SPECIAL REPORT 66-6

ORIENTATION IN AEROSPACE FLIGHT

Ashton Graybiel

JOINT REPORT

NAVAL AEROSPACE MEDICAL INSTITUTE

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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ORIENTATION IN AEROSPACE FLIGHT*

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PENSACOLA, FLORIDA

Aerospace flight has created unique patterns in the force environments to which man may be exposed. The magnitude of these linear forces may be so great that the force of gravity is small by comparison, and the angular accelerations may be far different in pattern from those ordinarily experienced. When combined with immanent accelerative forces, they constitute a complex, dynamic pattern which varies as a function of time. Moreover, these physical forces initiate functional changes elsewhere than in receptor organs which may or may not be compensatory in the sense that they act to minimize or abolish the stresses.

SENSORY SYSTEMS

In Figure 2 is shown a simplified analysis of cues to space perception provided under terrestrial conditions and some of the possibilities for interaction among them. The great concordance between cues from the gravitational and visual environments is obvious in natural environments and yet more so in artificial ones which are based on the gravitational coordinate system.

Some of the possibilities for interaction can be artifically contrived, not only by manipulations of the visual and force environments but also by the use of subjects with or without labyrinthine function. In general, manipulations are far easier to accomplish in the visual than in the force environment; moreover, with vision a unique situation exists in which one can study nonvisual influences on visual space localization in the absence of visual cues to space. This is represented by the broken lines in Figure 2. It is important to emphasize that in the articulation between sensory information from the visual and force environments, visual cues are absent although a slight influence is demonstrable.

EXPERIMENTAL PROGRAMS

SUBJECTS

In many of our experiments in addition to normal controls we have used deaf persons with bilateral loss of labyrinthine function (L-D subjects), Table I. It is a pleasure at this time to acknowledge their splendid cooperation and important contribution to our experimental program.

The selection of normal as well as L-D subjects raises the problem of functional tests of the semicircular canals and otolith organs. With regard to the canals, our current practice is to use a modification of the Hallpike test (2) and a so-called caloric threshold test (3).

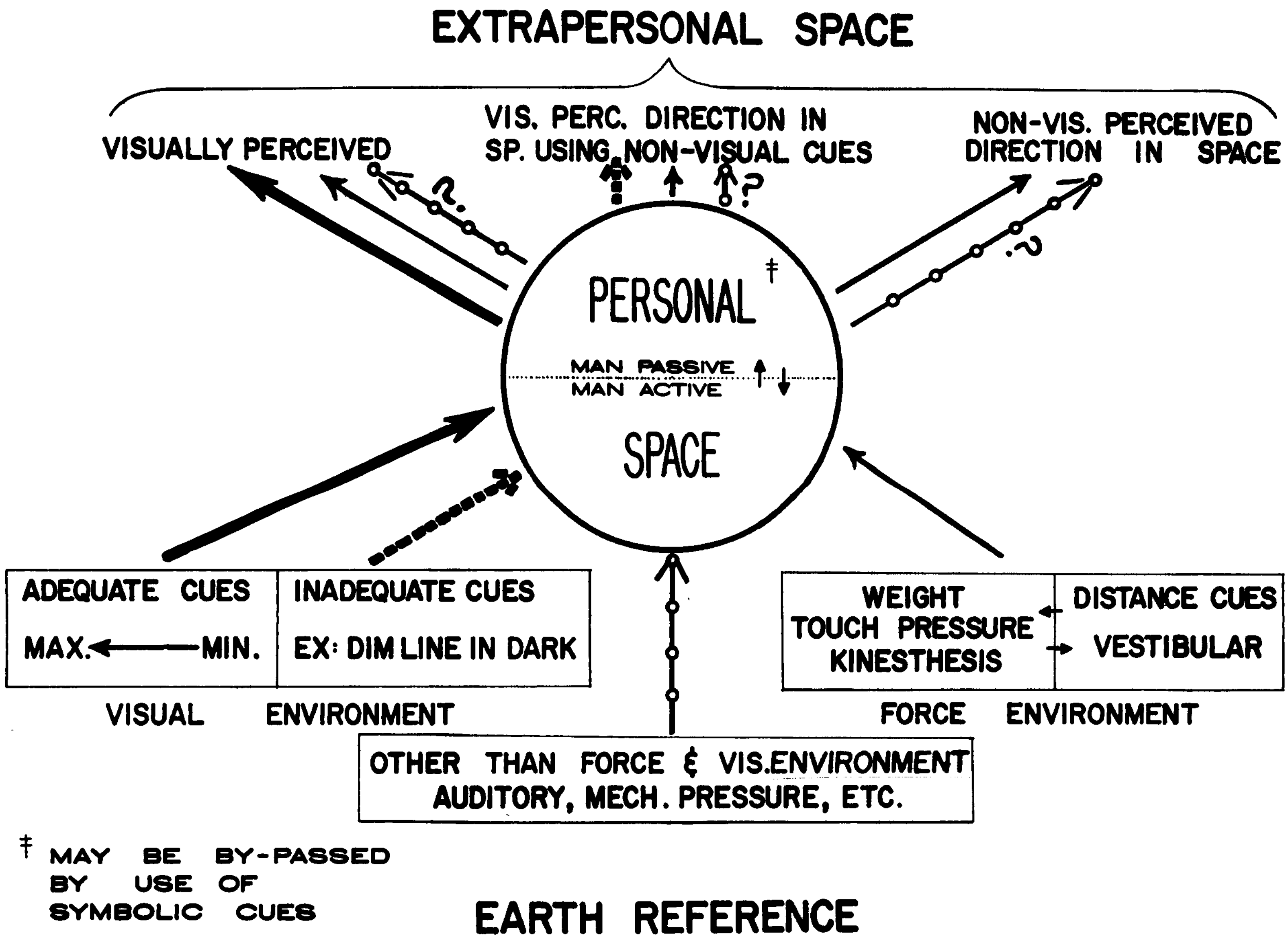

EXTRAPERSONAL SPACE
VISUALLY PERCEIVED
VIS. PERC. DIRECTION IN SP. USING NON-VISUAL CUES
NON-VIS. PERCEIVED DIRECTION IN SPACE
PERSONAL ‡
MAN PASSIVE
MAN ACTIVE
SPACE
ADEQUATE CUES
MAX. MIN.
INADEQUATE CUES
EX: DIM LINE IN DARK
VISUAL ENVIRONMENT
WEIGHT
TOUCH PRESSURE
KINESTHESIS
DISTANCE CUES
VESTIBULAR
FORCE ENVIRONMENT
OTHER THAN FORCE & VIS.ENVIRONMENT
AUDITORY, MECH. PRESSURE, ETC.
‡ MAY BE BY-PASSED BY USE OF SYMBOLIC CUES
EARTH REFERENCE

Figure 2

Table I

CLINICAL FINDINGS IN ELEVEN DEAF PERSONS WITH BILATERAL LABYRINTHINE DEFECTS

SUBJECT	AGE	AURICULAR DEFECTS		HEARING[1]		THRESHOLD RESPONSE CALORIC TEST		COUNTERROLL INDEX (MIN. ARC)[3] MAX. TILT[4]	
		ETIOL	AGE ONSET	R	L	R	L	50°	75°
DOMICH	48	MENINGITIS	13	NIL	NIL	N. R.[2] 10° C 3 MIN.	N. R. 10° C 3 MIN.	74	74
GREENMUN	48	MASTOIDITIS	12	NIL	160	N. R.	N. R.	60	—
GULAK	26	MENINGITIS	4 1/2	$\geq$ 145	$\geq$ 145	10° C 40 SEC.	10° C 40 SEC.	76	89
HARPER	29	MENINGITIS	13	NIL	NIL	N. R. 2.8° C 10 MIN.	N. R. 2.8° C 10 MIN.	47	53
JORDAN	34	MENINGITIS	7 1/2	NIL	NIL	N. R. 3.0° C 3 MIN.	N. R. 3.8° C 3 MIN.	126	176
LARSON	29	MENINGITIS	6	$\geq$ 115	$\geq$ 110	10° C 40 SEC.	?N. R.	73	109
MYERS	25	MENINGITIS	8	NIL	NIL	N. R. 2.8° C 10 MIN.	7.9° C 40 SEC.	63	82
PETERSON	33	MENINGITIS	12	NIL	NIL	N. R. 2.6° C 3 MIN.	N. R. 2.6° C 3 MIN.	21	30
PIPER	26	MENINGITIS	3	NIL	NIL	9.8° C 40 SEC.	NOT TESTED (INF.)	71	85
STEELE	25	MENINGITIS	12 1/2	$\geq$ 130	$\geq$ 135	10.0° C 3 MIN.	11.0° C 3 MIN.	110	117
ZAKUTNEY	25	MENINGITIS	3 1/2	$\geq$ 135	$\geq$ 130	2.8° C 10 MIN.	2.8° C 10 MIN.	22	36

1. Response to white noise up to 160 db
2. N. R. — No Response
3. One-half the sum of maximum roll right and left (min. of arc)
4. Angular displacement of body from vertical in frontal plane

Evaluation of otolith compared with canal function is far more difficult. Chief reliance is placed on measuring ocular counterrolling as a function of lateral tilt. This approach was initiated (4) by placing sutures in the conjunctiva and markers at the outer canthi (Figure 3a). The amount of roll for a given angle of lateral tilt was determined by comparing flash photographs taken in the two positions (Figure 3b). Dr. Woellner carried out measurements on normal and L-D subjects on a tilt chair and compared the results with those obtained for the same change in direction of the gravitoinertial vector on the human centrifuge (5,6). Dr. Miller introduced a photographic procedure (Figure 4) which depends on matching crypts in the iris between photographs taken with the subject upright and in lateral tilt (7).

EXAMPLES OF INTERACTIONS BETWEEN CUES FROM VISUAL AND FORCE ENVIRONMENTS

In Figure 5 (top) is shown a naive normal subject on an open centrifuge facing the center of rotation. When he is exposed to a centripetal force of 1.0 G unit, the centrifuge appears to slope upward away from him and the room appears similarly sloped (8). This is at once a demonstration of preternatural control over the force environment and a partial conformity of the visually perceived upright to the gravitoinertial upright. This has been termed the oculogravic illusion (9) based on the Earth reference. It might be argued, however, that there is nothing illusory about gravitoinertial force and that any lack of conformity between the visual and force uprights indicates a visual not a gravitational illusion.

In Figure 5 (below) he is exposed to 2.0 G units, and, some persons at least, soon feel as if they are stationary and on their back and perceive the room rotating around them. This is probably analogous to experiences of aviators in certain types of spin (10). Not only are visual cues overwhelmed but also there is overcompensation with reference to the gravitoinertial upright. The curious reversal with regard to relative motion between centrifuge and room might have its genesis in the fact that the force environment is static in the sense that the force pattern with reference to the subject is unchanging at constant velocity and is supernormal in magnitude.

In Figure 6a the subject is seated in a closed lighted room on a human centrifuge and facing in the direction of rotation. When exposed to a centripetal force of 1.0 G unit, he perceives the room as sloped with down on his right side. When visual cues are greatly reduced (Figure 6b) the slope increases, and there may be good concordance between the visual and force upright. This orientation of the subject creates a more favorable opportunity for him to indicate horizontality by clockwise or counterclockwise rotation of a visual target or rod than when he faces the center where estimates would be made as deviations above or below an imaginary horizon.

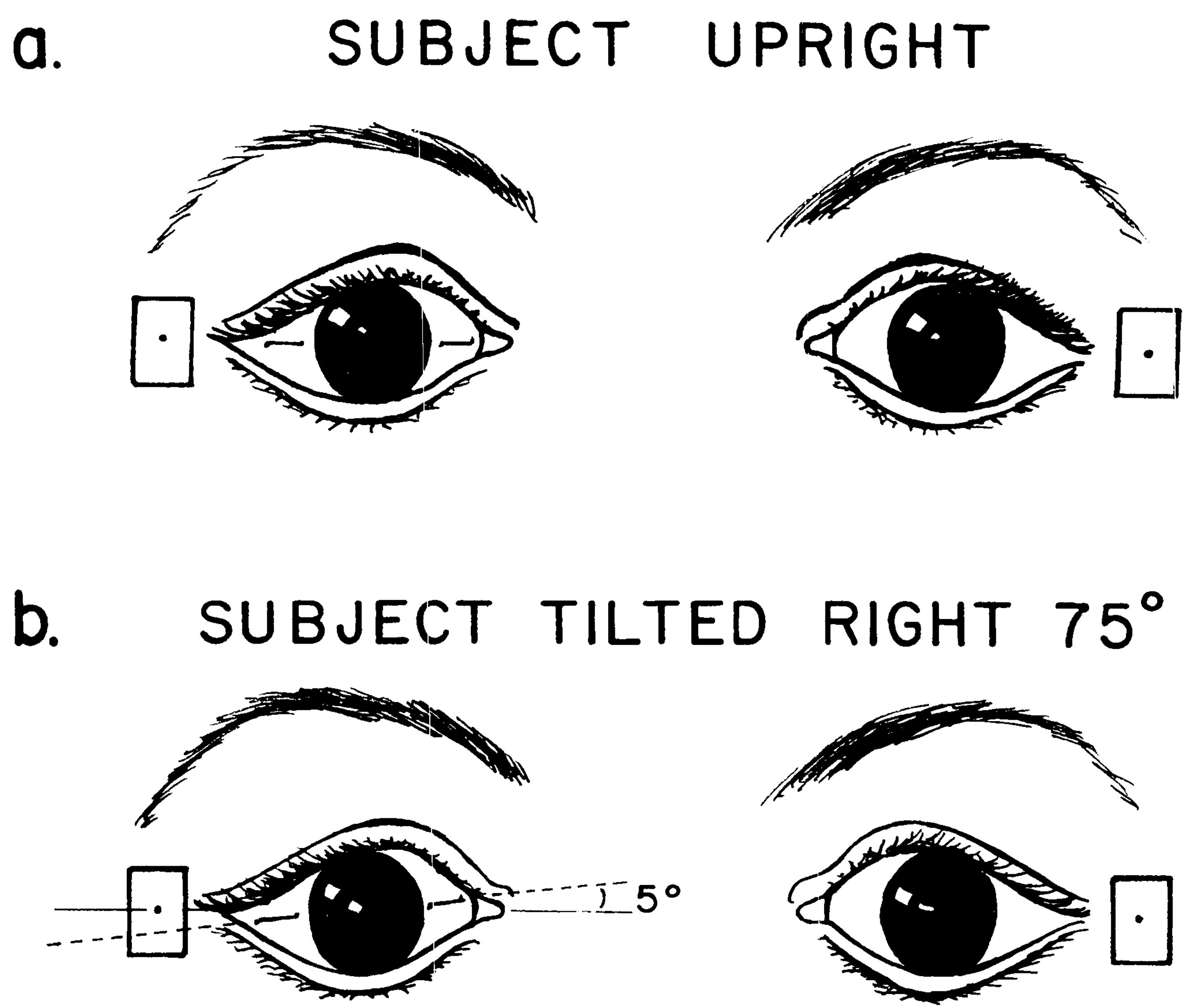


Figure 3

a) Showing sutures in conjunctiva and markers at outer canthi; b) Demonstrating counterroll of eye with lateral tilt.

COUNTERROLLING TEST DEVICE

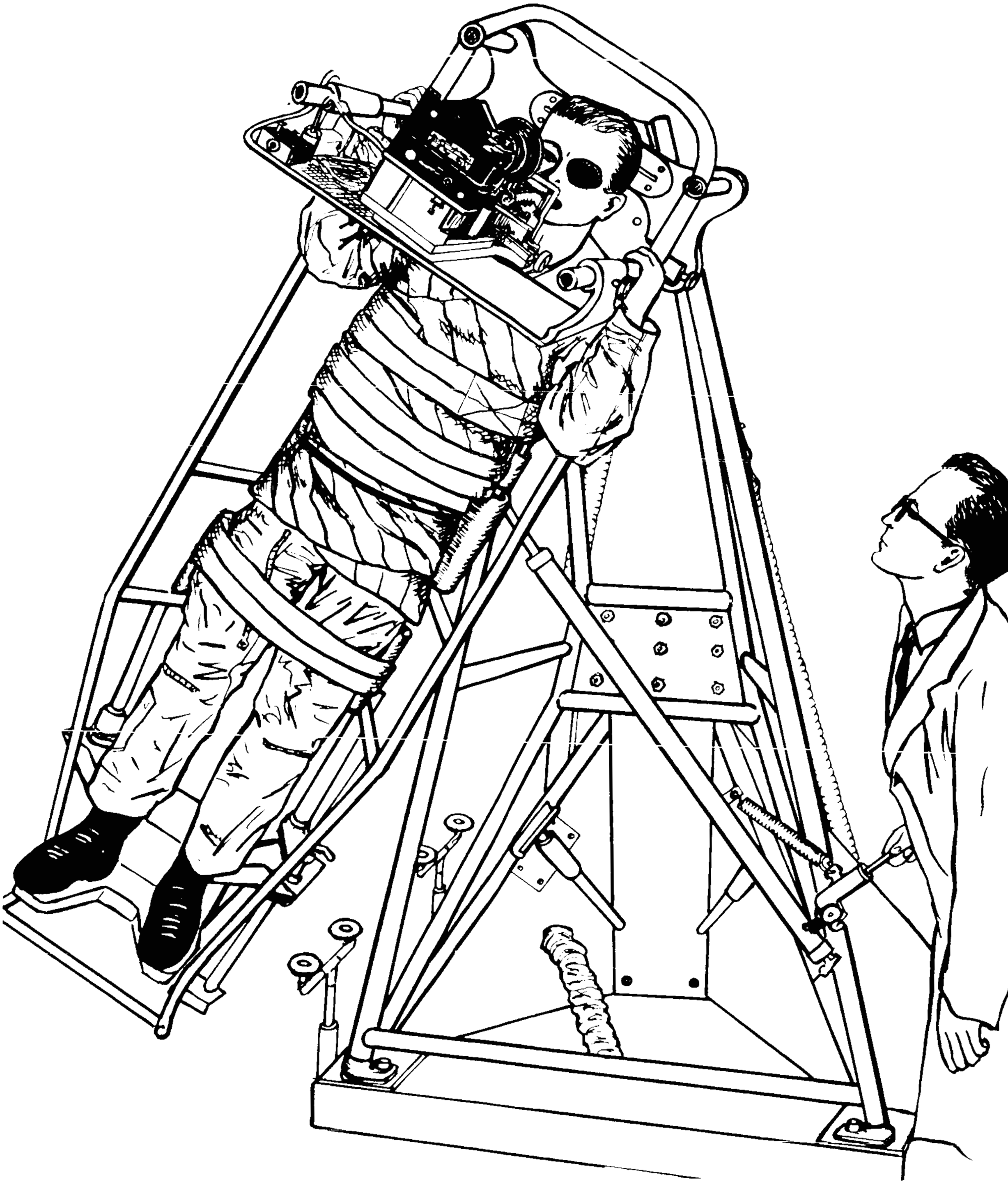
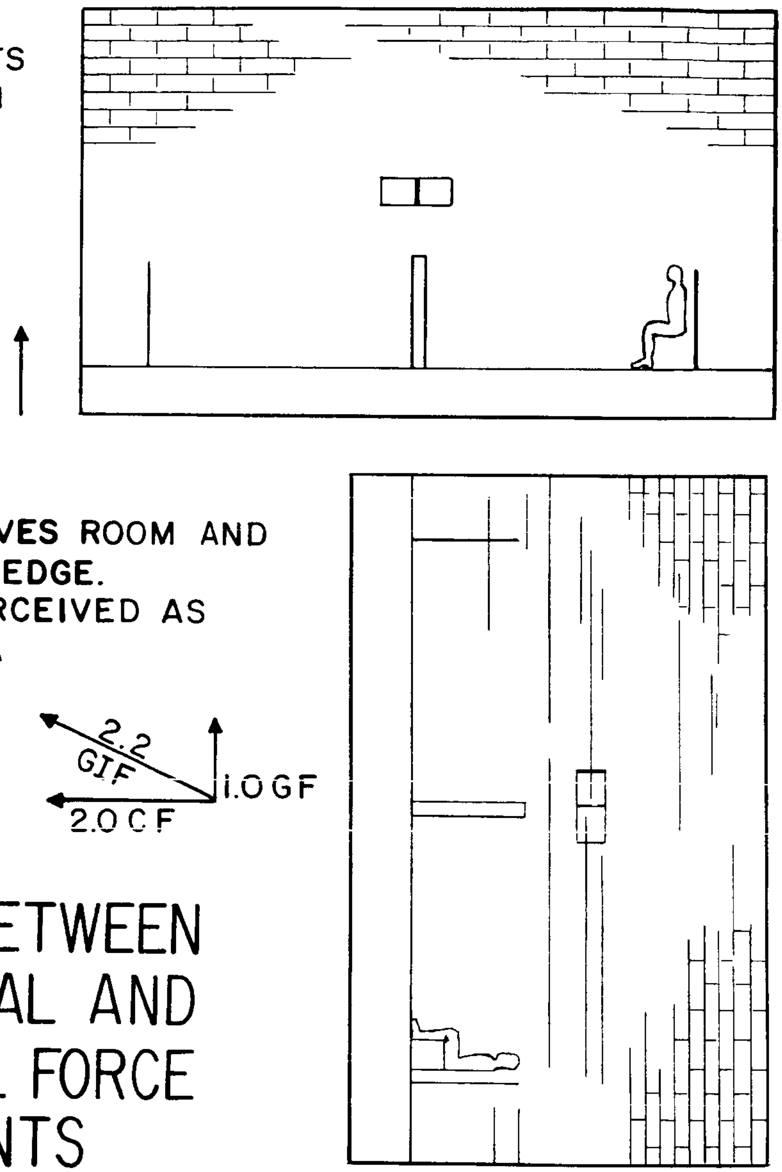
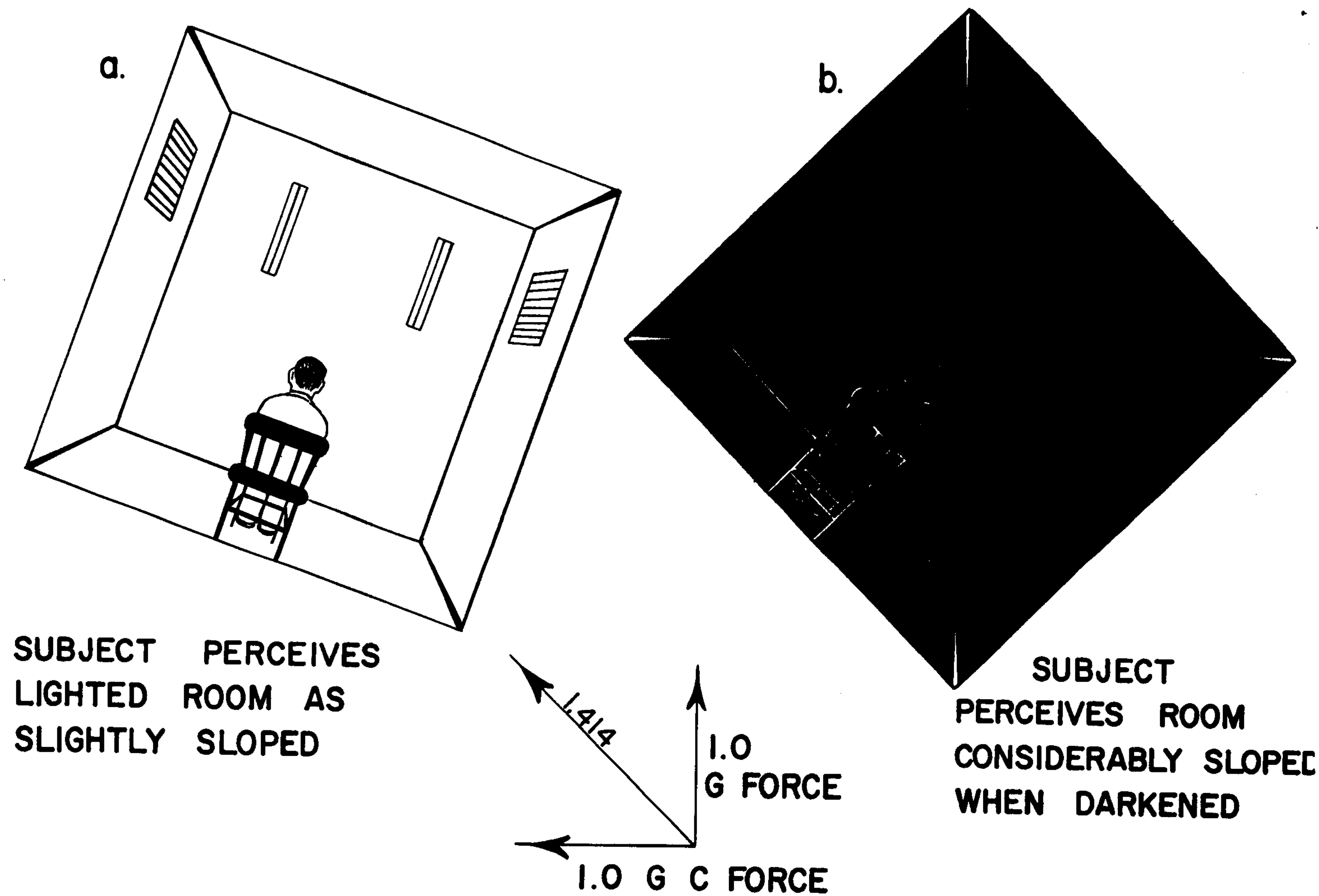


Figure 4



INTERACTION BETWEEN CUES FROM VISUAL AND GRAVITOINERTIAL FORCE ENVIRONMENTS

Figure 5



DEPICTING THE ILLUSORY TILT OF A PHYSICALLY UPRIGHT ROOM PERCEIVED BY A SUBJECT ON A HUMAN CENTRIFUGE

Figure 6

EXAMPLES OF THE INFLUENCE OF NONVISUAL CUES ON THE VISUALLY PERCEIVED DIRECTION OF SPACE

A large body of information has been obtained by having subjects set a visual target or rod in an otherwise uniform visual field either to internal or external spatial coordinates (11-15). Many investigators since Aubert (16) have explored the effects of tilting their subjects in the gravitational field, and with the introduction of the human centrifuge (17, 18) it became possible to change the direction of the gravito-inertial force vector with respect to the subject. There are interesting and important differences between the responses obtained with tilt and on the centrifuge, not all of which have been satisfactorily explained.

THE OCULOGRAVIC ILLUSION

In Figure 7 a subject is shown seated facing the direction of rotation while exposed to a centripetal force of 1.0 G unit (19). The sketch depicts the arrangement of physical objects as viewed by closed circuit television. Note the free swinging plumb bob which is the only indication of the gravitoinertial vertical. Figure 8 shows how a naive subject perceives the situation with eyes closed; he feels as if he is tilted to the right in an upright room. A sophisticated subject is also aware of the tilt but will realize his position has not changed with reference to the room. Both subjects, if viewing a luminous line in the dark while suddenly subjected to a centripetal force of 1.0 G unit, would perceive the line as rotating slowly clockwise from the horizontal position through an arc usually greater than 45°. This is an illusory or apparent motion representing influences of cues from the force environment on visual spatial localization. If the subject is requested to set the line to the Earth horizontal, he rotates it counterclockwise from its original setting toward the gravitoinertial horizontal, usually overcompensating at this level of force; grasping a swivel rod with eyes closed, he also sets this near the gravitoinertial horizontal. The results are scored in terms of correspondence of the settings to the gravitoinertial horizontal. With the visual target the threshold* of perception for perceiving the illusory rotation with the subject upright is 1.0003 G units, about equivalent to an angle phi of 1.5° (20).

The settings of normal and L-D subjects (19) who were requested to maintain the line at the horizontal continuously throughout an experimental trial in which they were subjected to a change in direction of gravitoinertial force of about 20° are shown in Figure 9. Note the delay or lag between the change in force vector and the apparent rotation of the line, indicating, presumably, the complex nature of this integrative mechanism (21).

The effects of having the subject delay in opening his eyes in a similar experiment, also conducted with Dr. Clark (22), are shown in Figure 10. This demonstrates that visual perception is not essential for the integrative action, although it tends to favor it slightly. Vision is essential only to display the effects.

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*75 per cent (or greater) correct responses.

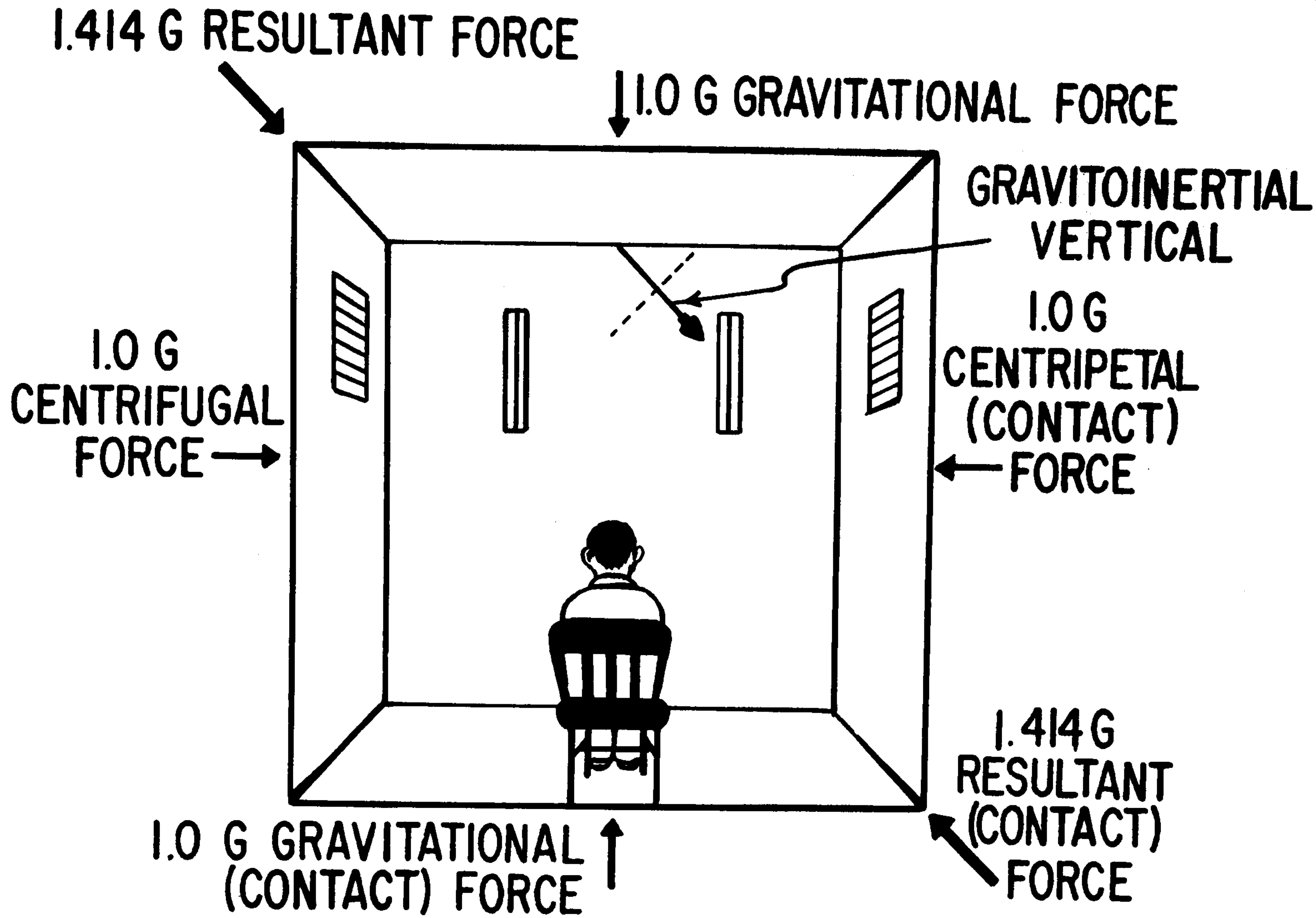
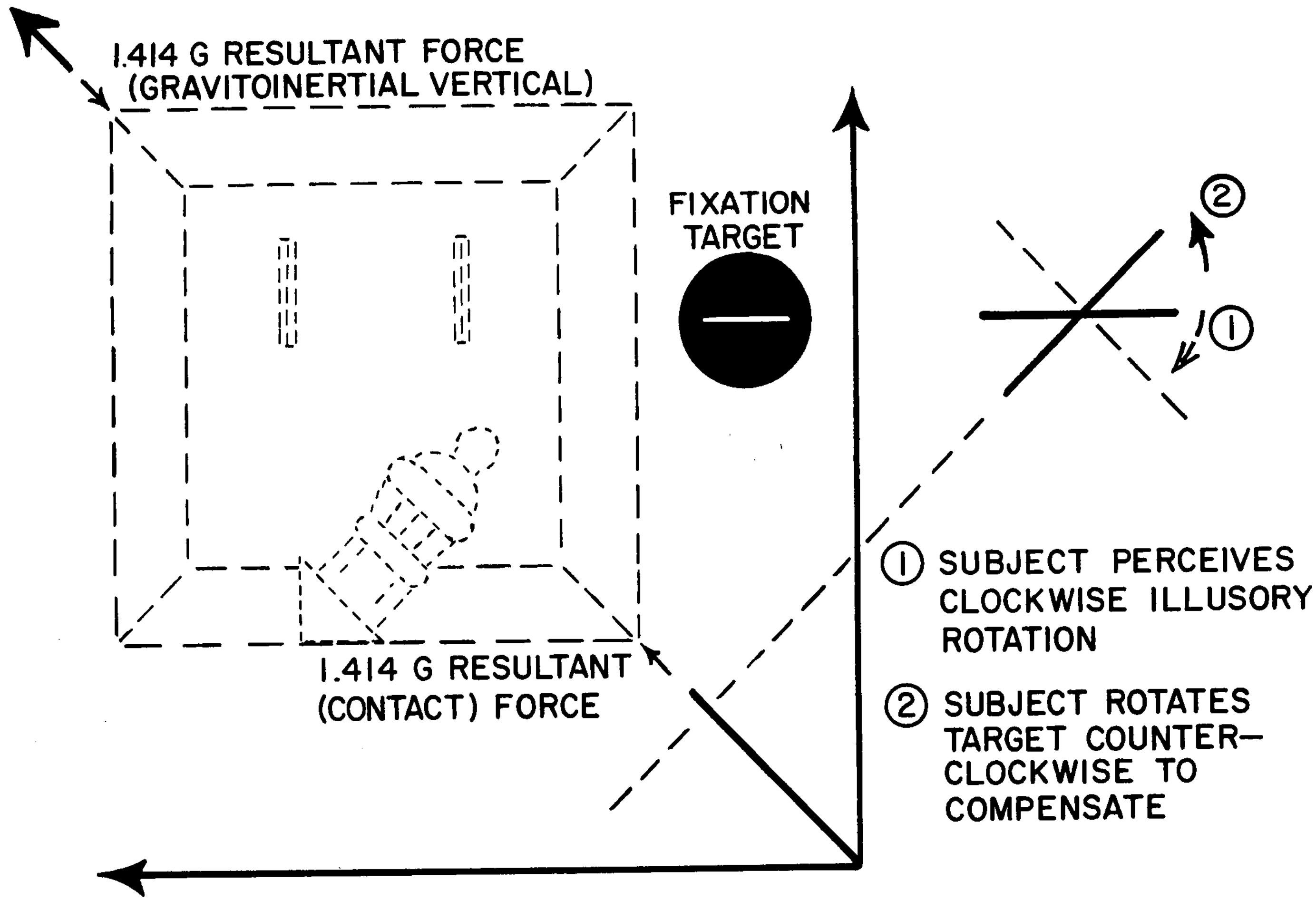


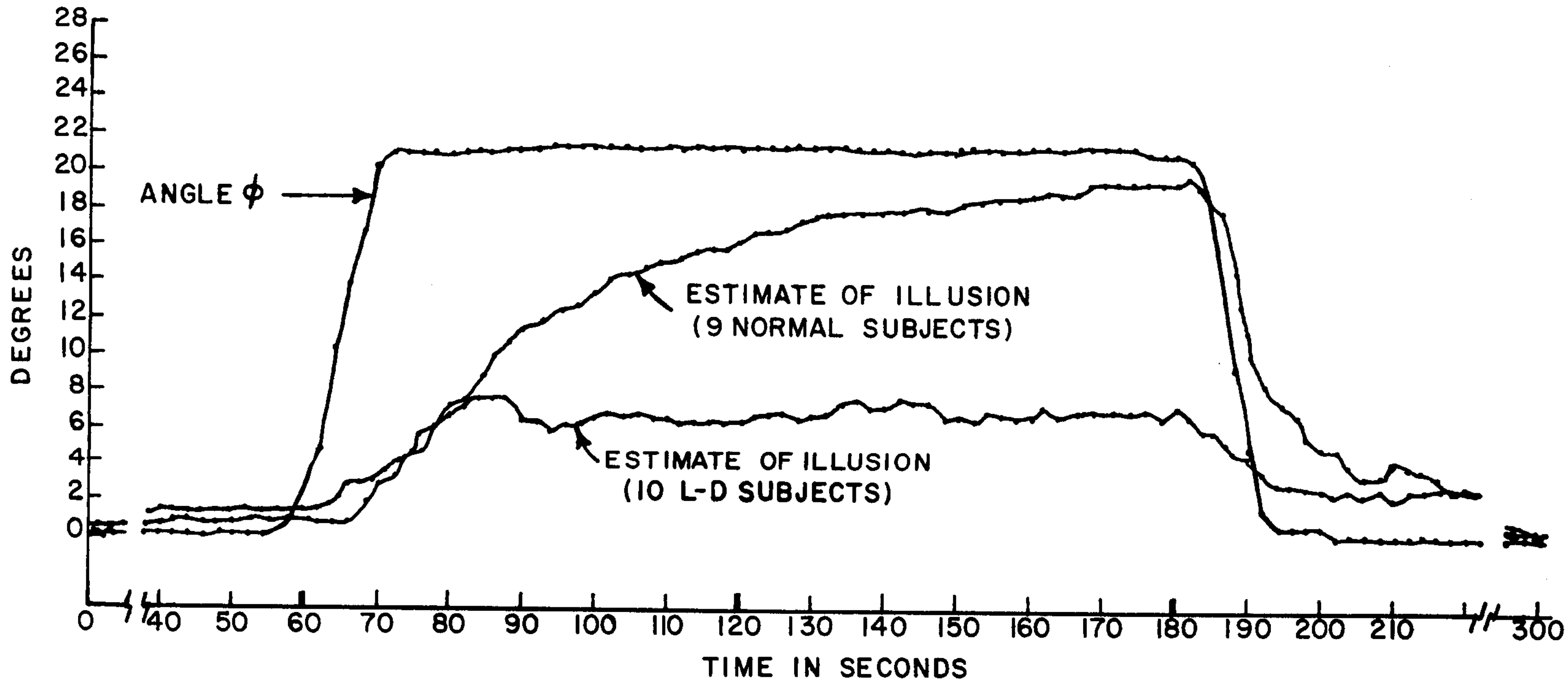
Figure 7

Physical conditions as perceived by closed circuit television with subject fixed during exposure on human centrifuge. Plumb bob only indication of change.



NAIVE SUBJECT FACING AWAY FROM DIRECTION OF ROTATION FIXATING A LUMINOUS LINE IN THE DARK REGARDS HIMSELF AS TILTED IN AN UPRIGHT ROOM

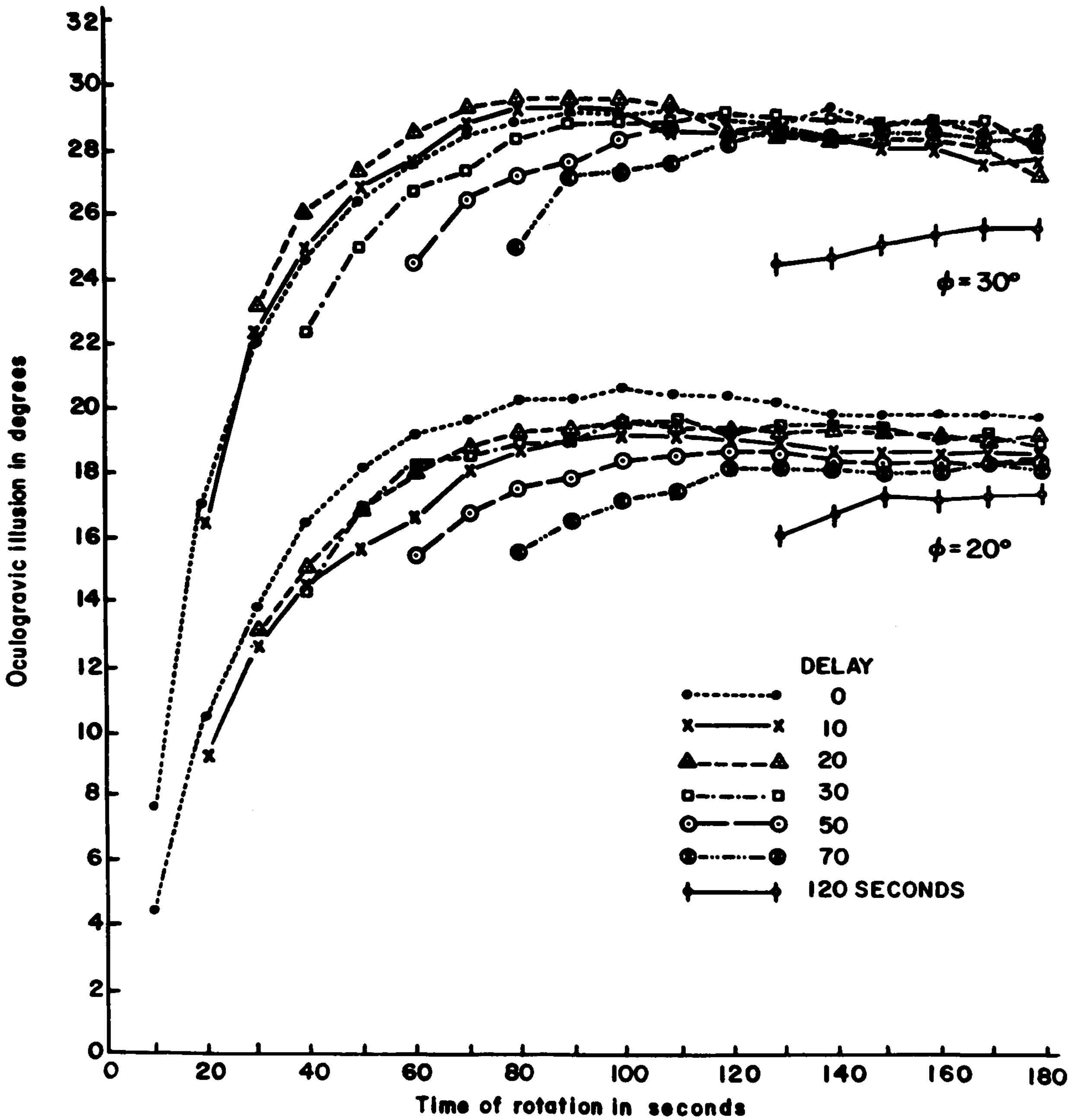
Figure 8



CHANGE IN SETTING OF STAR AS FUNCTION OF TIME COMPARED WITH CHANGE IN DIRECTION OF RESULTANT FORCE OF 20°. CURVES DEPICT MEAN VALUES

Figure 9

MEAN VALUES FOR THE OCULOGRAVIC ILLUSION IN FIVE NORMAL SUBJECTS WITH PROGRESSIVELY LONGER DELAY TIME IN PRESENTING THE TARGET



CONTINUOUS SETTINGS, NORMAL SUBJECTS

Figure 10

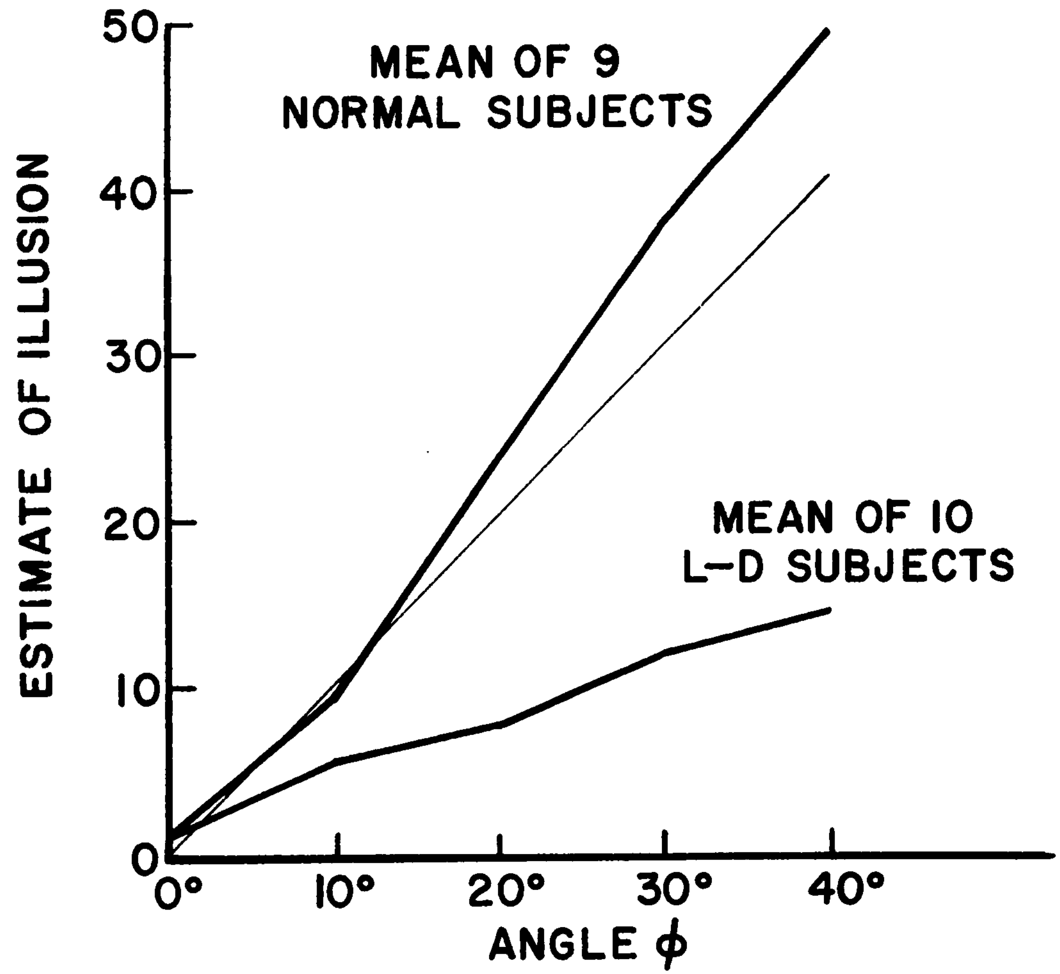
In Figure 11 is shown a comparison between the settings of naive normal and L-D subjects exposed to gravitoinertial forces corresponding to deviations from the gravitational vertical (angle phi) of 10°, 20°, 30°, and 40° (19). The variance was great in the case of the ten L-Ds, but not in the normal subjects. The group differences were attributed to the presence and absence of vestibular, and more likely otolith, function.

The L-D subjects over a period of time demonstrated "improvement" in the correspondence of their settings with the gravitoinertial horizontal. In addition to a possible practice effect, although the means of monitoring was not evident, the settings were greatly improved with prolonged exposure (23) and by encasing the subjects in Fiberglas molds. Some of these factors were evident in the experimental findings upon comparing the settings of the luminous line between normal and L-D subjects when exposed to identical changes in the gravitoinertial upright, once when submerged to the neck, and again under dry conditions (24). In the latter circumstance the use of Fiberglas molds tended to maximize the area of good contact with the centrifuge, while under water these contacts were minimal.

The curves in Figure 12 summarize the findings. Three normal subjects manifested little difference in setting the line to the gravitoinertial horizontal under dry and wet conditions. On the other hand, the L-D subjects manifested a great difference; submerged they set the line very close to the Earth horizontal which coincided closely with their internal horizontal coordinate; when dry, the settings were qualitatively similar but quantitatively about half the value indicated by the normal subjects. Put in other terms, the loss of cues from the receptor organs responding to mechanical force had only a slight effect in the normal subjects inasmuch as the distance receptors in the otolith organs were functioning normally; the quantitatively slight decrease might be said to represent the contribution of the nonotolith receptors under dry conditions. The L-D subjects under dry and favorable conditions demonstrated that the nonotolith receptor organs provided good cues to the force environment despite the absence of distance receptors, and their settings were a measure of these cues alone. Underwater, the cues were greatly diminished, and in the absence of distance receptors there was shown to be little influence from gravitoinertial cues.

CERTAIN EFFECTS OF LATERAL TILT IN THE GRAVITATIONAL AND GRAVITOINERTIAL FIELDS

Seated upright in a tilt chair normal subjects set a luminous line approximately to the gravitational horizontal but manifest a characteristic bias as they are tilted leftward or rightward through 90°. Initially, the bias appears as an over- and later as an under-compensation termed, respectively, the E- and A-phenomenon, as shown in Figure 13 (25). The bias is greater and the consistency less in L-D subjects.



ESTIMATES OF THE OCULOGRAVIC ILLUSION BY NORMAL AND L–D SUBJECTS. SINGLE SETTINGS OF STAR.

Figure 11

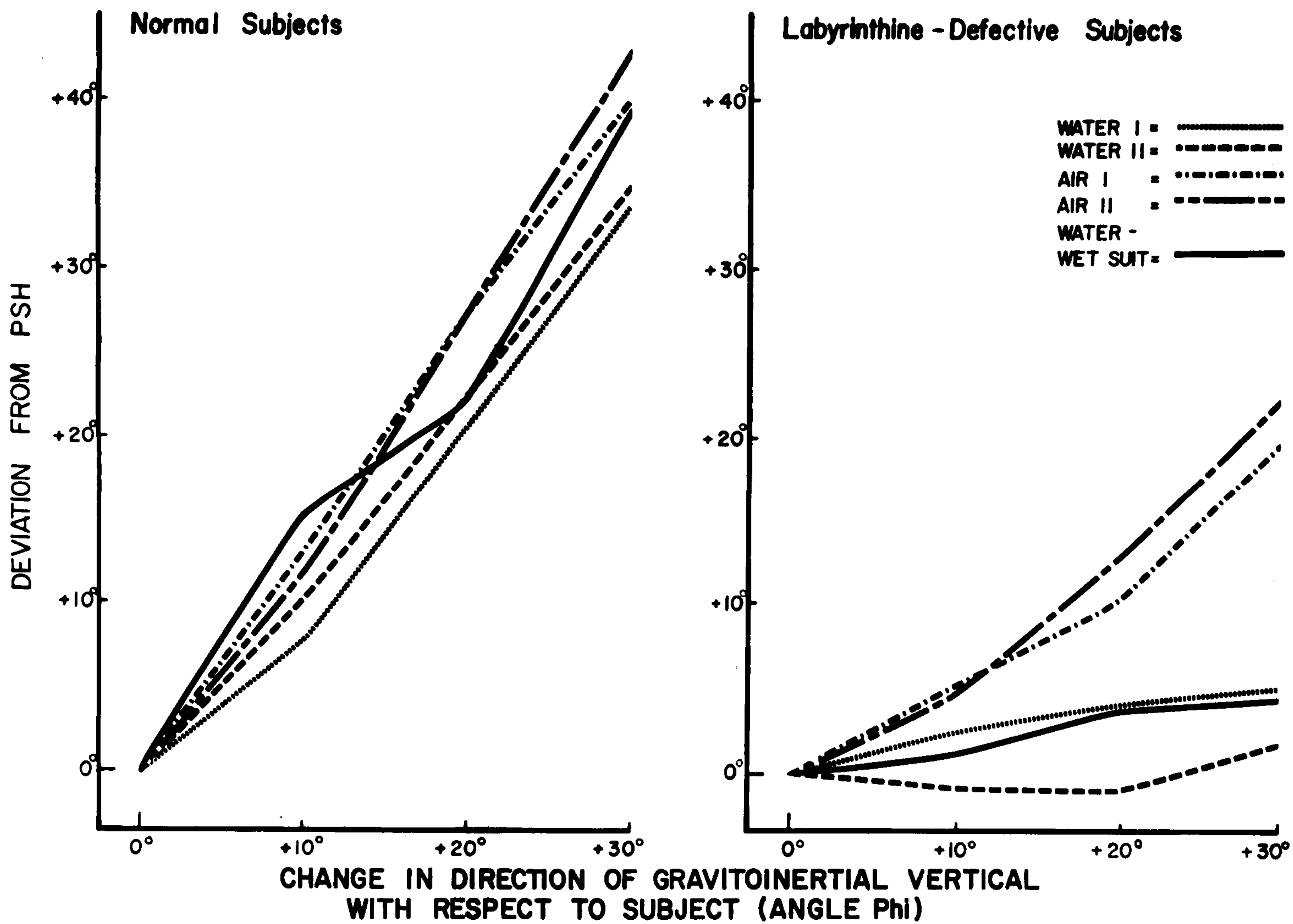
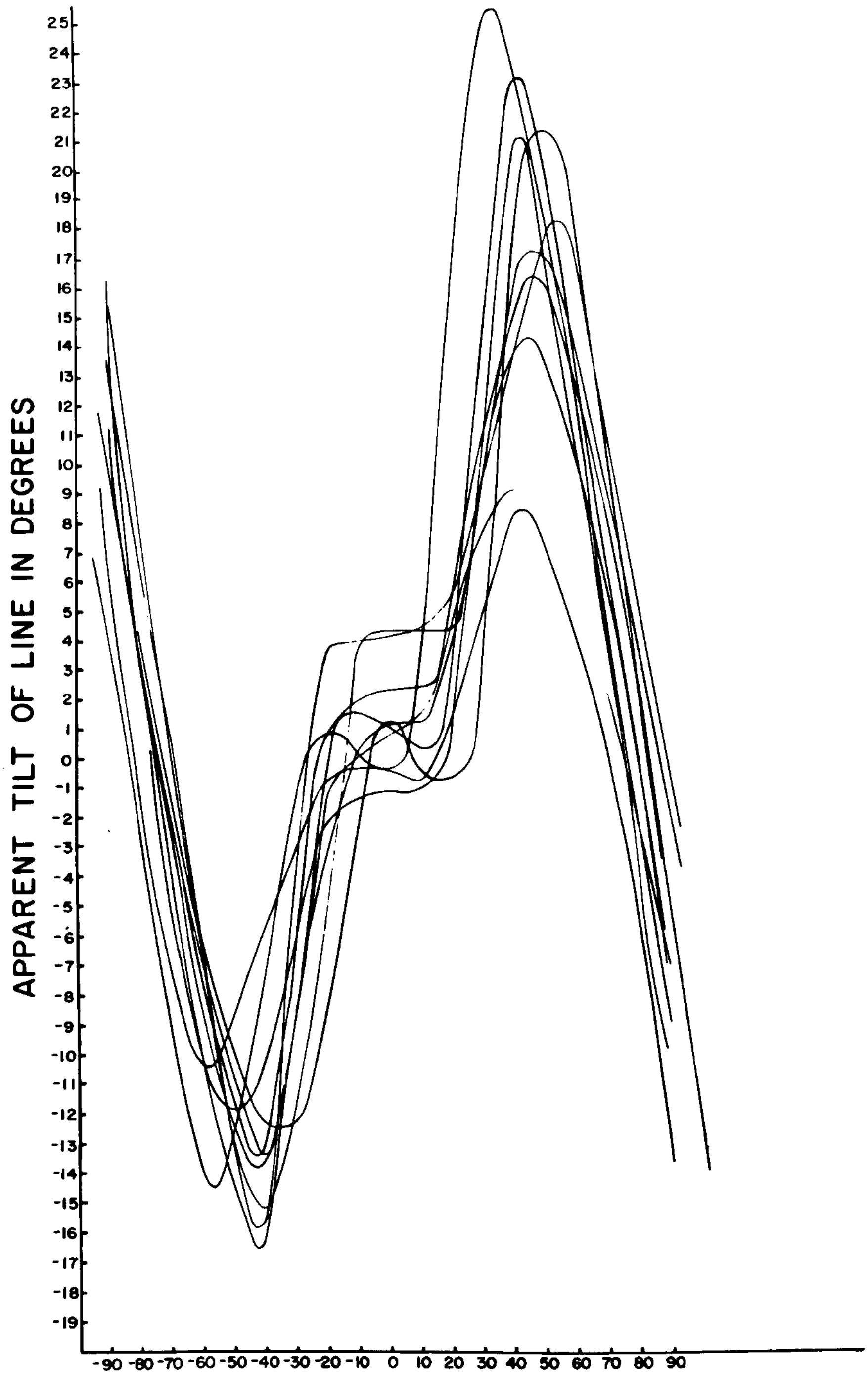

Normal Subjects
Labyrinthine - Defective Subjects
DEVIATION FROM PSH
+40°
+30°
+20°
+10°
0°
WATER I =
WATER II =
AIR I =
AIR II =
WATER - WET SUIT =
0°
+10°
+20°
+30°
CHANGE IN DIRECTION OF GRAVITOINERTIAL VERTICAL
WITH RESPECT TO SUBJECT (ANGLE Phi)

Figure 12



MEAN CURVES REPRESENT E & A PHENOMENA OF INDIVIDUAL TEST SESSIONS OF ONE SUBJECT

Figure 13

This bias as a function of increasing G load was measured on the centrifuge by controlling the deviation of a freely swinging platform from the gravitoinertial upright (26). In Figure 14 the family of curves obtained from eight normal subjects shows the increase in bias with increasing magnitude of force, and in Figure 15 are the findings under similar conditions in two subjects without vestibular function. Note that the change from the E- to A-phenomenon occurs with smaller angles of tilt in L-D compared with normal subjects and that the bias tends to be greater and the variance in the settings far greater.

When fixating the luminous line while lying on the side as depicted in Figure 16, not only is the A-phenomenon prominent but also, for some subjects, the line appears slowly to rotate clockwise and counterclockwise, a form of apparent motion (27). The estimations of a Mercury astronaut, of a normal, and of an L-D subject are shown in Figure 17 (28). The estimations of the astronaut were typical for two subjects while those of the normal and L-D subjects represented the modes for both groups who manifested great individual variance.

These findings indicate that the best concordance between nonvisual and visual cues to the gravitational vertical is provided with man upright or nearly upright. Presumably, this is the result of much practice with excellent monitoring possibilities. A constancy bias with regard to nonvisual cues can be demonstrated with increasing angles of tilt from the upright and with increasing G load for the same angle of tilt. In most of these circumstances the bias is greater and the variance in the settings greater in persons without compared to those with normal vestibular function. Probably, however, the more noteworthy finding is the extent to which nonotolith organ receptors responding to mechanical force are able to compensate for loss of the otolith function. This emphasizes again the habituation to specific sensory environments and the plasticity of central nervous system integrative mechanisms mentioned at the outset of this paper.

On the basis of this experience, we suggested that astronauts be given the task of setting the luminous line to the horizontal of the spacecraft. This was done in Gemini V and VII flights. The probable sensory conditions have been summarized in tabular form (Figure 18). The data collected aloft are being readied for publication, but I can tell you the chief results. The settings of all of the astronauts during flight were similar in one important respect; namely, the variance in a single series of trials was usually smaller but never greater than under control conditions pre- and post-flight. The accuracy of the settings in terms of the horizontal of the spacecraft was excellent in three astronauts; one revealed a strong but constant bias. Our tentative conclusions are that three of the astronauts at least, and probably all, had adequate sensory anchoring to their couches but that the agravic sensory input had little influence on visual mechanisms.

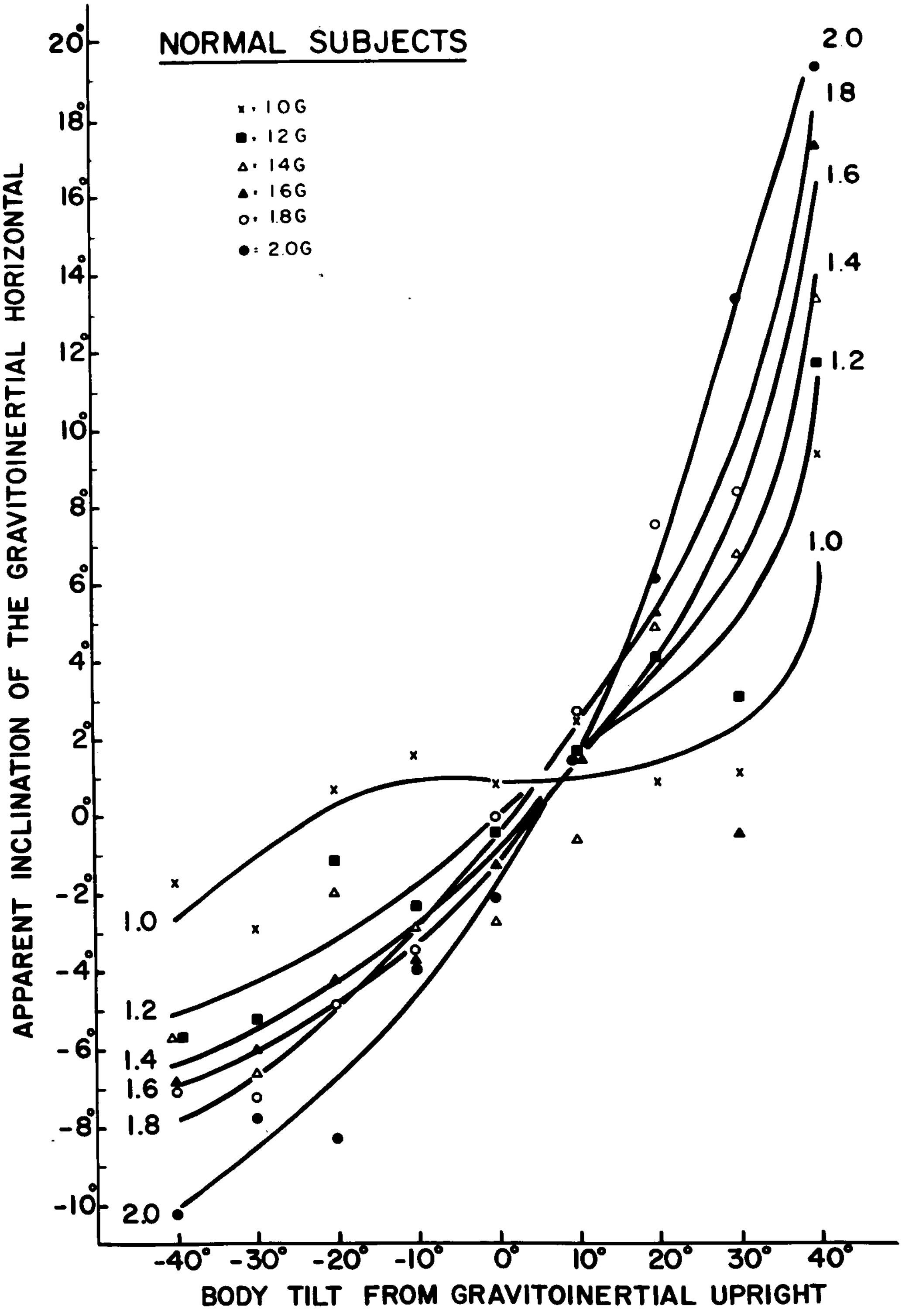


Figure 14

Change in E-phenomenon as a function of increasing G level in normal subjects.

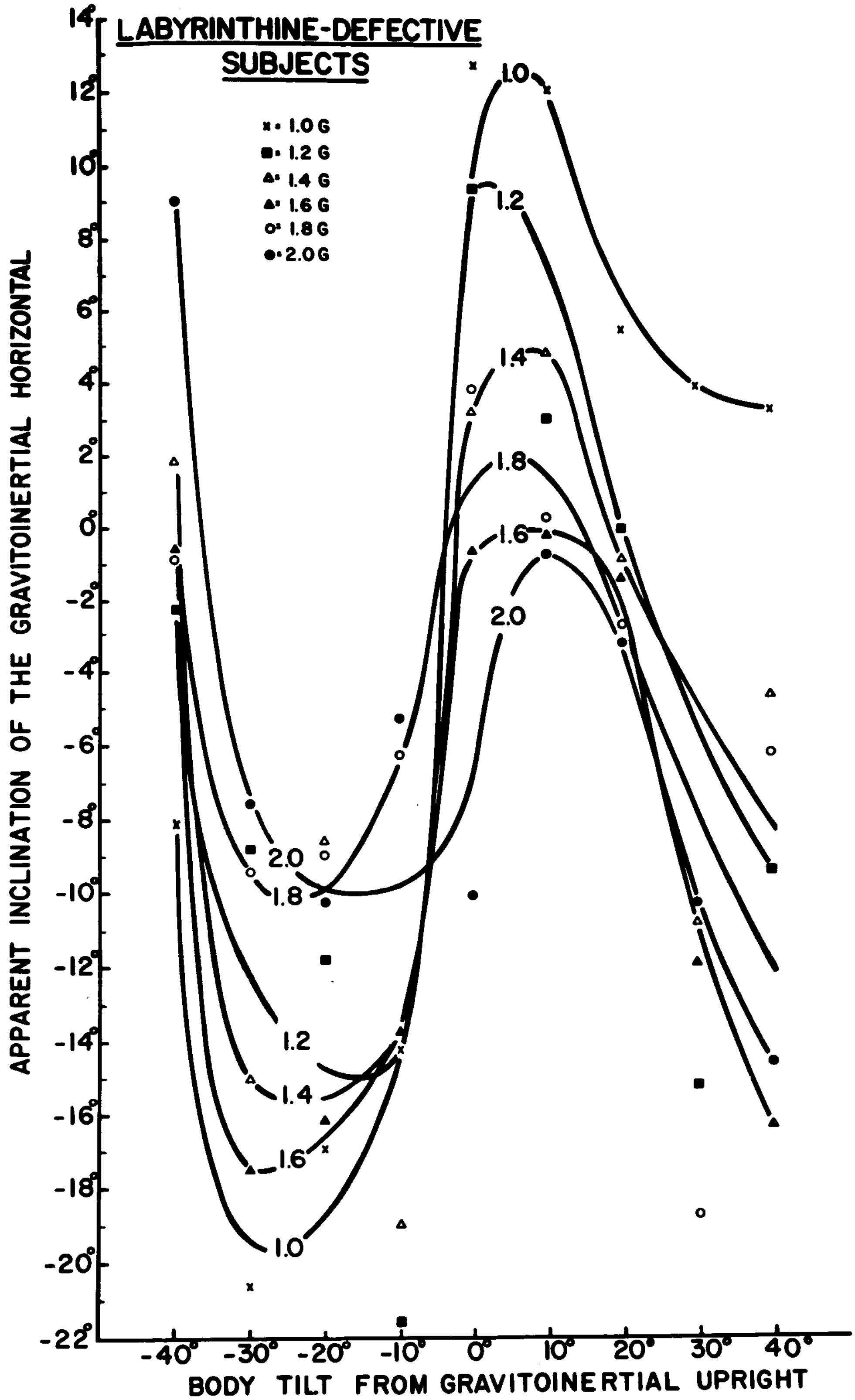


Figure 15

Change in E- and A-phenomena as a function of increasing G level in L-D subjects.

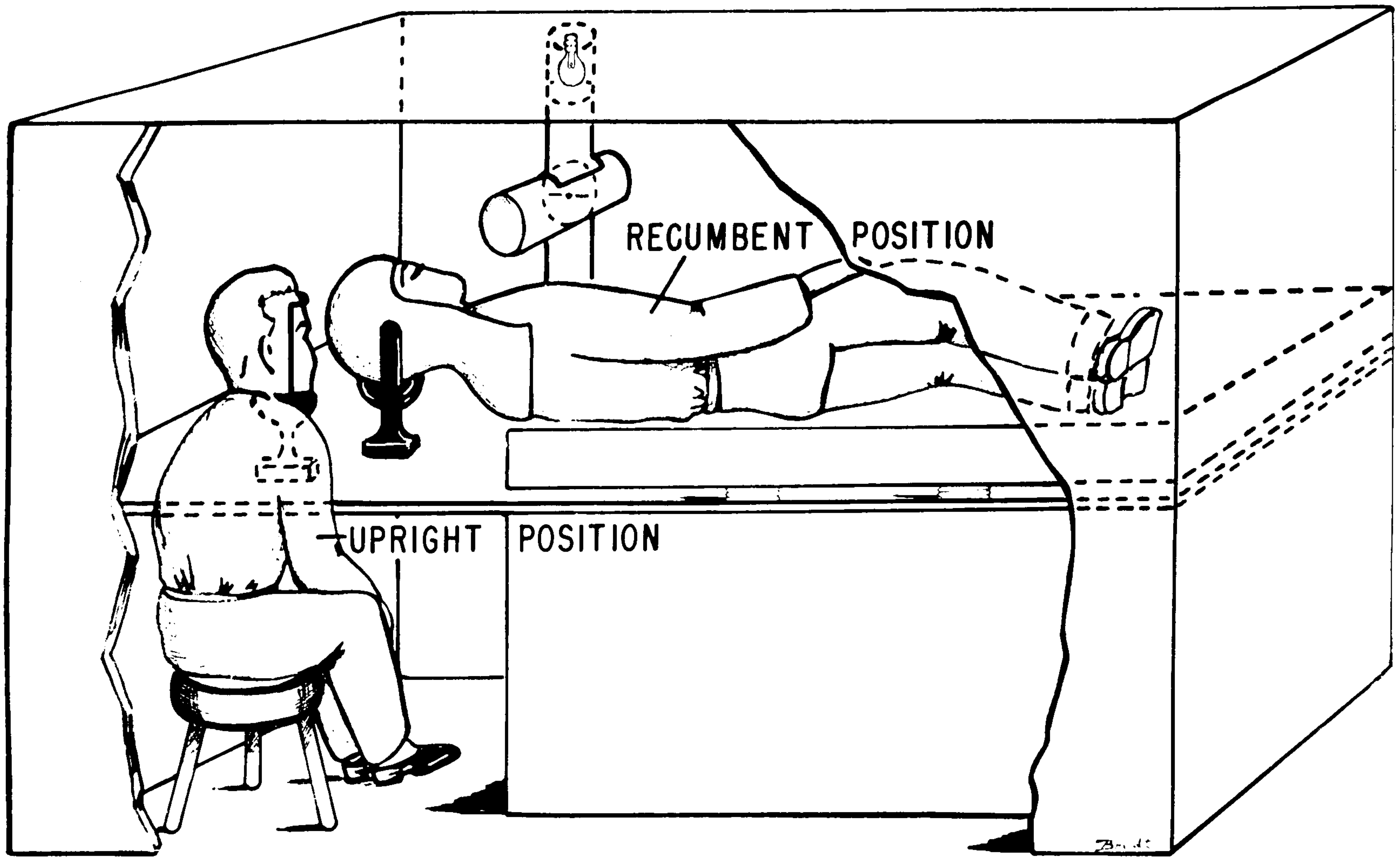


Figure 16

Diagram of apparatus used to determine location of visual horizontal with subject in upright or recumbent position.

LOCALIZATION OF A DIM LINE OF LIGHT IN THE DARK TO THE HORIZONTAL BY 3 SUBJECTS LYING ON THEIR LEFT SIDE

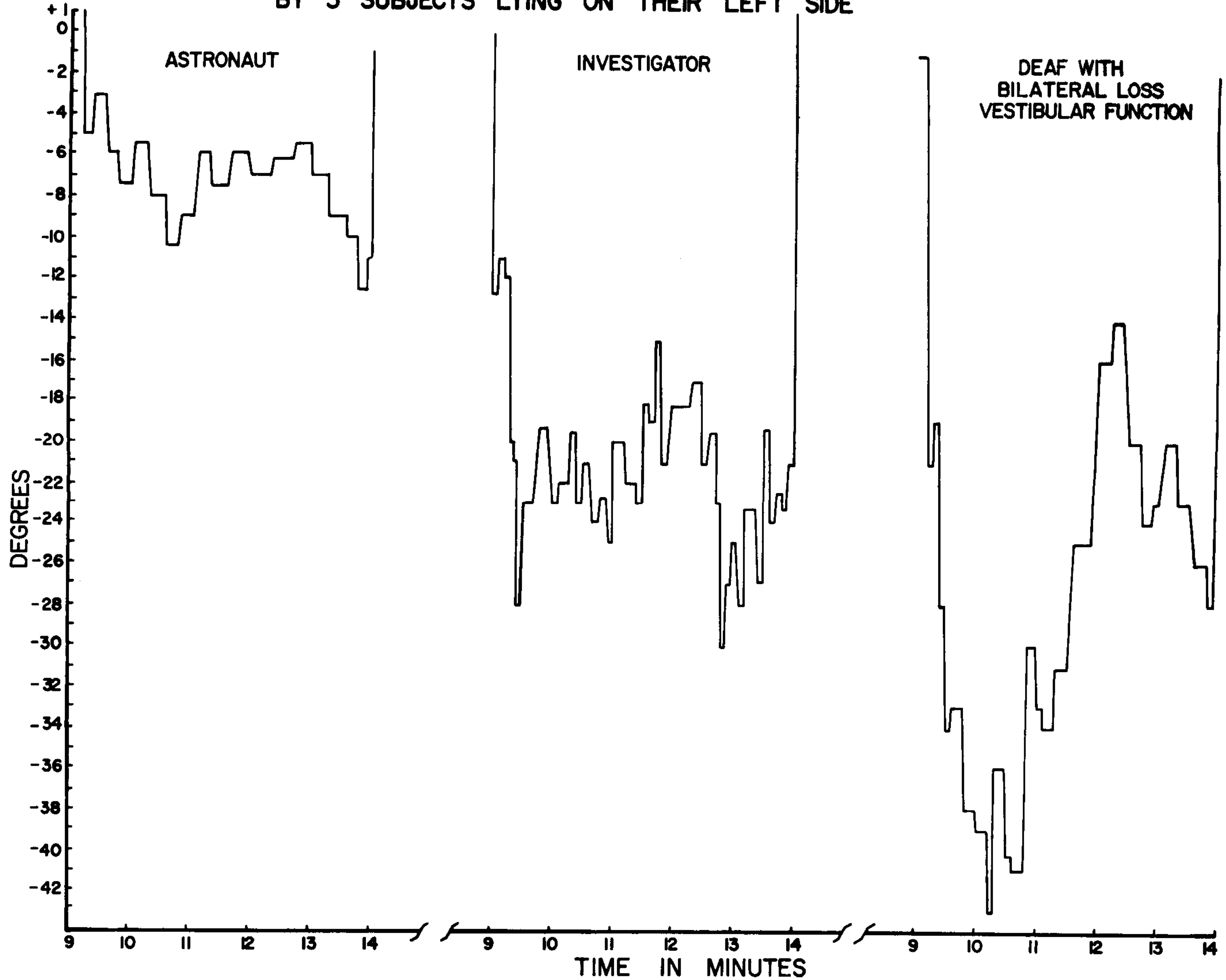


Figure 17

PERCEPTION Extrapersonal Space (EPS)

SENSORY SYSTEMS		NATURAL COND.		WEIGHTLESS SPACECRAFT[3]	
		PHYSIOL. STIMULUS		PHYS STIM.	CONTRIB. TO E.P.S.
VISUAL		VISUAL ENVIRONMENT		TARGET	INADEQUATE[4]
VESTIB-ULAR	CANAL.	GIFE[1]	ANGULAR[2]	I.F. $\overline{>}$ THRESH.	? NIL
	OTOLITH.		LINEAR	I.F. $\overline{>}$ THRESH	NIL
TACTILE	TOUCH	MECH. FORCES	GIFE (wt.)	AGRAVIC T	POSTURE AGRAVIC STEREOGNOSIS: COUCH, ROD ETC.
	PRESS.		OTHER THAN GIFE (wt.)[5]	AGRAVIC P	
KINESTHETIC				AGRAVIC Jt. C & D	
AUDITORY		SOUND PRESSURE		AMBIENT	? INADEQUATE

1. Gravitoinertial force environment. 2. ? Linear forces under special circumstances
3. Astronaut secured in couch; fixates line in dark. 4. Visual memory a factor.
5. Joint Capsule Compression & Displacement

Figure 18

WEIGHTLESSNESS

When a normal person first undergoes transition into true weightlessness, the otolith organs for the first time in his life are not stimulated. It is analogous to shutting out visual stimuli by closing the eyes, with one important difference; we are habituated both to eyes open and eyes closed. By generating and controlling linear accelerative forces in a weightless spacecraft one may stimulate receptors in the otolith organs and thus open up investigative opportunities not possible under terrestrial conditions. The opportunity is complicated of course by the effects of inertial weight on receptors responding to mechanical force. The truly remarkable advantage, however, is to have weightlessness rather than terrestrial gravity as the basic living condition.

Few vestibular experiments have been conducted in orbital flight due to the obviously great constraints of different sorts. We do have, however, the reports of the introspective observations of astronauts and cosmonauts; one of the most intriguing comments centers around the feeling or awareness of bodily uprightness in the absence or virtual absence of cues from the gravitoinertial environment.

THE INVERSION ILLUSION

During the course of some experiments conducted in collaboration with Captain Kellogg at Wright-Patterson Air Force Base, our interest was piqued by the incidental report of an aviator who had been free-floating in the after-portion of a KC-135 aircraft during parabolic maneuvers (29). During the weightless phase of the parabola (Figure 19) he experienced "a sudden reversal of up-down." The illusion lasted only a matter of seconds and had two related aspects, a bodily feeling of sudden reversal of the upright and a belief that the plane was flying upside down. He determined that at least two additional factors seemed to be essential for the perception of the illusion. The more important of the two was a head-lower-than-foot position with reference to the cabin; indeed, the more closely he assumed the inverted position the more readily he experienced the illusion. The second condition was the necessity to face the forward end of the cabin, the long axis of which had the "characteristics of a tunnel." He stated that these were the only occasions during which he had experienced disorientation in flight.

Three normal subjects, of whom two were sophisticated, were instructed to assume the position they had found most advantageous for experiencing the illusion. Upon entering weightlessness, the men, through their own efforts, assumed a head-down position with respect to the aircraft and faced the long axis of the cabin. This was usually accomplished within a period of two to six seconds. Although all reported that "down" was where their feet were, only the naive subject thought that the plane was upside down.

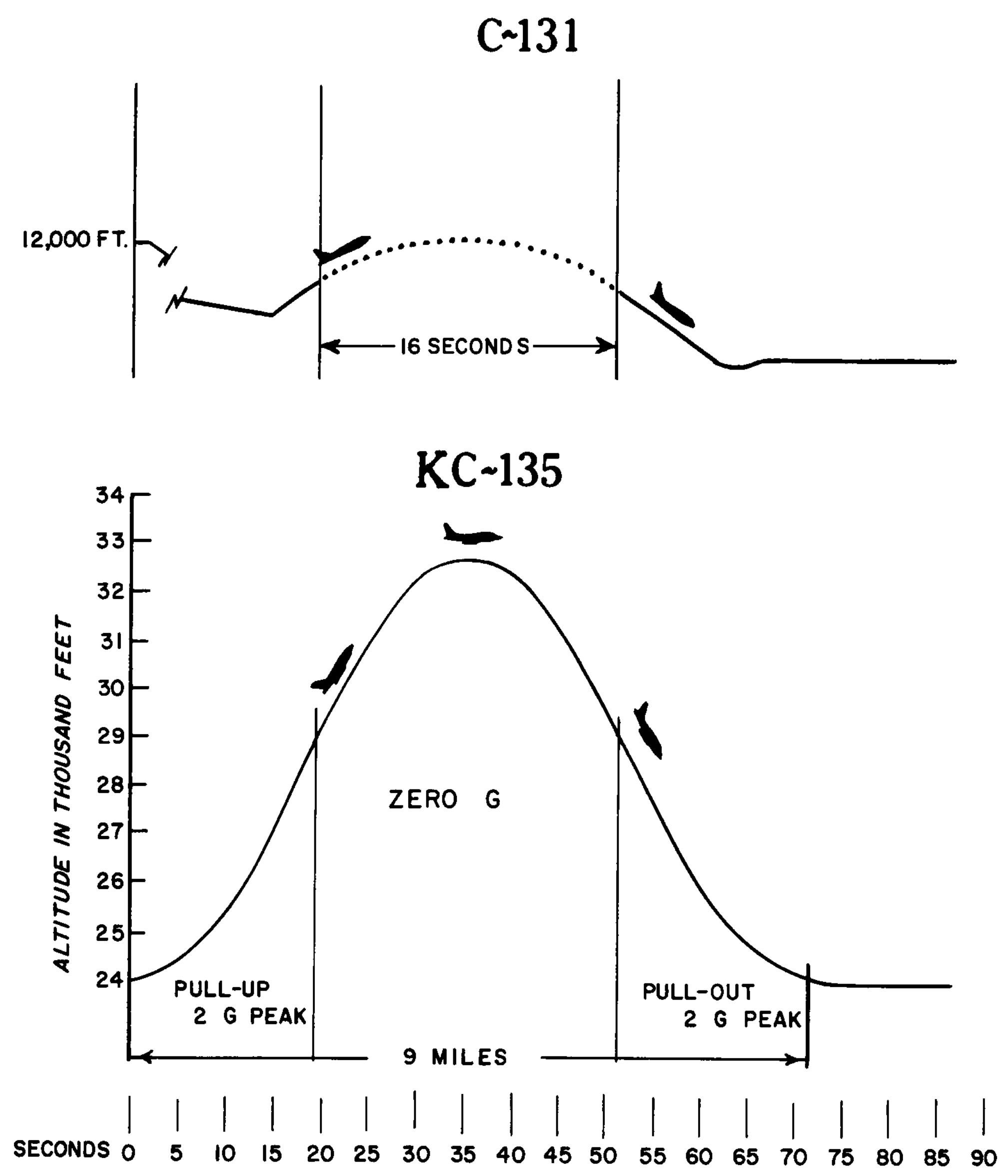


Figure 19
Characteristics of parabolic maneuver in C 131 B and KC 135 flights.

Advantage was taken of an ongoing experiment to collect introspective reports of subject's perception of the upright with reference to the cabin, while rigidly secured in darkness to a tilt device. Two naive normal and three L-Ds participated. Each subject was exposed to five parabolas while in four different positions with reference to the cabin upright, and at 30°, 60°, and 90° tilt, making 20 trials in all.

After completion of all trials, each subject was asked whether he experienced any change in body position during the weightless phase of the parabola. The two normal subjects stated that they perceived a change in body position from "head-up" to "head-down" on entering weightlessness and a return to the head-up position on the pullout. This occurred in every parabolic maneuver regardless of body position in the tilt device. The L-D subjects did not experience a head-down feeling on any occasion.

The findings of this experiment strongly suggest that our normal subjects were responding to sensory information not available to the L-D subjects which must have had its origin in the vestibular apparatus inasmuch as these two groups were alike with respect to the physiologic deafferentation of nonotolithic gravireceptors. There are two reasons for ruling out the semicircular canals as the source. First, the changes in angular velocity were very small, and second, the perception reported by the subject was that of up-down and not of rotation.

In another experiment both normal and L-D subjects participated. The parabolic trajectory in the C-131 was altered in order to generate small negative G loadings (Table II) lasting a matter of seconds. It is important to point out that during these brief periods, the gravitoinertial upright was directed toward the floor approximately 180° from the visual upright. The subjects' task was to "stand" on an especially designed walkway on the overhead of the aircraft. Each of the L-D subjects expressed himself differently, but all felt upside down with reference to the cabin. Two of three sophisticated normal subjects regarded themselves simply as being upside down in a right-side-up aircraft. In other words, their experience was similar to that of the L-D subjects. The remaining three subjects, one of whom was sophisticated, reported that they regarded themselves as right side up in an aircraft flying in an inverted position.

Discussion

Although the American astronauts in describing their experiences in Mercury and Gemini space flights did not report a feeling of being upside down, comments by Soviet authors on the experience of their cosmonauts during orbital flights are in accord with our experimental findings in parabolic flight. Gazenko (30) writes as follows: "In some of the cosmonauts (G. Titov, A. Nikolayev, P. Popovich) illusory feeling as to the wrong position of the body in space occurred at once, while in other cases, the illusion developed gradually (K. Feoktistov, B. Yegorov)." Vasil'yev and Volynkin (31) add the interesting note that Feoktistov's and Yegorov's illusion of being upside down occurred throughout the period of weightlessness whether their eyes were open or closed. It disappeared only with the beginning of acceleration when the craft was being braked. Of

Table II

LEVEL AND DURATION OF NEGATIVE G TO WHICH FOUR LABYRINTHINE-DEFECTIVE SUBJECTS WERE EXPOSED IN MODIFIED PARABOLIC FLIGHT

SUB.	Trial	TOTAL PERIOD		PEAK PERIOD	
		DUR. (SEC)	G LEVEL	DUR. (SEC)	G LEVEL
JO	1	6.5	-0.075	0.5	-0.10
	2	6.5	-0.048	0.25	-0.072
	3	8.0	-0.049	0.5	-0.09
HA	1	6.5	-0.04	0.05	-0.058
	2	8.5	-0.048	2.8	-0.058
PE	1	9.1	-0.049	0.5	-0.09
	2	7.5	-0.048	0.25	-0.07
MY	1	7.0	-0.048	0.1	-0.06
	2	7.5	-0.049	1.5	-0.06

considerable significance too is the cosmonauts' observation that the nature and intensity of the illusion and vertigo were the same in free-flight as when the craft was stabilized. Gazenko adds, "It was especially interesting to note that, when the cosmonauts gained a foothold on the chair by straining their muscles, the illusions either diminished or even completely disappeared. This fact underscores the significance of cutaneous and muscle reception in restoring a correct analysis of the position of the body in space."

In weightlessness, with body (head) fixed and without visual cues, knowledge of the upright of the cabin must come from contact with objects whose relation to the cabin has been remembered. These cues, however, must not be confused with normal contact cues, although some of the same sensory receptors may be involved. In weightlessness these cues should be termed agravic contact cues to emphasize qualitative and quantitative differences in the information they furnish. They include agravic touch-pressure, agravic kinesthesis, and their derivative, agravic stereognosis. Bodily movements contribute additional information, and, in the case of the vestibular organs, the stimulus to the semicircular canals on moving the head is normal although the response may be slightly different from normal; the stimulus to the otolith apparatus resulting from body and head movements would of course be greatly different in the absence of gravity.

If it is assumed that conditions existed for Feoktistov and Yegorov in which these nonvisual agravic cues were inadequate for proper orientation to the spacecraft, important questions must be raised. Why should a person feel upside down rather than simply a lack of awareness of the upright? And, if the contact cues did not vary, what precipitated the illusion on one occasion and not another? How are individual differences explained?

The feeling of being upside down with eyes open described to Feoktistov and Yegorov is even more difficult to explain if there were strong visual cues to the upright of the spacecraft. That it lasted for some time was suggested by Gazenko (30), as noted above. Although there are few reports of this inversion illusion in weightlessness in the presence of visual cues, they point to a tendency toward its occurrence. This is extraordinary in view of the great influence of vision in the interaction between visual and gravitational cues not only under normal terrestrial conditions (32) but also under conditions of moderately increased G loadings (9). It suggests that persons in weightlessness are vulnerable to influences which determine the feeling of up or down based on gravitational cues. This "vulnerability" exposed by weightlessness seems to consist of "up-downness" having the character of a qualitative phenomenon. Under the "influences" investigated in parabolic flight it would appear that this vulnerability is greater in normal persons than in persons who have lost the function of the vestibular organs.

ATAXIA IN ROTATING ENVIRONMENTS

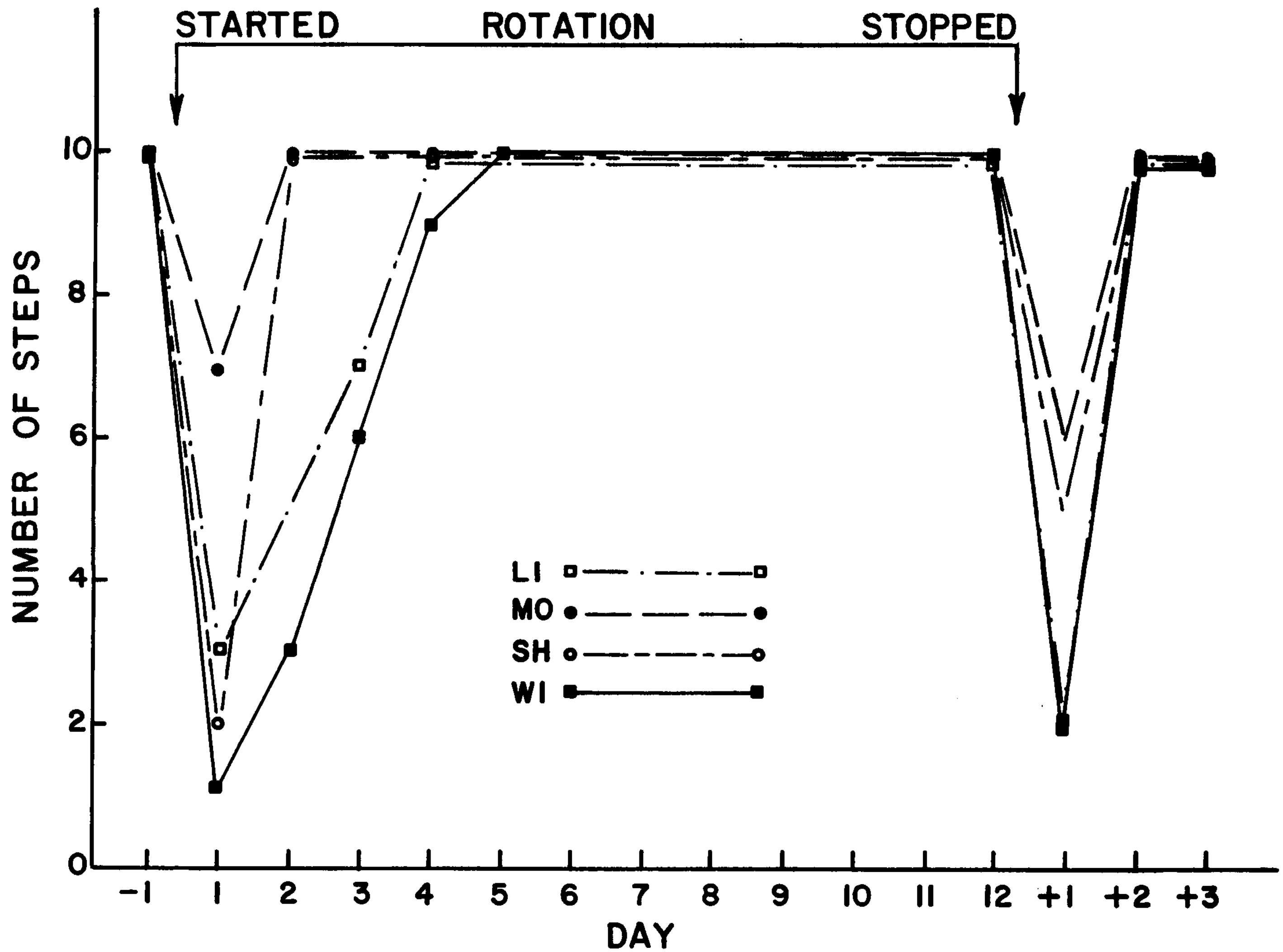
Important questions arise if it is considered essential or desirable to generate artificial gravity by rotation of the spacecraft. One obvious question is "how much?" which cannot be answered without consideration of specific goals epitomized in the phrase, "what for?" Before final decisions are reached at least two other parameters must be thoroughly explored, namely, the operational feasibility and the unwanted side effects of living and working in a rotating orbiting spacecraft.

These side effects fall into two major categories which are, to some extent, related, namely, canal sickness and disorientation (33). The former is an etiologic type of motion sickness due mainly to bizarre stimulation of the semicircular canals and to which a person adapts. Disorientation includes illusory phenomena and neuromuscular disturbances including ataxia which will be discussed as one of the problems properly within the subject matter of this report.

In a rotating orbiting spacecraft, at least three factors influence the degree of ataxia (34): 1) the angular velocity, 2) the radius of rotation, and 3) a derivation of the two, level of centripetal force. Attempts to define tolerance limits beyond which handrails must be provided and within which difficulty in walking may be expressed as slight, moderate, or great have been based in part on observations made under space simulated conditions.

Our contribution has included the development of a new ataxia test battery (35) and its use in following the time-course of habituation in normal and L-D subjects to the force environment of slowly rotating rooms.

Although the vestibular organs contribute to the ataxia experienced by normal persons, L-D subjects manifest considerable ataxia and a rather similar time-course of habituation. Heel-to-toe walking scores for normal subjects are shown in Figure 20, and a comparison of pre- and post-flight ataxia test data, including more items than in the prerotation test, are shown in Table III (36). Rail walking test performance of four L-D subjects during and after habituation to rotation (10 rpm) over a period of twelve days is shown in Figure 21 (37). No attempt has been made to distinguish between habituation effects and acquisition of skill through learning or to determine to what extent the favorable effects can be telescoped in time. The validity of ground-based findings can only be determined by comparison with observations made under actual flight conditions.



HEEL-TO-TOE WALKING SCORES FOR FOUR SUBJECTS

Figure 20

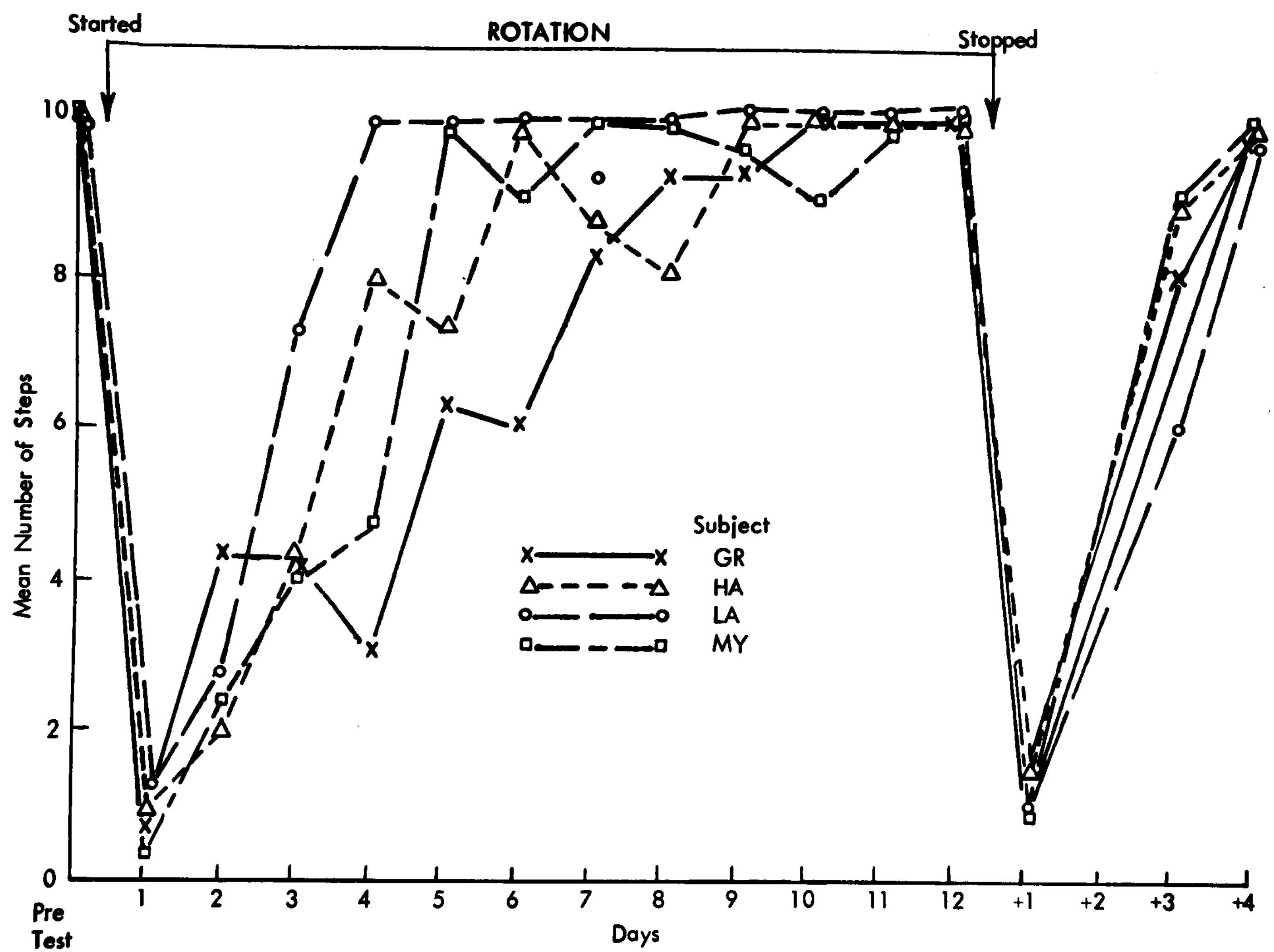
Ataxia test scores in normal subjects as a function of habituation in per- and post-rotation in the Slow Rotation Room.

Table III

RESULTS OF POSTURAL EQUILIBRIUM TEST BEFORE AND AFTER ROTATION

SUBJECT		LI		MO		SH		WI	
WALKING TEST	BEFORE ROTATION	11	%★ 31	8	% 11	10	% 26	8	% 11
	AFTER ROTATION	11	31	13	56	13	56	8	11
STAND EYES OPEN TEST	BEFORE ROTATION	18	27	21	36	16	20	9	3
	AFTER ROTATION	21	36	38	68	23	45	10	4
STAND EYES CLOSED TEST	BEFORE ROTATION	129	61	82	46	33	17	14	6
	AFTER ROTATION	40	26	52	32	23	12	14	6
ROTATION EFFECTS	WALK	0		+		+		0	
	STAND OPEN	+		+		+		+	
	STAND CLOSED	–		–		–		0	

★ Percentile rank in a distribution of scores on several hundred normal males.



INDIVIDUAL WALKING TEST PERFORMANCES OF FOUR L-D SUBJECTS ON A 3-INCH WIDE RAIL ALONG THE TIME AXIS OF ROTATION

Figure 21

SUMMARY AND CONCLUSIONS

In this presentation the point of departure in discussing orientation in space flight has been the evolutionary manner in which orientational homeostasis is acquired under terrestrial conditions. Its slow acquisition represents a major accomplishment in terms of central nervous system integrative mechanisms responding to sensory information from environmental sources, especially the visual and force environments. This inheritance and experience did not fully prepare man to adjust suddenly to the new and unique force environments incidental to space flight, and the wonder is not that he experiences functional disturbances but that he is able to cope with them so successfully. This success is due only in part to his natural powers of adaptation, great as they are. An equally important factor is represented by his ingenuity in obtaining and synthesizing symbolic orientational information and in avoiding stresses beyond his tolerance limits.

Some problems either will remain unsolved, or tentative solutions to problems remain unverified, until the necessary observations have been made under actual flight conditions. This applies both to weightlessness and to the force environments in rotation orbiting spacecraft.

Weightlessness poses less of a problem than anticipated. It was reasonable to expect that sudden deafferentation of the otolith apparatus, to which we have never had the opportunity to habituate, combined with loss of stimulation to receptor organs responding to weight, might result in disorder consequent to alterations in integrative patterns. The mildness of the disorders reported either of an illusory nature or symptomatic of motion sickness have affected only to a small degree the performance of the persons involved. From the scientific standpoint, however, the weightless spacecraft offers an opportunity to investigate the functions of the vestibular organs, especially the otolith apparatus, far beyond anything possible on Earth. The central feature here is the ability to remove the stimulus to the otolith organs, analogous to closing the eyes, and to provide a controlled stimulus through the generation of inertial force.

The rotating orbiting spacecraft in providing artificial gravity poses problems in orientation and in an etiologic type of motion sickness. With regard to the latter, stimulation studies probably have better predictive value than they do in orientational disturbances. Fortunately, predictions based on stimulation studies can be validated under safe conditions aloft.

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13. ABSTRACT

In delimiting the subject matter for purposes of this report, attention is focused on some of the problems involved in spatial orientation which have been studied during many investigations at the Naval Aerospace Medical Institute. The first part is a review of these long-time studies and this is followed by a discussion of some experiments carried out in weightlessness.

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