GPO PRICE $ ____

CFSTI PRICE(S) $ ____

Hard copy (HC) $2.00

Microfiche (MF) .50

ff 653 July 65

NSAM - 942

VISUAL LOCALIZATION OF THE HORIZO

BODY TILT UP TO ±90° FROM GRAV

Earl F. Miller, II, Alfred R. Fregly, Gert var

[redacted]

JOINT REPO

N66-15580	
(ACCESSION NUMBER)	(THRU)
29	1
(PAGES)	(CODE)
CR 69427	04
(NASA CR OR TMX OR AD NUMBER)	(CATEGORY)

FACILITY FORM 602

UNIT

VISUAL LOCALIZATION OF THE HORIZONTAL AS A FUNCTION OF BODY TILT UP TO ± 90° FROM GRAVITATIONAL VERTICAL*

Earl F. Miller, II, Alfred R. Fregly, Gert van den Brink, and Ashton Graybiel

Bureau of Medicine and Surgery
Project MR005.13-6001
Subtask 1 Report No. 118

NASA ORDER No. R-47

Released by

Captain H. C. Hunley, MC, USN
Commanding Officer

---

* This research was conducted under the sponsorship of the Office of Life Science Programs, National Aeronautics and Space Administration.

3 August 1965

U. S. NAVAL SCHOOL OF AVIATION MEDICINE
U. S. NAVAL AVIATION MEDICAL CENTER
PENSACOLA, FLORIDA

SUMMARY PAGE

THE PROBLEM

To obtain a quantitative description of the perception of horizontality in the absence of visual cues, egocentric visual localization (EVL), as a function of body tilt up to ± 90° from gravitational upright; to study statistically the nature of individual differences and variations in this perception among three sophisticated subjects tested over a period of several days.

FINDINGS

The task had adequate intratest reliability but there were considerable intertest and intersubject quantitative variations. The pattern of visual localization of the horizontal as a function of tilt, however, was qualitatively similar among all subjects and among repeated test sessions of each subject. Around upright (within ± 20° to 40° tilt of the subject) there was on the average no significant rotational shift in the frontoparallel plane of the visual horizontal from its true physical location. Beyond this range of accurate judgment, the apparent horizontal tended to co-incline in ever increasing magnitudes with body tilt (E-phenomenon) until it reached its limit bilaterally at approximately the 40° to 50° tilt position; it then reversed direction, reaching a point of no deviation on the average somewhere around the 60° to 80° position. Further increase in tilt produced an increasing deviation in the direction counter to tilt (A-phenomenon). The function as described is based on average curves which in themselves were not entirely smooth in form but reflected the considerable inter- and intrasessional quantative variations. Responses were bilaterally symmetrical around the upright position in terms of constant and variable error in one subject and in variable error only in another. Variable error among all subjects followed a similar (curvilinear) function with body attitude: least deviation at or near the upright position, increasing to a maximum usually within the middle third of each quadrant, then decreasing beyond this point.

Training in the form of repeating the test without immediate knowledge of results did not as a rule lead to a reduction of the illusion.

INTRODUCTION

The well-known Aubert or A-phenomenon and its counterpart, the E-phenomenon of Müller, have been the subjects of numerous studies covering a period of over one hundred years. In spite of the wealth of information accrued by these studies, certain basic issues concerning these phenomena remain controversial or unknown. Evidence has been found which indicates that the vestibular (otolith) apparatus acts to reduce the illusions of movement (19) and displacement of the subjective horizontal (20), but a complete analysis of individual causal mechanisms has not been made. Such an analysis is hampered by the surprising scarcity or incompleteness of quantitative data concerning visual localization in the absence of a visual framework. The limited quantitative data that are available cannot be satisfactorily integrated to obtain a general description of visual orientation as a function of the subject's position with respect to gravity because of great inter- and intraindividual differences that are typically found in this perception. Variations in results reported among the available studies undoubtedly derive from differences in experimental procedure, subject training, and instruction (understanding)(14).

In an attempt to reduce the influence of at least these last named factors in causing intersubject differences in visual orientation, three sophisticated subjects having complete knowledge of the design and purpose of the experiment were tested by the same procedure over a period of several days.

PROCEDURE

SUBJECTS

Three of the authors served as subjects. All had good general health, normal hearing, and normal vestibular function as indicated by their subjective responses in the Pensacola Slow Rotation Room and scores attained on the Graybiel - Fregly ataxia test battery (11).

APPARATUS

The tilting apparatus consisted essentially of a chair surrounded by a metal ring support which could be rotated upon its supporting stand. The chair could be tilted, by means of a hydraulic power system, around its fore and aft axis up to ± 90° from its upright position. A protector dial placed on the rear of the chair and visible only to the experimenter was used to indicate the tilt position of the chair to the nearest one-half degree. The subject was adequately held within the chair by a shoulder harness and seat belt, plus head and foot supports. In addition to the head rest, one subject (MI) in all test sessions except the first and twelfth used a dental bite to fix rigidly his head position with respect to the target. Attached to the tilting ring of the apparatus was an optical system which provided a line target of collimated light which could be adjusted in intensity and in position relative to the subject. A round knob providing no tactual cue of position was used by the subject to control the speed and direction of flow of hydraulic fluid to a motor drive, which in turn caused the target to rotate clockwise or counterclockwise about its center. The angular position of the target with respect to gravity to the nearest 0.25° was relayed to a dial readout, 18 inches in diameter, by means of a pair of selsyn repeater motors. The entire apparatus was placed in a light-tight room.

METHOD

Each subject was tested essentially by the same method thirteen times, and for the most part on consecutive days. The subject was seated, then fastened securely with the supportive applicances in an upright position in the tilt chair. The target was adjusted so that it appeared directly in front of the subject's right eye; his left eye was occluded with an opaque patch. The subject was instructed to open his eyes only when required to set, by means of the control knob placed in his right hand, the luminous line so that it appeared horizontal. After completely darkening the test room so that only the luminous target was visible, the subject was tilted slowly (about 1 1/2°-2° per sec) to each of nineteen positions. These positions covered in 10-degree intervals the range between -90° (leftward tilt) and + 90° (rightward tilt) with respect to gravity. The direction (+ or -) of tilt was alternately changed, and its magnitude randomized. In each test session, the consecutive settings of the target to the visual horizontal at each tilt position were made by the following method. Upon reaching the desired tilt position, the experimenter offset the target, at randomly varying speeds and magnitudes, then signalled the subject to reset the target to the horizontal. When satisfied with his setting, the subject closed his eyes and signalled the experimenter, who recorded the position of the target indicated on the instrument dial. A red light of low intensity was used to illuminate the dial for this reading.

RESULTS

TEST-RETEST VARIABILITY

Constant Error[+]

For a given test session, the mean constant error was calculated for each subject at each tilt position. These values were then averaged to obtain a single measure of constant error for the test session. The values, thus calculated, for the first, second, final, and all sessions combined were intercorrelated. Inspection of Table I reveals

---

[+] A difference between visual and physical space as well as a variation in response is sometimes referred to as an error in this discussion since it is a commonly used term in statistics. Better terminology probably would be "deviation","illusion", or "effect" and simply "variability" for constant and variable parameters, respectively, of these psychophyiological data.

Table I

Test-Retest Correlation of Constant ($\bar{x}$) and Variable (σ) Errors

	Second Session						Final Session						All Sessions Combined					
	Reliability Coefficients of Subjects																	
	BR		FR		MI		BR		FR		MI		BR		FR		MI	
Session	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ
First	.87**	.50*	.31	.42	.76**	.49*	.08	.46*	.57*	.68**	.69**	.58**	.81**	.71**	.51**	.66**	.71**	.54*
Second							.03	.60**	.56*	.70**	.73**	.31	.85**	.63**	.78**	.80**	.86**	.17
First and Second							.05	.41	.63**	.69**	.74**	.50*	.86**	.75**	.82**	.82**	.79**	.48*
Final													.40	.58**	.73**	.82**	.82**	.35

** $p \leq .01$
* $p \leq .05$

that all eight of the mean constant error reliability coefficients computed for subject MI are highly significant** (see footnote ++), while seven of these eight coefficients for subjects BR and FR are significant*/**.

Variable Error

A study of variable error was made which paralleled that of constant error. The computed test-retest correlation coefficients of the mean variable error are also shown in Table I. Nineteen of these twenty-four (eight per subject) correlation coefficients are significant*/**, five in subject MI, and seven each in subjects BR and FR.

INTRATEST VARIABILITY

Comparison of the First Three With the Last Three Settings

Constant error differences between the mean of the first and last three settings of all sessions were computed for each subject in each of the nineteen tilt positions. Significant*/** changes in magnitude of error occurred in five tilt positions in subject MI. Four of these five changes were in the direction of increased error. Subject FR demonstrated a significant* change (increase) at only one tilt position, while subject BR revealed no significant change at any of the nineteen tilt positions. It was observed that subject MI used considerably more time in making his judgments than either of the other two subjects.

The correlation between the mean constant errors of the first and final three settings for all nineteen tilt positions combined was .949*, .789*, and .946* for subjects BR, FR, and MI, respectively. Similarly, the over-all correlations between the mean variable errors of the first and last three settings for subjects BR, FR, and MI, respectively, were .686*, .851*, and .728*.

VISUAL HORIZONTAL VERSUS BODY TILT

Constant Error

The curves (narrow lines) portraying the constant errors in judging horizontality in each test session as well as the curve (broad line) representing the average constant error of all test sessions as a function of body tilt are shown in Figure I for each subject. The direction of tilt of the physical horizontal as it would appear to the subject is indicated in the Figure by the slope of the line within the small circles placed at the four most deviant points of the curves for each subject. From a constant error standpoint, the average deviation of subject MI associated with rightward and leftward tilt,

---

[++] In the discussion to follow, a significance at .05 or better level of confidence is denoted with superscript*, at .01 or better with superscript**.

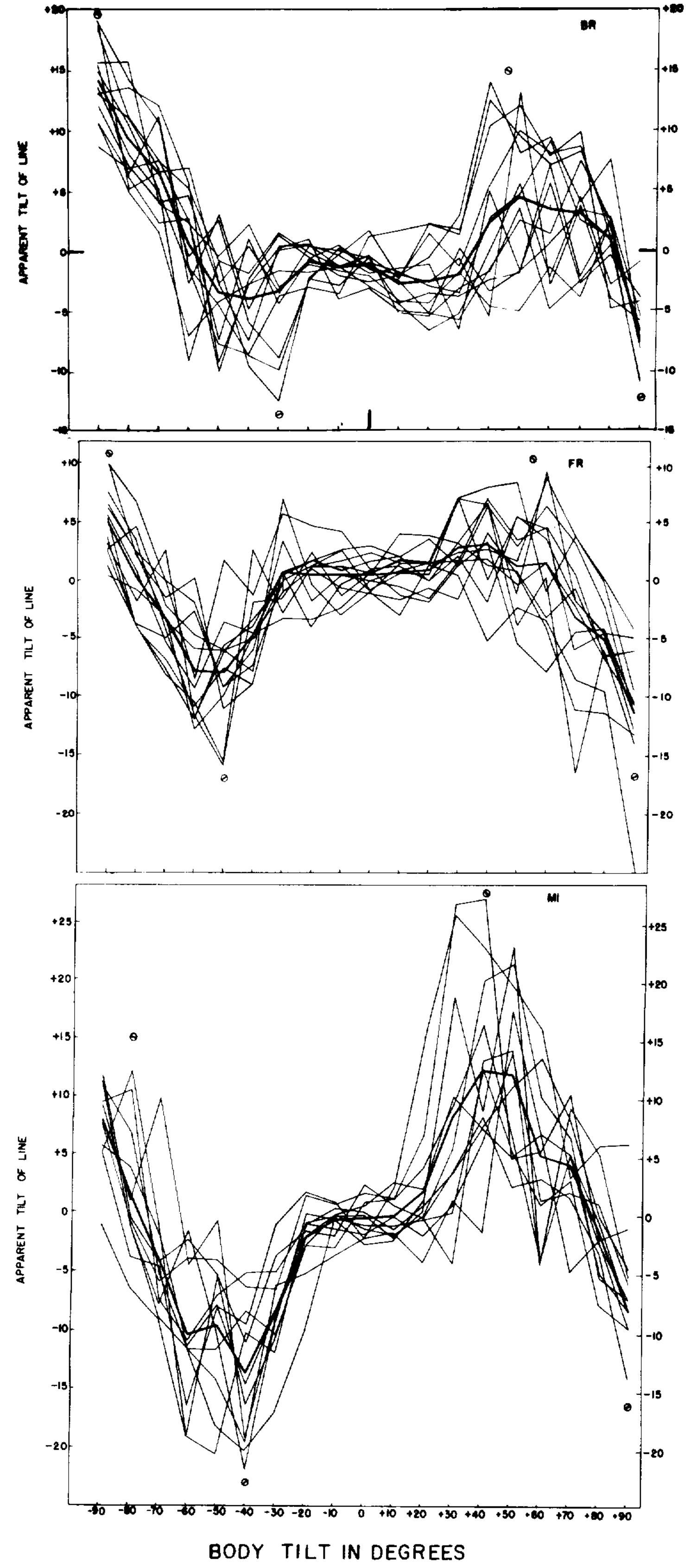

Figure I

The Visual Horizontal of Three Subjects as a Function of Body Tilt up to ± 90° from Upright. (——— Sessional Curve, ▬▬▬ Mean Curve of all Sessions) considered separately and combined, relates well to that of the other two subjects with correlations ranging from .58 to .90 (.05 to .01 level of confidence) (Table II). In contrast, no significant relationship in similar constant error measurements was found between subjects BR and FR (Table II). When the over-all curve configurations (Figure I) are considered, however, qualitative similarities are evident among the subjects in their response to head tilt. Around the upright position, there was a certain range of body tilt that produced no illusion. The range in which there were no significant mean constant error differences (Table III) between response to tilt and nontilt varied with the individual. In subject BR this range extended from upright through -20°, in subject FR, from + 10° through -30°, and in subject MI, from + 10° to -10°. Beyond these individual ranges the apparent visual horizontal tended to incline in the same direction (E-phenomenon) as body tilt. The increasing inclination of the subjective horizontal in proportion to tilt reached its limit bilaterally at approximately the 40- to 50- degree position, then it reversed direction, resulting in a progressive reduction in the magnitude of deviation until a body inclination, 60° - 80° on the average, was reached in which the subjective was coincident with objective horizontal. Tilting of the head beyond this point produced further illusory displacement in the direction counter to head inclination (A-phenomenon). In all cases, the average deviation in the Aubert direction continued to increase with head inclination beyond the point of shift from E- to A-phenomenon so that the greatest Aubert deviation occurred at the maximum positions (±90°) of tilt used in this study. As revealed clearly in Figure I, this description is based upon the average curves (straight lines connecting average points) which in themselves are not entirely smooth in form, but reflect the great intraindividual variance in this perception.

The experimental method in which the subject was tilted alternately rightward then leftward could have contributed to the intraindividual, interpositional variability reflected in the saw-tooth appearance of the curves. This seems probable as a cause of variability based upon certain studies of Fischer (7). When the position of tilt was varied at random and without informing the subject of the direction or magnitude of inclination, Fischer found considerably larger variations in settings even within one series, compared to his results using methods in which the subject was either always returned to upright between tilt positions or continuously inclined in a clockwise or counterclockwise direction. The fact that, in the present study, considerable deviations were recorded for the upright position in which extreme accuracy in localization is the rule (10, 12, 20, 23, 26, 27, 29) would seem to indicate further that these visual judgments were biased by the position(s) of tilt that preceded.

Although the general configuration of each subject's mean curve was strikingly similar, there were interindividual quantitative differences, such as in the points of flexion in the curves and the maximum magnitudes of the A- and E-illusions which ranged from about 3° to 8° and 8° to 14°, respectively. Subject FR in his judgments of horizontality was least affected by being tilted. His mean constant errors, for example, were significantly greater than when upright at only eleven of the other eighteen positions (11:18), in contrast to the ratios of 16:18 for subject BR and 15:18

Table II

Correlations Between Subjects in Constant and Variable Error Curve Configuration

Subjects	Tilt					
	Bilateral		Rightward		Leftward	
	^{r}C. E.	^{r}S. D.	^{r}C. E.	^{r}S. D.	^{r}C. E.	^{r}S. D.
BR/FR	.36	.85**	.43	.73*	.40	.85**
BR/MI	.55**	.62**	.68*	.45	.73*	.60
FR/MI	.79**	.47*	.90**	.10	.70*	.72*

* $P \leq .05$
** $P \leq .01$

Table III

Mean Constant and Variable Error at Each Body Tilt Position
Significant Intersubject Differences Noted

	Tilt in Degrees	Constant Error ± Standard Deviation Subject: BR		Constant Error ± Standard Deviation FR		Constant Error ± Standard Deviation MI		Significance of Intersubject Differences BR/FR	BR/MI	FR/MI
Clockwise	+90	-6.6**	±5.3	-11.3**	±5.9	-8.0**	±4.7	††		††
	+80	+0.8**	±5.4	-5.2**	±4.4	-1.3	±5.7	††	†	††
	+70	+3.2**	±7.1	-3.2**	±6.7	+4.3**	±6.1	††		††
	+60	+3.5**	±6.8	+1.5	±6.0	+5.1**	±8.7	†		†† ..
	+50	+4.6**	±6.9	+1.2	±4.8	+12.1**	±8.6	†† ..	††	†† ..
	+40	+2.4**	±7.0	+3.1**	±4.4	+12.4**	±9.9		†† ..	†† ..
	+30	-1.9*	±3.8	+2.8**	±3.2	+8.5**	±10.9	†† .	†† ..	† ..
	+20	-2.3**	±3.3	+0.9**	±2.1	+2.0**	±5.9	††	††	††
	+10	-2.6**	±2.7	+0.7	±2.2	-0.1	±2.0	††	††	††
	0	-1.0	±2.1	+0.5	±1.6	-0.4	±1.9	††	†	††
Counterclockwise	-10	-1.3	±2.0	+0.5	±2.3	-0.7	±1.9	††		††
	-20	-0.8	±2.2	+0.6	±2.7	-2.0**	±3.7	††	† .	††
	-30	-3.3**	±5.1	+0.7	±3.3	-8.2**	±5.7	†† .	††	†† .
	-40	-3.9**	±4.9	-4.7**	±3.9	-13.6**	±8.2		†† .	†† ..
	-50	-3.4**	±5.9	-8.0**	±5.4	-9.4**	±7.7	††	††	
	-60	+0.6*	±5.6	-7.9**	±5.2	-10.3**	±7.1	††	††	†
	-70	+6.5**	±4.8	-3.5**	±4.6	-4.0**	±6.4	††	††	
	-80	+9.4**	±5.1	+0.3	±4.8	+1.6*	±6.5	††	††	
	-90	+14.2**	±5.2	+5.0**	±4.2	+7.9**	±5.1	††	††	††

**	P of difference between the mean constant error in the tilted and nontilted positions, $\leq .01$.
*	P of difference between the mean constant error in the tilted and nontilted positions, $\leq .05$.
††	P of difference in constant error between subjects, $\leq .01$.
†	P of difference in constant error between subjects, $\leq .05$.
..	P of difference in variable error between subjects, $\leq .01$.
.	P of difference in variable error between subjects, $\leq .05$.

for subject MI (Table III). Interindividual differences in the magnitude of the A- and E-Illusions can also be demonstrated in significant constant error differences found: 1) between subjects FR and MI in fifteen of the eighteen inclined positions, 2) between subjects BR and MI in fourteen of the eighteen inclined positions, and 3) between subjects BR and FR on sixteen of the eighteen . Even in the upright position the subjects differed significantly* from each other.

Variable Error

Differences between subjects in terms of mean variable error (standard deviation, Table III) in judging the visual horizontal are presented graphically in Figure 2. Subject MI differed significantly* from subject FR at six positions and from subject BR at four positions, whereas subject FR differed significantly* from BR at three positions.

In spite of these individual differences, the average curves of the three subjects are similar in form. Each subject was least variable at or near the upright position and became increasingly less consistent with greater head inclinations up to a maximum point which fell in most cases within the middle third of each upper quadrant of tilt; variability then tended to decrease with further tilt, yet always remained considerably higher than that found in small angles of tilt. Passey (28) found no increase in variability of adjustments of a tiltroom to its upright position within a range of body tilt of ± 20° from gravitational vertical. With greater magnitudes of tilt (28°, 42°, 90°) Witkin and Asch (35) measured a progressive increase in mean variability (as indicated by the mean range in scores). Differences in individuals, apparatus (visual targets), and methods of testing and analysis make impossible a direct quantitative comparison of these studies with that of the present. Qualitatively, however, there would appear to be no important conflicts among the findings of these studies with respect to variability as a function of tilt.

With respect to variable error in rightward, leftward, or bilateral tilt our subjects were found to be quite similar as determined by intersubject correlations of mean variable error. It can be seen (Table II) that six of the nine intersubject comparisons were significant*/**.

Clockwise versus Counterclockwise Tilt Positions

In terms of both constant and variable error, only one subject (MI) revealed similar (opposite sign) perceptual responses to rightward and leftward tilt. The nearly perfect symmetry in the two halves of this subject's average curve, plotted as a bold line in Figure 1, is apparent and further evidenced by the highly significant* right-left correlations of 0.95 (constant error) and 0.88 (variable error). In subject BR, on the other hand, no significant right-left similarity in constant or variable error was found with respect to the upright position, but if the fulcrum is shifted to + 10° the mean constant error curve appears symmetrical. This is significant in that it indicates an inaccurate centering of the otoliths or other gravireceptor organs within the body

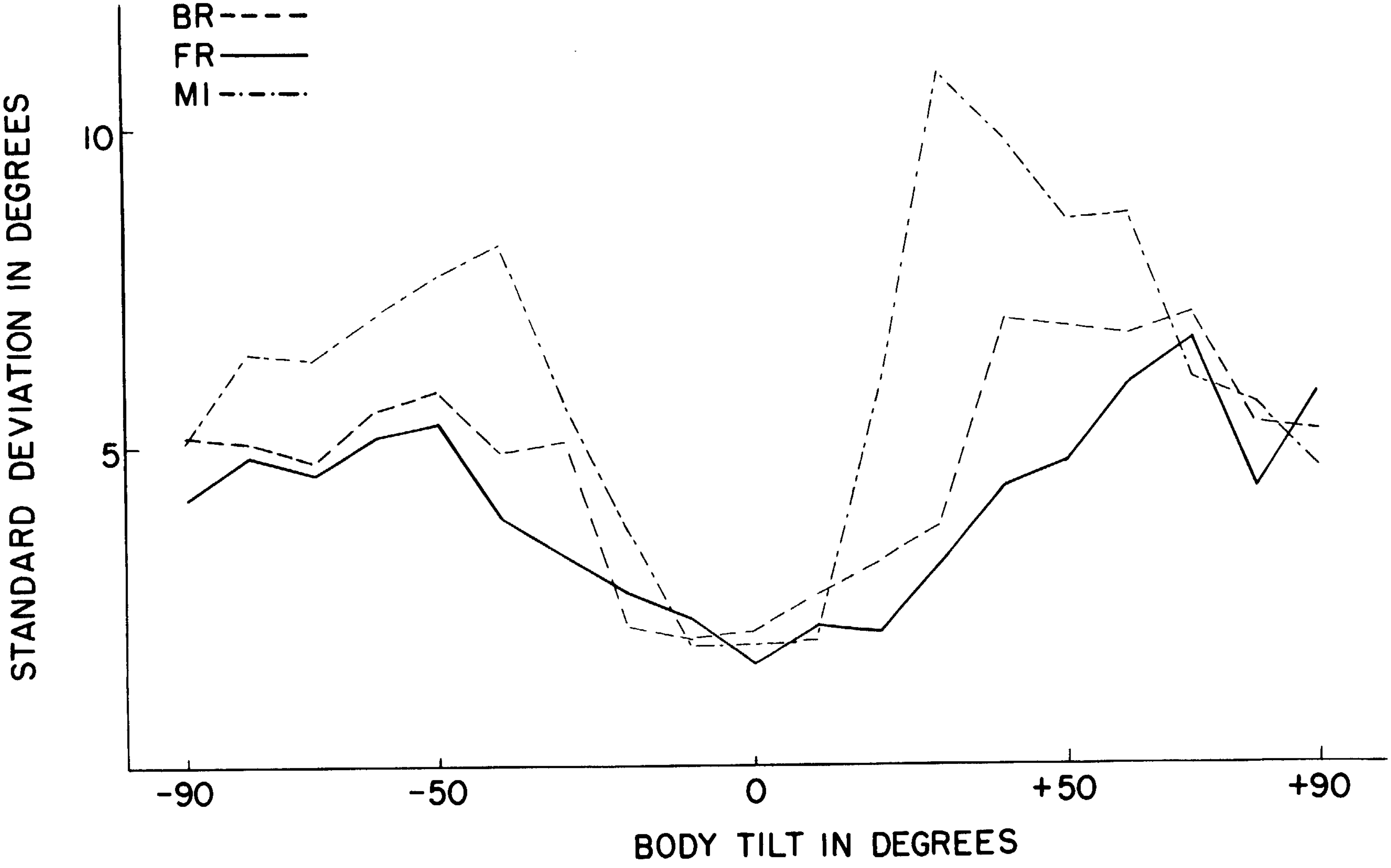

Figure 2

Variable Error (Standard Deviation) of Three Subjects as a Function of Body Tilt up to ±90° from Upright as found for the vestibular (21) and perceptual (22) response of certain subjects. In subject FR a significant* correlation indicating symmetry was found only in the variability of his judgments of horizontality. Bilateral differences in response of each subject can be determined also by inspection of the plots of the data as a function of head position (Figure 1).

INFLUENCE OF "PRACTICE"

Changes in the magnitude of the mean constant and variable error between performance on the first and last day of testing were used to determine the practice effect of repeated testing upon the judgment of the visual horizontal.

Constant Error

The first day versus last day comparison of the constant error values found for each subject at each tilt position is presented in Table IV. It can be seen that changes in both direction and nagnitude of error occurred in all subjects.

With subject MI quantitative intertrial changes in constant error were significant */** except those for positions + 50°, +90°, -10°, -20°, -40°, -60°, and -80°. Improved accuracy in localizing the horizontal, however, was found in only five of twelve tilt positions in which there were significant changes. The magnitude of the constant error for subject FR changed significantly*/** at all tilt positions except +50°, +60°, +70°, +90°, and -70°. Seven of these thirteen significant changes revealed improved performance from the first to the last day. In the case of subject BR, all differences except those at the + 10°, + 20°, + 50°, -60°, and -70° positions are significant*/**. Eight of the eleven significant differences indicated an increase in accuracy on the final test day.

Variable Error

First day with last day comparisons of the variable errors of each subject are presented in Table V. With subject MI, differences were significant*/** at eleven of the nineteen positions. In eight of the tilt positions variability decreased between the first and final day.

With subjects FR and BR only six differences were significant*/**, and all of these save one for each subject represent a decrease in variability between the first and last day.

INFLUENCE OF A FIXED HEAD POSITION

In general, in the case of subject MI it would be impossible to identify the data curves of those sessions (first and last) in which the head was not rigidly fixed from amongst those curves representing the results obtained in those sessions in which a

Table IV

Comparison Between Constant Error of the First and Last Sessions

Subject:		BR			FR			MI		
	Magnitude of Tilt	Constant Error		Diff- erence	Constant Error		Diff- erence	Constant Error		Diff- erence
		First Session	Last Session		First Session	Last Session		First Session	Last Session	
Clockwise	+90	4.2	10.9	6.7*	13.2	10.7	2.6*	5.3	5.7	0.4
	+80	4.8	2.6	7.4*	11.4	6.4	5.0**	5.2	1.1	4.1**
	+70	9.9	3.9	13.8**	11.1	0.7	10.4**	9.3	2.0	7.3**
	+60	7.9	1.4	9.3**	4.1	3.2	0.9	4.0	1.3	5.3**
	+50	12.1	5.0	17.1**	0.9	0.7	0.2	14.2	13.9	0.3
	+40	10.4	4.6	14.9**	1.4	4.1	2.8*	13.3	6.3	7.0**
	+30	1.8	1.7	3.5**	3.2	1.6	4.8**	4.1	0.8	4.9**
	+20	2.4	4.3	6.6**	0.1	0.7	0.6	0.3	1.8	1.5
	+10	2.2	4.1	2.0	1.2	1.7	2.9**	0.7	0.2	0.9
	0	0.4	2.0	1.6*	1.0	1.2	2.2*	2.2	1.7	4.0**
Counterclockwise	-10	2.8	1.5	1.3*	4.2	0.7	4.9**	1.9	1.3	0.5
	-20	2.2	1.0	1.2	4.6	1.0	3.7**	1.4	0.9	0.6
	-30	12.5	2.9	9.6**	5.8	1.1	6.8**	3.7	11.8	8.2**
	-40	9.6	2.4	11.9**	1.3	4.8	3.5**	12.0	10.2	1.8
	-50	0.8	0.3	0.5	1.7	10.0	11.7**	5.4	20.6	15.2**
	-60	5.2	2.4	2.9	8.5	12.8	4.3**	19.0	19.1	0.1
	-70	7.5	7.5	0.0	0.1	3.2	3.2**	1.2	9.1	7.9**
	-80	11.3	6.8	4.4*	6.6	0.8	7.4**	1.2	6.4	5.3**
	-90	18.5	8.7	9.7**	9.9	0.4	9.5**	11.0	1.0	12.0**

** $P < .01$
* $P \leq .05$

Table V

Comparison Between Variability of the First and Last Sessions

Subject		BR			FR			MI		
	Magnitude of Tilt	Standard Deviation		Diff-erence	Standard Deviation		Diff-erence	Standard Deviation		Diff-erence
		First Session	Last Session		First Session	Last Session		First Session	Last Session	
Clockwise	+90	6.0	4.7	-1.3	3.5	2.1	-1.4	4.3	2.2	-2.1*
	+80	5.0	6.2	+1.2	3.2	1.9	-1.3	6.6	4.8	-1.8
	+70	3.8	6.2	+2.4	3.5	3.7	+0.2	7.4	4.4	-3.0
	+60	7.0	3.8	-3.1*	4.9	3.5	-1.5	5.4	2.8	-2.6*
	+50	8.1	1.1	-7.1**	3.1	2.2	-1.0	9.4	3.7	-5.6**
	+40	3.4	2.8	-0.5	1.3	1.2	-0.1	6.5	3.9	-2.6
	+30	3.3	1.5	-1.8*	1.8	1.0	-0.7	3.1	1.1	-2.0**
	+20	1.2	1.4	+0.2	2.3	0.9	-1.5**	1.5	0.3	-1.1**
	+10	2.1	2.1	+0.1	1.6	0.8	-0.7*	1.1	0.6	-0.6*
	0	1.3	1.3	+0.0	2.1	0.5	-1.6**	0.8	1.6	+0.8*
Counterclockwise	-10	1.0	1.0	+0.1	1.4	1.1	-0.3	0.8	0.7	-0.1
	-20	3.1	0.8	-2.2**	1.1	0.8	-0.3	2.6	0.6	-1.9**
	-30	2.2	1.8	-0.3	1.0	1.8	+0.8*	2.8	1.9	-1.0
	-40	3.8	2.4	-1.7	2.4	2.1	-0.3	4.7	1.8	-2.9**
	-50	1.8	3.8	+2.0*	3.0	1.7	-1.2	3.6	8.8	+5.2**
	-60	3.9	1.4	-2.5**	4.1	3.0	-1.1	2.4	2.9	+0.5
	-70	2.4	3.0	+0.6	8.6	2.0	-6.7**	5.7	7.0	+1.3
	-80	3.3	3.6	+0.2	6.1	1.9	-4.2**	2.3	4.9	+2.6*
	-90	4.2	6.1	+1.9	4.3	2.6	-1.7	3.8	4.7	+0.9

** $P \leq .01$
* $P \leq .05$

dental bite brace was used (Figure 3). It would appear, therefore, that rigid fixation of the head is not a critical variable in this perception. During one session (twelve), however, the dental bite was inserted inadvertently in such a way that the subject's head was abducted somewhat to his right while seated upright. This produced a relative stretching of the neck muscles on the left side. Due to the fact that the body was not perfectly restrained, a certain amount of lateral sliding movement in response to gravity occurred which increased in the clockwise and decreased in the counterclockwise direction of tilt. The results are portrayed as a solid line curve in Figure 3. It can be seen that the constant error configuration for the twelfth session (bite board) differs markedly in magnitude, principally in the positive direction of tilt, from that of the first and thirteenth sessions (no bite board). Curve differences were statistically significant*/** at fourteen of the nineteen positions. Qualitatively, however, the curves are similar; the correlation between session 12 and 13 was significant (r= .667). Since the variable of neck bending was not controlled, it is possible to state only that the stimulation receptors in the neck may influence orientation as claimed by other authors (4, 8, 33). Subject MI reported not only considerable discomfort from prolonged exposure to asymmetrically increased neck muscle stimulation but also considerably more difficulty in judging horizontality.

DISCUSSION

Within the standard gravity field, an individual deprived of visual cues derives a frame of reference for judging the horizontal in accord with the position of his head and body. This reference system, however, is not rigidly fixed in space or time and in its relationship to physical space varies remarkably with posture. The genesis of the fluctuations of the principal axes of visual space like their subjective localization is unknown, but there are undoubtedly many factors involved. For example, it has been claimed (9, 31, 32) that a target moderately inclined with respect to the principal physical coordinates of space may appear more nearly vertical or horizontal (actually increase in error) as a result of observation alone; the quantitative studies (9, 32) of this factor, however, were limited to the upright position. Passey and Ray (30) in a study involving body tilt within ± 20° of the upright position failed to find a significant difference in the visual vertical setting between exposure and nonexposure of the reference target for thirty seconds prior to rendering a judgment. Similar critical studies with greater body tilts or longer observation times have not been conducted. Except for one instance, in the present study no significant intrasessional change in constant error as determined for each tilt position occurred in two of the subjects. In the third subject (MI) who used considerably more time in making his judgments, there was a significant increase in deviation between the first and last three settings in four of the eighteen tilt positions. This finding would be in keeping with an effect of "visual" tilt-adaptation, but in tilted positions one must also consider the possibility of "postural" tilt-adaptation (7, 16-18, 29) and its influence upon spatial judgments. In view of the results of the present and former studies (2, 20, 24-26) in which an apparent conflict exists as to an increase, decrease, or constancy of illusion as a function of observation time, rotation of the frame of reference in time must be highly individualistic and

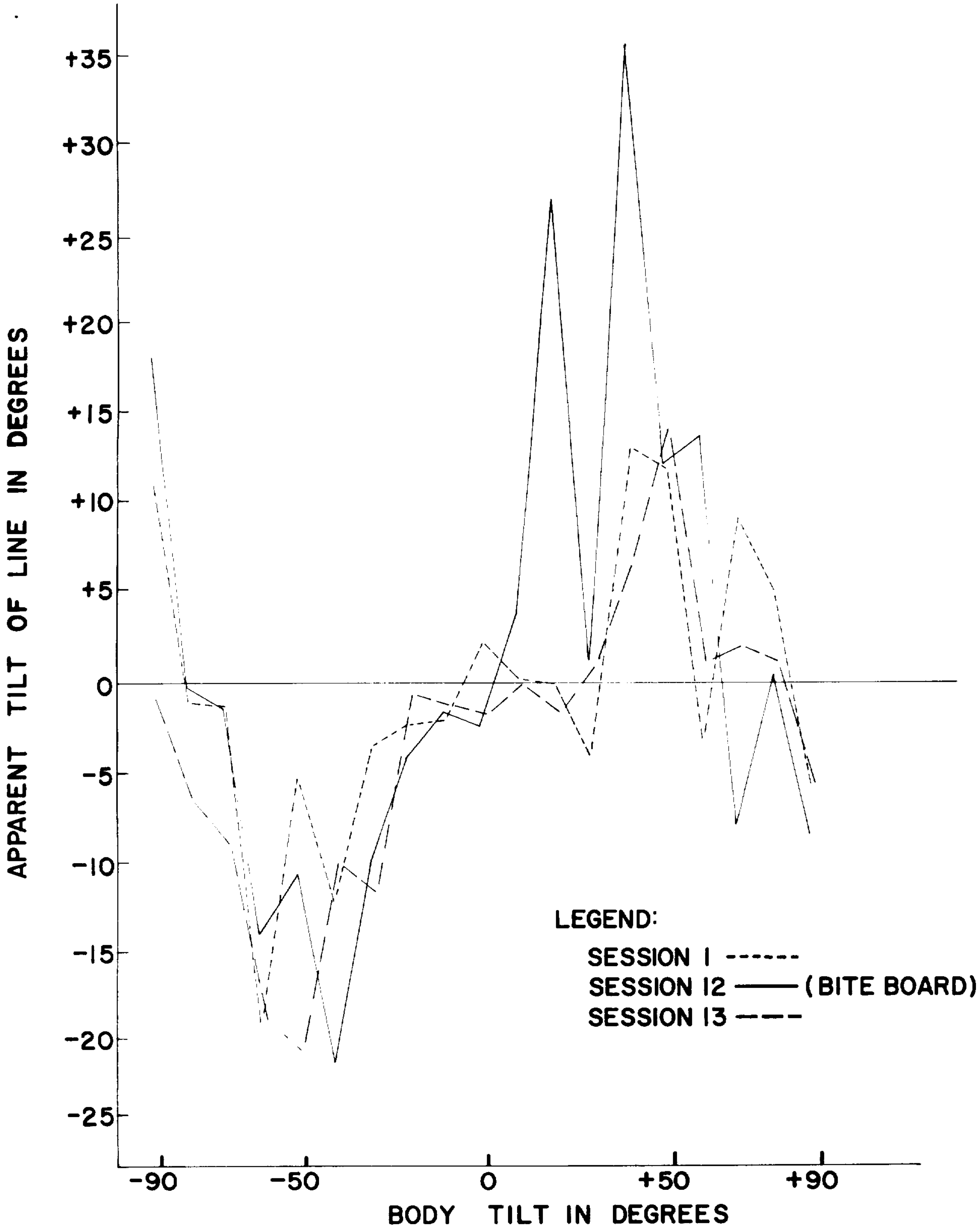

Figure 3
Comparison between Measurements of the Visual Horizontal under Asymmetrical Stimulation of the Neck Muscles as Induced by a Bite-Board Arrangement (Session 12) and Those Found in Sessions 1 and 13 in Which this Device was Not Used

dependent upon the posture of the individual. The magnitude of the variable error, on the other hand, in all subjects tested varied as a function of body attitude: least deviation in or near the upright position, increasing to a maximum usually within the middle third of each quadrant, then decreasing slightly beyond this point.

In spite of these temporal and postural variations, visual localization is not a random event in time and space but within certain limits is an orderly, predictable product of body position. Although denied by Nagel (26) there is corroborative evidence (5-7, 28, 35) that a definite proportionality exists between the posture of a subject and his visual localization. Arguments based principally upon previous studies, however, are weakened by the fact that the observations reported were sometimes qualitative, limited in range of tilt or to large step increases in tilt over a wide range. The lack of more extensive quantitative measures of visual localization using the same subjects over a period of several days, furthermore, prevented any valid statement concerning the relative constancy of an individual's visual space as influenced by lateral changes in position within the gravitational force field. The data of our study, however, clearly show that the essential character of response is typical of an individual and apparently independent of time, at least within a period of several days and probably longer. Fischer (6), for example, noted that his personal estimations of the visual vertical did not change qualitatively (although there were quantitative differences) during the course of a three-year period of experiments. Witkin (34) also found high test-retest correlations between measures of visual orientation separated in time by more than a year.

The data portrayed in Figure I necessarily incorporate the "noise" resulting from the substantial intersessional and the much smaller interpositional variability within any given test session. In an attempt to make the response signal "more prominent" and to provide an indication of visuopostural interaction effects without temporal and other variations, the average data of MI were empirically fitted with a symmetrical curve (Figure 4). By use of curves having the same general configuration as the average (Figure 4), the data points of each session were similarly fitted as diagrammed in Figure 5. It would appear from such a smoothing treatment of the data that rightward and leftward as well as magnitudinal shifts in the maxima and minima occur from session to session. In spite of these significant quantitative differences which appear to be characteristic of visual orientation (6, 20, 24, 26) the wax and wane of the E- then a shift to an ever increasing A-phenomenon as the subject was tilted laterally from upright gave rise to a reclining "S" pattern which would qualitatively describe the typical response of each subject used in this study. The reclining "S" pattern description is obviously (Figure I) an oversimplification of the actual response in all cases. Among other things, the patterns for right and left inclinations were not symmetrical for subjects BR and FR. Also within a range, which varied among the subjects, of moderate tilts from upright judgments were not significantly different from those found in the upright position. This differs from the study of Passey (28) in which there was a small but significant average increase in illusion (A or E) as an almost linear function of body tilt from 0° to 20° in 5° steps. Nagel (26), at the other extreme, usually

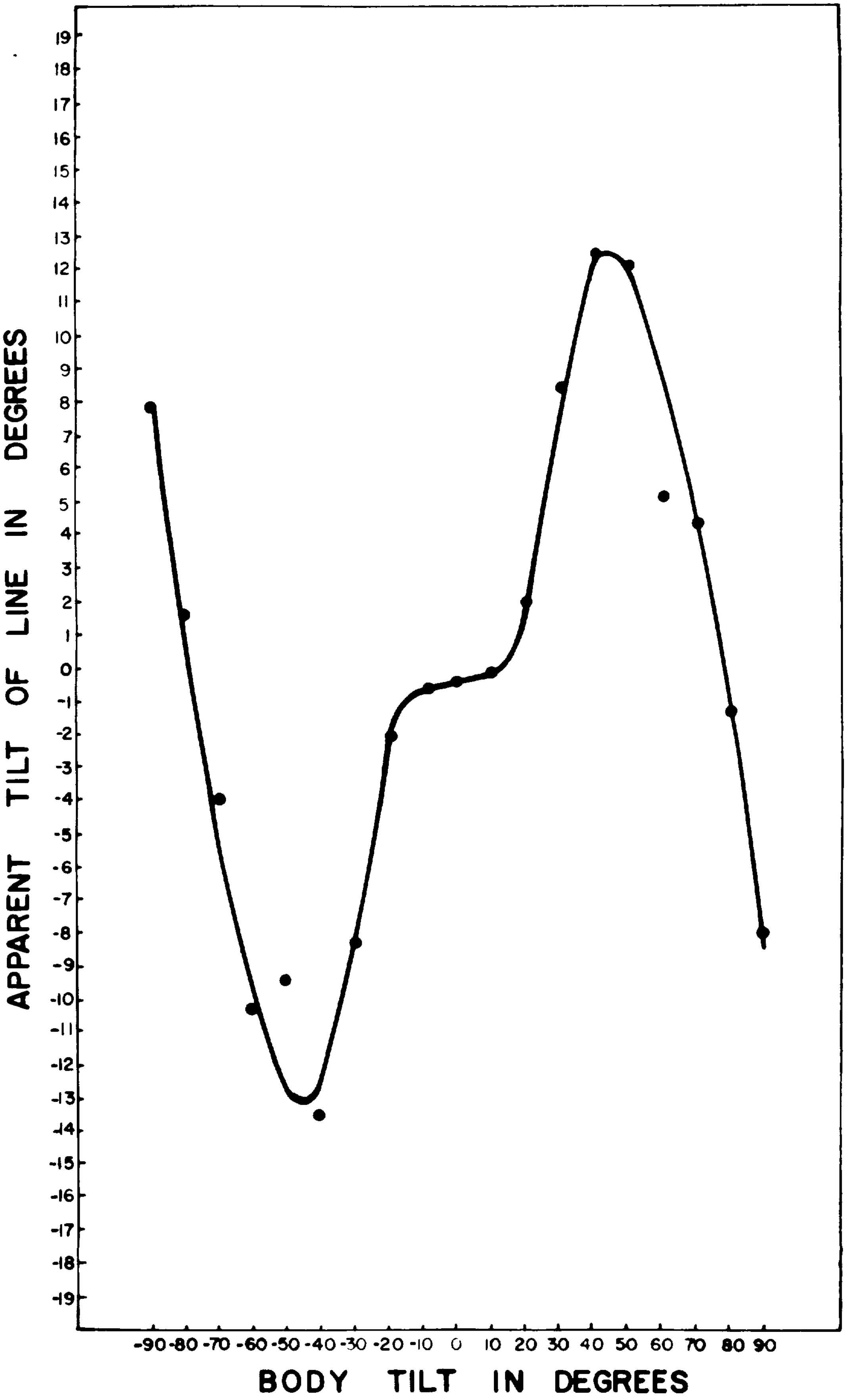

Figure 4

Mean Deviation of the Apparent Horizontal Position of a Line Target from Its Physical Horizontal Position as a Function of Body Tilt (Subject MI)

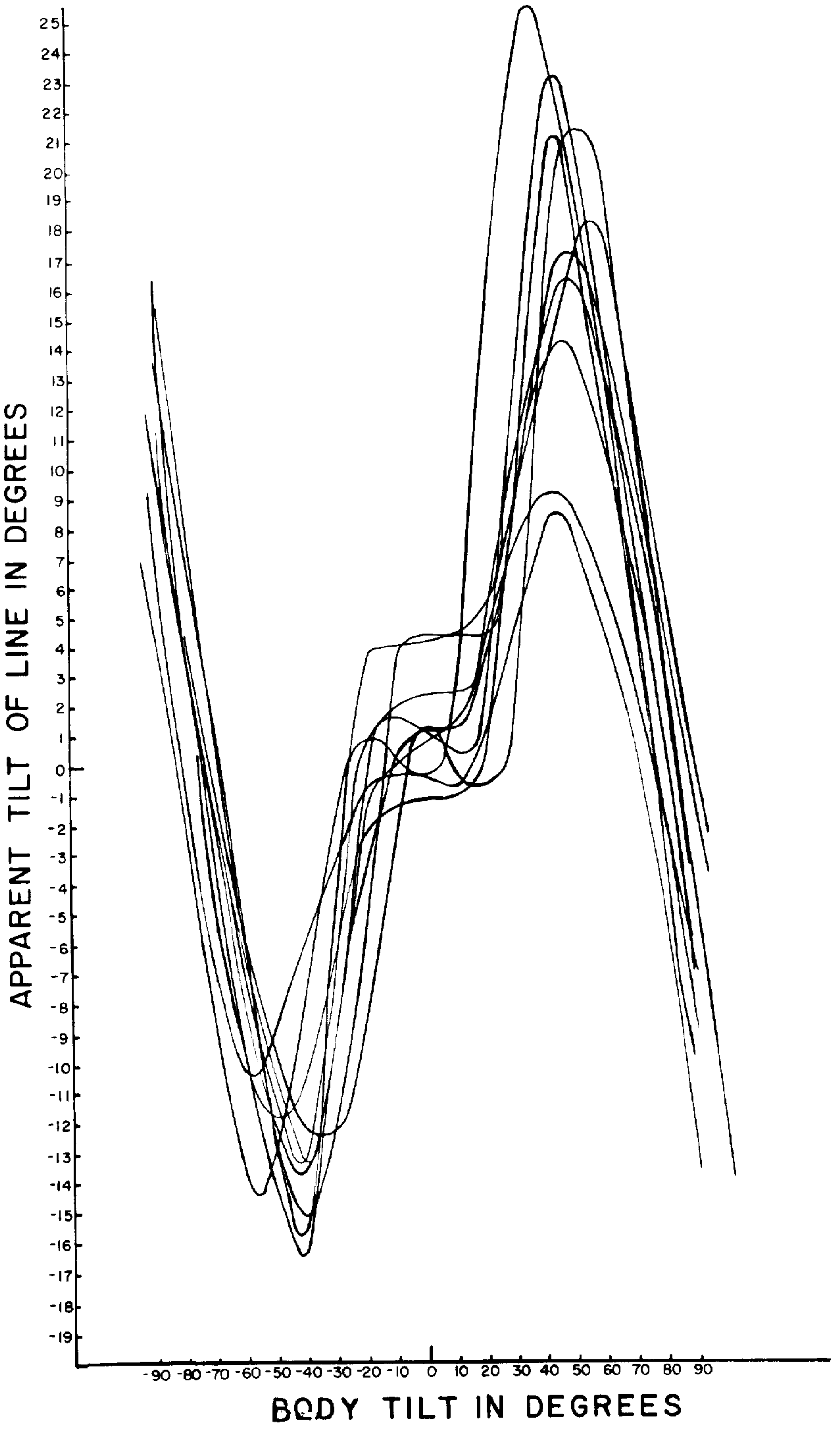

Figure 5

Data of Individual Test Sessions of Subject MI (Figure 1) Fitted with Curves Having the General Configuration of the Average Data Curve of Figure 4 observed no illusion within ± 50° to ± 60° from upright.

From this study, it should not be assumed that the reclining "S" pattern involving a shift from E- to A-phenomenon is the universal mode of response although it may be the predominant one; Witkin and Asch (35) found that among a large group of subjects the majority of judgments deviated in the E direction for moderate tilts (28° to 42°) and in the A direction for a greater tilt (90°). In this and other studies (6, 7, 24, 25,28), including unpublished data involving the testing of other subjects with the same apparatus, important variations in pattern of response including in some cases the complete absence of the E-phenomenon were found. Interindividual differences no doubt reflect the many factors involved in this perception.

In the absence of visual cues one is entirely dependent in visual localization upon the interaction of his various gravireceptor cues and subjective factors (3, 13, 20, 34). It is possible to gain some notion as to the importance of one group of cues, tactual or kinesthetic, in the perception of horizontality by comparing certain of the present experimental results with those of a previous study (20) involving subject MI only. The two studies used a common inclination (90°) of the longitudinal axis of the body with respect to a gravitational vertical. In the present study the tilt chair was rotated to achieve this attitude, while in the former study a molded Fiberglas appliance securing the head and shoulders was oriented in the horizontal direction and the body rested in a recumbent position on a 4-inch foam rubber mattress. The target in each study was identical. In the older experiment subject MI consistently manifested over twice the magnitude of Aubert phenomenon found with the tilt chair. Since the effect of prior tilt attitudes upon judgments in each successive position in the chair experiment and the difference in time between studies cannot be assessed, one may only hypothesize that the reduction in localized tactual cues through a more uniform distribution of body weight may have acted to decrease his ability to orient visually. Support to such an hypothesis is given by Aubert (2) who noticed an increase in illusion if when lying on his side he placed a soft cushion under his head, and Mulder (25) who observed that the illusion for a number of subjects was generally greater if the recumbent position was achieved with a couch rather than with his tilting-box apparatus. Even the introduction of a soft padded seat in a tilt chair was found to reduce the precision in the judgment of postural vertical (15).

Since little is known concerning the individual mechanisms subserving the preception of horizontality, it is only conjecture that the variability of response results from the dynamic interplay among the vestibular, kinesthetic, and other cues. Evidence has been reported (19, 23) which indicates that the vestibular organ provides useful information for visual orientation. If this be so, then other mechanisms must underly the illusory changes. Asymmetric stimulation of receptors located in the neck, for example, may induce an increased amount of deviation as found in this study when the head was abducted, although the response qualitatively was unmistakingly the same as when the head-body were essentially aligned.

10. Graybiel, A., and Clark, B., Perception of the horizontal or vertical with head upright, on the side, and inverted under static conditions and during exposure to centripetal force. Aerospace Med., 33:147-155, 1962.

Training in the form of repeating the test without immediate knowledge of results did not appear as a rule to reduce the magnitude of the illusion, but in certain tilt positions there was a greater tendency for variability to decrease than to increase with this procedure. The fact that the illusion appeared generally to be independent of experience in such an experiment has been noted by other authors (2, 25, 26).

11. Graybiel, A., and Fregly, A. R., A new quantitative ataxia test battery. NSAM-919. NASA Order No. R-93. Pensacola, Fla.: Naval School of Aviation Medicine, 1965.

12. Jastrow, J., On the judgment of angles and positions of lines. Amer. J. Psychol., 5:214-248, 1893.

13. Kleint, H., Versuche über die Wahrnehmung. Z. Psychol., 140:109-138, 1937.

14. Mann, C. W., and Boring, R. O., The role of instruction in experimental space perception. J. exp. Psychol., 45:44-48, 1953.

15. Mann, C. W., Berthelot - Berry, N. H., and Dauterive, H. J., Jr., The perception of the postural vertical. Visual and non-labyrinthine cues. J. exp. Psychol., 39:538-547, 1949.

16. Mann, C. W., and Passey, G. E., The perception of the vertical. V. Adaptation effects. NSAM-468. Pensacola, Fla.: Tulane Univ. and Naval School of Aviation Medicine, 1949.

17. Mann, C. W., and Passey, G. E., The perception of the vertical. VIII. Adjustment to the vertical as a function of the magnitude of tilt and the duration of exposure. J. exp. Psychol., 41:108-113, 1951.

18. Mann, C. E., Passey, G. E., and Ambler, R., The perception of the vertical. VII. Effect of varying intervals of delay in a tilted position. NSAM-471. Pensacola, Fla.: Tulane Univ. and Naval School of Aviation Medicine, 1950.

19. Miller, E. F. II, and Graybiel, A., Comparison of autokinetic movement perceived by normal persons and deaf subjects with bilateral labyrinthine defects. Aerospace Med., 33:1077-1080, 1962.

20. Miller, E. F. II, and Graybiel, A., Rotary autokinesis and displacement of the visual horizontal associated with head (body) position. Aerospace Med., 34: 915-919, 1963.

21. Miller, E. F. II, and Graybiel, A., A comparison of ocular counterrolling movements between normal persons and deaf subjects with bilateral labyrinthine defects. Ann. Otol., 72:885-893, 1963.

22. Miller, E. F. II, and Graybiel, A., Magnitude of gravitoinertial force, an independent variable in egocentric visual localization of the horizontal. J. exp.

observed no illusion within ± 50° to ± 60° from upright.

From this study, it should not be assumed that the reclining "S" pattern involving a shift from E- to A-phenomenon is the universal mode of response although it may be the predominant one; Witkin and Asch (35) found that among a large group of subjects the majority of judgments deviated in the E direction for moderate tilts (28° to 42°) and in the A direction for a greater tilt (90°). In this and other studies (6, 7, 24, 25,28), including unpublished data involving the testing of other subjects with the same apparatus, important variations in pattern of response including in some cases the complete absence of the E-phenomenon were found. Interindividual differences no doubt reflect the many factors involved in this perception.

In the absence of visual cues one is entirely dependent in visual localization upon the interaction of his various gravireceptor cues and subjective factors (3, 13, 20, 34). It is possible to gain some notion as to the importance of one group of cues, tactual or kinesthetic, in the perception of horizontality by comparing certain of the present experimental results with those of a previous study (20) involving subject MI only. The two studies used a common inclination (90°) of the longitudinal axis of the body with respect to a gravitational vertical. In the present study the tilt chair was rotated to achieve this attitude, while in the former study a molded Fiberglas appliance securing the head and shoulders was oriented in the horizontal direction and the body rested in a recumbent position on a 4-inch foam rubber mattress. The target in each study was identical. In the older experiment subject MI consistently manifested over twice the magnitude of Aubert phenomenon found with the tilt chair. Since the effect of prior tilt attitudes upon judgments in each successive position in the chair experiment and the difference in time between studies cannot be assessed, one may only hypothesize that the reduction in localized tactual cues through a more uniform distribution of body weight may have acted to decrease his ability to orient visually. Support to such an hypothesis is given by Aubert (2) who noticed an increase in illusion if when lying on his side he placed a soft cushion under his head, and Mulder (25) who observed that the illusion for a number of subjects was generally greater if the recumbent position was achieved with a couch rather than with his tilting-box apparatus. Even the introduction of a soft padded seat in a tilt chair was found to reduce the precision in the judgment of postural vertical (15).

Since little is known concerning the individual mechanisms subserving the preception of horizontality, it is only conjecture that the variability of response results from the dynamic interplay among the vestibular, kinesthetic, and other cues. Evidence has been reported (19, 23) which indicates that the vestibular organ provides useful information for visual orientation. If this be so, then other mechanisms must underly the illusory changes. Asymmetric stimulation of receptors located in the neck, for example, may induce an increased amount of deviation as found in this study when the head was abducted, although the response qualitatively was unmistakingly the same as when the head-body were essentially aligned.

Training in the form of repeating the test without immediate knowledge of results did not appear as a rule to reduce the magnitude of the illusion, but in certain tilt positions there was a greater tendency for variability to decrease than to increase with this procedure. The fact that the illusion appeared generally to be independent of experience in such an experiment has been noted by other authors (2, 25, 26).

REFERENCES

1. Alexander, G. and Bárány, R., Psychophysiologische Untersuchungen über die Bedeutung des Statolithenapparates für die Orientierung im Raume an Normalen und Taubstummen. *Arch. Ohrenheilk.*, *65*:187-192, 1905.

2. Aubert, H., Eine scheinbare bedeutende Drehung von Objecten bei Neigung des Kopfes nach rechts oder Links. *Arch. path. Anat. Physiol.*, *20*:381-393, 1861.

3. Backhaus, E., Über den Einfluss der Kopfhaltung bei einem besonderen Fall der Lageempfindung. *Z. Biol.*, *70*:65-94, 1918.

4. Cohen, L. A., Role of eye and neck proprioceptive mechanisms in body orientation and motor coordination. *J. Neurophysiol*, *24*:1-11, 1961.

5. Feilchenfeld, H., Zur Lageschätzung bei seitlichen Kopfneigung. *Z. Psychol.*, *31*:127-150, 1903.

6. Fischer, M. H., Messende Untersuchungen über die Gegenrollung der Augen und die Lokalisation der scheinbaren Vertikalen bei seitlicher Neigung (des Kopfes, des Stammes und des Gesamtkörpers.) I. Neigungen bis zu 40°. *v. Graefes Arch. Ophthal.*, *118*:633-680, 1927.

7. Fischer, M. H., Messende Untersuchungen über die Gegenrollung der Augen und die Lokalisation der scheinbaren Vertikalen bei seitlicher Neigung des Gesamtkörpers bis zu 360°. II Mitteilung. *v. Graefes Arch. Ophthal.*, *123*:476-508, 1930.

8. Fischer, M. H., Messende Untersuchungen über die Gegenrollung der Augen und die Lokalisation der scheinbaren Vertikalen bei seitlicher Neigung des Körpers, Kopfes und Stammes. III. Mitteilung. Untersuchungen an einem Ertaubten mit Funktionsuntüchtigkeit beider Vestibularapparate und einem einseitig Labyrinthlosen. *v. Graefes Arch. Ophthal.*, *123*:509-531, 1930.

9. Gibson, J. J., and Radner, M., Adaptation, after-effect and contrast in the perception of tilted lines. I. Quantitative studies. *J. exper. Psychol.*, *20*:453-467, 1937.

10. Graybiel, A., and Clark, B., Perception of the horizontal or vertical with head upright, on the side, and inverted under static conditions and during exposure to centripetal force. *Aerospace Med.*, *33*:147-155, 1962.

11. Graybiel, A., and Fregly, A. R., A new quantitative ataxia test battery. NSAM-919. NASA Order No. R-93. Pensacola, Fla.: Naval School of Aviation Medicine, 1965.

12. Jastrow, J., On the judgment of angles and positions of lines. Amer. J. Psychol., 5:214-248, 1893.

13. Kleint, H., Versuche über die Wahrnehmung. Z. Psychol., 140:109-138, 1937.

14. Mann, C. W., and Boring, R. O., The role of instruction in experimental space perception. J. exp. Psychol., 45:44-48, 1953.

15. Mann, C. W., Berthelot - Berry, N. H., and Dauterive, H. J., Jr., The perception of the postural vertical. Visual and non-labyrinthine cues. J. exp. Psychol., 39:538-547, 1949.

16. Mann, C. W., and Passey, G. E., The perception of the vertical. V. Adaptation effects. NSAM-468. Pensacola, Fla.: Tulane Univ. and Naval School of Aviation Medicine, 1949.

17. Mann, C. W., and Passey, G. E., The perception of the vertical. VIII. Adjustment to the vertical as a function of the magnitude of tilt and the duration of exposure. J. exp. Psychol., 41:108-113, 1951.

18. Mann, C. E., Passey, G. E., and Ambler, R., The perception of the vertical. VII. Effect of varying intervals of delay in a tilted position. NSAM-471. Pensacola, Fla.: Tulane Univ. and Naval School of Aviation Medicine, 1950.

19. Miller, E. F. II, and Graybiel, A., Comparison of autokinetic movement perceived by normal persons and deaf subjects with bilateral labyrinthine defects. Aerospace Med., 33:1077-1080, 1962.

20. Miller, E. F. II, and Graybiel, A., Rotary autokinesis and displacement of the visual horizontal associated with head (body) position. Aerospace Med., 34:915-919, 1963.

21. Miller, E. F. II, and Graybiel, A., A comparison of ocular counterrolling movements between normal persons and deaf subjects with bilateral labyrinthine defects. Ann. Otol., 72:885-893, 1963.

22. Miller, E. F. II, and Graybiel, A., Magnitude of gravitoinertial force, an independent variable in egocentric visual localization of the horizontal. J. exp. Psychol., in press.

23. Miller, E. F. II, and Graybiel, A., Role of the otolith organs in the perception of horizontality., *Amer J. Psychol*. To be published.

24. Müller, G. E., Über das Aubertsche Phänomen. *Z. Sinnesphysiol*., *49* Part II: 109-244, 1916.

25. Mulder, M. E., Ons oordeel over verticaal, bij neiging van het hoofd naar rechts of links. Festschrift f. Donders, Ned Tyjdschr. Gennesh., *8*:340-352, 1888. (Cited after abstr. in *Arch. Anat. u. Physiol*., II.)

26. Nagel, W. A., Ueber das Aubert'sche Phänomen und verwandte Täuschungen über die vertikale Richtung. *Z. Psychol*., *16*:373-398, 1898.

27. Neal, E., Visual localization of the vertical. *Amer. J. Psychol*., *37*:287-291, 1926.

28. Passey, G. E., The perception of the vertical. IX. Adjustment of the visual vertical from various magnitudes of body tilt. NSAM-474. Pensacola, Fla.: Tulane Univ. and Naval School of Aviation Medicine, 1950.

29. Passey, G. E., and Guedry, F. E., The perception of the vertical. III. Adaptation effects in four planes. *J. exp. Psychol*., *39*:700-707, 1949.

30. Passey, G. E., and Ray, J. T., The perception of the vertical. X. Adaptation effects in the adjustment of the visual vertical. NSAM-476. Pensacola, Fla.: Tulane Univ. and Naval School of Aviation Medicine, 1950.

31. Sachs, M., and Meller, J., Ueber die optische Orientierung bei Neigung des Kopfes gegen die Schulter. *v. Graefes Arch. Ophthal*., *52*:387-401, 1901.

32. Vernon, M. D., The perception of inclined lines. *Brit. J. Psychol*. (Gen. Sect.), *25*(2):185-196, 1934.

33. Wapner, S., Werner, H., and Chandler, K. A., Experiments on sensory-tonic field theory of perception: I. Effect of extraneous stimulation on visual perception of verticality. *J. exp. Psychol*., *42*:341-345, 1951.

34. Witkin, H. A., The nature and importance of individual differences in perception. Interrelationships between perception and personality: A symposium. Part II. *J. Personal*., 18:145-170, 1949.

35. Witkin, H. A., and Asch, S. E., Studies in space orientation. III, Perception of the upright in the absence of a visual field. *J. exp. Psychol*., *38*:603-614, 1948.

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)* U. S. Naval School of Aviation Medicine Pensacola, Florida	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP

3. REPORT TITLE
Visual Localization of the Horizontal as a Function of Body Tilt up to ± 90° from Gravitational Vertical

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

5. AUTHOR(S) *(Last name, first name, initial)*
Miller, Earl F., II; Fregly, Alfred R.; van den Brink, Gert; and Graybiel, Ashton.

6. REPORT DATE 3 August 1965	7a. TOTAL NO. OF PAGES 25	7b. NO. OF REFS 35

8a. CONTRACT OR GRANT NO. NASA R-47	9a. ORIGINATOR'S REPORT NUMBER(S) NSAM - 942
b. PROJECT NO. MR005.13-6001 Subtask 1	
c.	9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)* 118
d.	

10. AVAILABILITY/LIMITATION NOTICES Qualified requesters may obtain copies of this report from DDC. Available, for sale to the public, from Federal Clearinghouse for Scientific and Technical Information, Springfield, Virginia. 22512

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY

13. ABSTRACT

The visual horizontal was determined for three sophisticated subjects tilted laterally in 10° intervals within ±90° from gravitational vertical. The task had adequate intratest reliability, but there were considerable intertest and intrasubject quantitative variations. Visual localization as a function of body tilt, however, was qualitatively similar among all subjects and among the thirteen test sessions of each subject. Around upright there was a range (totaling 20° - 40° on the average) of body positions in which the deviation was not significant from that of upright. Inclinations beyond this range caused the E-phenomenon to appear and increase bilaterally up to a maximum of about the 40° - 50° position; with further inclination the deviation reversed direction and passed through the position (60° - 80°) of zero deviation to grow as the A-phenomenon. Responses were bilaterally symmetrical in certain respects for each of the subjects. The variable error among all subjects followed a similar (curvilinear) function of body attitude. Repetition of test without immediate knowledge of results did not as a rule end in reduction of errors.

DD FORM 1 JAN 64 1473

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Visual perception						
Space perception						
Orientation						
Illusions						
Tilt effects						
Aubert phenomenon						
E-phenomenon						
Vestibular apparatus						
Practice effects						
Psychophysiology						

INSTRUCTIONS

1. ORIGINATING ACTIVITY: Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization *(corporate author)* issuing the report.

2*a*. REPORT SECURITY CLASSIFICATION: Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2*b*. GROUP: Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. REPORT TITLE: Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. DESCRIPTIVE NOTES: If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. AUTHOR(S): Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. REPORT DATE: Enter the date of the report as day, month, year; or month, year. If more than one date appears on the report, use date of publication.

7*a*. TOTAL NUMBER OF PAGES: The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7*b*. NUMBER OF REFERENCES: Enter the total number of references cited in the report.

8*a*. CONTRACT OR GRANT NUMBER: If appropriate, enter the applicable number of the contract or grant under which the report was written.

8*b*, 8*c*, & 8*d*. PROJECT NUMBER: Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9*a*. ORIGINATOR'S REPORT NUMBER(S): Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9*b*. OTHER REPORT NUMBER(S): If the report has been assigned any other report numbers *(either by the originator or by the sponsor)*, also enter this number(s).

10. AVAILABILITY/LIMITATION NOTICES: Enter any limitations on further dissemination of the report, other than those imposed by security classification, using standard statements such as:

(1) "Qualified requesters may obtain copies of this report from DDC."

(2) "Foreign announcement and dissemination of this report by DDC is not authorized."

(3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through
_______________________________________."

(4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through
_______________________________________."

(5) "All distribution of this report is controlled. Qualified DDC users shall request through
_______________________________________."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. SUPPLEMENTARY NOTES: Use for additional explanatory notes.

12. SPONSORING MILITARY ACTIVITY: Enter the name of the departmental project office or laboratory sponsoring *(paying for)* the research and development. Include address.

13. ABSTRACT: Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as *(TS)*, *(S)*, *(C)*, or *(U)*

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, roles, and weights is optional.