more emphasis will be turned toward studies of man's ability for cross-adaptations and tolerance for combined stresses.

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Flying Hazard Following Dental Anesthesia

The reporting flight surgeon in a recent JD-1 accident points out the potential danger of flying too soon after dental work. Although it was not a contributing factor in this case, the pilot in question took off immediately after dental treatment involving the use of a local anesthetic. His mouth and lip were still numb. Often it is difficult to predict the degree of discomfort which will be experienced after an anesthetic wears off. Meanwhile, the numbness can seriously affect speech and radio transmission.—Notes from Your Flight Surgeon: *Approach*, November 1958.