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INDIVIDUAL DIFFERENCES IN VESTIBULAR INFORMATION AS A
PREDICTOR OF MOTION DISTURBANCE SUSCEPTIBILITY

H. J. Moore and Fred E. Guedry, Jr.



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Motion sickness
Vestibular system
Sensory conflict

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Bureau of Medicine and Surgery
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U. S. Army Aeromedical Research Laboratory

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SUMMARY PAGE

THE PROBLEM

Persons lacking labyrinthine function are immune to motion sickness, while stimuli that induce intralabyrinthine sensory conflicts are among the more provocative. These facts suggest that individual differences in motion disturbance susceptibility might therefore positively correlate with differential accessibility of vestibular sensory information to the spatial perceptual process. The experiments described herein comprise several experimental probes with relatively small groups of subjects to estimate whether or not a simple measure of one component of vestibular information would reveal individual differences in motion disturbance susceptibility.

FINDINGS

The results of two experiments did not demonstrate a relationship between a vestibular response variance measure and motion disturbance susceptibility at the conventional significance level. However, the direction of the results was consistent with the hypothesis. The test-retest reliability of the measure utilized was not found to be favorable.

The slope of the vestibular stimulus-response relationship did not achieve statistical significance in predicting motion disturbance susceptibility. While the reliability of this slope measure approached adequacy, it was not so high as that observed in previous studies. Test-retest reliability findings with both measures are discussed.

ACKNOWLEDGMENTS

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The findings in this report are not to be construed as an official Department of the Army position, unless so designated by other authorized documents.

INTRODUCTION

Several sensory modalities provide spatial orientation information. In the natural environment these modalities operate together in a coordinated fashion. Situations or environments that provoke motion sickness are many times characterized by deviations from natural synergistic sensory patterns. This observation has led to the "conflict hypothesis" that motion sickness is the consequence of fundamental conflict among senses providing motion and spatial orientation information (8,16). Vestibular mechanisms would apparently play the key role in the putative conflict since individuals lacking labyrinthine function are generally immune to motion sickness. For normal subjects, on the other hand, motion stimuli that disrupt the coordination of intralabyrinthine sensory elements can be among the more provocative.

Great individual differences exist in the susceptibility to motion disturbance, and the assessment of susceptibility can be utilized to predict performance in flight training (1,10). Since a functioning vestibular apparatus seems to be a necessary condition for motion sickness, it is reasonable to suppose that individual variation in susceptibility might be positively related to a differential informational contribution by components of the vestibular contributions to the spatial orientation percept. Informal data from a small number of clinical referrals with the presenting symptoms of debilitating airsickness or aviator's vertigo seemed to reinforce this notion. When rotated about an Earth-vertical axis, these subjects manifested unusually high stimulus-response correlations for retrospective displacement estimations of discrete rotary stimuli (9).

To the extent that stimulus information is available and used accurately, response variance is reduced. The amount of statistical dependence between stimulus and response variables in explicitly informational units may be calculated using uncertainty analysis (7). A somewhat more convenient approach is afforded by ordinary correlation analysis, however. In contrast to a measure of contingent uncertainty or "information transmitted," the correlation coefficient indexes the degree of statistical dependence. The equivalence of the two approaches is verified by the fact that information and correlation measures may be calculated from each other under certain conditions (2). For a psychophysical function, a high stimulus-response correlation coefficient would indicate relatively great access and utilization of stimulus information.

The success of traditional cupulometry in uncovering correlates of motion disturbance susceptibility is somewhat equivocal (15). Recent evidence suggests that sensation and nystagmus cupulograms have little value in this regard (4,5). There is some evidence, however, that the slope of various linearized psychophysical functions may be of value as a predictor of susceptibility (18,19).

A pilot study utilizing an estimation task of discrete angular displacements suggested significant relationships between the correlation coefficient for this psychophysical function and several indices of motion disturbance susceptibility. The pilot study task was similar in many ways to a procedure formulated by Guedry et al. (11) for the determination of vestibular response parameters. It is worthwhile to determine

whether or not the variance and slope measures additionally obtainable from this type of procedure are useful as predictors of motion disturbance susceptibility.

EXPERIMENT I

PROCEDURE

SUBJECTS

Twenty-one U. S. Navy aviation officer candidates served as subjects. These men were new entrants in the service undergoing the first week of "boot camp" type military indoctrination. All had passed standard Navy flight physical examinations in the preceding few days. Ages ranged between 20 to 24 years. Selection was randomly made from a group of volunteers out of the available pool of individuals.

APPARATUS

Discrete angular displacements about an Earth-vertical axis were generated on the Periodic Angular Rotator (PAR) device maintained at the Naval Aerospace Medical Research Laboratory (12). The torque motor servomotor was operated in its "velocity" mode. The command signal for angular velocity was produced by a low-frequency waveform generator (Servomex LF51) set for outputting a complete cycle of a single cosine waveform.

The rotator chair was encapsulated in a lightproof shroud. Dim illumination within the capsule was provided by a small bulb affixed to the interior overhead. Auditory masking was accomplished utilizing audiometric earphones and a random noise generator.

Instrumentation of both chair displacement and subject response was effected using Rotaswitch 815 pulsers, which give an output of 360 pulses for each complete rotation of the shaft. These signals were monitored on digital counters (Hewlett-Packard 5321B and 5301A) that were reset immediately before each stimulus presentation.

A disc with a diameter of 25.5 cm and its centrally mounted rotary pointer of length 10.5 cm were utilized by the subject to indicate displacement estimates. This device was affixed in a horizontal plane on a movable arm so that it could be adjusted to a comfortable position before the seated subject. The face of the disc was unmarked except for a single 2.0 cm reference line at the twelve o'clock position as seen by the subject.

METHOD

Each subject completed the Reason Motion Sickness Questionnaire (18) from which a susceptibility quotient (MSQ) is derived on the basis of reported motion sick-

ness history. MSQ is calculated as the sum of two subquotients, one relating to disturbance history prior to age 12 (MSQ_1) and the second based on subsequent history (MSQ_2).

Next, each subject was administered a vestibular information assessment procedure based on subjective estimates of Earth-vertical z-axis (13) angular displacements. The method of retrospective angular displacement estimation (11) was employed for this purpose. Clockwise (seen from above) angular displacements having a sinusoidal acceleration waveform (Figure 1) served as the stimuli. The root mean square or effective acceleration of this waveform was 40 deg/sec^2 . The stimulus series consisted of eleven displacements programmed to lie at 60-deg intervals over the range 60 deg to 660 deg, inclusive. The experimental series was presented in a set random order and was preceded by a practice trial of 720 deg.

Each subject was seated in the chair with the dial indicator comfortably before him, and his instructions were then read by the experimenter. Care was taken to ensure that the subject would not be surprised or confused by the range of the stimuli, but he was left uncertain as to both range and incremental values. An instruction to disregard any sensation of reversal following the chair's clockwise movement was included, together with a warning against head movement while the chair was in motion. Finally, a demonstration was given by manually moving the chair and illustrating an appropriate response.

Stimuli were presented as fast as the appropriate machine settings could be made, so that an interval of approximately one minute elapsed between stimulus onsets. Following each trial the subject made his estimation of the angular displacement by moving the dial pointer clockwise from twelve o'clock through the perceived amount of turn. (This deviates slightly from the previous studies (11,17) in which subjects made a compensatory pointer displacement.) The pointer displacement was recorded, together with the actual displacement of the chair.

Each subject received a vestibular information score based on the product-moment correlation between the perceived displacement estimates and true displacements. The correlation coefficient was converted by the transform $Z = \tanh^{-1} r$ (Fisher's transform) as a corrective for an anticipated skew in the distribution of r . The least-squares regression coefficient m (slope) was also derived, and the slope angle Θ of the regression line was calculated by $\Theta = \tan^{-1} m$.

Three days later fourteen of the subjects were also administered the Brief Vestibular Disorientation Test (BVDT). The BVDT assesses motion disturbance susceptibility on the basis of reactions to the cross-coupled Coriolis stimulus (1,10). Two BVDT scores were derived for the subjects, one based on the judgments of raters, and the second based on the subject's self-appraisal.

The relationship between vestibular information (Z) and motion disturbance susceptibility was analyzed by product-moment correlations of Z and the several indices of susceptibility. Similar analyses were performed on Θ .

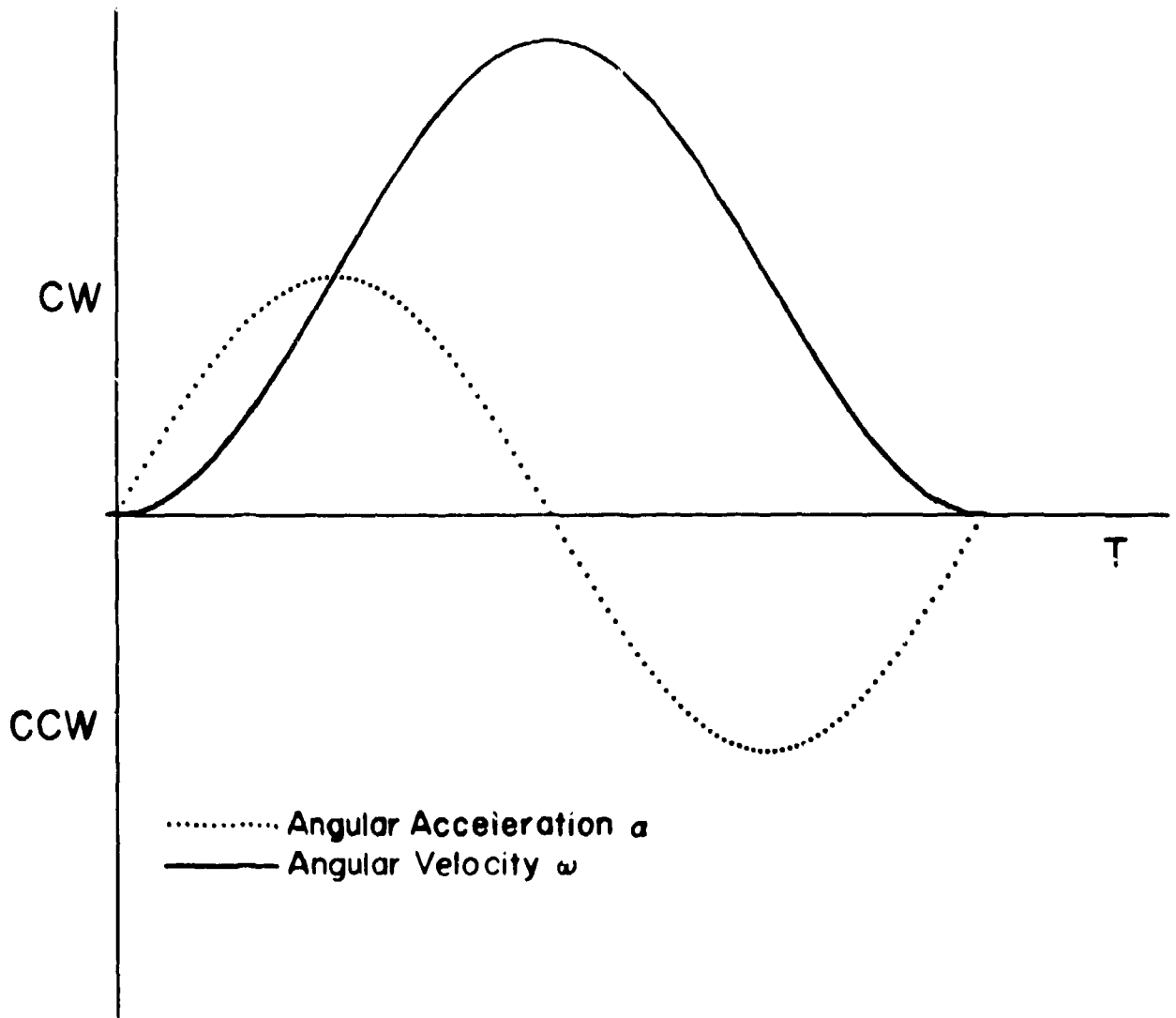


Figure 1

Stimulus waveform. Angular acceleration and velocity with respect to time.

RESULTS

Z was found to have a mean of 1.6819 and standard deviation of 0.5410. The distribution of Z appeared approximately normal (Figure 2). The median of the sample was 1.662 which compared favorably with the mean. Eleven sample points were below the mean, and ten were above. Hence, it is likely that Fisher's transform adequately served to normalize the distribution of correlation coefficients.

In general, product-moment correlations between Z and indices of motion disturbance susceptibility were not significant (Table I). However, they did lie in the predicted direction, with the exception of the BVDT self-rate score. MSQ appeared to be the strongest correlate of Z. A Spearman rank order correlation was also calculated for MSQ and Z, but the rank order coefficient likewise failed to attain significance.

Table I
Motion Disturbance Susceptibility and Z
Summary of Correlations

Index of Susceptibility	r	t	df	P< *
MSQ	.281	1.226	19	.125
MSQ ₁	.170	<1	19	NS
MSQ ₂	.250	1.123	19	.125
BVDT Rater	.054	<1	12	NS
BVDT Self	-.013	<1	12	NS
<u>MSQ (Rank Order)</u>	$\rho = .196$	<1	19	NS
*one-tail				

The distribution of the slope angle Θ also appeared to approximate normality (Figure 3). Product-moment correlations between Θ and measures of motion disturbance susceptibility failed to attain significance (Table II). With one exception the correlations were positive, but the relationships were all very weak.

In examining the stimulus-response scatter plots for the subjects, it seemed apparent that a disruption of the psychophysical function was occurring at the displacement range greater than a full circle. Not only was the scatter typically increased, but there often seemed to be a change or an outright discontinuity in slope as well (Figure 4). To further investigate this phenomenon, the stimulus series was partitioned

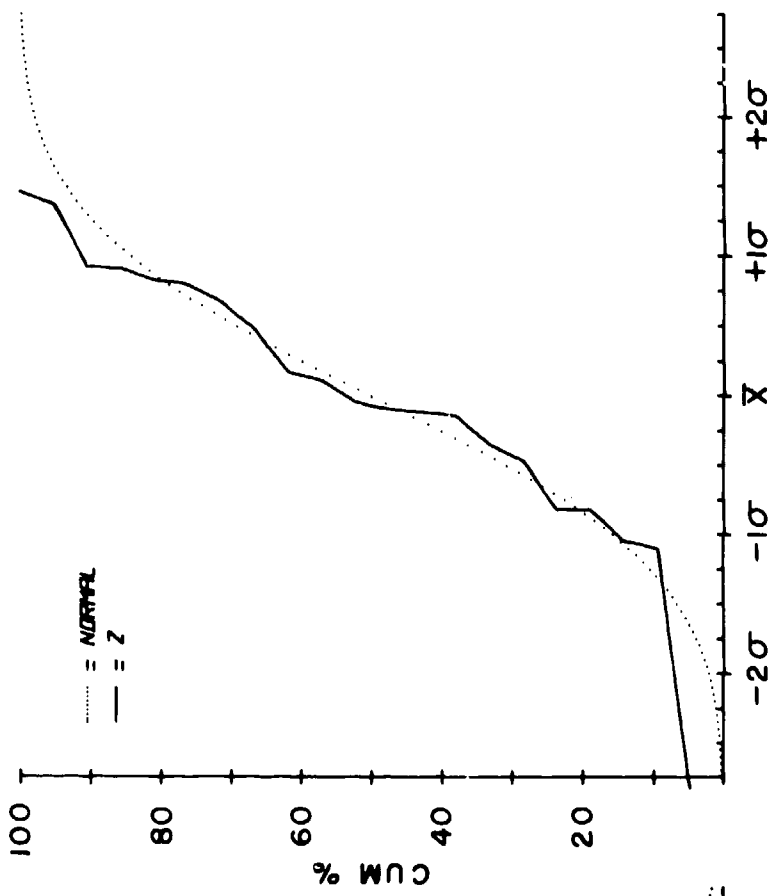


Figure 2a

Frequency distribution of Z

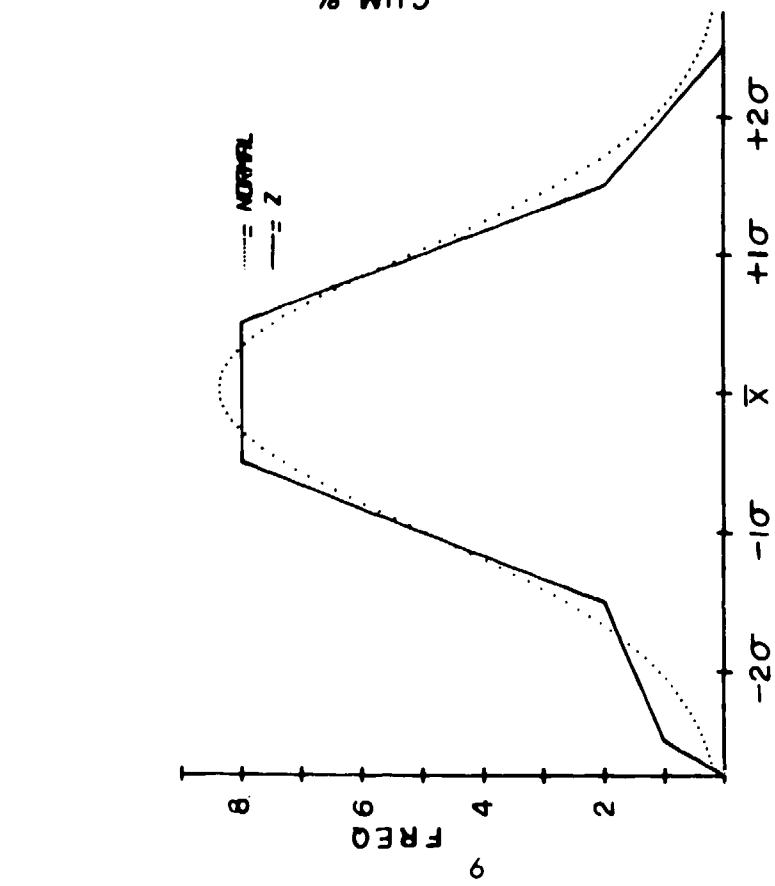


Figure 2b

Cumulative percentage of Z. $\bar{X} = 1.6819$, $\sigma = 0.5410$, $N = 21$.

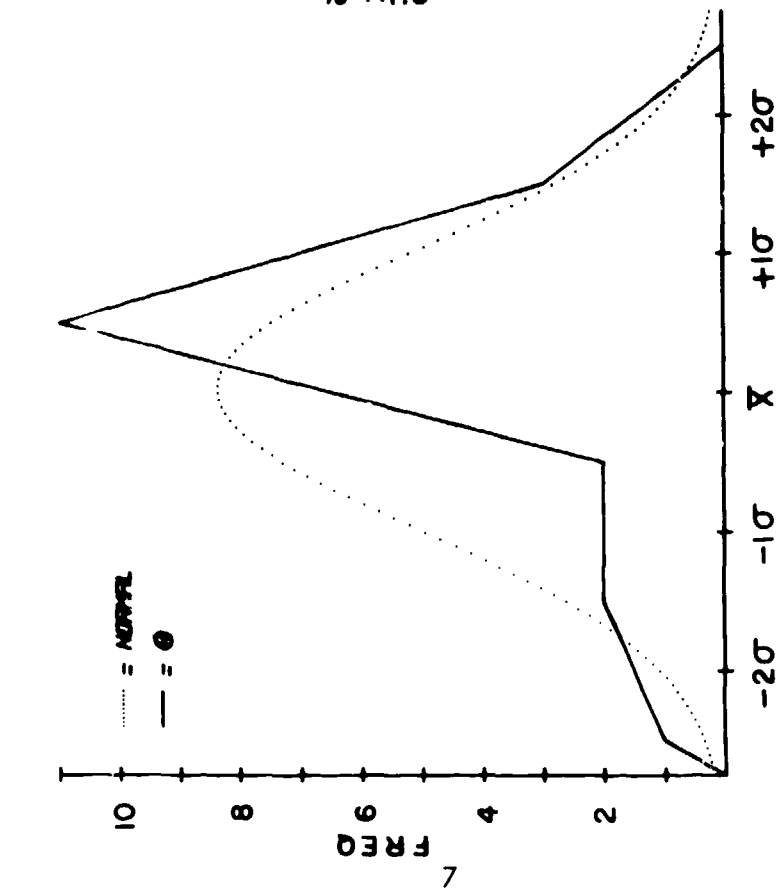


Figure 3a

Frequency distribution of Θ

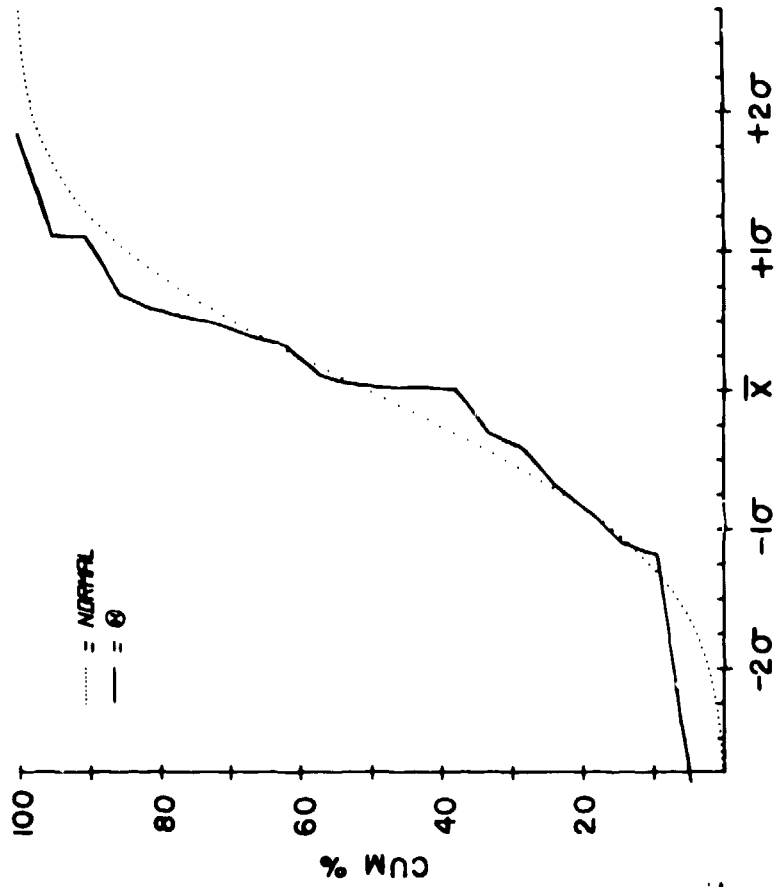


Figure 3b

Cumulative percentage of Θ . $\bar{X} = 36.3^\circ$, $\sigma = 11.0^\circ$, $N = 21$.

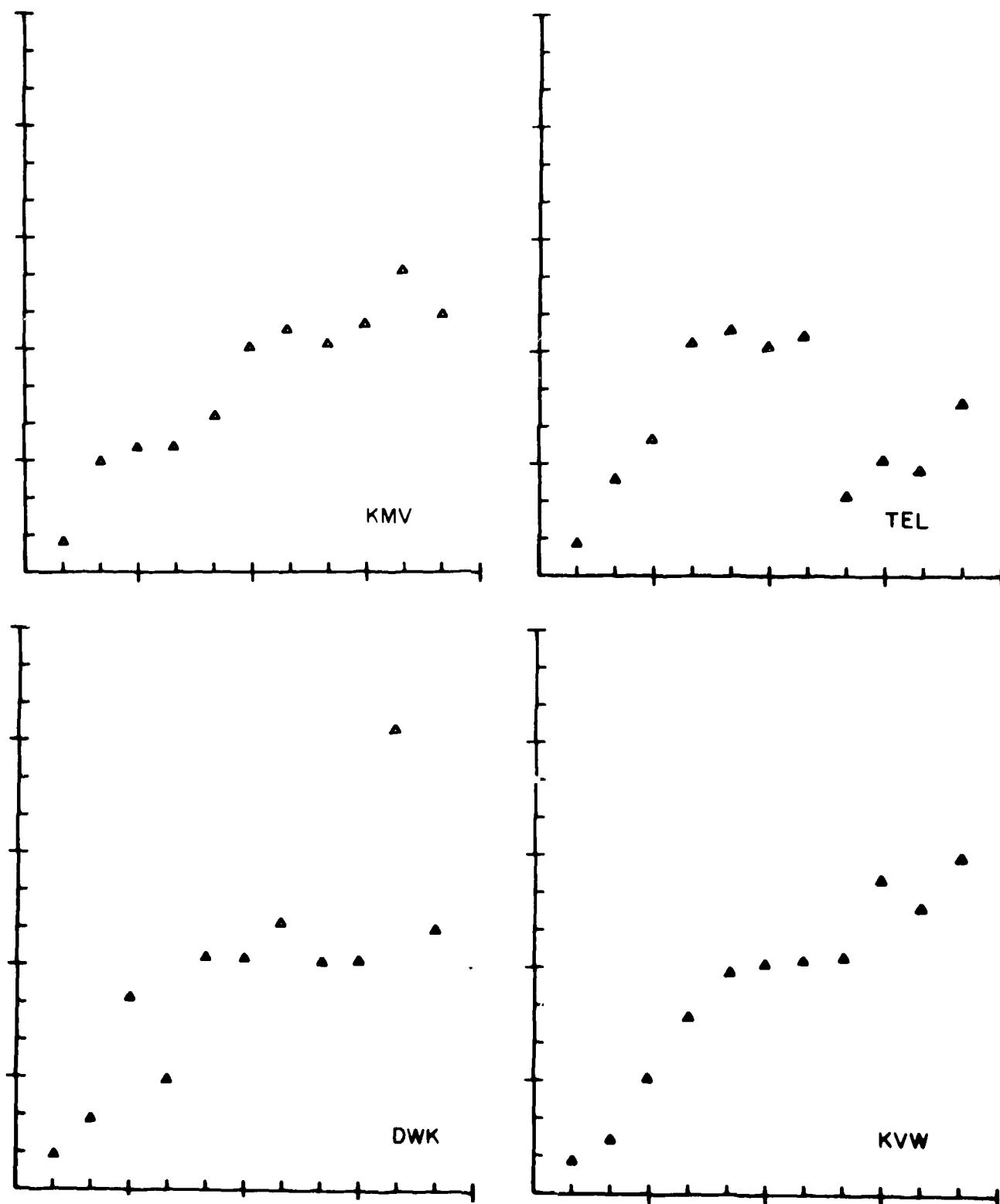


Figure 4

Representative scatter plots for subjects in Experiment 1. Displacement on abscissa and response on ordinate. Each small scale increment equals 60° .

into subsets of displacements of a full circle or less and displacements greater than a full circle. Z and Θ values based on these subsets were calculated for each subject. In comparing nonindependent means, Z was found to be depressed in the higher stimulus range an average of .781, and this difference was significant ($\underline{t} = 3.79$, $\underline{df} = 20$, $P < .01$). Likewise, Θ was depressed for the higher stimulus set an average of 17.7 deg, which was also significant ($\underline{t} = 5.08$, $\underline{df} = 20$, $P < .001$). Correlations between the stimulus subsets were also calculated. For Z, the product-moment coefficient $r = .156$ was derived (NS, $\underline{t} < 1$, $\underline{df} = 19$) while the correlation of Θ yielded the coefficient $r = .584$ ($P < .005$, one-tail, $\underline{t} = 3.19$, $\underline{df} = 19$).

Table II

Motion Disturbance Susceptibility and Θ
Summary of Correlations

Index of Susceptibility	r	t	df	P < *
MSQ	.202	<1	19	NS
MSQ ₁	.148	<1	19	NS
MSQ ₂	.192	<1	19	NS
BVDT Rater	.167	<1	12	NS
BVDT Self	-.036	<1	12	NS

*one-tail				

In view of the poor correlation of Z for the two stimulus subsets, it was decided to examine the predictive strength of each subset Z on the indices of motion disturbance susceptibility. In general, the correlations again were not significant (Table III), though with two exceptions they did lie in the predicted direction. Superficially, at least, the information scores based on the smaller displacements seemed to be the better predictors of motion disturbance susceptibility. However, the difference in the correlations of the subset Z's with MSQ was not significant ($\underline{t} < 1$, $\underline{df} = 18$).

In an effort to clarify the rather tenuous relationship between vestibular information transmission and motion disturbance susceptibility, a second experiment was conducted with several procedural modifications.

Table III
Correlates of Z Based on Stimulus Subsets

Index of Susceptibility	Displacements < 360 deg			
	r	t	df	P < *
MSQ	.243	1.094	19	.20
MSQ ₁	.146	<1	19	NS
MSQ ₂	.330	1.526	19	.05
BVDT Rater	-.325	1.189	12	.4**
BVDT Self	.006	<1	12	NS
	Displacements > 360 deg			
MSQ	.128	<1	19	NS
MSQ ₁	.079	<1	19	NS
MSQ ₂	.122	<1	19	NS
BVDT Rater	.008	<1	12	NS
BVDT Self	-.092	<1	12	NS

*one-tail				
**two-tail				

EXPERIMENT II

PROCEDURE

SUBJECTS

Subjects were 27 U. S. Navy aviation officer candidates, procured from the same source as in Experiment I. Sixty-eight persons in the available pool were administered the MSQ. Voluntary participation was solicited from those persons with an MSQ score of 5 or less, or a score of 20 or more (corresponding approximately to the first [N=14] and third [N=13] quartiles of the MSQ sample obtained in Experiment I).

APPARATUS

Apparatus was the same as for Experiment I.

METHOD

Each subject received a series of stimuli with characteristics like those of Experiment I. Displacements were programmed at 60-deg intervals over the range of 60 deg to 300 deg, inclusive, and each stimulus value occurred twice in the set random order of the stimulus series. The series was preceded by a practice trial of 360-deg displacement. Subjects were instructed that displacements greater or less than a complete circle might occur, but were not otherwise advised of the range or incremental values.

One to four days later, those subjects not detained in other activities ($N = 22$) were retested with a second stimulus series. The second series consisted of ten displacements with characteristics like those of Experiment I but programmed at 30-deg intervals over the range 30 deg - 330 deg, inclusive. The series was preceded by a practice displacement of 180 deg. Subjects were instructed as before and were also advised that the two stimulus series were nonidentical.

Z and Θ were calculated as in Experiment I for each stimulus series and for the set of points from both series taken together. The means of the two susceptibility groups (high and low MSQ) were then compared, using data from the first stimulus series only ($N_1 + N_2 = 27$) and also the set of data taken from both series ($N_1 = 11 + N_2 = 11 = 22$). Finally, the reliability of Z and Θ was assessed by the product-moment correlation of scores from the parallel forms of the experimental test.

RESULTS

Differences in mean Z 's for the two susceptibility groups were not significant, though they did lie in the predicted direction. Differences in mean Θ 's between the susceptibility groups were also not significant (Table IV).

Parallel forms reliability for the information score was quite poor ($r = .135$, $t < 1$, $df = 20$, NS). The reliability of the regression line slope angle, while statistically significant ($r = .445$, $t = 2.23$, $df = 20$, $P < .05$, two-tail), was not so favorable as that observed in a previous study (17).

An inspection of the stimulus-response scatter plots for subjects in Experiment II revealed a potentially interesting phenomenon. For some the scatter of points about the regression line was fairly uniform over the entire stimulus range. Other subjects, however, manifested a marked increase in the scatter for displacements greater than 180 deg (Figure 5). To further investigate these patterns, subsets of displacements less than 180 deg and displacements greater than 180 deg were taken from the set of data points of both stimulus series. Z and Θ values were calculated on the basis of each subset. A two-way analysis of variance (repeated measures on one factor) was then employed to assess the main effects and interaction of motion sickness susceptibility and displacement subset on each of Z and Θ (Table V).

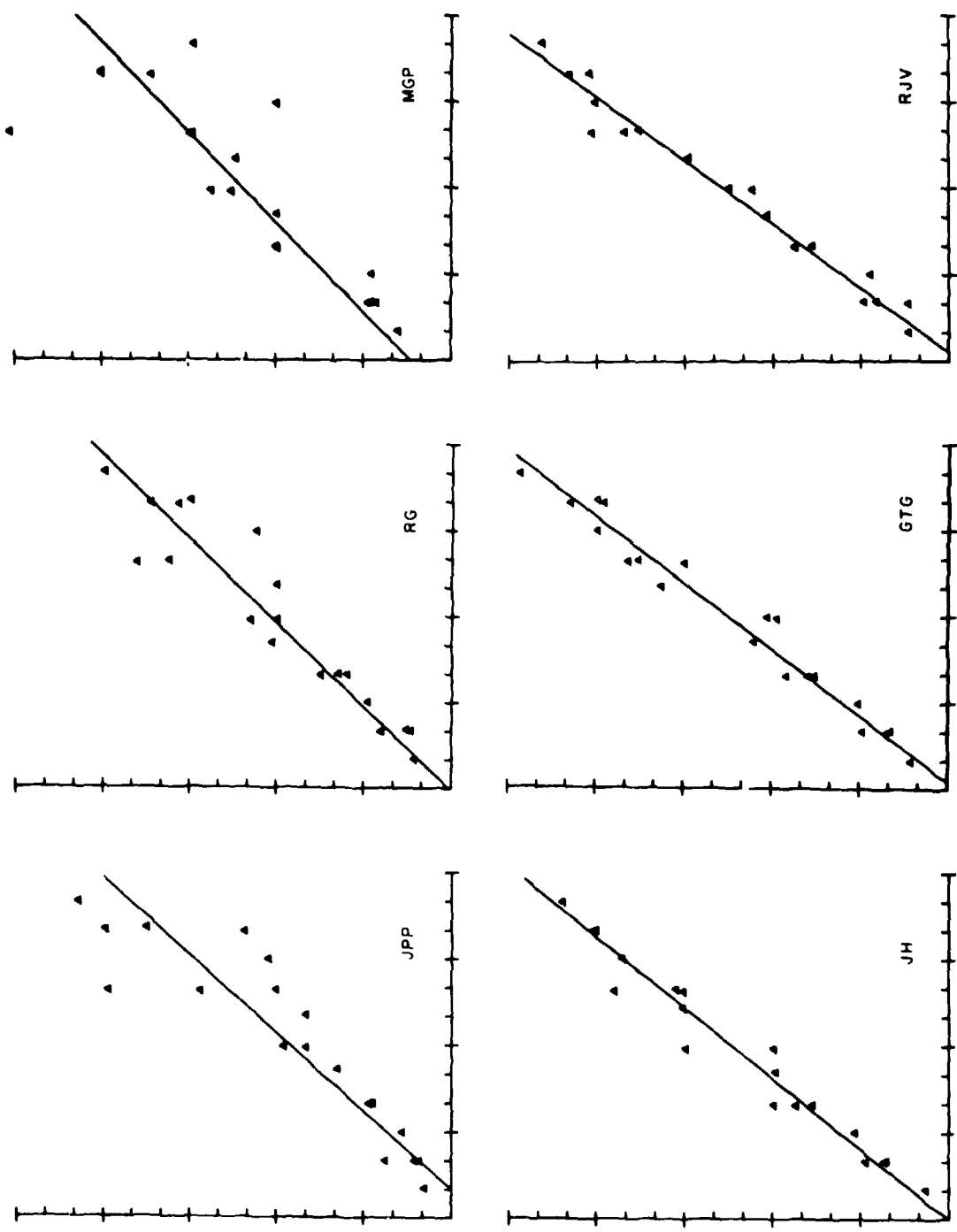


Figure 5

Representative scatter plots and least squares regression lines for subjects in Experiment II. Displacement on abscissa and response on ordinate. Each small scale increment equals 30°.

Table IV
Summary of Means - Experiment II

Source	Low MSQ			High MSQ			t	df	P < *
	\bar{X}	σ	N	\bar{X}	σ	N			
1st Stimulus Series									
Z	1.830	.338	14	1.955	.372	13	<1	25	NS
⊖ deg	46.3	9.5	14	46.2	6.9	13	<1	25	NS
1st and 2d Stimulus Series									
Z	1.735	.417	11	1.914	.388	11	1.153	20	NS
⊖ deg	46.5	6.2	11	47.9	5.1	11	<1	20	NS

*one-tail

For information scores, the analysis revealed a significant change across the stimulus subsets. Mean Z was 1.824 for displacements less than 180 deg and .917 for displacements greater than 180 deg. Thus, more information was accessible in the lower displacement range than in the higher. Differential MSQ did not produce a significant change in Z, nor did the interaction of MSQ and displacement subset.

Table V
Analysis of Variance: Z

Source	SS	df	MS	F	P <
Between Subjects	4.510	21			
MSQ	.228	1	.228	1.07	NS
Error	4.282	20	.214		
Within Subjects	9.650	22			
Stimulus Subset	9.046	1	9.046	301.53	.001
Subset x MSQ	.013	1	.013	<1	NS
Error	.591	20	.030		
TOTAL	14.160	43			

$F_{\max} = 1.479, df = 10, k = 4, p > .05$

The analysis of variance for ⊖ did not reveal any significant main effects or interaction (Table VI).

Table VI
Analysis of Variance: ϵ

Source	SS	df	MS	F	P <
Between Subjects	2370.26	21			
MSQ	35.08	1	35.08	<1	NS
Error	2335.18	20	116.76		
Within Subjects	52220.78	22			
Stimulus Subset	3.11	1	3.11	<1	NS
Subset x MSQ	90.35	1	90.35	<1	NS
Error	52127.32	20	2606.37		
TOTAL	54591.04	43			

$F_{\max} = 1.91, df = 10, k = 4, P > .05$

DISCUSSION

While a relationship between access to or utilization of semicircular canal sensory information and motion disturbance susceptibility was not demonstrated, the direction of the results was not inconsistent with the hypothesis. For MSQ the outcome of both experiments conformed with expectations at about the 15 percent confidence level (one-tail).

A poor test-retest reliability of the information measure was revealed in Experiment II. It is quite likely that alertness fluctuations contributed to this instability. Since the subjects utilized were undergoing "boot camp" type military indoctrination at the time of testing, substantial fluctuations in emotion, alertness, and fatigue would be expected. Many subjects appeared fatigued when released from the dimly lighted capsule after a test session, and some spontaneously indicated boredom with the procedure. Such conditions may account for the poor test-retest reliability of the information measure and for the fact that the test-retest reliability (.445) of the slope-measure, though statistically significant, was substantially lower than that (.94) reported in an earlier study (11). In regard to these differences between experiments in test-retest reliability of slope measures, it appears that three factors may be involved: 1) the subject fatigue and boredom in the present study, not noted in the earlier experiment. This may be attributable to differences in subject pools, but it may be attributable to lesser elapsed time between judgments within test sessions in the earlier study. 2) Differences in elapsed time between test and retest sessions -- one to four days in the present study as opposed to about 20 min in the earlier study. 3) Differences in the distribution of stimulus values between test and retest sessions in the present study, whereas in the earlier study, the same stimulus sequence was used in the test and retest sessions.

The poor reliability of the information measure and the low reliability of the slope measure may well have contributed to the failure to obtain conventional levels of statistical significance with the motion disturbance susceptibility criteria. In addition, error variance in the instruments by which these criteria scores were obtained would also degrade the apparent significance of any real relationship that might exist. It is known, for example, that the BVDT provides a low index, albeit statistically significant, for prediction of subsequent airsickness (10) and that motion sickness questionnaires are also of limited predictive value (15). Moreover, the distributions of individuals tested in the present experiments did not contain extremes in regard to either the criterion measures or the sensation (slope or information) measures. The correlations in the expected directions may therefore not have attained statistical significance because of restricted ranges in both the criterion and sensation scores in the samples tested. For these various reasons, the questionable statistical significance of the correlation in the "expected" directions should not be regarded as evidence that there is not a low significant correlation between the sensation measures and motion disturbance susceptibility.

Of course, the appropriateness of the task and the psychophysical vestibular function which is consequently scrutinized is also open to question. The mechanical properties of the cupula-endolymph system effectively integrate an angular acceleration stimulus with respect to time so that the neural representation of the stimulus is angular velocity (3,6,11,14). The displacement judgment task, however, requires the subject to perform an additional integration. Intersubject variation in the noisiness of this final integration may be quite unrelated to motion disturbance susceptibility. Secondly, the psychophysical data are based on stimulation of only the horizontal semicircular canals, with responses measured in only one direction. This measure cannot be taken as being representative informationally of vestibular sensation as a whole. If conflict among spatial orientation inputs is an important factor in motion sickness, then reduced information from this one channel could reduce the magnitude of one of several sources of conflict, but reduction of information from other unmeasured sources could be equally important. From this point of view, it is reasonable to expect that measures of any one of these components would have only a low, though quite possibly significant, correlation with motion disturbance susceptibility. From another point of view, higher correlations might be expected. Reason (18,19) suggested that some "receptive" individuals are characterized by inability to attenuate sensory inputs and reported relationships between such diverse phenomena as magnitude estimates of visual spiral after-effect illusions, of auditory signals, of vestibular sensations and motion sickness susceptibility. Following this line of reasoning, either the information measure or the slope measure might be expected to correlate significantly with the indices of motion disturbance susceptibility. Such was not the case at least for the restricted range of responders observed in this study.

It can scarcely be doubted that motion disturbance susceptibility depends on a number of factors in addition to its hypothesized dependence on the magnitude of one of the several channels of vestibular information. Reason and Graybiel (20), for example, demonstrated a significant relationship between susceptibility and "adaptivity," or the rate at which adjustment is achieved to sensory rearrangement. For whatever credence may be allowed the "conflict hypothesis" of motion sickness, conflict tolerance

would figure with as much importance as intersubject variation in access to the various vestibular channels of information.

CONCLUSIONS

1. A normally distributed vestibular information score may be obtained from estimates of discrete angular displacements about the z-axis.
2. A positive relationship between the apparent accessibility of semicircular canal information and motion disturbance susceptibility is neither overruled nor conclusively demonstrated by the present experimental probes.
3. Estimates of angular displacement become more variable in higher displacement ranges.
4. Slope of the psychophysical angular displacement function was not observed to be related to motion disturbance susceptibility for ranges of slopes and information scores observed.
5. With the method employed, the slope of the psychophysical displacement function is depressed for the displacement range above a full circle. No change is observed over displacement ranges less than a full circle.
6. The vestibular information index lacks test-retest stability. Test-retest measurements of slope were significantly correlated, though the reliability coefficient was not as high as previously reported. Greater elapsed time between trials within sessions, greater time between test-retest, different test groups, and subject fatigue are suspected reasons for the lower test-retest correlation of slope measures in the present experiment, and some of these factors probably degraded the reliability of the information measure as well.

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