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Psychophysiological Aspects of Space Flight

Drugs, Space, and Cybernetics: Evolution to Cyborgs

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A wanderer is man from his birth.
He was born in a ship
On the breast of the river of Time;
Brimming with wonder and joy
He spreads out his arms to the light
Rivets his gaze on the banks of the stream.

As what he sees is, so have his thoughts been.

"*The Future*" *by Matthew Arnold*

Man must first conceive that which he would create. Viewed from a cosmic time scale, today we fumble and crawl, having barely crossed the threshold of existence; because a rattle responds when we shake it, we are swollen with instant pride and label ourselves "masters of the universe." We have not yet even learned to conquer disease, we are ignorant as to the basic nature of electric, magnetic, and nuclear forces—of the very nature of force itself. We can only communicate with each other in the most inarticulate fashions, and we do not know how to create life. Our presumption is even greater than our ignorance: when we cannot understand something we call it UNKNOWABLE MYSTERY or ULTIMATE. The Epimetheans among us then cry "sacrilege" when the problem is even approached. As if God's infinity were but a finger's grasp beyond our own limitations!

Participant Evolution. The challenge of space travel to mankind is not only to his technological prowess, it is also a spiritual challenge to take an active part in his own biological evolution. The great scientific advances in the years to come may be utilized to permit existence under environments radically different from those provided by natural circumstances today. This task of adapting his body to whatever milieu he chooses will be made easier by increased knowledge of homeostatic functioning, the cybernetic aspects of which are

just beginning to be investigated and understood. It is also likely that through a study of his psychological and physical needs in unusual environments a clearer understanding of man's needs in his home environment will be found.

In the past, the altering of bodily functions to suit different environments was accomplished through evolution. From now on, at least in some degree, this can be achieved without alteration of heredity by suitable biochemical, physiological, and electronic modification of man's existing modus vivendi.

Homeostatic mechanisms found in organisms are designed to afford a stable operation in the particular environment of the organism. Three examples of some successful alternate solutions provided by biological mechanisms to the body-environment problem, with regard to operating temperature, are man, hibernating animals, and poikilothermic fish (organisms with blood that takes on the temperature of the environment).

Various biological solutions have also been developed for another regulatory problem: respiration. Mammals, fish, insects, and plants have each a different biological solution with its inherent limitations but eminently suitable for its field of operation. Should there be a desire for an organism to live outside its field, an "insurmountable" problem exists. The problem, however, is only apparently insurmountable. If a fish wanted to live on land it could not readily do so. If, however, a particularly intelligent, dissatisfied fish could be found who had studied a great deal of biochemistry and physiology, and who was a master engineer and cybernetician and had excellent laboratories, this fish would be able to design an instrument that would allow him to go on land and breathe air quite readily. To what degree this instrument would resemble lungs is an interesting question which we clearly cannot answer today because we are not as intelligent as this fish would have to be. However, it is apparent that we will have sufficient knowledge in the future to design our own instruments to make it possible for our bodies to do feats no less difficult than breathing on land would be for a fish.

The environment wished for by man at this present stage of development is that of empty space. Biologically, what are the changes that would be necessary for man to live adequately in such surroundings? The solution of artificial atmospheres encapsulated

in smaller or larger enclosures is only temporizing. It is also a dangerous temporizing, much as it would be dangerous for the fish to take a small quantity of water with him to live on land. The bubble all too easily bursts.

The Problems. In the following pages some of the biological difficulties which others feel exist in respect to space travel are reviewed, as well as some new problems. Two sets of possible answers are furnished. One provides solutions which probably could be devised with presently available knowledge and techniques. The others are projections into the future which, by their very nature, must resemble science fiction. To illustrate, there are possibly much more efficient ways of carrying out the functions of the respiratory system than by breathing, which in space is cumbersome. One proposed solution for the not too distant future is relatively simple—don't breathe!

Even though they offend terrestrial common sense, eventualities predicted of space travel, such as time distortion, will be hard realities, and resultant physiological and psychological conditions must be considered. We must consider not only flights of days, months, or years, but also journeys of several thousand years' duration.

The New Frontier. If man attempts a partial adaptation to the conditions of space instead of being insistent that he carry his entire environment with him, a number of new possibilities appear. One is led to ask what are then the biologic changes that would have to be made in his homeostatic mechanisms for man to be able to live in space *qua natura*?

Cybernetic Aids for Space Life. The autonomic nervous system and the endocrine glands cooperate in man to maintain the multiple balances required for his continued existence. They do this without conscious control, although they are amenable to its influence. The necessary readjustments of these automatic responses and levels under extra-terrestrial conditions require the aid of control theory as well as extensive physiological knowledge.

What are some of the devices necessary for creating self-regulating man-machine systems? This self-regulation needs to function without the benefit of consciousness, in order to cooperate with the body's own autonomous homeostatic controls. For the artificially extended homeostatic control system functioning unconsciously,

one of us (Manfred Clynes) has coined the term Cyborg. The Cyborg deliberately incorporates exogeneous components extending the self-regulatory control function of the organism in order to adapt it to new environments. If it were necessary for us to continuously check to maintain our heart at the appropriate rate, keep our respiratory rate at approximately 16 per minute, and see that digestion was proceeding with proper peristaltic waves, there would be little time left for other activities. If we also had to adjust these rates upward or downward depending on whether we were doing more or less activity, we would be a slave to keeping the human body functioning. Similarly, if a man in space, in addition to flying his ship must be taking continual checks and making continual adjustments in order to keep himself alive, he becomes a slave to the machine. The purpose of the Cyborg is to provide an organizational system in which these robot-like problems are taken care of automatically and unconsciously, thus freeing man to explore, to create, to think, and to feel. One device helpful toward the construction of Cyborgs, which is already available, is the ingenious osmotic pressure pump capsule developed by S. Rose (1) for the continuous slow injections of biochemically active substances at a biological rate. This Rose osmotic pressure pump capsule is incorporated into the organism and allows administration of a selected drug at a particular organ and at a continuous variable rate (as low as 0.01 ml a day or less), without any attention on the part of the organism.

The whole device can be buried in an animal, which can lead a reasonably normal life while the injection is going on. The mode of force of the injector depends on the osmotic pressure developed by a saturated aqueous solution of Congo red against water. This solution is contained in a partially collapsed rubber compartment and is separated from a second water compartment by a semipermeable cellophane membrane. Water moves by osmosis into the Congo red solution and expands the rubber compartment. It is this expansion which provides the mechanical force to eject the drug out of the apparatus. The pump need be only two and a half times the total volume that it is intended to deliver. The rate can be changed by altering the area and/or thickness of the cellophane which separates the water and the Congo red solution. If blocked, the injector is capable of developing two atmospheres of pressure. This means that

any resistance which develops in the fine plastic tubing going to the site of injection is easily overcome and thus does not alter the rate of injection. The following description is abridged from Rose (1).

Figures 1 and 2 show component parts and assembled apparatus. It consists of three compartments: a drug compartment, a water compartment and a Congo red compartment with a clamp to hold the semipermeable cellophane membrane. When 16.5 square mm. of membrane are exposed the injector delivers fluid at 0.12 ml per diem. However, any desired rate can be achieved by using a suitable cellophane and an appropriate sized hole in the clamp. The Congo red compartment consists of a latex bag of 3.0 ml capacity. Distilled water in the quantity of 0.5 ml and Congo red (.06 gm) are placed in the bag. This makes a saturated solution with 0.52 gm of excess Congo red out of solution. The bag is partially collapsed to remove all the air and is then tied over the clamp. The clamp and latex bag are fixed in the glass ampoule by means of ties which utilize the splayed edge as fixation points. The drug compartment (H) consists of the space between the Congo red bag and the glass ampoule. When the bag expands, fluid is forced out through the nipple of the glass ampoule and is then carried by means of plastic connecting tubing to the desired organ. The water compartment consists of a second latex bag (I) which is tied over the splayed edge of the glass ampoule. This compartment is filled with distilled water either at the time the apparatus is assembled, or later, by means of a syringe and needle when the injector is buried in the animal. The water can now move under a constant osmotic gradient through the cellophane membrane into the Congo red compartment. More dye dissolves and a saturated solution is maintained. The Congo red bag expands and forces fluid containing the drug through the nipple. The whole arrangement is such that at least 2 ml of water can diffuse into the bag. Thus 2 ml of drug will have been slowly and constantly forced through the nipple down the plastic tube to the desired organ. Apparatus is already available which will deliver 0.01 ml per day for 200 days, and there exists no reason why this time could not be considerably extended. The apparatus has been used on rabbits, dogs, large rats, and for continuous heparin injection in man. It should be noted that polythene tubing is superior to stainless steel for needles as well as connecting tubes. No untoward general effect

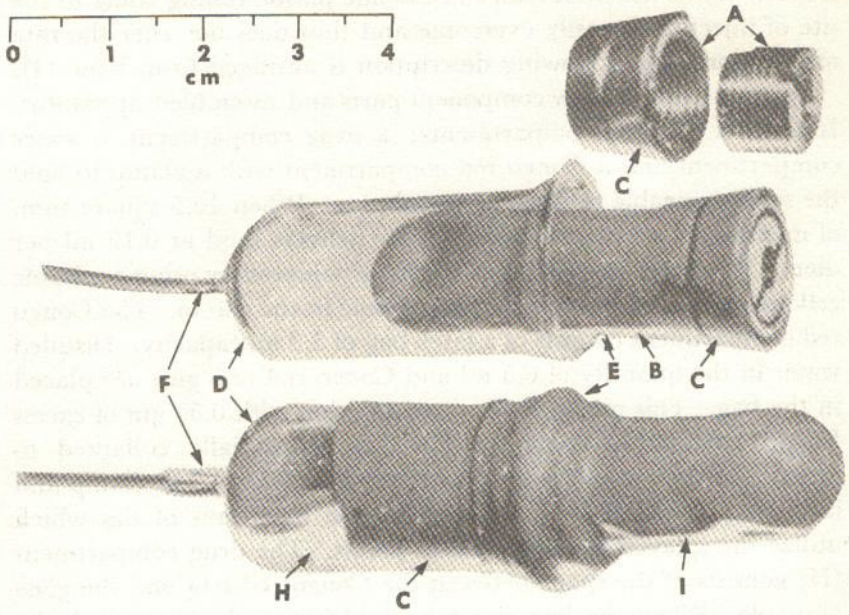

Figure 1. Rose Osmotic Pressure Pump

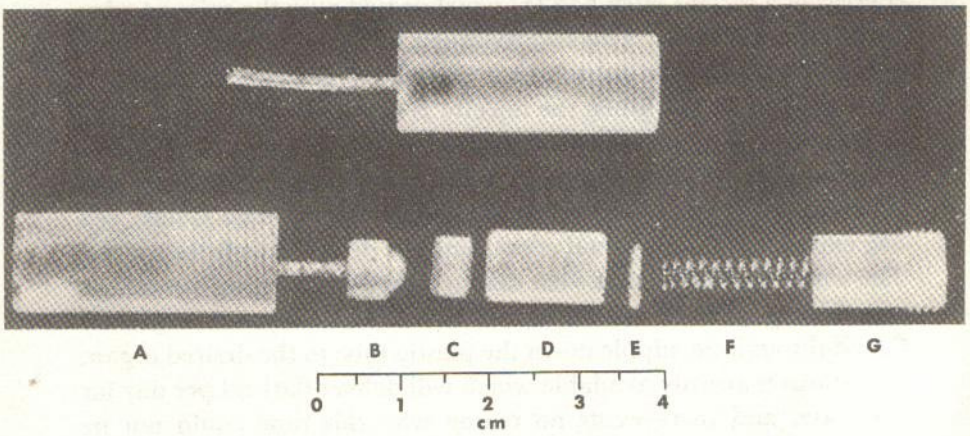

Figure 2. Component Parts of Rose Osmotic Pressure Pump

on the animal's health was noted when the small injector was buried in a large animal. Even five years ago an injector 7 centimeters long and 1.4 centimeters in diameter weighing 15 gms was successfully buried in rats weighing 150–250 gm. Figure 3 shows a rat weighing 220 gm. with an injector in situ (1).

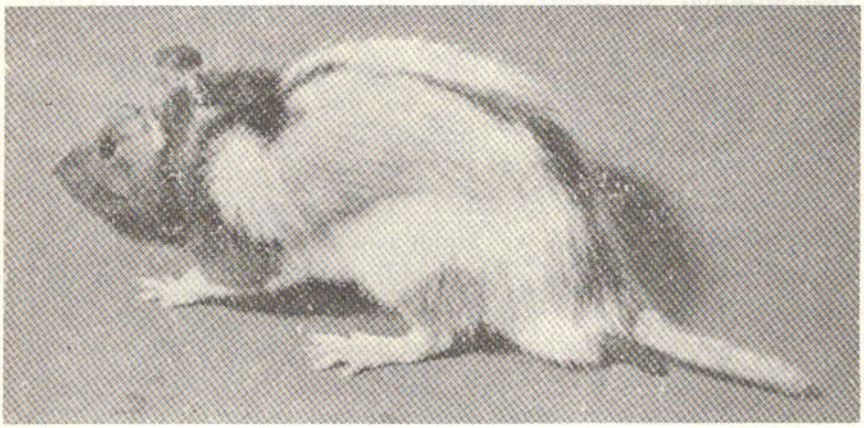

Figure 3. Rose Osmotic Pressure Pump In Situ

The combination of the osmotic pressure pump capsule with sensing and controlling mechanisms can form a continuous machine-man controlled loop which will operate as an adjunct to the body's own autonomous controls. In this way these controls can be changed to the desired performance characteristics under various environmental conditions. Such a system is possible today, with the selection of appropriate drugs. For example, systolic blood pressure may be sensed, compared to a reference value dependent on space conditions encountered, and regulated by letting the difference between the sensed pressure and reference value control the administration of an adrenergic or a vasodilator drug. Of course, it presupposes that we should be cognizant of what the optimum blood pressure under various space conditions should be.

The "Natural" Biological Boundary. How are we to set the upper limits of "natural" human physiological and psychological performance? We can take as minimal the capabilities demonstrable under control conditions such as yoga or hypnosis.

At such institutions as the yoga colleges in India, the human imagination is stretched by the muscular control of which even the average undergraduate is capable. Hypnosis per se may prove to have a definite place in space travel, but there is prior need for much more information about the phenomena of dissociation, generalization of instructions, and abdication of executive control.

We are presently working with a new preparation which may greatly enhance hypnotizability, so that pharmacological and hypnotic approaches may be symbiotically combined.

The Physical Parameters. At the time of this writing a cluster of eight rockets is sufficient to place a 25,000-pound pay load in orbit. As to the ultimate future, we cannot assume a set limit on either pay load or power. It is entirely conceivable that there might exist a space station more than a mile in diameter and capable of creating its own gravitational field. Once established it would be difficult to change the orbit of such a space station, but if properly placed it would be able to traverse a considerable part of the solar system. Under these circumstances it might even be possible for the object to create its own atmosphere. It is rumored that the Russians among others are already operating on such a space station—known as Earth.

SPECIAL PROBLEMS

Wakefulness. On August 2, 1958, Marion "Pat" Boling completed a solo nonstop flight of approximately 7,000 miles from Manila, in the Philippines, to Pendleton, Oregon, in a single-engine Beachcraft Bonanza. Almost the entire flight was made over water, and it was without radio communication for sizable periods of time. Except for a very brief period the pilot was awake for the 24 hours preceding the flight and almost all of the 48 hours during which he was airborne. Upon arrival he was feted and it was almost 48 hours longer before he obtained any substantial amount of sleep. Certainly the conditions of the trip required the highest degree of alertness, involving both clear judgment and full executive control. As a veteran airline pilot Captain Boling was quite familiar with many of the difficulties he would face, and highest on the list of physiological problems was the questions of how to remain awake and alert. It was decided to try one of the group of drugs known as psychic energizers, which

were capable of reducing fatigue and increasing the ability to concentrate.

Preliminary testing was done because of variations in individual sensitivity, latency, and side effects, and since there was no information available as to the effects of altitude with its concomitant change of physiological conditions. Medication was started on May 13 at 3:00 P.M., and total sleep that night occurred between 0400 and 0600. The next night, however, with the same dosage, there was a full night of nine hours' sleep; but, on May 15 there were a total of only two hours sleep again, and on May 16 only one hour. Medication was continued for approximately one more week on half the former dosage without side reactions. It was then discontinued because it appeared to potentiate the Pyribenzamine which had been started for hay fever on May 19. A letter describing the experience states: "During the time I was trying the medication, I never felt any nausea or any of the possible effects you mentioned except possibly a slight headache for a few minutes . . . . I sent the cabin of the plane up to 10,000 feet for several hours and felt, if anything, slightly better than I had in the past."

A preparation containing 5 mg. of amphetamine was provided for emergency use. It should be noted that this dosage of a stimulant is usually quite temporary, and certainly one tablet is an impossibly low dose to counteract marked fatigue for any extensive period when used alone. The pilot continues: "I felt real fine on generally about 3–4 hours of sleep a night and the (amphetamine) worked very well in conjunction with it. There was a very slight drowsiness immediately after taking it, changing to an alert exhilaration within 20 minutes." Essentially the same regime was followed during the actual flight.

For flights up to a few weeks or even a few months it would thus appear desirable pari passu to utilize one of the psychic energizers. If reduced temperatures are used to lower metabolic rate (to be discussed later), the energizers should be tested to determine if they are capable of enabling the individual to retain alertness. It should be pointed out that another possible advantage of a psychic energizer is resultant reduction in physiological and psychological "stress." In a paper which has been submitted for publication (2) there was reported a highly significant decrease in eosinophile count following

cortisone injections after patients were placed on psychic energizers as contrasted with their reaction without such medication. Certainly, the energizers should also be tested for their effect on sensory deprivation, sensory invariance, action limitation, and sensory overload. Because of the increase in nitrogen retention resulting, the energizers, which are also monamine oxidase inhibitors, may also make for more efficient food utilization.

Radiation Effects. There are experts far better informed in respect to chemical protection against radiation than the present authors. We will consider the Cyborg to handle chemical radiation protection. Dr. Walter H. Whitcomb of the Radiobiology Branch of the School of Aviation Medicine at Brooks Air Force Base reported on increase of radiation resistance resulting from combined administration of aminoethylisothioronium and cysteine to monkeys. This is not a complete feedback loop, because there is no sensor to measure radiation protection, but for practical purposes an open loop is adequate.

For the present we must assume that radiation is unavoidable and work toward the development of improved drugs for protection against radiation damage. It would appear most sensible to administer such drugs only during the periods when they are indicated rather than continuously. Here a servomechanism responsive to background count with proper anticipation would be ideal, since a self-regulating mechanism could be retained without the pilot's direct attention and he would be free to carry out some of the other functions which cannot be automatically regulated in this manner.

Metabolic Problems and Hypothermic Control. In view of the estimated consumption of ten pounds a day of human fuel (two pounds of oxygen, four pounds of fluid, and four pounds of food) the supply problem becomes immense even with reutilization of extractory products. Except for hop-skip orbiting the question must be asked as to whether all this consumption is necessary. The purpose of flight is to make certain observations and to carry out certain control functions. In the short flight periods, up to a month or two, through the use of physic energizers and adjunctive medication no more than a few hours a day of sleep would be required in the normal environment. This regime has been tried for periods ranging from a few days to a number of months, and in addition to sleep reduction there is evidence that efficiency increases rather than decreases.

Patients have been on this regime for as long as three years, so that extended usage appears entirely feasible.

For *prolonged* space flight, however, it would appear highly desirable to follow exactly the opposite approach. During a flight of months or years, assuming that the space ship itself was performing satisfactorily, there would be little or no reason for the passenger to be awake unless he were passing close to some interesting object or through some field which required observation. It should not be too difficult to create a system which would arouse the passenger to become a pilot if any of the flight conditions being followed passed outside the safety threshold. Similar arrangements could be made in respect to observational data, so that the passenger could be aroused to become an observer if detection apparatus indicated phenomena worth observing. The psychological advantages of this will be discussed subsequently, but the present relevance is to the possibility of radically reducing the metabolic needs of the organism. Antithyroid preparations which are presently available commercially are not entirely satisfactory. Their use tends to disturb the balance of other endocrine organs, and a number of them appear to possibly be carcinogenic. Ablation of the thyroid would also tend to throw other endocrine organs out of function in addition to producing some of the unwanted effects of hypothyroidism.

At present the most practical solution would appear to be a reduction of body temperature, somewhat in the nature of that used in certain types of heart surgery.[1] Much work needs to be done in respect to determining the nature of metabolism under these circumstance. It is probable that quite different enzyme systems will be dominant. Eventually enzymes and drugs might be used to establish body temperature through a change affecting the brain center controlling temperature rather than through external refrigeration.

The recent brilliant investigations of C. H. Li demonstrate that the pituitary growth hormone acts differently on the brain than on other parts of the body. Mice hypophysectomized shortly after birth died at the end of one month. Although the skull and other organs stopped growing the brain did not, with the result that death was

[1] It would be interesting for experimental purposes to lower body temperature via a vascular shunt in which the blood passes through a miniature thermoelectric cooling device and is returned to the vascular system. C. William Hargens of the Franklin Institute is working with this type of instrument adaptable to small animals.

caused by cerebral compression. The differential action between the brain and the rest of the body suggests some intriguing possibilities. It may be feasible with hormone action to lower metabolism in the rest of the body but to maintain it in the brain so that, although there are over-all reduced food and oxygen requirements, mental activity will tend to be unimpaired. Alternatively, the entire body may be cooled homeostatically, but the brain heated electronically.

The extensive and original work of Dr. William Sacks of our staff utilizing radio-tagged glucose has provided a technique of measuring cerebral metabolism in vivo. He has demonstrated in humans that glucose was not the sole brain metabolite as was at one time widely believed. (There is also a difference between schizophrenics and nonschizophrenics which may open the way to a clearer understanding of the nature of the disease.) It would be most interesting and appropriate to determine changes in glucose consumption and brain metabolism measured in this way under conditions of low temperature.

Presumably hibernation is also under pituitary control, and if the hormone controlling this can be identified and reproduced (or at least accumulated) it becomes possible to reduce metabolism without resorting to external cooling devices. In view of the differential hormone action on the brain relative to the growth hormone it suggests that it may not be impossible to reduce metabolism in the rest of the body by means of the hibernating hormone but to maintain the brain in an alert state.

Oxygenation and Carbon Dioxide Removal. Breathing is an excellent system for metabolism in an atmosphere with adequate oxygen supply and low carbon dioxide content. In space and on other planets atmospheric conditions are all wrong for this purpose. Carrying sufficient oxygen for any length of time is prohibitive in terms of weight (2 pounds a day), and even a closed ecological system is awkward and must allow for major losses due to low efficiency and possible disruption by meteorites.

Ideally, an artificial organ should be provided to replace the lung. Blood should be shunted from the pulmonary artery through a microsystem capable of reducing the CO_2 and adding appropriate quantities of O_2 after which it returned to the pulmonary vein. Theoretically, an inverse fuel cell process might convert the CO_2 to

C and O_2 with the latter remaining in the blood stream. Energy for such a system could be supplied either externally from solar energy or from atomic processes within the system.

Under these conditions breathing would be not only unnecessary but impossible. The mouth could be opened for food intake and speech articulation for limited periods of time. Alternatively, a digestive tract tube (entering through the rectum) or intravenous feedings might be preferable.

Because of the great acceleration at blast-off, it appears possible that if respiration is carried out in the usual manner there will likely be a period ranging from four to eight minutes during which no breathing can be accomplished. One possible solution is prior oxygen saturation, which was discussed some three years ago in a Russian journal (3).

The removal of carbon dioxide during this blast-off period presents a more critical problem but there has been little literature on this subject. The fuel-cell technique possibility would appear to take care of both of these problems.

The reduced (or absent) oxygen and pressure in the space ship also reduces the danger resulting from puncture by meteorites.

Fluid Intake-Output. Even with lowered temperature, the maintenance of fluid balance is a major problem. Following the same general approach as before, we believe that the development of an "adaptive" system should be attempted. It is theoretically possible to reshunt the urine after suitable processing directly into the bloodstream. The greatest problem in utilizing urine as a source of fluid is the occurrence of urea which amounts to 25 to 30 grams a day. If the urine could be fed directly from the ureter through a shunt containing urease, the urea would be converted into carbon dioxide and ammonia. The carbon dioxide could then either be handled by our postulated fuel pump or, if this were not available, serve as a source of substrate for conversion to oxygen by algae. The amount of carbon dioxide produced in this manner would incidentally form an excellent check on the adequacy of kidney function, since the quantity of urea produced is quite stable. Ammonia could be handled by the use of nitrifying bacteria with conversion to nitrates or nitric acid. At the present time this would be largely discard and could not be fed directly back to the bloodstream. On the

other hand, the remaining filtrate could be treated with ion exchange resins and predetermined levels of blood sodium, potassium, chlorides, and phosphates released to maintain appropriate homeostasis. There are unquestionably alternate systems, but even the one proposed here would be portable so that it would not preclude long periods of travel away from a "space womb."

The 7 grams of feces produced daily in fasting man or the 10–12 grams if intravenous feeding is used would be measurably less under conditions of lowered metabolism. Through the use of a miniaturized septic tank, CO_2 would be produced and could be handled in the manner described above. The residual fluid could be again passed through columns and the filtrate containing the trace metals reinjected into the vascular system. By sterilizing the gastrointestinal tract even the 7 grams of feces might be largely eliminated. Appropriate pathogens could be reintroduced when needed as has been done in animals. This would also reduce the possibility of dangerous bacterial mutations which might be produced by radiation.

The absence of breathing will conserve the substantial amount of fluid which is normally lost in this manner so that replacement will be complete, except for a small quantity disappearing through surface evaporation, which would be minimized by a reduction in body temperature and appropriate insulation through clothing and/or plastic coatings suitably applied.

Enzyme Systems. Under conditions of lowered body temperature it is already known that certain enzyme systems would tend to remain more active than others. For instance, those enzymes acting on lipids and lipid derivatives continue to function even at 0° C. (in other words, butter will turn rancid at temperatures that would act to prevent spoilage of other foods). The extent to which pharmaceutical or chemical agents could influence this enzyme activity has not been systematically investigated but, beyond question, will play an important role.

Since the metabolism is subject to the control of the enzyme systems, there exist a number of intriguing possibilities. Following radiation it may be possible to convert certain organisms from aerobic to anaerobic states and by studying the changes in the enzyme systems possibly to adapt them to eventual human use. In the same manner selective atmospheres of other types could be investigated,

as well as the possibility of developing enzymes which would convert CO_2 to O_2 in vivo (as in plants) which would eliminate the necessity for a fuel-cell conversion.

Since many enzymes when crystallized have a charge, there appears to be no reason why they could not eventually be accelerated electronically in a cyclotron, which would give us some idea of possible performance under special condition of space travel. In point of fact, there is no reason to expect the slightest change! If acceleration force exceeds cohesion force changes might be expected, but this bears no relation to speed; relative to distant galaxies we are already traveling better than 50,000 miles per second. Even if the enzymes (or a biological organism of any kind) were to race along at 180,000 miles per second, not only would there be no change, but the organism would be unaware of its speed. Enzymes would be excellent material for testing the biological properties under these circumstances, since it is relatively simple to determine whether they have retained catalytic activity. Speed should have no effect if acceleration is not excessive. Some biologists have questioned whether chronological age and biological age parallel each other. By rapid acceleration of a radio-tagged organism with a known half life it would be possible to compare biological aging and physical time.

Vestibular Function. A possible source of misinformation during space flights might be through vestibular function. At the present time either the astronaut will exist in a situation of weightlessness or the rotation of the space ship could be deliberately increased so that sufficient centripetal force is created to establish a "pseudo-gravity." Even under the latter condition the vestibular organs might provide disturbing misinformation, since any change in distance of the head from the outer shell could upset such adaptation as had occurred. The extremely "primary" nature of vestibular function makes it less adaptable to begin with. The conditions of pseudo-gravity require almost continuous readaptation, while under conditions of weightlessness any random movement of the head is likely to spread the endolymph in an unpredictable manner. The conflict of vestibular sensations with those derived from other sense organs could only contribute to disorientation and probably produce nausea and vomiting.

Rather than depend entirely on pharmaceutical means which reduce sensitivity of the vomiting center, there are a number of alternate solutions. The vestibular organs could be rendered temporarily nonfunctional in a reversible manner by temporarily draining off the endolymphatic fluid or, alternately, filling the cavities completely. This ought to be done well in advance of actual flight, in order to permit the individual to become adapted to a universe without vestibular cues. This problem of vestibular function has also been of concern to the Soviets, since they have reported on alteration of vestibular function both by drugs and surgery with substitution of touch and sight receptors under conditions of weightlessness and tumbling. Streptomycin and a number of its cogeners produce loss of vestibular function as an unwanted side effect in sensitive individuals. Most desirable, of course, would be a procedure whose effects were entirely reversible. The nearest approach to this available at the present time is the introduction into the endolymph of an anesthetizing substance of the cocaine series or paralyzing injections into the vestibular branch of the eighth nerve, but the duration of action tends to be rather limited. Using the Rose osmotic pressure pump administration technique it may be possible to greatly prolong such action.

Hypnosis must also be considered as a means of control of vestibular function, but it cannot be depended upon from present evidence. Some fifteen years ago one of us ran a series of experiments using a modification of the Barany chair (4, 5) in which, under hypnosis, it was possible to induce the nystagmoid reactions characteristic of acceleration and deceleration with the subject in a stationary position. Despite a trance extending to a depth of negative hallucinations, it was impossible to eliminate nystagmus while the patient was accelerating or decelerating. It therefore appears unlikely that hypnosis would eliminate the subjective clues produced by the vestibular organ.

It is also possible that vestibular function will not be a problem at all, but at present we cannot be sure and must be prepared to deal with the contingency.

Cardiovascular Control. At the present time a beginning is being made in the quantitative study of the multiple homeostatic functions of the

cardiovascular system, from a control system point of view (6, 7, 8, 9). In this field the application of control system theory of biology (10) has already yielded some fruitful results. It can be expected that, eventually, enough will be known about the system dynamics involved to make it possible to alter the homeostatic functioning by the Cyborg technique.

By reason of different metabolic needs, as well as haemodynamic considerations, the biologically optimum heart rate and blood pressure under extraterrestrial conditions may be considerably different from that on earth. If a reduced body temperature is maintained, further adjustments of cardiovascular functioning would be necessary to regulate appropriate blood flow. Presently available drugs, which may be used in the Cyborg technique applied to the cardiovascular system, include epinephrine, norepineprine, reserpine, digitalis, quinidine, amphetamine, apresoline, ephedrine, and a host of others. Some of these act on specific portions of the system, while others have a more widespread effect. By a suitable rate of administration of these drugs and hormones through Rose osmotic injectors, cardiovascular functioning can be altered in the required directions through external commands. These commands can be made a dynamic function of the sensed cardiovascular functioning of the organism.

Cyborg technique also envisages the alteration of the specific homeostatic references within the brain. Through this approach, regulation of function might be obtained with a minimizing of expected strain, since in this method the regulated homeostatic level is changed without interfering with the organic control loop itself.

Electric stimulation may replace drug action in certain respects. It may eventually become desirable to regulate heart rate through electric stimulation. The possibility of affecting selected brain centers through appropriate electric stimulation, in order to control cardiovascular functioning, should also be considered.

It is thus clear that, eventually, man will have techniques available to radically change the cardiovascular functions so as to biologically optimize them for the particular environment chosen. Such a step, previously carried out by evolution through selective survival, would now eventuate through the purposeful construction of Cyborgs.

Muscular Maintenance. If prolonged sleep or limited activities are enforced for periods of months or years the maintenance of adequate musculature becomes a real problem. Quite possibly the reduction of body temperature and metabolism may defer this process but it cannot entirely avoid it. Although there are pharmaceuticals which help maintain muscular tonus, one must really understand the chemical reasons for atrophy to develop methods of pharmaceutical protection.

Perceptual Problems. The lack of atmosphere will create markedly different conditions of visual perception than those to which we are accustomed. In all probability it would be most desirable to make observations through a medium which would reintroduce some of the distortions to which we are accustomed, and to which the subject could be acclimated before the flight began. Part of the problem will result from searching for an adequate "frame of reference." In this regard it is possible that the factors which influence autokinesis may have an influence on space problems of perception (5). Whether pharmaceuticals would influence autokinesis has yet to be determined. There is nothing to stand in the way of such investigation at the present time. The effect of tonus-inducing stimuli on visual perception has been described (11).

There are a number of articles, such as that of Yarbus, in the Soviet literature indicating interest on their part in this same area (12).

Pressure. Under pressure lower than 60 millimeters of mercury man's blood begins to "boil" at his normal body temperature. Therefore, if he is to venture out of his space ship without a pressure suit he will have to reduce his normal operating temperature sufficiently so that the vapor pressure of his fluids is no greater than the internal tissue pressures. This is no problem as far as arterial blood pressure is concerned, but it may become problematical for venous blood pressure. This is another in the series of reasons why body temperature must be lowered if we are to avoid constrictive pressure suits. The device previously referred to for the selective cooling of blood might be useful here under special circumstances. The Russians, too, have described "decompression tissue emphysema" (due to vapor formation) in the brain and have found that this can be controlled by the lowering of temperature (13).

Not referred to in available literature on this subject is the presence of cold agglutins which appear to be much more prevalent in certain individuals than others. Since their presence can cause cardiovascular difficulties, the blood of potential candidates for space travel should be tested for this in advance.

Variations in External Temperature. At the real extremes of temperature man will require the protection of a space ship or space station. There are quite likely to be intermediate conditions, however, which are within, or close to, the limits of human tolerance. If pressure is not excessive, oxygen consumption–CO_2 disposal regulated by the mechanism previously described, and internal body temperature lowered it might then become possible for man to walk about relatively unencumbered, except that the absence of an atmosphere would produce almost unbearable contrast between sunlight and shadow. Even in such mundane places as Mexico City or Kabul, stepping from daylight to an enclosure is a surprising experience. With unsuitable enough conditions the part of the body turned away from the sun (or its equivalent) could be in deep freeze while the part turned toward the sun would be overdone.

The same approach to handling this problem could be used for the humans as is used on the space vehicle itself, i.e., the control of reflectance and absorption. This could be in the form of clothing, but, ideally at least, the hands and face should be protected directly so that they need not be encased. There are already in existence pharmaceuticals which produce changes in pigmentation, while substances like para-aminobenzoic acid provide quite effective protection against actinic rays as they reach us here on earth. Needed is a chemically regulated system responsive to incident light as a homeostatic process to adjust to its own reflectance in such a way as to maintain the desired body temperature.

If space travel for weekends on excursion flights ever becomes common, a super-sunburn heat-insulating preparation offers alluring promotional possibilities—"Try Solar-Polar on your next Space Flight"; "Use Planet-Aire, the All Purpose Celestial Cream"; or, "Star-light, the Space Resistant Face Lotion."

Gravitation. The effectiveness of the force available to a biological organism for its own locomotion and for its encounters with other

objects or organisms is a function of the ratio of molecular (f) to gravitational ($\vec{g}$) and inertial forces ($\vec{m}$), i.e., $\frac{f}{\vec{g} + \vec{m}}$. The forces generated during contraction of a single muscle fiber are primarily molecular forces. These are independent of gravitational and inertia effects. The effective relative mobility which they produce is a function of the ratio of the total muscular forces developed to the total inertia and gravitational effects. If we consider organisms of different sizes, such as an ant, a man, and an elephant, it is clear that the available mobility ratio is largest for the ant. The average man can lift his own weight with some effort. The elephant cannot, while the ant, of course, can lift many times his own weight. This is not surprising, since the ant muscle cells are basically utilizing the same molecular forces as those in the elephant muscle cells. To explain this apparently strange phenomenon we may consider a similar behavior pattern displayed by a liquid. In a pail, water is unable to overcome the effects of gravitation and the level rises only at the very edges of the surface. Surface tension, which is a molecular force phenomenon, is effective against gravitation only to a minute degree. If we consider, however, a porous material, the water has no difficulty in climbing up such material to great heights, overcoming gravitational forces. This is merely because the small space of the pores of this material allows the molecular forces of the liquid a greater ascendancy over the much smaller gravitational forces, since the molecules are of fixed size. This illustrates that whenever the ratio of molecular to gravitational forces is changed a considerable change in behavior can result. It is clear that biological size is not an accident, but is in part dictated by an appropriate ratio of molecular to gravitational and inertia forces.

Until now there was no possibility of significantly changing this ratio under the normal living conditions of an organism. Space life alters this ratio by changing the gravitational component while the molecular and inertia effects remain the same. On earth the elephant can run faster than man. On the moon, could man beat the elephant in a race, or would he be left behind even more? The limit of running speed is given by the maximum speed of moving the legs in the opposite direction. With low gravity the legs are relieved of their supporting function and can consequently

concentrate exclusively on their propelling function. The inertia forces the elephant has to contend with in moving his legs are considerably greater than man's even in proportion to his strong musculature, so that man would benefit more from an increase in rapidity of his leg motion. On the moon, or planet X, with reduced gravity, it is likely that man would be able to catch up with an elephant. On the other hand, because of his long and slender legs, the giraffe would be relatively many times swifter than he is on earth.

However, since the inertia forces remain the same, a change in direction would still require similar muscular effort at a given speed. Thus, the general mobility pattern is basically altered.

The molecular forces available are, however, influenced by temperature. It is, therefore, a possibility that for smaller gravitational fields than those found on earth a low body temperature would be desirable and for larger gravitational fields a higher than earth-normal temperature would be optimal. It is here that suitable drugs could be highly useful in establishing a different homeostatically controlled temperature. It may even be possible for a servomechanism to work in conjunction with homeostatic human controls so that the body temperature is automatically regulated by the prevailing gravitational field. In this way the reference inherent in the biological homeostatic temperature regulating mechanism would be adjusted according to the gravitational field prevalent so as to set the temperature of the body at a higher level in strong gravitational fields and at a lower temperature for weak fields. To the already existing biological control loop an additional control loop would be added, designed by man for his better homeostatic operation, i.e., Cyborg. Of course the drugs developed would have to be specific, so that side effects due to change of body temperature would be avoided or controlled. Note that abnormal temperature is not necessarily synonymous with disease.

The body temperature chosen by the evolution of an organism is optimal only in its own gravitational environment. It determines a ratio of molecular to gravitational and inertia forces as well as the speed of biochemical reactions. Thus, the speed of molecular concentration leading to muscle movement is also linked to the speed of molecular action leading to biochemical change. The biological rhythms inherent in a given organism are conditioned by

the $\frac{f}{\vec{g} + \vec{m}}$ ratio as well as diurnal variations. Thus the optimal heart rate, for example, may be significantly altered (for a biological optimum) under conditions of existence different from those found on earth.

Magnetic Fields. In the past there has been relatively little reason for concern with the effects of strong or weak magnetic fields. The nature of magnetic forces and the possible effects they may have constitute two of the unknowns of space travel. We do know that in the Soviet there is a considerable amount of research in this area. In our own country Heller has demonstrated that strong magnetic forces could play a role, and perhaps a quite important one, in biological organisms. If magnetic forces do have an important influence it may be that chemicals and alteration of temperature might act to either retard or facilitate specific effects. At this juncture the most useful action is to identify the problem and indicate which areas are capable of investigation.

Sensory Invariance and Action Deprivation. It is a truism that asking the proper question constitutes a large portion of the answer. The search for phlogiston occupied several centuries because of an inappropriate conceptualization of the problem. It may well be that current research in "sensory deprivation" may lead to a good deal of fruitless research if caution is not exercised.

As is so ably stated in the introductory paragraph of a recent review of the subject,

> Isolation phenomena have received wide attention since the first newspaper reports, some eight years ago, of experiments performed at McGill University on problems described by the term "Sensory deprivation." This work made a profound impression on both the medical and the lay press. A volume of magazine and newspaper stories resulted, generalizing from the technical reports and drawing conclusions that have given rise to some gross misconceptions. It was implied that a new psychologic technic had been demonstrated which (a) involved isolation and reduction of sensory stimulation, (b) had the power of reducing normal healthy people to mental incompetency, and (c) was probably involved in the "mysterious and diabolical technics of brainwashing and thought control" practiced by the Communists. Fact and fancy, intermingled in these second- and third-hand reports, were repeated indiscriminately by responsible men of several scientific disciplines. (14)

Original investigators such as Hebb and Lilly have been careful to define in operational terms what it is that they are doing. The general conceptualization, however, is less discriminating, and many investigators have started work along this line assuming as a proven fact that the crux of the problem is sensory deprivation. We would first like to point out that it is often not sensory deprivation but sensory invariance which has been evaluated in past studies. It makes comparatively little difference whether there is a continuous sound of the same pitch and volume or whether there is "silence." It is the *lack of change* in kinesthetic, proprioceptive, auditory, and visual fields rather than the *absence* of perceptions which has been the common denominator.

In a preliminary study now in progress we have hypothesized that it is not sensory invariance but action invariance (or action deprivation) which is the key point.[2] The conditions under which "sensory deprivation" have been capable of producing hallucinations, delusions and other psychotic behavior have also served to limit the activity of the subject. Some of the circumstances under which hallucinations, delusions, or psychotic reactions can be induced in normal subjects do *not* limit sensory intake in any common sense meaning of the word. In a recent experiment simulating space flight (reference withheld on request), two of the four subjects developed marked visual hallucinations despite the fact that they were allowed to move about the simulated space vehicle, were in radio contact with a transmitting station, and in visual communication via a television screen. Thus, although the senses were allowed to function in an unimpeded manner, hallucinations and delusions nevertheless developed. Rather than sensory deprivation the situation is better described as one in which action is severely circumscribed. It may be that either sensory invariance or limitation of activity (or a combination of the two) is capable of producing psychotic behavior. In view of the emphasis on the sensory aspects we believe it useful to stress the activity limitation.

There exists a constant feedback between activity and sensation,

[2] Shurley, in a paper given at the American Psychiatric Association in May, 1960, referred to the "desire for action" on the part of the individuals who were subjected to "sensory isolations." Dr. George E. Ruff in the discussion of this paper pointed out the desire of subjects he tested under similar circumstances "to make their actions or thoughts meaningful ones."

with the latter providing confirmation of the functioning of the former. In recent work it was shown that the occurrence of "meaningless" stimulation did not prevent hallucinations. Similarly, we would predict that meaningless or purposeless activity would not prevent psychotic symptoms. In contrast, if sensory invariance or action restriction were meaningful or purposeful, according to our thesis, they would *not* produce abnormal symptoms. Thus, the monotonous roar of a plane motor or confinement to a sick bed may be irritating but not psychotogenic because they are each "for a reason." This is not pure speculation but a theory capable of experimental confirmation or disproof. The shape of future research in this area will in large part be determined by the conceptualization of the problem, and with the adequacy of the concept rides the probability of success.

During prolonged flights of many months or years there will be very little to see, and that will be of negligible interest. To reduce both sensory invariance and action limitation the most practical way of dealing with the problem might well be to have the pilot sleep twenty-three of the twenty-four hours. This could be done either through the use of pharmaceuticals such as are used in Dauerschlaf, with the addition of an amphetamine-like compound to arouse the pilot rapidly or, perhaps more practically, by the use of an apparatus which could induce sleep by the passage of an electric current through the brain in the manner of the Soviet Electroson apparatus.[3] The control device of the machine governing sleep and wakefulness could be preset for regular periods but, in addition, geared in such a manner that the pilot will be aroused by any emergency condition. With the increase of speeds and the lowering of metabolism, consideration of flights running several hundred or even thousands of years cannot be off-handedly dismissed as mere fantasy.

For a number of reasons it would appear desirable to render the passenger unconscious during blast-off. The extreme physical and psychological discomfort which would result from wakefulness does not serve any useful purpose. Obviously anesthesia could be induced pharmacologically, but it would appear simpler to utilize an apparatus to induce sleep by the passage of an appropriate electric

[3] Interestingly, S. Rose whose osmotic pump we have described, wrote on electrical anesthesia over 15 years ago (15).

current through the brain. The waking time could be automatically preset and a safety precaution introduced by also providing control over this apparatus from an earth station.

During the period when he is awake, mere observation is probably not sufficient to ward off psychotic reactions, and the pilot should be involved in a series of actions which serve a measurable and known purpose. An individual of creative ability would be able to carry out much more satisfying activity in a circumscribed space than one who required "the thousand nothings of the hour" to benumb him. Writing is one obvious way of usefully occupying time, but of more pertinence would be the ability to play a musical instrument which would provide activity and direct pleasure. A violin would seem to be an ideal instrument for space travel. The opportunity to increase one's skill and musical understanding would be a welcome motivating factor, coupled with the ease with which the violin may be held in the absence of gravitation.

Erotic and Emotional Satisfaction. Recent work by Olds has demonstrated the existence of a so-called "pleasure center." The animal will choose stimulation of this brain center in preference to other activities. The existence of a subjective feeling of pleasure can, of course, only be inferred. Whether there exists an analogous center in humans and whether it will provide a substitute for erotic satisfaction is not known. Since emotions involve considerably more than sensations it remains to be seen whether stimulation of the brain area will produce complex reactions of this type. In any case, a careful evaluation is needed to make certain that other judgments and reactions are not negatively influenced or distorted by stimulation of this type.

Psychoses. Despite all the care exercised there remains a possibility, if not a probability, that somewhere in the course of events a psychotic episode might occur. This is one condition for which no servomechanism can be completely designed at the present time. An emergency osmotic pump containing one of the high potency per milligram phenothiazines together with reserpine would be included in the complete picture of the well-armed space man. Not infrequently the individual undergoing an acute psychotic episode denies that his mentation, emotions, or behavior are abnormal. Under these circumstances he would obviously refuse to voluntarily accept

medication. For this reason, assuming that monitoring is adequate, there should also be a release device capable of being activated from the earth station or by a companion if there is a crew.

It is important to point out that knowledge as to the effect of pharmaceuticals in alleviating hallucinations induced by sensory invariance or action limitation may provide valuable information as to the nature of hallucinations in mental disease and also serve as a screening technique for new treatments. We could learn a great deal about the use of pharmaceuticals in mental disease as well as in space travel if facilities were available for studying the area of overlap.

Limbo. The contingency of possible extreme pain or suffering as a result of unforeseen conditions must also be considered. The pilot should therefore be able to elect a state of unconsciousness if he feels it necessary. Prolonged sleep introduced either pharmacologically or electronically seems most obvious.

Ad Nauseum. There exist quite a number of medical problems amenable to pharmacological influence which we have not dealt with in the present paper. This is because both too much and too little is known (the former by others and the latter by us). We merely wish to state our awareness of having neglected to include conditions such as nausea, vertigo, motion sickness, vibration tolerance, and the like, so that although our presentation may be exhausting, it is not equally exhaustive.

SUMMARY

It is proposed that man should use his creative intelligence to adapt himself to the space conditions he seeks rather than take as much of earth environment with him as possible. This is to be achieved through the Cyborg, an extension of organic homeostatic controls by means of cybernetic techniques. Both chemical and electronic means are to be used in the control systems to be built, which will cooperate with the body's own autonomic controls. The necessary change of these controls for space survival cannot be conveniently supplied for us by evolution; they have to be created by man himself, using his acquired knowledge of cybernetics and physiology. Thus, man's activity in this regard complements evolution, freeing him from the need of conscious attention to the regulation of his own internal environment.

Methods applicable to several control systems are suggested. Particular use is made of the Rose osmotic pump for the continuous injection of drugs at biological rates, simulating secretory activity. The object of these controls is to achieve a biological optimum, considerably different for various extra-terrestrial conditions from the earth-normal. Control of levels of cardiovascular operation, body temperature, metabolic systems and psychic energy are discussed.

It is suggested that such existence in space may provide a new, larger dimension for man's spirit as well.

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