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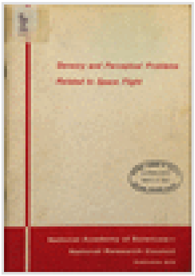

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Sensory and Perceptual Problems Related to Space Flight

**Report of a Working Group
of the
Panel on Psychology
Armed Forces-NRC Committee on Bio-Astronautics**

**Edited by John L. Brown
Chairman of the Working Group**

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PREFACE

In reviewing the psychological problems of space flight, the Panel on Psychology of the Armed Forces - National Research Council Committee on Bio-Astronautics selected several areas for special consideration. One of these dealt with human sensory and perceptual problems in the space flight environment, with the visual sense modality being of primary concern. A working group was appointed to evaluate critically the unique conditions of space flight in terms of their effect on human sensory and perceptual capabilities. This report presents the analysis prepared by this group.

The Working Group on "Sensory and Perceptual Problems Related to Space Flight" worked under John L. Brown, as Chairman, and a major portion of the report is his work. Other members of the working group who also contributed to the report were William Bevan, John W. Senders, and Richard Trumbull. A meeting of the working group was held at Woods Hole, Massachusetts, on 29 and 30 August 1960, at which time the materials presented here were reviewed and discussed. Others who attended the meeting and contributed to the discussion were Walter F. Grether and George T. Hauty (representing the Panel on Psychology), Henry A. Imus (representing the NRC Vision Committee), Edward R. Jones and Robert B. Voas (guests).

WALTER F. GRETHER
Chairman, Panel on Psychology
Committee on Bio-Astronautics

Wright-Patterson Air Force Base, Ohio
January 12, 1961

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I. INTRODUCTION

A variety of sensory and perceptual problems will arise in connection with space flight, both for occupants of space vehicles and for ground support personnel. It is the purpose of this report to define some of these problems as they relate to the occupants of space vehicles. As a basis for uncovering problem areas, an attempt has been made to predict types of space flight which may be undertaken within the immediately foreseeable future and to delineate their phases. The functions which will be required for the accomplishment of such flights in which human capabilities may be employed provide a basis for predicting possible perceptual problems.

II. SPACE FLIGHT MISSIONS

In the immediately foreseeable future we can anticipate three basic kinds of manned space flight missions. The first of these will be orbital flight around the Earth, the second will be lunar flight, and the third will be interplanetary flight within our own solar system.

A. Launching

Two types of launching may be considered. In the first of these the vehicle will be launched from an approximately vertical position from the surface of the Earth by the action of booster rocket engines. In the second, the vehicle will be carried aloft by a launching aircraft, and released at altitude at what may be an approximately horizontal position. During the launching phase, thrust will be applied to the vehicle and the vehicle's orientation must be so controlled that at the termination of thrust an appropriate velocity has been achieved and an appropriate trajectory has been established for the specific mission.

B. Orbital Flight

Orbital flights around the Earth will be at altitudes which range from approximately 100 miles to approximately 500 miles. The minimum altitude is established by the increasing aerodynamic drag which is provided by the Earth's atmosphere as altitudes are reduced below 100 miles. The maximum altitude is imposed by the location of the Van Allen radiation belt at altitudes above approximately 500 miles. An orbit within the region of the Van Allen radiation would expose men to seriously hazardous radiation dosages.

C. Lunar Flight

A flight to the moon would consist essentially of the placement of a vehicle in an orbit about both the Earth and the moon. The flight would probably consist of a single trip to the region of the moon for the purposes of photography followed by immediate return to Earth or landing on the moon and later return to Earth.

D. Interplanetary Flight

Interplanetary flight will be accomplished by launching vehicles from the Earth at velocities such that they can escape the gravitational field of the earth and go into their own orbit about the sun. In the immediate future successful interplanetary flights will require fairly accurate establishment of terminal vehicle velocity and orientation of trajectory at burnout. A flight to Mars may require the establishment of a velocity to within 1 foot per second with an angular accuracy of within .001 degrees in order to come within 6000 miles of the target. The degree of accuracy will depend on the conditions which prevail at the time of launching and optimum launching times will have to be selected very carefully. With the development of systems of propulsion which will permit the application of power more nearly continuously, accuracy requirements may be reduced. The interplanetary routes will probably remain substantially the same, but the availability of power will permit corrections enroute and thus reduce the critical accuracy requirement at launch. With the development of higher thrust propulsion units increases in vehicle payloads may be achieved. Higher thrusts will not be used for the achievement of higher velocities, since there will be an optimum velocity for any given interplanetary flight, as long as elliptical flight paths are employed.

It seems certain that as in the case of orbits around the Earth, interplanetary flight will be along preselected routes and there will not normally be gross alterations in vehicle flight path enroute, even after propulsion systems which may afford the continuous application of thrust have become available. The time when sufficient energy will be available for radical changes of flight path enroute is a long way off and problems related to this kind of flight will not be considered.

E. Landing

Two types of vehicle landings may be considered. These will be classified as aerodynamic landings and reaction landings. In the case of an aerodynamic landing, a vehicle in orbit or approaching the gravitational sphere of a planet with a gaseous atmosphere will fire rockets to provide thrust which will reduce velocity to the point where the vehicle will fall in toward the surface of the planet. Control of the landings beyond this point may be accomplished in either of two ways. First, the physical characteristics of the vehicle may be such that there will be a relatively high drag to further decelerate the vehicle as it passes through the atmosphere during its descent. When the rate of fall has been sufficiently reduced a parachute may be deployed for the final stages of descent. The precise nature of such a landing will depend upon the strength of the gravitational field of the planet and the characteristics of its atmosphere. A different type of vehicle, the design of which will afford relatively high lift, may be landed on a planet having an appropriate atmosphere in much the way that conventional aircraft are landed.

Reaction landings will be controlled by the application of reactive thrust from rocket engines on the space vehicle.

III. UNIQUE ASPECTS OF SPACE FLIGHT

One condition of space flight which will be unique for man will be the prolonged lack of any detectable gravitational force. The accelerations required for launch and recovery of a space vehicle may also be unique with respect to their magnitude and duration although similar accelerations can be produced with the aid of a centrifuge. The relatively confined and isolated environment, cut off except for radio communication from the planet Earth, will be a unique experience. These factors may be expected to have profound effects on both sensory and perceptual processes.

IV. VISION OUTSIDE THE SPACE VEHICLE

A. Classification of Tasks

There are a number of ways in which the ability of a man to observe the environment outside his spacecraft may be useful in the accomplishment of a space mission. The purposes of visual observation, although in a different context, will be similar to the purposes for which an aircraft pilot makes outside visual observations. These purposes may be classified in the following way:

a. Visual reference to horizon or other external reference criteria for the purpose of vehicle orientation in pitch, roll, and yaw and vehicle heading.

b. Visual observations of a ground plane for purposes of reconnaissance or determination of vehicle location.

c. Visual observations in the surrounding space for purposes of vehicle reconnaissance or maintenance of relative position of one vehicle with respect to another.

d. Stellar navigation and astronomical observation.

e. Observation of external indications of the function or malfunction of one's own vehicle.

B. Relation of Tasks to Phases of Space Flight

1. Launch

One of the few functions to which a human operator might conceivably contribute during launch is the achievement and maintenance of proper vehicle attitude, but this seems an unlikely possibility. During this phase of flight, observation and reconnaissance functions outside of the vehicle may be dismissed as of negligible importance. It will be necessary to maintain proper roll and yaw angles and to follow a prescribed flight path. Outside vision may afford reference for some of these functions in the form of the horizon or stars. However, particularly at night, booster flare may reduce visual capability. Instruments will afford more complete reference and more precise reference, however. Although external vision may provide a primary reference in the initial stages of a horizontal launch, it probably should be considered of importance only as secondary or as a backup reference during launch in most other circumstances. Some external cues, such as steam clouds from correctly functioning reaction nozzles, may afford indications of proper vehicle function during launch as well as during other phases of flight. The checking of these indications, however, should not involve unique or difficult visual perception tasks.

2. Orbit

During an orbital flight it will be of importance to maintain a check on the position of the vehicle over the earth's surface, the time at which various check points are passed, and the attitude of the vehicle itself with respect to its orbital path. In the present Mercury system, external visual cues may play a primary role if the man is involved in these tasks. The normal attitude of the vehicle will be such that he will have a direct view of the horizon to provide a roll reference. In addition, by means of a periscope he will be able to see the ground beneath him out to the horizon in all directions. With the horizon visible at a distance of approximately 900 miles for an altitude of 100 miles, the visible surface of the earth will be represented by a circular area having a diameter of approximately 165° of angle subtended at the vehicle. The periscope field will be so positioned with respect to the vehicle that the vehicle attitude in pitch and roll will be correct when the earth's visible surface is centered in the periscope field. The vehicle, traveling at approximately 18,000 miles per hour at an altitude of 100 miles, will be traversing approximately five miles on the earth's surface every second. In the periscope field this will be readily discriminable in terms of the motion of the pattern within the field, provided there is discriminable pattern. The orientation of the vehicle in yaw may then be observed in terms of the direction of relative motion of the earth's surface as seen in the field of the periscope. If there is no discriminable pattern within the periscope field, control in yaw may be achieved by visual reference to star patterns. It may be assumed that in the case of failure of an automatic system, outside visual reference may be considered important for control of the vehicle, and that in any case it will provide positive cross-checks of the automatic system and of the proper functioning of instruments. In an orbital vehicle, outside observations will be complicated to some extent by a daylight and darkness cycle of approximately 90 minutes. The portion of the earth's surface traversed in daylight may change on successive cycles. The problems of external vision have been considered in

detail in connection with the Mercury Project (Jones, 1960):
"CLOUD COVER - The most conspicuous visual effect at orbital altitude, other than day-night cycle, is the wide variation in cloud cover. Clouds have two significant visual effects: they block the view of the earth and create shadows, and they reflect sunlight to increase illuminance. These have implications for both navigation and protection of the astronaut from high intensity light. The mean cloudiness over the earth has been estimated as 54 per cent for land and 58 per cent for water. However, in the latitudes for the Mercury mission, a 6/10 or more cloud cover is estimated to occur only about 30 per cent of the time. This value will be lower in summer and somewhat higher in winter. Some water or land should be visible almost all the time through the periscope because of its wide field of coverage. However, a NASA Tiros I picture shows a cyclonic cloud 2000 miles in diameter in the central Pacific. The albedo, or proportion of sunlight reflected back in space, has a mean of around 0.35 for the earth, and about 0.50 for clouds. By comparison, the moon's albedo is 0.07. This has significance for the occupant of the vehicle in terms of comfort and adaptation. At night translucent clouds may serve as a diffusing medium for the light from major population centers, possibly producing a distinguishable landmark.

"HORIZON - The earth-sky discontinuity is an important exterior visual reference for backup control of the capsule's attitude in pitch and roll. During daylight, the ground horizon is often obscured by haze and is not sharp. The upper boundary of the haze or 'photometric horizon' is presumed to correspond to the height of the troposphere and usually appears sharp. However, the sharpness will vary with the haze bands that cause multiple horizons or stratums, and in about two out of eight cases there will be a diffuse boundary. A different situation exists on the dark side of the earth, since the discontinuity results from the earth masking the heavens and will appear as a black hole against a star background. The stars will no longer scintillate, they should be brighter by about 30 per cent, and some differences in color might be apparent. Stars will be visible and constellation patterning recognizable at night when the observer is dark-adapted and capsule lighting conditions are appropriate. The moon, airglow, starlight, galactic light, and zodiacal light in decreasing order of intensity, will furnish a very faint light when the vehicle is on the dark side of the earth. Air glow will be below the vehicle.

"DURATION OF LIGHT - Light will change from dark to light and back to dark every 90 minutes during each orbit. Equal amounts of darkness and light will be encountered because of the orbital path. The increase in daylight because of orbital altitude will be negligible."

If for any reason the vehicle should go into a tumbling mode, external cues may afford a reference for regaining stability. Rate indicators will provide a better reference than external cues, but after stabilization has been achieved, locking of gyroscopes during tumbling may require that gyroscopes be caged and that visual cues be used for assuming the desired vehicle attitude prior to uncaging gyros.

The location over the earth of an orbital vehicle at altitudes of 100 to 500 miles may be determined by the visual identification of characteristic features of the earth's surface if cloud-cover does not obstruct visibility. This problem may be illuminated by an additional quote from Jones:

"APPEARANCE OF THE EARTH - Simulation studies using Mercury parameters, and examination of orbital altitude photographs suggest some of the gross topography that may be distinguishable during daylight. Vision at orbital altitudes is characterized by the perception of shape and pattern rather than the resolution of small objects.

"a. Coast lines such as the west and east coasts of Florida differentiated by their contour and location with respect to the water boundary.

"b. Large lakes as Victoria, bays as San Francisco, and gulfs as California which have clearly defined shapes and positions in relation to land masses.

"c. Moderate sized islands with distinctive shapes, as Madagascar.

"d. Mountain ranges with characteristic ridges as the Rockies, especially when shadows increase their contrast.

"e. Patterning of groups of small islands, especially in the South Pacific.

"f. Major river systems, as the Rio Grande, bordered by vegetation that contrasts with the area and accentuates their width.

"The area from Australia and the East Indies to the west coast of the United States contains few perceptually distinguishable features except for some islands of moderate size, and the patterning of smaller islands.

"The extent to which various types of earth's surface reflect sunlight has significance since this may differentiate areas visually, especially if sharp boundaries occur as where the dark sea contrasts a light snowcovered shore. Some representative values are:

Surface	Sunlight Reflected (%)
Ocean	3 to 5
Dry grass	3 to 6
Deciduous forest	3 to 10
Ground	10 to 20
Rocks	30
Lush grass	15 to 25
New snow	70 to 86

"The color of the earth viewed from orbital altitudes will be cold and probably not distinct. It will tend towards blue-green for the water and vegetated regions and reddish brown over desert areas.

"The texture of the earth and water, which might serve as an exterior visual reference for yaw control, usually will be homogeneous and of marginal value.

"Topographical features will be visible rarely on the dark side of the earth. Artificial light from major population centers such as New Orleans might be seen and occasionally have a distinctive outline caused by a lake or coastline."

The human eye can be assumed to possess a resolution capability of between one and ten minutes of arc for a wide range of illumination conditions. The recognition of a pattern which includes a number of identifiable characteristics may be assumed possible if distinguishing elements of the pattern subtend visual angles of ten minutes of arc or more at the eye of the observer. The required length of an object in feet to meet this criterion is equal to fifteen times the distance of the observer in miles. At an altitude of 100 miles the horizontal linear dimensions of recognizable objects or patterned elements should therefore be of the order of 1500 feet. Geographical features will meet this criterion for direct vision. Many man-made objects will not. When a periscope which provides magnification is available many more objects on the earth's surface will become resolvable, but the duration of time the object is within the field of the periscope will be substantially reduced if the periscope is fixed in relation to the vehicle and does not track a ground point. It has been estimated that, under certain conditions, an object imbedded in a pattern should be exposed for twelve seconds in a stationary display to maximize the probability of its detection. Magnification of small objects (20 to 30 feet in length) to the point where they become resolvable may reduce the time they are visible to one or two seconds, or even a fraction of a second and they will be part of a pattern which is moving rapidly over the visual field. Increases in magnification will increase angular velocity and acuity will be affected at rates as low as 30 - 40^{o}/sec. Swartz et al have analyzed the problem of reconnaissance in considerable detail for orbital vehicles at altitudes from 100 miles to over 22,000 miles. It may be concluded that the visual observation of man-made objects, unless these are fairly large (e.g., cities, highways, railroads) will not be a practical possibility from an orbiting satellite.

A problem of considerable importance within the very near future will be that of reaching an orbital vehicle with another vehicle launched at a later time. The creation of an orbiting space station of any appreciable size will probably require a step by step construction procedure in which part at a time is placed in orbit. The problem will be to place those parts which are launched subsequent to the first not only in the same orbit, but at the same point in that orbit. The accuracy required with respect to trajectory and burnout velocity to accomplish this within miles affords a tremendous challenge. Terminal rendezvous will require a system within the rendezvousing vehicle which can assess the error which exists between its orbit and position and those of its target. The system then must afford controlled application of thrust which will correct the error in order to achieve the terminal rendezvous. It is quite possible that a man, employing direct vision, may be included in such a system, at least in its final stages. Estimates of the shape, size, and distance of objects located in otherwise empty space may present a difficult problem. Such estimates are strongly dependent upon other elements in the visual field, and the absence of any other elements will create difficulties. It would seem desirable to study this problem in the laboratory in a simulated setting.

External visual observations for the purpose of detecting other space vehicles or objects in space may be considered of negligible importance except in situations where contact with such vehicles or objects has been specifically planned. Relative velocity between two objects increases rapidly as their orbits deviate and the amount of time in which an object the size of a space vehicle (e.g., 50 to 100 feet in diameter) would be visible decreases commensurately. Vehicles will not be placed in orbit to search for other vehicles that are not already known to be in a specific orbit, and vehicles already in orbit may expect to be approached by other vehicles in a restricted manner. The approaching vehicles will be assuming essentially the same orbit as the target, probably even when their mission is hostile. The accuracy requirements considered in conjunction with time available for correction in almost any other case will be beyond practical limits for some time to come.

Visual observations of stars from an orbiting vehicle may be of considerable importance for the purpose of fixing position. Visual astronomical observations will probably not be of scientific importance, however. Although an orbiting vehicle may be above the earth's atmosphere and hence will be exposed to approximately 30 per cent more visible light in addition to which observations will not be subject to atmospheric shimmer, there are other factors which will minimize the importance of astronomical observations. In the first place, considerable attenuation of the available energy will be necessary to afford protection of the man from ultraviolet radiation. The nature of materials required in any system which permits vision outside of a space vehicle will be dictated to some extent by the requirement that the vehicle's structural integrity be maintained. This will also result in the attenuation of available visible energy. In addition to required attenuation of energy, it will not be possible to include telescopes which begin to approach the size of terrestrial installations in orbiting vehicles. Finally, the maintenance of stability in a manned orbital vehicle of moderate size will pose a serious problem for astronomical observations of precision.

3. Lunar and Interplanetary Flights

During the major portion of an earth-lunar, or interplanetary flight, there will be no available horizon or ground plane to provide a reference for visual observations. External visual observations of the stars and planets may be of importance to check position and course as a check on the stellar guidance system which may be used. Such observations will require training in the recognition of celestial patterns and in the nature of changes in patterns with respect to positions of planets which will occur on a specific flight. Such training may be accomplished in a specially designed planetarium which can simulate an appropriately moving point of observation.

As in the case of an orbiting vehicle, it does not seem likely that direct visual search for other vehicles, the presence of which is not previously known, will be of appreciable importance. Outside visual observations of other vehicles may be of importance in terminal stages of a rendezvous. Whether such visual observations will provide a primary basis for control or only a secondary basis will depend on the availability of other equipment, presumably radar, and its accuracy at various ranges.

4. Landing

The nature of external visual tasks which may be required of a pilot during landing will vary with the conditions under which landing is made. In many circumstances landing will be initiated from orbital flight around the target by firing a rocket which is oriented to reduce orbital velocity. This will result in the vehicle falling in toward the surface of the target. The timing of firing of a retrograde rocket must be carefully controlled in order to land in the desired area. Such timing is best controlled from the ground where precise fixes of orbital vehicle position can be made. Ground support will not always be available, however, and vehicle position may be marked visually by observation of transit of some recognizable landmark on the surface. The deviation of surface position of an earth satellite at 100-mile altitude by five miles for each second of error in firing of a retrorocket is not extreme so that timing of firing by a man in the vehicle might be within necessary limits of accuracy. Landing from orbit about a relatively unknown planet or moon will be far more difficult than landing on the surface of the earth. It will be difficult to select appropriate landmarks when the character of the surface is relatively unknown and the relative position of available landmarks with respect to a desirable landing site are not known. Several reconnaissance orbits may afford visual information upon which some decision can be made. For purposes of communication the earth-side of a distant body may be preferred. The relative difficulty of final selection of a desired landing site will be reduced with reductions in the horizontal component of vehicle velocity. In virtually all cases there will be a considerable component of velocity along the surface of the body upon which landing is to be made in the initial stages of landing. The extent to which it may be reduced or eliminated will depend upon the nature of the landing.

If the target has an atmosphere, such as earth, the atmosphere will be utilized for deceleration of the vehicle prior to landing. Landing may be accomplished by aerodynamic control as in the case of conventional aircraft and the X15 research vehicle. In this case it will be necessary for the pilot to maintain continuous control. Limits of dynamic pressure, acceleration, and heating must not be exceeded and it seems probable that the human pilot can function in this kind of situation better than any automatic system. During the early stages of re-entry into an atmosphere, instruments will probably provide the best source of information for the control task. In the final stages when speed has been reduced and actual landing is about to be made, external visibility of the surface upon which the landing is to be accomplished and the surrounding terrain can be expected to be important for selection of the final location or for alterations in the point of touchdown.

In addition to pilot-controlled aerodynamic landings, aerodynamic landings which involve the high-drag capsule must be considered. In this case, less control can be effected by the occupant of such a vehicle. Some control will be possible, however, by alteration of capsule attitude or by the use of reaction nozzles for modest alterations of flight path. It is unlikely that external vision will provide a reference here, but it is at least a possibility in the final stages. In the last stage of such a landing a parachute will probably be deployed. This will be controlled automatically. If the automatic system should fail the pilot may effect parachute release when an appropriate altitude and speed have been achieved. It is doubtful that the point of release will be determined by external visual reference except as an emergency backup. This will be difficult over water and other areas with relatively homogeneous surfaces.

In the absence of a suitable combination of atmosphere, gravitational field, and vehicle design, landing will have to be effected by the application of a reaction thrust to slow the vehicle. When such a landing is made from orbit, it will involve initial retrofiring to drop out of orbit, followed by the continued application of retrograde thrust to reduce both vertical and horizontal components of velocity with respect to the surface of the target. The horizontal velocity may be reduced to zero in a variety of ways somewhat arbitrarily. The vertical velocity, however, must be so controlled for a given instantaneous value at a given altitude in a given acceleration field that it will just be reduced to a value which is sufficiently low at impact that no damage to the vehicle or injury to the vehicle occupant will occur. It will be wasteful of power to reduce velocity too rapidly. The satisfactory solution of this problem will require information concerning altitude, velocity and acceleration of the vehicle during descent. It seems questionable that the efficient solution of this problem will be possible by means of direct visual reference without the availability of other information. It is a possibility, however, which should be examined further. A dominating concern in selection of an optimum method of landing will concern economy of energy. In the final stage of a landing direct vision may be essential for a decision as to the adequacy of the landing site.

C. Additional Problems Relating to Vision Outside of the Space Vehicle

1. High illumination levels

Outside of the earth's atmosphere light from the sun will be less attenuated and the danger of retinal burns from the direct view of the sun will therefore be increased. Ports and optical systems will present some attenuation, however. Even if the sun is viewed directly, it has been estimated that exposure for 15 seconds will be required for serious injury to the retina. The problem is therefore not considered to be of serious concern. The time course of recovery from exposure to a bright light flash has been investigated and it is possible to estimate the duration of relative blindness following exposure for a variety of conditions.

2. High contrast

In the absence of any diffusion as found in the earth's atmosphere, it may be predicted that contrast within the visual field will be much greater than that to which we are normally accustomed. This may influence judgments of size and distance outside of the space vehicle during landing on bodies having no atmosphere or in rendezvous with other vehicles.

3. Empty field myopia

The absence of any other elements of detail in the visual field may prove to be no problem in space flight outside the earth's atmosphere. The lack of atmospheric dispersion will permit constant visibility of stars. These will afford cues for distance accommodation.

4. The limits of visual acuity

In searching for relatively small target vehicles in space the lack of dispersion of light in the absence of an atmosphere may prove of benefit. The brightness of the background will be approximately one-tenth the brightness of the sky on a moonlit night. The object for which the search is being made will be illuminated by reflected light from the sun and will thus consist of a light spot on a dark field. Visual acuity is not a limiting factor in this case. Visibility will be limited solely by the amount of available energy in the visible range reflected from the target.

D. Suggested Areas of Research

1. Attitude control

The ability of man to control vehicle attitude by reference to a horizon, a ground plane and celestial patterns as these will be observed from the vehicle should be investigated for both "day" and "night" conditions.

2. Reconnaissance

Studies should be made of man's reconnaissance capability for detection of objects within a pattern which moves across the visible field defined by a magnification system or a viewing port. Work on the problem of dynamic visual acuity may provide background for these studies.

3. Detection

It will be of value to study man's capability for detection of a small reflecting object against a dark field in which a number of visible stars are located. The probability of detection in this kind of situation will depend upon the amount of light reflected from the target, the familiarity of the observer with the star pattern in which the target is to be detected, and the relative size of the visual field in which search must be conducted. A preliminary experiment performed at the Hughes Aircraft Company suggests that this may be an extremely difficult problem.

4. Rendezvous

It will be desirable to study the efficiency with which a human operator can control approach to a distant isolated object in space by direct visual observation.

5. Navigation

The location of a space vehicle and its orbital path about the earth, the sun, or some target planet can be determined by simultaneous observation of two or more known bodies, or successive observations of a single body. Simultaneous multiple observations will afford highest precision. The ability of a man to make simultaneous observations by direct vision may be extremely limited however. It would be desirable to develop and evaluate techniques for astronomical navigation in space flight. As mentioned above, a special planetarium might be developed for the purpose.

6. Landing

The problems of landing as outlined above, including the timing of retro-rocket firing, the control of reaction thrust for deceleration during approach to the surface, and the selection of a landing site may all be studied in a laboratory situation, in terms of man's ability to perform some role which employs direct vision.

V. VISUAL PROBLEMS WITHIN THE SPACE VEHICLE

A. Aspects of the Problem Which Are Unique to Space Flight

The possible roles which man may play in various phases of a space flight mission have been discussed above. It has been mentioned in several instances that the implementation of man's role may frequently depend upon information derived from instrument displays. Instrument display problems as such are not novel, but in space flight, in the absence of any gravitational field, certain novel aspects may arise. It is not anticipated that zero G will pose any problems with respect to basic visual functions, but the absence of a gravitational field may exert some influence on visual perception. On the other hand, the high accelerations which may be required in launching and recovering space vehicles can be expected to exert a direct negative effect on efficient visual function.

B. Visual Display Problems

Frequently techniques for the communication of information visually in a terrestrial environment are to some extent dependent upon orientation of the visual display with respect to the vertical. Even more often, orientation of the display with respect to the position of the observer is of importance. It is often true that indicators and printed material may be interpreted with the observer in any relative position, but interpretation is accomplished only with difficulty and with a considerable increase in the probability of error when the orientation of the observer with respect to the display is not the usual one. Much of the difficulty which is encountered may be attributed to training and experience. In a spacecraft there may be long periods when there is no acceleration and consequently no "up." It may prove undesirable or impractical to design the interior of a space vehicle, particularly if there is more than one man in the crew, so that there is any consistent visual "up." If this is the case, it may be necessary to design visual displays so that they can readily be interpreted by an observer in any position with respect to the display. This will require that all information in the display be dependent upon relationships among elements of the display itself without relation to any part of the background or surround. Individual elements within the display must have unique, recognizable characteristics which are independent of their position. It will be necessary to conduct extensive training of crew members so that they can discriminate relations within the display for any display orientation. Visual coding by color and shape factors which are independent of position will be of importance.

C. Display Design

When the crew of a space vehicle includes more than one man it may be necessary for two or more men to view an instrument panel simultaneously. It is quite possible that they will not be oriented side by side in the same relative position. As suggested above, the display must be so designed that information can be interpreted for any position of the observer. It should also be designed to minimize the probability of any negative transfer effects with change in observer's position. The exact nature of visual displays will depend on precisely what operations man is expected to perform in a given mission. This will determine the nature of information which he will require. A statement of what this information may be must await a complete system analysis and cannot be answered in specific terms except in connection with some specific mission. Certain general questions may be posed, however, such as whether or not the man will be required to conceptualize his vehicle situation in such a way that he can explicitly state navigational problems and generate solutions for them in terms of available information, or whether all of his problem solution efforts will be in terms of the use of formulas, the bases for which he is not required to understand. The answer to such a general question as this will lead to more specific questions such as whether or not pictorial displays may be useful in the presentation of information. It seems probable that in certain situations where the time and distance scales and the nature of relative motions lie in certain domains it will be impossible for a man to interpret information which he receives by direct external vision or from a pictorial type of information presentation. In other situations such as the terminal stages of a soft landing, direct or synthetic pictorial information may provide a basis for the most rapid analysis of the situation by a man. The kind of information necessary for the understanding of a complex situation which is unique in terrestrial experience poses an interesting problem in the subject of complex perceptual processes. Non-linear displays and other relatively novel display characteristics should not be overlooked or neglected in attempting to find an adequate solution to this problem.

D. Orientation Within the Space Vehicle System

The problem of orientation in a spacecraft will depend primarily on visual cues in the absence of vestibular and many tactual and kinesthetic cues which are dependent upon a gravitational field. On the surface of the earth man has constantly available his perceptions of the force of gravity and indications of the direction of "up." The presence of this reference along with the fact that he usually performs gross movements in only two dimensions greatly simplify the problem of navigating his body within the confines of his immediate physical environment. In a spacecraft this reference may be lacking and in addition, at some future time when large space stations have been established man may have the added complication of being required to maneuver his body in three dimensions almost continuously. Some of the possible complications of this situation may be discussed. As long periods of time will be spent by occupants of spacecraft under conditions of zero gravity, the layout of the interior of such a craft may be quite different from the interiors of terrestrial vehicles of comparable size. It will not be necessary to have any floors or ceilings as such. The day may come when individuals will be able to move in any direction within the vehicle and not with reference to a specific ground plane. The stations of different crew members within a single compartment may be oriented such that these individuals are at unique angles with respect to one another. It is to be expected that man's training and experience in earthly surroundings may cause him some difficulty in his initial experiences in such a novel situation. Man is accustomed to a rectangular organization of the artificial enclosures in which he lives on the surface of the earth. His rooms are constructed with four sides and the streets of his cities cross each other at approximately right angles. Orienting within a building or a large city is strongly dependent on what we may consider a right angle unit for the perception of direction. There are innumerable examples of problems arising from a nonrectangular spatial organization. Two prominent examples of such problems are the city of Washington and the Pentagon. Strangers to each of these places find it extremely difficult to orient themselves. It is necessary for them to unlearn orientation schemes based on right angle layouts and to learn other appropriate techniques before they can get about without difficulty. The Ames Demonstrations dramatize in a remarkable way the extent to which we depend upon the assumption that all artificially enclosed space is in fact enclosed with perpendicular rectangular planes. Judgments of distance and size show remarkable distortion in situations where this assumption is not justified. The most efficient layout of a spacecraft designed for multiple occupancy will probably not be rectangular. It will be necessary for occupants to learn to move continuously in three-dimensional space and not on a single reference or ground plane in any given compartment. Under conditions of zero G, restriction on body positions which apply at 1 G will not apply and the most efficient design of work spaces and the integration of the locations of the several occupants of a given compartment will require a careful consideration of the additional flexibility afforded by the weightless state. Perceptual problems will undoubtedly arise and it would be desirable to study re-learning problems which will occur during adaptation to such new environments. Such problems must be considered in planning training programs for the future occupants of such an environment.

E. Suggested Areas of Research

1. Display design

It would be desirable to devise and test displays which can be interpreted entirely on the basis of relations within the display and independent of the orientation of the display with respect to any visual or gravitational vertical or any observer. Such displays should be tested for training time required to achieve a minimum base level of interpretation time, for the frequency of misinterpretation, and for their compatibility with other displays. Various techniques of layout for the use of multiple displays should also be examined. The scanning pattern of an observer using multiple displays may have to be changed when his position with respect to a panel is changed. Negative transfer may accompany such changes. This should be investigated. In addition, studies of vigilance should be extended to this kind of situation.

2. Astronomical navigation

The ability of a man to calculate position of a space vehicle quickly and accurately from information displayed on instruments may be assessed. Various systems should be compared.

3. Vehicle illumination

The problem of satisfactory vehicle illumination and color will be far more critical in a space vehicle than in submarines where it has been studied extensively. Much information is available and it should be carefully considered in relation to this problem so that additional information can be obtained if necessary.

4. Visual orientations in environments having unique geometry

The ability of crew members to adapt to environments which may be employed in zero G space stations can only be studied in advance of the existence of such space stations by the use of water-filled simulators in which subjects, with their bodies appropriately weighted for neutral buoyancy, can swim about freely.

VI. NON-VISUAL SENSORY AND PERCEPTUAL PROBLEMS

A. Man is limited in the number of senses available to him but his integration as a component of a space vehicle system may require that his senses be employed in unique ways. The weight and space restrictions on a space vehicle are such that information flow to the man must be accomplished in the most efficient manner possible. This may require, for example, the use of olfactory cues for the presentation of discrete signals which may be widely spaced. Such signals might be employed to signify equipment component malfunction. Some equipment malfunctions may result in olfactory cues which do not occur by design. Olfactory signaling systems may be constructed of very small size and very low power requirements while at the same time they may encompass an appreciable number of discretely coded signals.

B. In recent years tactual signaling systems, as studied by Geldard, have received considerable publicity. The efficiency of these systems has been demonstrated for the receipt of information at a fairly high rate. Such systems may prove useful in spacecraft where large numbers of non-interfering information channels may be required.

C. It has been demonstrated that normal speech sounds may be altered in a variety of ways without becoming unintelligible. It is evident that the information capacity of speech is dependent on a relatively small proportion of the total bandwidth which is occupied by normal speech. Successful efforts have been made to synthesize speech from a small number of auditory components. Communications systems in space vehicles may require a consideration of synthetic speech techniques which afford a reduction of bandwidth with resulting economies of power.

D. The careful control of all sensory inputs to the man will be extremely important. It will be desirable to utilize all sensory inputs to maximum advantage. It would seem desirable to eliminate extraneous non-information bearing stimuli insofar as possible. This is particularly true of aversive stimuli such as noise and unpleasant odors which may be derived from paints and other materials employed in the construction of a space vehicle or which are of the occupants' own production. It is probable that noise can be controlled by proper acoustic treatment of the vehicle and the use of a sound shielding helmet and phones on the man. On long missions, it may be desirable to make some provision for recreational or relaxing stimuli such as music, or low amplitude vibrations which may provide massage.

E. There are several specific sensory problems which may arise in connection with zero gravity. For example, the regulation of complex motor performance such as that which may be required of the occupants of spacecraft is probably dependent to a large extent on kinesthetic feedback from the muscle groups involved. In a gravitational field the position of a limb, its orientation, and its component of motion in the direction of action of the gravitational field all influence patterns of tension on the musculature involved in a way which is dependent upon the strength and line of action of the gravitational force. It is difficult to surmize the extent to which highly coordinated motions may depend upon this kind of feedback. It is possible that certain types of complex motor performance may be extremely difficult when kinesthetic perceptual cues dependent upon gravity are absent. The problem may become particularly important in connection with the manipulation of objects and tools in unusual ways as may be required in maintenance operations. It will be highly desirable to study various aspects of this problem. Preliminary studies can be conducted on the surface of the earth in which changes of the motor performance capability are observed when organisms trained at one level of acceleration are placed in an environment at a different level of acceleration. The important limitation of these studies is the fact that experiments can not be conducted in the terrestrial laboratory at accelerations of less than 1 G for periods of any practical duration. Experiments at less than 1 G will have to be performed in orbiting vehicles initially. The importance of such experiments should be carefully considered and, if they are warranted, preliminary plans for carrying them out should be developed. In the absence of a gravitational field the usual vestibular effects of gravity will, of course, be absent. There has been considerable speculation as to the significance of the lack of these effects for the man, but there does not appear to be any good reason to expect that this absence will pose a serious problem. The intensity of sensory effects of head motions within a vehicle may be increased in the absence of any continuously acting gravitational field and other problems may arise, but it seems likely that rapid adaptation will render these problems of minor importance.

It has been speculated that in the absence of acceleration with the resulting lack of the requirement of continuous muscle tension to maintain posture the occupants of the space vehicle may require little or no sleep. This may grossly effect such things as the perception of the passage of time. The gross distortion of the time perception might have severe effects, both practical and psychological, on an individual who has undergone protracted training in the sequence of operations at 1 G without time distortion. It may also render irrelevant work done at the surface of the earth in a 1 G environment on the subject of sleep-rest cycles.

It has been suggested that it may be desirable to create a gravitational field for the astronaut by rotating his vehicle at a constant rate so that he will be acted upon by the resulting centrifugal force. The vehicle will be so constructed that its outer perimeter will serve as a floor and he will move about on his perimeter with his head oriented toward the center of rotation. Certain physical reasons are sometimes put forward in support of this kind of system. It has been said that liquids will be more readily manageable in a gravitational field, that convection currents which result in circulation of air will depend upon the presence of a gravitational field, and that the physics of the circulation of the blood may require the action of a gravitational force during long-term confinement. The validity of each of these reasons is open to question. It seems probable that the negative effects of rotation about a relatively short radius may be a more important factor in the consideration of such a system. Man has difficulty tolerating rotational rates of greater than five or six rpm. Although some adaptation occurs, nausea and disorientation are frequent results of exposure to a rotating environment. Unless the radius is substantial, only a relatively low acceleration component can be achieved by rotation at five or six rpm. The problem of making external observations in a rotating vehicle may be considerable, and if for any reason the central hub of the vehicle is stationary electrical communication will require the use of slip rings.

F. Suggested Research

1. Olfactory cues

It would be desirable to investigate the practicality of utilizing olfactory cues for the presentation of information.

2. Water Immersion

Preliminary investigations of simulated weightlessness may be performed in a liquid medium to determine effect of prolonged immersion on sleep requirements, time perception, and other variables.

3. Effects of zero gravity

Plans should be made for experimentation on the effects of zero gravity, to be conducted in an orbiting space laboratory.

4. Reduction of sensory inputs

In order to check reliability of space vehicle systems it would be desirable to investigate the capability of the astronaut to perform a useful function when various sensory inputs are cut off, as in the event of failure of the illumination system within the vehicle.

VII. THE RELEVANCE OF THEORIES OF SENSATION AND PERCEPTION TO PROBLEMS IN SPACE FLIGHT

Situations will be encountered in space which are unique in man's perceptual experience. Theories of perception may afford a basis for predicting what man will do in these situations. It is also possible that different theories will predict different outcomes. If this is the case, the space flight environment may provide a proving ground for theories of sensation and perception. A discussion of this problem was presented to the Working Group by William Bevan. His remarks are included as Appendix A of this report. They are followed in Appendix B by brief comments on the relation of perceptual theory to space flight made by several prominent perceptual theorists.

VIII. BIBLIOGRAPHY OF THE LITERATURE RELEVANT TO SENSORY AND PERCEPTUAL PROBLEMS IN SPACE

A. The Armed Forces-NRC Vision Committee has been given the assignment of developing a bibliography relevant to problems of space flight in the broad area of vision. This will include problems of physical optics, the pathological effects of exposure to the fumes of exotic fuels and a variety of other topics in addition to work related to sensory and perceptual problems. The members of this working group have agreed to cooperate with the Vision Committee in the collection of items for this bibliography in the areas of sensory and perceptual problems. Dr. William Bevan will represent this group in liason with the Vision Committee.

B. It is the opinion of this working group that it would be highly desirable to have an annotated, indexed bibliography of literature relevant to perceptual and sensory problems of space flight.

C. A preliminary bibliography has been collected by William Bevan and is presented below.

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APPENDIX A

The Relevance of Theories of Sensation and Perception to Problems of Space Flight

William Bevan

As the anchor man on the agenda I suspect that what I have to say will be for the most part anticlimactic. I approached my assignment of commenting on the relevance of perceptual theory to problems in space with some uneasiness for two reasons:

(1) First of all, there is a dearth of information about the perceptual processes as they have been observed under conditions that simulate the space environment. In addition, my knowledge of what is available has come from the literature. I suspect there are some profound differences between the first-hand knowledge of certain members of the panel who are working in laboratories where space-related research is going on and my book-knowledge.

(2) But secondly, and, more importantly, I feel, perhaps intuitively, that my title implies a kind of logical trap of the sort used by the village jokester when he asks if you have stopped beating your wife. It implies that extant perceptual theory is relevant for problems of space. The one general impression that I have gained from reading what is available in the literature and from talks with people who are more directly involved in the area of space psychology is that what is new is, indeed, very very new and what is old is plain routine. This in turn yields the feeling that in the latter case recourse to theory is unnecessary, and in the former, probably, at this stage of knowledge, of little help.

Certainly, with the most widely publicized goal of space programs being the successful engineering of both unmanned and manned flight, there are many problems that are of an applied or, at least, of a purely empirical nature. These are either carried out successfully on the broad base of existing theory or don't need theoretical justification. Representative of this class are studies which take questions that have been asked and solved for, let us say, high speed aircraft, and ask them in the context of space operations. There is, for example, a rather large literature on tracking. In recent years, it has been important to ask, as Fletcher, Collins, and

Brown have asked, how the performance of this skill is influenced by loads of positive "g". Or as Gerathewohl and his colleagues have asked, how is eye-hand coordination affected by zero "g"? Into the same category one might classify the Lockheed studies of the role of fatigue in multiple-task performance that extend the work of Bartlett and of Payne and Hauty with mission profiles that are a matter of days. Still another example is Jerison's studies of efficiency of monitoring during periods of intense noise and of quiet. It is quite meaningful to ask what relationship exists between these variables without reference to explanatory concepts like vigilance, expectancy, reactive inhibition, or even the excitatory state of the hypothalamus.

In order to comprehend more clearly the possible implications of present theories of perception for predicting the perceptual data of space flight, I have employed a variation of Ernest Mach's version of the method of introspection. I have tried to imagine what the perceptual world of the astronaut will be like on a round-trip flight from earth into space. I have concerned myself briefly with two perceptual environments, the one inside and the one outside of the space vehicle, and two conditions of flight, launch and reentry, and orbital or interplanetary flight.

During the relatively short periods of launch and reentry, the astronaut will probably be most keenly aware of the forces of acceleration upon him and of the changes that accompany this as he passes through regions of different atmospheric density. During launch he will also experience changes in acceleration that are related to multiple-stage firing. In addition to acceleration, he will be exposed to low frequency vibration and briefly to the intense noise of blast-off. Intelligibility of speech will probably be influenced by the narrow band-width necessary for communication. Except for vibration, his visual environment within the vehicle, as he perceives it, should undergo no change. Meanwhile, if he has a port available for visual reconnaissance, the rate of flow across the latter will be so great as to preclude the visibility or recognition of forms. Until he becomes experienced, he will also sense tension of some sort to greater or less degree. To the monitor of his behavior there will be evidence of visual disturbances of the sort reflected in the oculo-gravic illusion. These will also show up in systematic errors in orienting movements and in greater variability in sensorimotor performance. Movements will, of course, be more difficult than normal and will be restricted to manipulative movements of the fingers.

If the most impressive aspect of the astronaut's experience during launch and reentry is his awareness of positive "g", than the most impressive part of his experience of interplanetary flight will be his reaction to weightlessness. If he has overcome his anxiety, he may feel elated and expansive. But he may also experience frustration on his early flights, as he attempts to orient and to move about without the benefit of vestibular input and with reduced kinesthetic feedback. If he is on a space station rather than a space ship he will have the more complicated problem of adjusting to changing g as he moves between the center and the edge.

Just as the blind come to depend upon subtle auditory cues for orientation, so the astronaut will probably have to develop a dependence on vision. But this will be more than learning to get along without proprioception; it will involve developing a new frame of reference. Without proprioception and contact with surface he will fail to perceive an "up" and "down". This will probably be confounded by the physical configuration of the space vehicle, should this be spheroid or tubular rather than the cuboid he has become conditioned to and should he be required to move in several planes in order to perform his duties. There will be visual disturbances. Here, however, the constant errors of location will tend to be the complement of those observed during high-positive g. Furthermore, there may be additional perceptual distortions associated with the expansiveness found in the weightless state and with the relatively long periods of confinement involved in space flight. This might be expected particularly when it is a solo flight, the area of free movement is restrictive, and the inflight responsibilities are limited to monitoring. One may in addition expect during periods of monitoring a restriction of the dynamic visual field and a severe reduction in vigilance. At the same time, in the absence of the shifts in muscle tension ordinarily involved in postural changes that prelude sleep, he may find going to sleep to be extremely difficult. The consequences of this problem will, of course, depend in part on the ease with which he fatigues during space flight.

Visibility outside the space ship will depend upon the part of the retinal field stimulated and the refractive condition of the eye. Since there is little in space to produce diffusion of light from the stimulus object there will be no penumbras. Thus solid objects will lack their characteristically solid appearance. Rather those surfaces that face the sun will appear as planar views. The rest will be indistinguishable from the black void beyond. Hence, the viewer will have to learn to see these configurations as familiar objects in some such way as Ames' subjects came to see distorted rooms as distorted or Kohler's subjects adapted to their aniseikonic lenses. With no ordinal stimulation there will be no appreciation of distance. Rather, space will appear to be populated by thousands of shining discs, uncomfortably close, probably somewhere just beyond the outer limit of convergence. Size constancy, as we know it, like form constancy, will be absent. Apparent size, at a single assumed distance, will conform to the Law of Visual Angle. Direction, if it is perceived, will be referred to the viewer's perceived orientation within the vehicle.

Unless pains have been taken to preserve diurnal cycles, temporal disorientation is most certain to occur. And even if such precautions are taken, subtle effects identified with the altered rhythms of movement during weightlessness are conceivable. Indeed, in the extreme, such interruption in characteristic movement and orienting patterns could cause spatial confusion and some blurring of the body image.

Before one examines the possible contributions that extant theory makes to the study of perceptual processes in space, it is appropriate to mention the complementary relationship. If I am allowed the foregoing flight into science fiction as a set of givens, then a cursory review suggests certain inferences that are pregnant for perceptual theory: (a) First, the structure of perception is profoundly affected by the level of impingement. This generalization has several facets. There are the effects of nonspecific stimulation as suggested by Zarriello and Norsworthy's report that blackout thresholds are lower under conditions of scotopic than under conditions of photopic stimulation. There are also the effects of specific stimulation as indicated by Brown's data on the identification of the vertical referent under conditions of neutral buoyancy. Finally, there is the problem of variety in impingement as revealed in the McGill studies on the pathology of boredom. (b) Secondly, perception reflects the interaction of the several dimensions of impingement. Again there are several facets to be considered. There is first of all the long-studied cooperation of the senses in orientation. There are also the dimensional interactions that occur within the same modality - for example, the role of brightness in apparent size. Finally, there has accumulated, particularly in the past thirty years, a great deal of data on intermodal interactions. This literature is typified by the work of Graybiel and his colleagues on the oculogravic and oculogyral illusions. (c) And thirdly, learning is an important prerequisite to the establishment of stable perceptual frames of reference. This is apparent in the problem of spatial orientation in the condition of weightlessness and is necessary to any possible success in visual reconnaissance.

The study of perceptual processes in extraterrestrial space can also accommodate perceptual theory in ways that are broadly methodological. It has, for example, been customary to define stimulus dimensions in terms of a physical referent. The data of perception in space may prompt other criteria. For instance, studies of the visual perception of the vertical may prompt a classification of inputs in terms of the function they perform in providing the referent for judgment. Similarly, the study of form, size, or distance perception in the impoverished visual environment outside the space vehicle may require the description of stimulation in terms of variety or dimensional complexity. Garner and Hake several years ago reported data on psychophysical judgments as a function of the number of stimulus dimensions on which variation occurred. Or the observations of the effect of monotony may suggest a classification of variables in terms of their tendency to induce perceptions that are autistic.

The study of perceptual processes in space will, of course, uncover new phenomena and thus confront theory with new questions. Thus, Westheimer's demonstration of the effect of an empty visual field on accommodation suggests further examination of the role of this variable in depth perception.

The space environment, furthermore, has the potential of providing the special conditions necessary for the testing of the implications of certain perceptual theories. The space ship during orbital flight would seem to be the ideal laboratory for testing hypotheses about the role of tonus in visual perception, the effects of schedules of reinforcement on vigilance, or the evolution of adaptation-levels with more precisely regulated residuals and background. Other examples are as readily available.

The term, perceptual theory, has been applied to a wide variety of formulations ranging from those devised to define some particular relationship between two stimulus variables (e.g. Graham, Brown, and Mote's formulation of the area-intensity problem in vision) to those intended to account, at least in thematic terms, for all aspects of a perceptual event (e.g. the view of the transactionists). Graham has on numerous occasions pointed out that the distinction between the sensory and the perceptual is essentially a matter of theoretical preference not laboratory practice. While I agree with this position completely, I have considered, for purposes of the present discussion, only theories that deal with variables, like form and distance, which have been traditionally classed as perceptual.

That level of impingement is a significant determinent of perceptual structure would be anticipated by Hebb's cell-assembly theory and by interactive theories like Werner and Wapner's sensory-tonic theory and Helson's adaptation-level. It is more than coincidental that Hebb has, in recent years, been interested in the reticular formation and in problems of sleep and wakefulness. Both his theory and work from his laboratory indicate emotional distress with the withdrawal of sensory input. Helson, meanwhile, would expect a change in the perceptual content with sensory isolation, and would predict a shift toward the autistic in perception as the residual became more heavily weighted in the determination of the subjective norm. By the same token he would expect wide individual differences in response to weightlessness. Along with Werner and Wapner he would predict threshold changes and changes in vigilance with shifts in overall input. The sensory-tonic theory yields rather precise predictions concerning the relation of acceleration and weightlessness to phenomena like the oculogravic and oculogyral illusions and shifts in orientation. These, of course, may also be fitted to the A-L paradigm.

The importance of interactions across modalities is an explicit part of Werner and Wapner's theory. They also may be accommodated with little difficulty by the pooling model, for inputs have two essential properties, intensity and frequency of occurrence, and one common destiny, contribution to the norm. Explanations framed in informational terms may be appropriately used to describe the cooperation of the senses. Phenomenal distortions are harder to account for.

Our description of the visual world outside the space vehicle has been constructed after a consideration of both the classical cue theory of depth perception and Gibson's theory of texture gradients. Except for the possibility of a gradient of flow in depth, there is nothing to yield the impression of depth, solidity, or precise location in space. Other views would yield similar expectations. Gestalt psychologists, for example, might describe the end result in terms of the schematizing effect of the organizing principles. However, one must turn to other sorts of theories if one wishes to rationalize his optimism that man can be trained to orient himself competently and carry out reconnaissance in this environment. These theories are all functionalistic. They share with Woodworth the assumption that perception is a motivated process of analyzing and interpreting signals, not a picture of the world. Recognizing the validity of the notion of equivalent configurations, one may set out to build up a three-dimensional assumptive world of space, by arranging for appropriate transactions between the perceiver and the space environment, in the manner of Ames, Cantril, and their colleagues. Bruner and Postman's theory of hypothesis testing and Brunswik's view of probability learning would make similar provisions.

A glance back over the theories I have mentioned immediately above indicates that they have at least one thing in common: They are concerned primarily with central mechanisms. It also reveals that relevance is a many-faceted affair. A theory is relevant when it allows the prediction of a specific perceptual response for a particular perceptual situation. It is relevant when it provides a reasonable post hoc explanation of a perceptual observation. It is relevant when it provides a conceptual avenue by which to approach an area of inquiry. It is relevant when it provides a method that may be fruitfully applied to an area of inquiry. Finally, it may be relevant if it is preoccupied with the same variables, or even if it asks the same questions as are being asked in the area of inquiry. Relevance is a matter of degree. And the determination of degree is a purely heuristic matter.

Early in August it occurred to me that it would be appropriate to solicit the views of prominent theorists on the matter of the relevance of perceptual theory to the problems of space flight. Their replies will appear as Appendix B of the Working Group's report. A review of their comments indicates two things: (a) Their primary concern appears to be with central nervous system variables; and (b) the contribution of theory at this point can at best be said to be to provide an orientation on line of attack rather than to yield precisely stated predictions of the hypothetico-deductive sort.

APPENDIX B

Comments of Perception Theorists on Perceptual and Sensory Problems in Space Flight

1. James J. Gibson

"I am, of course, interested in your topic, and it seems to me a deeply theoretical one. A terrestrial theory of space perception which I have advocated ('surface' theory as distinguished from 'air' theory) seems to me the only sound basis for the new research needed on perception in relatively 'empty' space. The hypothesis of information in sight, the concept of the optic array, and the development of ecological optica (as distinguished from classical geometrical optics) would prevent many of the misconceptions which already seem to be hampering this research - or so it seems to me. But obviously these concepts need explanation and empirical elaboration. So I'd better get back to the job."

2. Harry Helson

"Regarding the problems of living in space capsules or even ships, certainly variety must be provided or perceptions and judgments will go haywire. Sensory inputs provide 'anchors' which determine levels with reference to which judgments, indeed the nature of perception itself, are determined. The reduced environments studied by the Hebb group and others show this, of course, and theory would lead us to conclude that since the organism pools what it gets, along with its own residuals, the less that comes in, the greater the role of the residuals, hence the less objective will the frame of reference be. I think something of this sort is needed in the way of theory to furnish a guide or thread for data which are beginning to come in in unordered and proliferating fashion. They may even have to resort to very intense stimuli, given at random intervals, electric, visual, sound, tactual, even pain, to keep the astronauts environmentally anchored. The possibilities of providing sensory input, as well as kinaesthetic feedback from their own muscles, etc. will have to be developed by psychologists in collaboration with the engineers who design the space vehicles."

3. W. C. H. Prentice

"It seems to me that the popular literature about space travel has put too limited an interpretation on the changes produced by a world without gravity. The fact is that our psychological world is highly structured with respect to vertical direction. We move along the surface of the earth in a way that must be contrasted sharply with the mobility of a fish, for example, who is free to move up and down almost as readily as he moves parallel to the earth's surface. If we achieve a genuinely three-dimensional space of locomotion, a number of radical perceptual changes may occur.

"It should also be noted that there are distinct differences between upper and lower halves of our visual fields. In general, far more contours appear in the lower half. Presumably the increased satiability of the lower part of the field is related to that fact. Still other differences are shown in our reactions to highlights and shadows. Hess has performed very interesting experiments suggesting that those reactions would be very different if we had not always lived in a world in which light tends to come from above. These are only a few of the kinds of changes that might be expected if man were to establish for himself an environment really free of terrestrial influence."

4. Seymour Wapner

"I wish there were more time available to think through the relevance of perceptual theory to problems of space flight-and in particular sensory-tonic theory-because I believe there is great relevance on many grounds.

"Some of our laboratory work on perception, as you know, has dealt with the effect of asymmetrical shifts of neuromuscular distribution, under conditions of body tilt, acceleration around the vertical axis of the body, stimulation to one ear or the neck muscle of one side. There are clearly predictive effects from the introduction of such conditions on localization in space. There may be space conditions, in vehicles, or other devices like space stations, where asymmetrical forces are imposed upon the organism. If the direction of such forces were specified, I believe, some guesses could be made as to the systematic changes in space localization that would occur."