U. S. VIEW OF HUMAN PROBLEMS TO BE ADDRESSED FOR LONG DURATION SPACE FLIGHTS

by

Charles A. Berry, M. D.
NASA Director for Life Sciences
National Aeronautics and Space Administration
Washington, D. C.

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Introduction

An American editor who was thunderstruck by the difference in the sizes of early American space capsules and the upcoming Skylab workshop said, "It's like stepping from a racing car cockpit into your house." This commodious, by former standards, orbital habitat is designed to accomodate three men for nearly two months in earth orbit. The size of the Skylab, about 3600 cubic feet of living and working volume per man, will permit us to look much more closely and systematically at the effects of the space flight environment on those who venture into it while they are maintained in an atmosphere of comfort unprecedented in space activities. No longer will astronauts be required to sleep in their couches. Private sleeping quarters will be provided. A wardroom arrangement will permit the occupants to dine rather than to merely eat. And the food will be better than it has been in the past. Defecation will no longer be the irksome public affair it has been, and cleanliness will take a quantum leap. In this atmosphere, the space crew will be both subjects and principal investigators in a series of experiments that will begin to tell us whether man can be safely committed to space missions that may one day take him to the planet Mars.

Space flight is an experiment; undoubtedly man's most successful, but essentially experimental all the same. Knowledge of man's response to space flight stresses is limited, and it can be reasonably expected that space flight missions for a long time to come will be dedicated in large measure to investigating and clarifying the nature of physiological changes that have been seen or may be seen in the future. Because this is the case, certain compromises must be made. For example, the mechanisms involved in calcium metabolism in space cannot be defined unless the diet is strictly controlled. While the space crewman would ideally like to have a diet that is as varied and tasty as any he might have in an earth bound restaurant, this may, at least for the immediate future, represent an unreasonable demand.

At the same time, every effort must be made to make the environment of spacecraft and space laboratories as habitable as possible within the framework of constraints imposed by the objectives of any given mission. If habitability considerations are disregarded or inadequately addressed, the goals of missions, particularly very long term ones, could be compromised. If, for example, hygiene facilities provided a level of personal cleanliness that crews considered substandard, psychological as well as physiological well-being could easily be affected on a mission of long duration. Indeed, the lack of adequate provisions for personal hygiene maintenance has been the source of significant irritation to the crews of missions lasting for less than two weeks.

As our task today is to take the long term view of the problems man will face in long duration space flight, we must base any enumeration of these problems on our current experience and not merely on conjecture. Short term flights have produced physiologic changes which must be evaluated as to progression and the need for countermeasures. In addition, other problems, principally those related to habitability of the spacecraft environment, have not been directly addressed so far. It has been presumed that inadequacies in systems, such as the waste management system, would be viewed by crews as little more than inconveniences during brief space flights. The same supposition has been made about aspects of the environment that might have psychologically negative impact. However, things which are tolerable in the short run can become problems of major proportion during long duration space missions. The effects of confinement could, theoretically, become more acute, and small group interactions more difficult. Additional data are needed in all of these areas. Nothing can be left to chance. This paper will briefly review the principal physiological changes seen in space flight and discuss various countermeasures which may prove to be useful in combating these changes in long term space flight, if such intervention is required. The remainder of the discussion will focus on the psychological aspects of living and working in space for long periods of time and describe those aspects of the environment which may be critical to maintaining psychological fitness.

Physiological Integrity of Space Crews

American astronauts have logged over 8600 man-hours in space, and to this time, no physiological changes have been seen postflight that were serious enough to cause lasting concern. Certain transient changes have, however, been seen. These are summarized in figure 1 and discussed below.

PRINCIPAL BODY SYSTEMS RESPONSIVE TO WEIGHTLESSNESS

- **Cardiovascular/Hemodynamic**
- **Musculoskeletal**
- **Endocrine/Electrolyte**
- **Microfloral**
- **Vestibular**

Figure 1

Cardiovascular and Hemodynamic Responses to Weightlessness

Cardiovascular responses in space crews have been examined extensively and closely, since the cardiovascular system was the first to show a dramatic response to the space flight environment. Figure 2 summarizes the principal cardiovascular and related hemodynamic responses thus far consistently observed. Heart rates, after initial elevation during the launch period, tend, on the whole, to stabilize at lower than preflight levels during the period of weightlessness. Postflight heart rates have been elevated in most astronauts, and normalization has been inhibited. Return to preflight baselines has required as much as two days.

CARDIOVASCULAR/HEMODYNAMIC RESPONSES

Heart Rate	—	**Stabilized at Lower Levels in Zero G**
Electrical Activity	—	**Normal Except for Bigeminis PAC's, PVC's in Apollo 15**
Cardiac Silhouette	—	**Decrease in Size Postflight**
Blood Pressure	—	**Normal Inflight — Labile Postflight**
Orthostatic Tolerance	—	**Decreased Postflight**

Figure 2

EKG's, recorded during all U.S. missions, had revealed nothing about the electrical activity of the heart more dramatic than rare extrasystoles and an occasional arrhythmia until the Apollo 15 mission. In this crew, irregular heart beats were observed both during lunar surface activity and during return flight to Earth. Twelve bigeminis were recorded, as were premature auricular and ventricular contractions. In one instance, the arrhythmia was accompanied by a heart rate of 28 beats per minute. Figure 3(a, b) illustrates the arrhythmias experienced over a 25 second period, 179 hours into the flight of Apollo 15. The normal beat shown at the top of figure 3a converted to a nodal bigemini rhythm which lasted for 14 seconds. One-half minute before the bigemini, a heart rate of 120 beats per minute was recorded and this dropped to 95 beats per minute just before the appearance of the irregular beat. In figure 3b the bigemini rhythm can be seen converting to a series of premature auricular contractions which did not appear as coupled beats. These irregularities in heart beat were thought to be linked to potassium deficits, and a program was initiated to preclude these deficits in the Apollo 16 crew. Any fears that might have been engendered by the arrhythmias and the long postflight recovery period in the Apollo 15 crew were generally allayed when a program to maintain fluid and electrolyte balance in the Apollo 16 crew appeared to prevent a recurrence of the earlier difficulties.

Recent studies have also revealed a decrease in the cardiac silhouette. Examination of pre- and postflight posterior and anterior chest films revealed a decreased heart size in all U.S. space crews postflight. These data are further confirmed by X-ray studies in the Apollo 16 crew. Correlation of X-ray views taken at the same time in the cardiac cycle, systole or diastole, also revealed an apparent decrease in the cardiac silhouette.

Blood pressure has been normal inflight for U.S. crews and labile for up to three days postflight.

A certain degree of deconditioning of the cardiovascular system was expected as a consequence of reduction in hydrostatic pressure gradients in zero gravity. Consistent postflight reduction in orthostatic tolerance indicates that this probably occurs. Deconditioning is further evidenced by decreased exercise tolerance postflight.

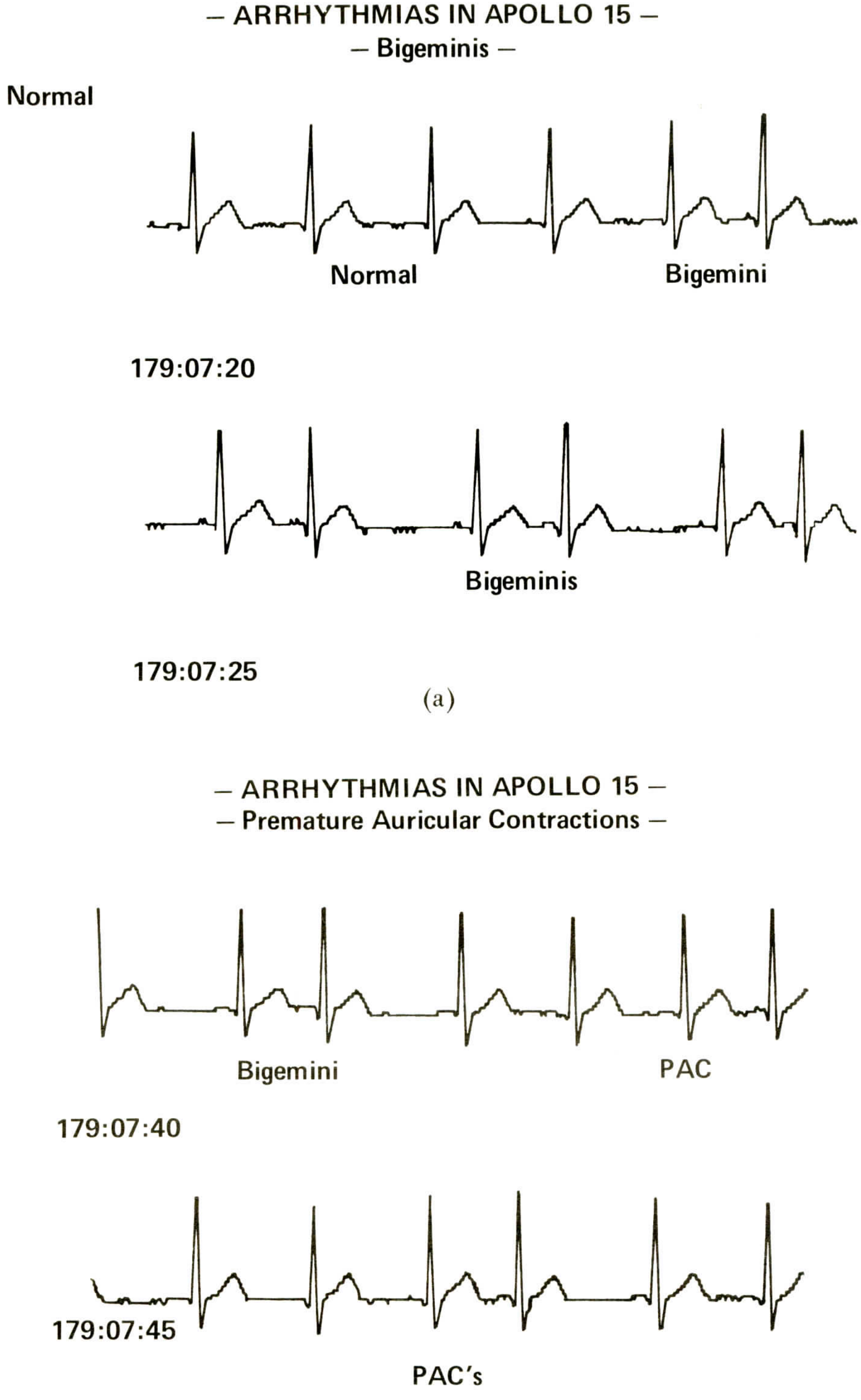
– ARRHYTHMIAS IN APOLLO 15 –
– Bigeminis –
Normal
Normal
Bigemini
179:07:20
Bigeminis
179:07:25
(a)
– ARRHYTHMIAS IN APOLLO 15 –
– Premature Auricular Contractions –
Bigemini
PAC
179:07:40
179:07:45
PAC's
(b)

Figure 3

Musculoskeletal Changes

Small but detectable changes have been noted in the skeletal system. These have been seen in U.S. and Soviet crews in the form of slightly reduced bone optical density. The causes of these changes are not clear but they do not appear to be progressive. Functional underloading of the skeletal muscles and a decrease in the energy expended during muscular effort in the weightlessness environment could certainly be linked with the changes which have been observed, but there are many other possibilities. Calcium metabolic mechanisms and endocrine changes could well be implicated. It is possible, for example, that calcium ions might be mobilized from the bone cation pool to correct electrolyte imbalances in the weightless state (Berry, 1971).

No gross neuromuscular changes have been observed in U.S. space crews. Slightly negative nitrogen balances which persisted postflight had been observed after two weeks of exposure to zero gravity by the Gemini 7 crew. Measurements of leg size were made in the Apollo 16 crew. These revealed postflight decreases of the size of both the calf and the thigh. Limb volumes showed consistent postflight decrements from 100 to 800 milliliters. These decrements persisted beyond 7 days postflight.

Figure 4 summarizes the musculoskeletal findings for U.S. space crews to date.

MUSCULOSKELETAL CHANGES

Slight Loss of Bone Mass
Decreased Leg Size (Apollo 16)
Decreased Cardiac Silhouette Size
Slightly Negative N_2 Balance (Gemini 7)

Figure 4

In sharp contrast to U.S. findings, the Soviet Soyuz 9 crew, after exposure to 18 days of weightlessness, exhibited severe problems in the motor sphere. Muscular pain was reported, as were measurable alterations in gait. Chekirda and coworkers (1070) reported that cyclogravammetric analysis revealed abnormalities in motor skills. No such changes have been seen in any U.S. crews.

Fluid and Electrolyte Balance

Of all changes seen in physiological systems during and after space flight, probably the most reliable clues to the mechanisms involved are offered by an examination of electrolyte response. Postflight retention of electrolytes has been an absolutely typical response. Total body gamma spectrometry has indicated significant decreases in total body potassium. Total exchangeable potassium studies using the isotope K^{42} have indicated a significant loss in total exchangeable potassium in the Apollo 15 crew but no loss in the Apollo 16 crew (figure 5). This must be attributed largely to attempts to prevent potassium deficit by dietary potassium supplements.

CHANGE IN TOTAL BODY EXCHANGEABLE POTASSIUM DETERMINED BY K^{42} STUDIES IN APOLLO 15 AND 16

(Premission vs Postmission)

APOLLO 15	PERCENT DECREASE
CDR	15
LMP	15
CMP	10
APOLLO 16	**PERCENT DECREASE**
CDR	0
LMP	0
CMP	0

Figure 5

Electrolyte changes have paralleled the time course of body weight loss and gain. Hormone changes, specifically postflight increases in antidiuretic hormone and aldosterone levels, consistent with electrolyte retention have been observed, and these paralleled the pattern of rapid recovery of inflight weight loss in the immediate postflight period.

Electrolyte response provides the basis for an hypothesis concerning the nature of man's adaptation to zero gravity. This hypothesis, if correct, might also explain changes in the muscles, including cardiac muscle. Figure 6 presents this hypothesis. Briefly summarized, electrolyte data appear to indicate that the redistribution of circulating blood volume upon entry into zero gravity is interpreted by the body as an increase in total circulating blood volume which the body attempts to reduce by a decrease in the production of ADH and aldosterone. This causes a decrease in plasma volume, which may then produce a secondary aldosteronism. The extracellular alkalosis which would result from such a response would produce an intracellular exchange of potassium and hydrogen ions. This loss of potassium, verifiable postflight, could produce loss of muscle cell potassium. If the heart muscle were also affected, and there is no reason to presume that it would not be, cardiac arrhythmias could also be explained. It is apparently at this stage in the postulated adaptation process that we find man after about two weeks of space flight. Possibly, longer residence in space might result in a completion of the adaptation process rather than a continuation of negative electrolyte balance trends. Given a sufficiently long stay in weightlessness, how long at this point it is not possible to say, respiratory and renal compensation could halt the negative balance trend to produce a physiological system which is stabilized with a new effective circulating blood volume and fluid and electrolyte balance. On the other hand, since it is not possible to say whether this reversal will indeed occur and, if so, how long a period of time will be required, countermeasures to these changes are being investigated so that man can safely return from space to earth at any point in the adaptation process without dangerous results.

OVERVIEW OF CURRENT HYPOTHESIS CONCERNING PROCESSES INVOLVED IN MAN'S ADAPTATION TO ZERO GRAVITY

Event	Response of Body
Entry into zero gravity. Redistribution of circulating blood volume.	Body attempts to reduce volume. ADH decreases, aldosterone production decreases.
Loss of water, sodium, potassium (loss of body weight).	Decrease in plasma volume. Aldosterone increases (secondary aldosteronism).
Increased sodium retention. Potassium loss continues. Cell: acidotic — extracellular fluid: alkalotic.	Intracellular exchange of potassium and hydrogen ions. Decrease in bone density, muscle cell potassium, and muscle mass; possibly including cardiac muscle.
Respiratory and renal compensation. Halt to weight loss trend.	Stabilizes with new effective circulating blood volume. New body fluid and electrolyte balance or "set."

Figure 6

Microbiological Changes

Certain changes in the character and distribution of the microflora have been noted in both U.S. and Soviet space crews. The growth of opportunistic organisms appears to be favored in space flight (Berry, 1970), and certain organisms become less resistent to antibiotics postflight (Kakurin, 1971). The etiology of these changes is not yet certain but they are not surprising against the background in which they occur. Space crews undergo a period of semi-isolation prior to space flight and are provided with diets which restrict bacterial intake inflight. The atmosphere control system in the spacecraft cabin also limits the number of microbes to which the crew is exposed. These factors, coupled with the change in distribution of microbe-bearing particles in an environment in which there are no gravity gradients to cause them to settle out and the unusually small size of the human population, cannot be expected to be without consequence in the microbiological sphere.

Figure 7 lists the clinically significant microorganisims isolated in the postflight period during the Apollo mission series. Overall changes from the pre- to postflight period are summarized in figure 8.

MICROFLORA OF POSSIBLE MEDICAL IMPORTANCE IDENTIFIED POSTFLIGHT IN APOLLO CREWS

Staphylococcus aureus	**Moraxella** species
epidermis	**Corynebacterium** species
faecalis	**Enterobacter** aerogenes
Klebsiella aerobacter	**Haemophilus** parahaemolyticus
enterobacter	**Herella** vaginicola
pneumoniae	**E. Coli**
Proteus mirabilis	**(Throat)**
Pseudomonas aeruginosa	β – **Streptococcus**
Serratia species	**Mycoplasma**
Mima polymorpha	**Candida** albicans

Figure 7

NET MICROBIOLOGICAL CHANGES PRE- TO POST-FLIGHT

- **Anaerobic Bacteria Decreased in Number**
- **Aerobic Bacteria Increased in Number and Type**
- **Microorganisms Isolated at More Body Sites**
- **Organisms Tend to Spread Across Crewmembers (especially Staphylococcus Aureus)**
- **Fungal Isolates Decreased in Number**
- **Higher Carrier States for Mycoplasma Indicated**

Figure 8

Vestibular Effects

U.S. crews have not reported vestibular-related difficulties of the severity or with the consistency reported by Soviet cosmonauts. Gemini crewmembers reported no vestibular-related difficulties. Some Apollo crewmen have reported problems that might be related to the vestibular system but these were in all cases reversible, subsiding after two to five days into any given flight. Figure 9 lists the incidence of vestibular problems. It should be pointed out that this listing represents the number of cases, not the number of individuals experiencing any particular difficulty, and that in at least one individual the symptoms were related to clinical illness in flight.

– VESTIBULAR-RELATED RESPONSES –
APOLLO

	No. Cases
Tumbling Illusions	3
Stomach Awareness	9
Nausea	4
Vomiting	3

Figure 9

That vestibular problems have been minimal during U.S. missions is very possibly attributable to the fact that U.S. astronauts all, so far, have had test pilot experience, and test pilots as a group suffer from a lower incidence of motion sickness than the general population. In future missions, when space crews will be drawn from a broader population including many persons who may have no aviation experience whatsoever, the incidence of vestibular symptomatology may increase.

Radiation-Related Effects

Thus far, the radiation doses received by space crews have been well below those which might be expected to produce biologically significant effects. Figure 10 lists the average radiation dose received by Apollo crewmembers for missions 7 through 16. Because the Apollo 14 mission occurred at a time of solar minimum, the cosmic ray flux was relatively higher for this crew than for those involved in previous missions. No demonstrable problems have been related to these radiation exposures. Because it has been suggested that a synergism might exist between radiation and other space flight factors, leucocyte samples have been examined for chromosomal aberrations for Gemini and Apollo astronauts. A small, but not statistically significant, number of aberrations of the chromatid type have been observable. There does not, however, appear to be a correlation between increase in chromosomal aberrations and mission duration (Gooch, 1972).

RADIATION EXPOSURE FOR APOLLO 7 – 16

	Rad		Rad
Apollo 7	.16	Apollo 12	.58
8	.16	13	.24
9	.20	14	1.14
10	.48	15	0.30
11	.18	16	0.53

Figure 10

The much publicized light flash phenomenon may also be associated with radiation. The most likely explanation for the light flashes first reported by the Apollo 11 crew is that they result from high energy, high atomic particle radiation generated in the ocular media or the retina. Inflight experiments are being directed toward firmly establishing the cause of the flashes, as well as their biological significance.

Countermeasures to the Effects of Space Flight on Man

The effect of space flight exposure on U.S. astronauts has not so far indicated the need for countermeasures more elaborate than dietary potassium supplements to prevent potassium deficits and the cardiac arrhythmias associated with these deficits. Nevertheless, because the effects of longer term exposure to zero g cannot be predicted for the cardiovascular system, or indeed for any other body system, evaluation of potential countermeasures to weightlessness continues. Figure 11 summarizes the techniques which have been investigated.

POTENTIAL COUNTERMEASURES TO WEIGHTLESSNESS

Exercise	Tumbling
Medication	Electrical Stimulation of Muscles
Diet	Exercise and LBNP
LBNP	Exercise and Venous Occlusion Cuffs
Gradient Positive Pressure	Exercise and Positive Pressure Breathing
G–Suit	Exercise and Bone Stress
Venous Occlusion Cuffs	Exercise and Hypoxia
Positive Pressure Breathing	Venous Occlusion Cuffs and Medication
Valsalva Maneuver	Venous Occlusion Cuffs and Leotards
Bone Stress	Hypoxia, LBNP and Exercise
Double Trampoline	Centrifugation

(Vinograd & Manganelli, 1972)

Figure 11

Cardiovascular System Protection. If it proves necessary to alter the cardiovascular response to weightlessness, the application of several techniques may prove to be useful. The most promising of these are the application of lower body negative pressure or its opposite number, gradient positive pressure.

Gradient positive pressure employs a reverse pressure garment which acts to simulate gravity by applying greater pressure in the upper body with a decreasing gradient down the body. The blood volume is effectively distributed in the way in which it is under the 1 g force. The net effect is the same as that produced by lower body negative pressure but the results are produced in the opposite manner, since lower body negative pressure causes blood to be drawn into the lower part of the body by reducing pressure in that part of the body. The one outstanding difference between the two techniques, besides the manner of application, is the application of a gradient in the one case and not in the other: lower body negative pressure applies the same negative pressure to the entire lower part of the body.

Lower body negative pressure shows substantial promise as a therapeutic technique against the effects of zero gravity on the cardiovascular system. The technique can be used to "train" the body to respond appropriately to the new environment by being applied intermittently as a stressor. This develops longitudinal g tolerance, that is, the ability to withstand blood shifts and insures that there will be an adequate venous return to the heart.

Ongoing studies are investigating the potential efficacy of lower body negative pressure applied for perhaps the week prior to reentry for spacecrews involved in long term missions. Preliminary results are promising. In one study the intermittent application of -70 mm Hg restored orthostatic tolerance in subjects who had been subjected to 5 days of water immersion and bedrest. Final LBNP endpoints after 5 days were reported to have risen to 165 percent of control values (Cramer, 1971). In a further study now in process (at the Public Health Service Hospital, San Francisco), a negative pressure of -30 mm Hg applied for 4 hours a day appears to be sufficient to (1) produce a post bedrest tilt response equal to the prebedrest response, and to (2) restore the drop in plasma volume caused by bedrest. It should be stressed again, these results are preliminary and the establishment of an LBNP profile suitable for space flight application awaits further data.

Provision of positive pressure, by the application of a G-suit, is also under consideration as a means of supporting the individual in the immediate postflight period. This approach will be investigated in conjunction with the Apollo 17 mission. Here again bedrest studies indicate promise.

Efforts were made to counteract the effects of zero gravity on the circulatory system in the Soyuz 11 crew by a complex of techniques which included the use of a treadmill device, a "gravity" suit, and medications. Inflight testing indicated adequate adaptive capability of the cardiovascular system, although a possible decline in orthostatic tolerance was indicated by LBNP. It was, nevertheless, believed that readaptation for the Soyuz/Salyut crew could have been less difficult than it had been for the Soyuz 9 cosmonauts, possibly as a result of the preventive measures taken (Gurovsky et al., 1972).

Inflight exercise regimes have been employed to safeguard the overall fitness of space crews. Exercise alone, however, is not effective in combating cardiovascular deconditioning. It may be helpful as an adjunctive therapy provided the technique employed raises the heart rate above 120 beats per minute. A bicycle ergometer device, such as the one which will be used on the Skylab missions, or a treadmill, as was used in the Salyut mission, will accomplish this. Exercise has also been examined as a means of preventing musculoskeletal disturbances but the results have not been impressive. The effectiveness of dietary potassium supplements in preventing potassium deficits and arrhythmias has already been noted. Many other approaches have been examined with mixed results.

Musculoskeletal Protection. Recent data from bedrest studies suggest that orally administered calcium and phosphate are more effective than exercise (no effect) or longitudinal compression (limited effect) for preventing the loss of minerals from the bones. The period of efficacy was, however, limited to ten weeks in a four month study (Hulley et al., unpublished data). Mineral loss was principally from weight bearing bones, and was recoverable in the post-test period. It is possible that in periods of prolonged weightlessness stabilization of mineral balance may occur. Calcium balance does, for example, appear to normalize after some years in paralyzed patients (Heaney, 1962). Nevertheless, these data indicate the requirement for high calcium and phosphate intake during long-duration spaceflight.

Disease Prevention. Protection for the individual whose microflora have undergone an alteration after exposure to the spaceflight environment should pose no real problem provided he is gradually reexposed to the microflora of Earth upon return from prolonged spaceflight.

Radiation. Thus far exposure to the radiations of the space environment appears not to pose a problem of any magnitude. However, radiation could pose a more serious hazard on longer term missions, particularly if they occur during periods of solar flare activity. Medications have been examined as a means of providing protection against radiation, but, unfortunately, those which offer some degree of protection have proved to be too toxic to be safely prescribed.

Vestibular Preadaptation. Future crews may be more prone to vestibular disturbances than past crews have been. As a consequence the possibility of preadapting the vestibular responses of individuals to the effects of zero gravity is being studied. Studies conducted in slow rotation rooms are expected to demonstrate the feasibility of preadaptation.

Artificial Gravity. A final approach to counteract the effects of zero gravity on man is to provide some system of artificial gravity in space vehicles. Two approaches are possible: rotation of the entire space vehicle or inclusion of an onboard centrifuge. It should however be pointed out that medical and performance data available at the present time do not support a requirement for artificial gravity systems in spacecraft. In the view of space crews, artificial gravity systems are unnecessary for task performance. Crews have learned to live in a zero gravity environment and feel confident in this state. Many have, in fact, expressed a preference for zero gravity since the absence of the g force increases the effective volume of what would otherwise be rather confined work spaces. While the provision of artificial gravity would undoubtedly increase the habitability of spacecraft, the engineering tasks associated with designing an adequate artificial gravity system are formidable and could be very costly.

Clinical Medical Care

The need for clinical medical care inflight becomes more important as mission durations increase. The longer the duration, the more pressing is the need for an onboard diagnostic and treatment capability. Partly, to this end, an integrated medical/behavioral laboratory measurement system, known by the acronym IMBLMS, is being developed. This sophisticated laboratory system will have among its capabilities supply of medical support for the crew. It will, for example, present the results of hematological studies on video tape.

For very long duration missions, it may be best for one crewmember to be a physician. It is now a well known fact that the first U.S. Skylab mission includes a physician in its crew. This approach has numerous advantages in addition to the obvious one of insuring that medical treatment is readily available. The astronuat physician will understand the purposes as well as the mechanics of any experiments which may be performed inflight and will, therefore, be able to assure that procedures employed safeguard their aims. In short, he can distinguish between trivial procedural variations and serious ones that might create a bias in results (Kerwin, McLaughlin, & White, 1971). He will, in the course of the mission, be alert for signs of changes which may not have been expected and recognize patterns of response. On this basis, he may suggest modifications to experimental protocols as missions progress. It is conceivable that a mission could be salvaged through intervention of an onboard physician should any serious problem of a clinical nature arise.

Psychological Fitness

Now that it is clear that the human organism can withstand the rigors of space flight, attention must properly turn from man as an organism to man as a psychological entity. We know man can live safely in space, but can he live productively hundreds of thousands of miles away from everything to which he is accustomed, in a microcosm, in a void, for six months or a year or possibly three? Principal emphasis has been placed on understanding the mechanisms of man's body in the space flight environment and while we know much more than was known a decade ago about bodily reactions, we still know very little about the effects of the space environmental complex on personality and psychic well-being. These aspects of the human could prove to be the factors which limit the duration of space flight if they do not now receive the attention required.

There is a data base upon which certain predictions can be made concerning the relative importance of psychogenic variables in long term space missions. But this base is admittedly small. Two and three month space cabin simulation tests which were principally oriented toward equipment verification in the past several years have also included some habitability assessments. The Skylab Project will look even more extensively at characteristics of the environment of a space habitat which make it more or less acceptable. These data should be invaluable for planning longer term missions as should data from Salyut missions. This information, coupled with observations of and reports from astronauts and cosmonauts who have engaged in space flights to date, should provide the basis upon which engineers and designers may alter the aspects of the spacecraft environment which it is possible to alter so that those aspects which cannot be altered will be that much more tolerable.

Confinement

Because booster technology had restricted payload, early space vehicles were extremely confining. The Apollo vehicle, while still small, did not prove to be as confining as it might have been expected to be. Earth based studies of volumetric requirements have tended to present a distorted picture of man's need for space because of the impossibility of simulating the critical dimension of zero gravity. While the volume of the Apollo command module was only 3600 cubic feet, this volume was felt by many astronauts to be adequate because of the enhanced facility for movement in the weightless state. Whereas a doorway of less than standard height is obstructive on earth, the ability to move in a swimming manner in zero gravity would make even a three foot hatch more than adequate in a space cabin. By these standards, the living and working area of the Skylab with its two-story, or two-compartment depending upon one's orientation, arrangement should seem exceptionally unconfining.

Isolation, Estrangement, and Privacy

The notions of isolation and sensory deprivation once expected to characterize space flight have thus far proved to be virtual non-issues. If anything, man is over-stimulated by the numerous tasks he must perform and the unique visual experiences of his new view of the cosmos. The "silence of the void" is replaced by the sound of machinery which makes the spacecraft cabin at least as noisy as any typical office and sometimes noisier. Audiovisual monitoring prevents man from being isolated in the strict sense, even to the point of denying him a modicum of privacy. If isolation is at all a problem in space it is an isolation that might better be termed estrangement. It is only natural for one to feel very much alone over a quarter of a million miles from all that is familiar. This response on the part of space crews was expected, and, as early as the Gemini 7 mission, efforts were made to combat the potentially demoralizing effects this estrangement might produce by supplying crewmen with news of events on Earth and arranging for them to talk with their families. These steps should be continued in future space flight missions, with all possible efforts being made to ensure that personal communications can be conducted privately.

The issue of private or privileged communications arises also in conncection with discussions between space crews and physicians monitoring their flight. It is essential that these communications be as private across the void of space as they are in an Earth based physician's office. While it is critical that telecommunications between Earth-based monitoring stations and space vehicles be maintained, it is still possible to afford space crews a certain degree of privacy. In a space vehicle with room for separate compartments, it may be perfectly adequate for only one member of the crew to be observed at any given time while others go about their activities in privacy.

Where the need for one crewmember to remain private from another is concerned, Earth-based studies have indicated that a feeling of privacy is not necessarily predicated on the provision of a specific amount of physical space. The subjects who participated in the NASA sponsored 90-day manned test of a regenerative life support system were confined to a chamber which provided only 90 square feet of floor space per man, yet the crew indicated that their privacy needs had been satisfied. They came to view privacy as the ability to separate one's self from others, if not in a physical sense, then in a psychological sense. Privacy was thought to be satisfied when all four men were located in the same area but were engaged in individual activities which did not require interaction (Jackson et al., 1972).

Crew Roles

Another element in the stability of the individuals in a group rests on the stability of the group itself. In order to insure that crew interaction is orderly and does not become a source of friction, roles must be strictly defined. The assignation of specific roles has been a feature of past space flight missions and will be a feature of future ones. As space crews grow larger and mission length increases, organizational structure will become even more important.

Crew Composition

Crew composition is as important as crew structure. For long duration missions crews will have to be even more carefully selected than they are now. It will be necessary to be psychologically and physiologically selective and, once adequate techniques have identified the most suitable individuals, to train those selected in psychodynamics so that they will better understand what they will face in long term space flight. Training in group dynamics, for example, should give the crewmember a better understanding of himself and a greater facility for solving his own problems and understanding the problems of his fellow crewmen. Such an approach, it is hoped, would contribute substantially to harmony and cooperation during long term space missions. Psychological selectivity in training will be even more important when crews are no longer composed of highly motivated, robust test pilots but include scientists and other civilian personnel.

Soviet scientists suggest that psychological compatibility of crews be given very careful attention and ample time be allowed for crews to adjust to each other. In a one year test of a manned regenerative life support system conducted in the Soviet Union in 1967-68, the three man crew was selected both on the basis of somatic and psychological compatibility. They underwent a series of group compatibility tests for an entire month prior to the start of the experiment. By the end of the experiment, no serious troubles had erupted among the subjects. This was attributed to the careful attention given to psychological selection and group preadjustment.*

It is quite possible that the lack of normal heterosexual relationships could cause a significant buildup of emotional tension during missions lasting for a year or more. The resulting unsettling effects could well undo all other efforts directed toward making environments habitable. For missions such as the Mars type mixed crews must be seriously considered. The issue of mixing of sexes in space crews in the future may not be the delicate one it has been traditionally expected to be. Sexual mores have changed significantly in the U.S. and throughout the world. As a consequence, living in close proximity with persons of the opposite sex may seem to future space crews a comfortable and natural thing. The population from which astronauts will be drawn in future years will more than likely have spent their years in university training, studying and working in mixed groups and living in sexually unsegregated dormitories. Indeed, many universities throughout the U.S. now feature such arrangements.

Habitability Factors with Impact on Space Mission Success

In addition to the factors just described which are related to the individual himself and his relationship to other individuals involved in space missions, factors external to the space crewman can have a tremendous impact upon his psychological state and ultimately upon his performance. Again, it must be borne in mind that any factor which has the potential to degrade morale in the short run has the potential to deteriorate performance in long term space flight.

*Translated by Boris Mandrovsky, Library of Congress, from articles which appeared in the Soviet press.

The Space Cabin Environment

Several aspects of the space cabin environment are particularly relevant to the psychic state of the inhabitant. Decor and lighting can be surprisingly important. A habitat designed for efficient living if it is not also appealingly decorated and cheerful will do little to buoy the morale of those who must live in it. Astronauts engaged in even the relatively brief Apollo missions have been critical of the lack of warmth and variety in their environment. On long term missions sleeping accomodations and entertainment facilities will also play a more important role. Early space flights and, particularly, long term ground-based studies have also shown that food becomes a critical morale building or degrading factor in isolated microsocieties. Finally, personal hygiene maintenance and body waste elimination provisions, which have received far too little emphasis in the past, could become a major problem area for very long term missions unless they are at last acknowledged to play a serious and key role in habitability. The problems of defecation in space must be dealt with directly and without a trace of embarrassment by those responsible for the procuring, design, and development of life support systems before the physiological and, particularly, psychological difficulties they create become any more irksome to crews than they are now.

Decor and Lighting

Sensory deprivation in the ordinary sense, as has been mentioned, is not a problem in space flight. On the other hand, sensory invariance can be. Innovative design in the environment of space vehicles for long term habitation can contribute much to providing sensory enrichment. Apollo 12 astronaut Alan Bean undoubtedly spoke for other astronauts as well when he indicated that variety in spacecraft decor was important for keeping up morale. He described the look of the interior of the Apollo spacecraft, which is conspicuously lacking in any decorations, as a "turnoff."

Participants in a three month manned space cabin simulator test evaluated features of the interior decor. The results of this test, which was the longest one of its type in the U.S., indicated that interior decor should be enhanced by the inclusion of more materials which have more and diverse surface textural gradients. The subjects also recommended that living and working quarters be sharply discernible from one another by virtue of design features such as lighting, furniture, and acoustics (Jackson et al., 1972).

Of all these factors, illumination may be the most important determinant of the visual environment. Here again, the details of the illumination system are more appropriately discussed by engineers. Suffice it to say, however, that a level of illumination which is adequate for work performance may be unsatisfactory from a point of view of personal preference. In the three month study, although the Skylab illumination of 5 to 9 foot candles was found to be perfectly adequate for work performance, subjects chose to employ a light level about four or five times as bright

(Jackson et al., 1972). Provisions must also be made to exclude illumination where it is not desired, for example in sleeping quarters. Rheostatic control might also be desirable.

There are many solutions to these problems which are better discussed by designers than scientists. But the point is this: while technological problems of a more pressing nature and economic issues dictated that the area of spacecraft decor would receive little or no attention in past and near future missions, for longer term missions this element of the environment must receive higher priority.

Sleeping Accomodations

Many space crewmen have experienced difficulty sleeping in space. Others have slept in the weightless environment with minimal difficulty or none at all. In several cases, during both U.S. and Soviet missions, sleeping medications have been prescribed. While lack of sleep or the taking of sleeping medications for short periods of time is acceptable during relatively brief missions, these will be unacceptable conditions for long term occupants of spacecraft. Because sleeping in an environment in which one floats is so radically different from sleeping in a 1 g environment, this problem cannot be adequately studied on the ground. Sleep experiments included in the forthcoming Skylab program may help to explain more about the nature of sleep in the weightless environment. Meanwhile, to insure that more restful sleep is obtained, special sleeping quarters will be provided. The sleeping compartment in the orbital workshop is illustrated in figure 12. Each individual is provided with an isolated sleep area. Partitions and curtains insure privacy and a sleep restraint which hangs on the wall provides a space "bed." At the right side of the figure, the occupant of the sleep compartment can be seen wearing a cap which contains EEG electrodes for sleep data collection.

Entertainment Facilities

Leisure time activities must be provided for long term space flight, and those entertainment facilities selected must, of course, suit the preference of the individual crewman and not disturb those who do not choose to participate. On the Skylab missions, personally selected off-duty equipment will be stored in the wardroom. Surprisingly, however, leisure time activities in space seem to take on less significance than they do on Earth. In one study which asked 30 astronauts to rank order their preference of off-duty activities (Eberhard, 1969), job related activites were ranked first. Reading was ranked second and physical exercises third. Amusements, as we commonly think of them, did not begin to appear in the listing of preferences until fifth place. The need to exercise and the desire of astronauts for this activity is reflected in the inclusion of a bicycle ergometer exercise device on the Skylab mission. This device replaces an earlier, less effective exercise device which many astroanuts found unsatisfactory.

Missions to date have been extremely active with experimental tasks. As missions become longer with the possibility of increased leisure time, the astronauts will undoubtedly place leisure time activity higher on their preference lists. To this end, off-duty activities equipment has been provided. Some of this equipment is illustrated in figure 13.

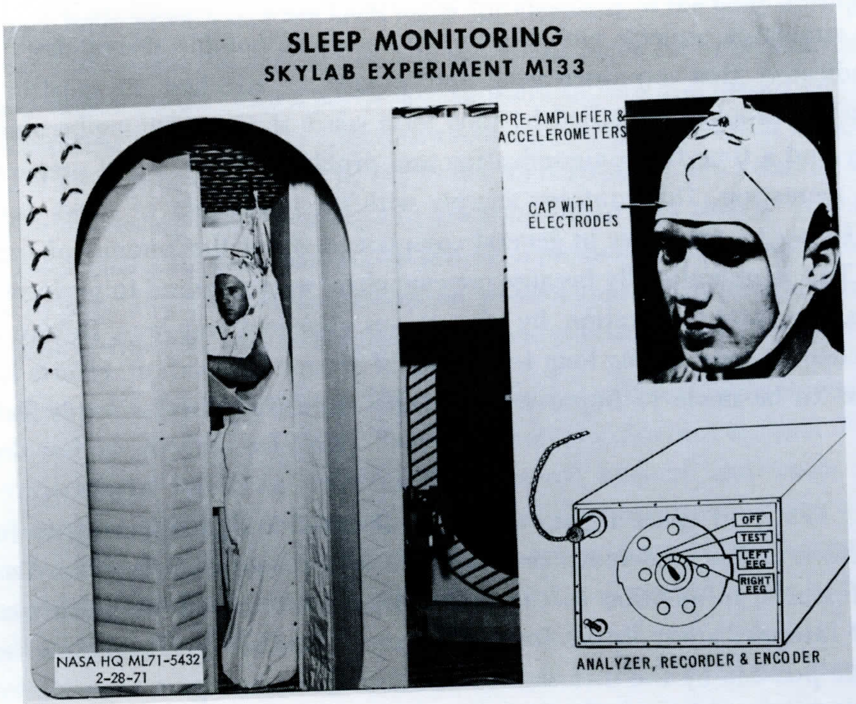

Figure 12

Figure 13

Food and Meal-Taking

Space cabin simulator projects and underwater missions, notably the 60-day Tektite mission, have clearly indicated that ever-increasing importance is attached to mealtime activities in environments such as would be typified by long term space stations. Dining became a major social event of the day and a time for communication and problem-solving. Food preparation itself was often viewed as recreation. This contrasts sharply with the experience of crews during short term space missions. Crews to date have in general complained about the amount of time required for preparing food. This is undoubtedly because crewmembers were required to perform numerous and important duties, and food preparation, by comparison, appeared mundane. However, based on the importance attached to food during long term tests of groups in isolation, efforts have been made and will continue to be made to improve the quality and variety of the foods for long duration flights.

The scientific nature of space flights will preclude an *ad libitum* approach to food for a long time to come. Nevertheless, the foods provided can and should be attractive. To this end, the Skylab mission features, in addition to the freeze dried foods served on earlier space missions, a greater variety of intermediate moisture foods that can be heated very simply in a heating tray and frozen foods made possible by the inclusion of onboard freezers. Figure 14 permits comparison of Apollo foods with the more natural Skylab diet. Meals which include such popular foods as steaks will be eaten with utensils. A separate dining facility, or wardroom, has been provided.

Figure 14

Personal Hygiene and Waste Management Facilities

Only the most basic provisions have been made for cleansing of the body during space missions to date, and, in many instances, not even these. The provisions made for urine and fecal collection have been completely unacceptable from a psychological point of view and inadequate from the point of view of good sanitation. The difficulty experienced in collecting fecal matter in weightlessness with a plastic bag which must then be handled by the crewman is apparent and need not be belabored. The potential for contaminating one's clothing and the atmosphere with such a "system" is also self evident. Nothing more elaborate than small wipes have been provided for washing the body. In both these areas, personal hygiene and body waste elimination, present approaches must be scrapped entirely and new ones substituted which are easy to use, automatic, and psychologically unobjectionable.

The Skylab hygiene facilities (figure 15) represent a significant improvement over the archaic methods employed on previous missions. They still, however, are not optimal. For the first time, a separate compartment has been provided for personal hygiene and waste management. The compartment contains running hot water which will be used to moisten towels for general body cleansing. Provisions have also been made for a "shower" to be taken once a week. The shower is admittedly a relatively unsophisticated device but it represents the first step toward whole body cleansing in space and it is the cleansing method of choice for most crewmen. The shower consists of a hand-held shower-head which permits the astronaut to spray his body with water. No vacuum drawing method is provided to remove the water from the body so that the individual must brush the water droplets off by hand and then remove the remaining moisture with a towel. The water remaining in the shower compartment will be removed by a vacuum cleaner intended primarily for other purposes.

Figure 15

Conclusions

This paper has reviewed the human problems which must be addressed for long duration space flights and has discussed solutions which appear to be promising for the most pressing of these problems. Long term bedrest data offer some clues to the potential effects of weightlessness upon physiological systems, but there is still a great deal to learn about these effects. There are, however, some indications that some zero gravity effects may be self limiting. Only flight data can provide definitive information. The collection of good inflight data for longer periods, coupled with ground based experiments is vital in any planning for longer durations space flight.

Countermeasures which have been explored have been needed in the U.S. space program only for the prevention of the cardiac arrhythmias noted in the Apollo 15 crew and, in this case, consisted of potassium supplements. While countermeasures have not yet been needed to reverse the effects of weightlessness on other physiological responses, cardiovascular system responses appear to be the most likely to require control. Fortunately, these responses also appear to be the most amenable to regulation by the application of inflight measures, such as the use of lower body negative pressure. If such techniques are employed, it may not be necessary to apply them for the entire duration of a space mission; a brief period of application prior to reentry may be sufficient.

Medications, in our experience, have not proved to be of value in treating either the cardiovascular deconditioning or the loss of exercise capacity noted in crewmen postflight. There is, however, some early indication from bedrest studies that combinations of calcium and phosphate help to forestall the loss of calcium from the bones. Oral administration of calcium and phosphate would seem, therefore, to be a suitable approach for space flight use.

The incidence of vestibular problems has not been great enough thus far for U.S. crews to require a preadaptation program. Such a program must, however, be considered as the number of potential crewmen is increased, particularly as scientists with no test pilot experience are added to crews. However, I do not at the present time see any physiological requirement for the addition of artificial gravity for long duration space flight.

Areas that have not posed problems thus far because mission durations have been short and crews have been very active may well pose problems on longer duration flights. In the future, efforts must be exerted towards selecting and training crews in the psychological sphere, for long duration space flight imposes many different types of stresses than those encountered in the flight durations thus far. Waste management and body hygiene provisions for all missions to date have been, frankly, archaic. Such conditions cannot be tolerated any longer, particularly as we look to long duration flights. Serious attention must be paid to planning and design of these systems so that they are completely acceptable to crews. In addition, attention must be given to providing a virtually automatic capability for sampling urine and feces.

By the end of the U.S. Skylab program, a substantial amount of data will have been collected that will provide an invaluable basis for planning of future missions. Further problems may also emerge that will require study. Ultimately, we envision a manned mission to Mars. Obviously, the relatively brief Skylab missions will not provide a sufficiently sound basis upon which to predict that man can tolerate space flight habitation for 2-1/2 years, but they represent a significant start toward this goal. I personally believe that six months of inflight data would provide an adequate basis for safe projection. In this period of time, all physical changes of a progressive nature could be identified. Certainly, within this period, any aspects of the environment having a deleterious psychological effect would become obvious. It is information of this degree of reliability toward which we must strive.

I believe that man can be supported for long duration space flight if we exert our energies to learn what is happening in that environment and then to define the responsible mechanisms. Once mechanisms are clearly understood, the proper countermeasures can be applied if necessary. I think we can gain this information and support man on a journey to the planets.

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