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SOME EFFECTS OF Y-AXIS VIBRATION ON VISUAL ACUITY

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JUNE 1968

AEROSPACE MEDICAL RESEARCH LABORATORIES
AEROSPACE MEDICAL DIVISION
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WRIGHT-PATTERSON AIR FORCE BASE, OHIO

FOREWORD

This research was performed by Cornell Aeronautical Laboratory, Inc., of Cornell University, Buffalo, New York, under Contract AF 33(615)-5279, with the Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio. Mr. Richard W. Shoenberger, Vibration and Impact Branch, Biodynamics and Bionics Division of the Biomedical Laboratory, was the contract monitor. The work was conducted in support of Project 7231, "Biomechanics of Aerospace Operations," Task 723101, "Effects of Vibration and Impact," and was partially funded by National Aeronautics and Space Administration Defense PR No. T-55353. This work was conducted during the period July 1966 to November 1967.

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This technical report has been reviewed and is approved.

WAYNE H. McCANDLESS
Technical Director
Biomedical Laboratory
Aerospace Medical Research Laboratories

ABSTRACT

Four experiments were conducted to measure vernier visual acuity during sinusoidal vibration of the head in the y-axis (side to side). In one half of each experiment peak acceleration amplitude was held constant at 1.0 G_y; in the other half, displacement amplitude was held constant at 0.03 cm. Frequency was the main independent variable. Experiments I and II examined the effects of vibrating the head at frequencies ranging from 13 to 78 Hz. The combined results from these experiments showed that in both the constant acceleration and the constant displacement conditions acuity is a U-shaped function of frequency and has a minimum in the frequency range of 26 to 34 Hz. Experiment III examined the effects of vibrating the target, using procedures similar to those employed in Experiments I and II. Decrements in acuity due to target vibration were smaller than those due to head vibration under comparable conditions. Experiment IV also examined the effects of vibrating the head using procedures similar to those in Experiments I and II except that the orientation of the vernier target with respect to the axis of vibration was changed from perpendicular (i.e., vertical) to parallel, (i.e., horizontal). No differences were found between the acuity scores produced by the vertically and horizontally oriented targets, for either the constant displacement or the constant acceleration condition.

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SECTION I

INTRODUCTION

Oshima (1962) has shown that decrements in visual acuity under vibration are not always due to the relative displacement of the eye and the target. He compared the changes in visual acuity obtained by vibrating only the target to the changes in visual acuity obtained by vibrating only the whole body of the subject. In addition to the static condition, he used vibration frequencies ranging from 2 to 25 hertz (Hz), with displacement amplitudes of .029 to .090 cm. Since no combination of displacement and vibration frequency yielded an acceleration greater than $\pm 1.1\ g_z$, the vibration level was somewhat low. He was able to show that between 2 and 10 Hz, performance was closely related to the relative displacement of eye and target. However, beyond 10 Hz, only vibration of the subject could produce any further decrements in acuity. He concluded that the larger decrements produced by vibrating the subject are due to disturbances of a visual system mechanism, but he does not specify the mechanism

Oshima also measured the displacement of the eyeball under these vibration conditions (although neither his technique nor its accuracy were described). From 2 to 12 Hz the eyeball displacement closely followed the input displacement. From 12 to 25 Hz the eyeball displacement was always less than the input displacement by a constant amount. Since Oshima and Dennis (1965) applied vibration to the whole body, it is probable that for frequencies of 12 Hz and above, the input vibration was attenuated by the body.

The attenuation of the vibration transmitted through the body to the eye resulted in greater relative displacement of the eye and target when the target was vibrated than it did when the subject was vibrated, within the frequency range of 12-25 Hz.; yet only vibrating the subject produced increased decrements in this frequency range. Therefore, this finding lends more support to the argument that vibration of the subject is more detrimental to performance than vibration of the target.

Other investigators (Dennis, 1965; Mozell & White, 1958; Coermann, 1938) have studied the effects of vibration on visual acuity. They all used whole body vibration, but their results are not in complete agreement. Mozell & White found that acuity, measured by numeral reading, declined steadily with increased frequency (for a given displacement) between 10 and 50 Hz. Dennis found a peak deterioration around 14 Hz. Coermann, whose tests covered the broadest frequency range, claims that two frequency ranges, 25-40 and 60-90 Hz produce the greatest decrements in acuity. Individual differences in resonance points at which vision was most disturbed were quite evident.

The experiments reported herein were also conducted to measure visual acuity under vibration over a wide frequency range. In these experiments, however, the input vibrations were applied directly to the head to ensure better transmissions of the input vibration to the eyes. On the basis of Oshima's and Mozell & White's results it was expected that for a constant displacement, acuity should decrease linearly with increases in frequency. On the other hand, for a constant acceleration, acuity should be poorest at the lowest frequency tested and return to normal with increases in frequency. This latter result is expected because to maintain a constant acceleration, multiplication of frequency by a factor of x requires a multiplication of displacement by a factor of $1/x^2$. Thus, displacement must be decreased as frequency is increased to maintain constant acceleration.

SECTION II

METHOD

APPARATUS

Acuity

The acuity task used in these studies was one in which the contrast between target and background was varied, while the angular subtense of the target was held constant. The conventional technique of varying angular subtense of the target while keeping the target-to-background contrast constant, was not used because of instrumentation difficulties, fully described elsewhere (Rubenstein & Taub, 1967). The variable contrast method used here provides somewhat greater flexibility.

The visual targets and their dimensions are shown in Figure 1. The test targets were stepped lines vertically bisecting projected discs. They were projected from the stereo compartment of an automatic slide projector directly onto a white paperboard screen. The targets were oriented perpendicularly to the y-axis so that they would be blurred by the vibration. (Specifications of direction of vibration in this report will refer to standard physiological axes with regard to the man; i.e., x-axis, front to back; y-axis, side to side; z-axis, head to foot.)

The luminance of the discs was varied with a series of neutral density filters (Wratten No. 96), which ranged in density from .1 to 4.0 log units in .1 log unit steps; thus, the contrast between target and background was adjustable. The filters were stored in the slide magazine of the projector in order of decreasing density, so that on successive presentations the luminance of the disc increased in .1 log unit steps. The exposure duration at a particular luminance, and the interval between successive exposures, were each 1 second. These durations were controlled by the projector's own timer.

The viewing screen was illuminated by overhead lighting fixtures which were changed from incandescent to fluorescent between Experiments II and III. The luminance of the projected disc was 66 millilamberts without filtering. The luminance of the screen under the incandescent illumination

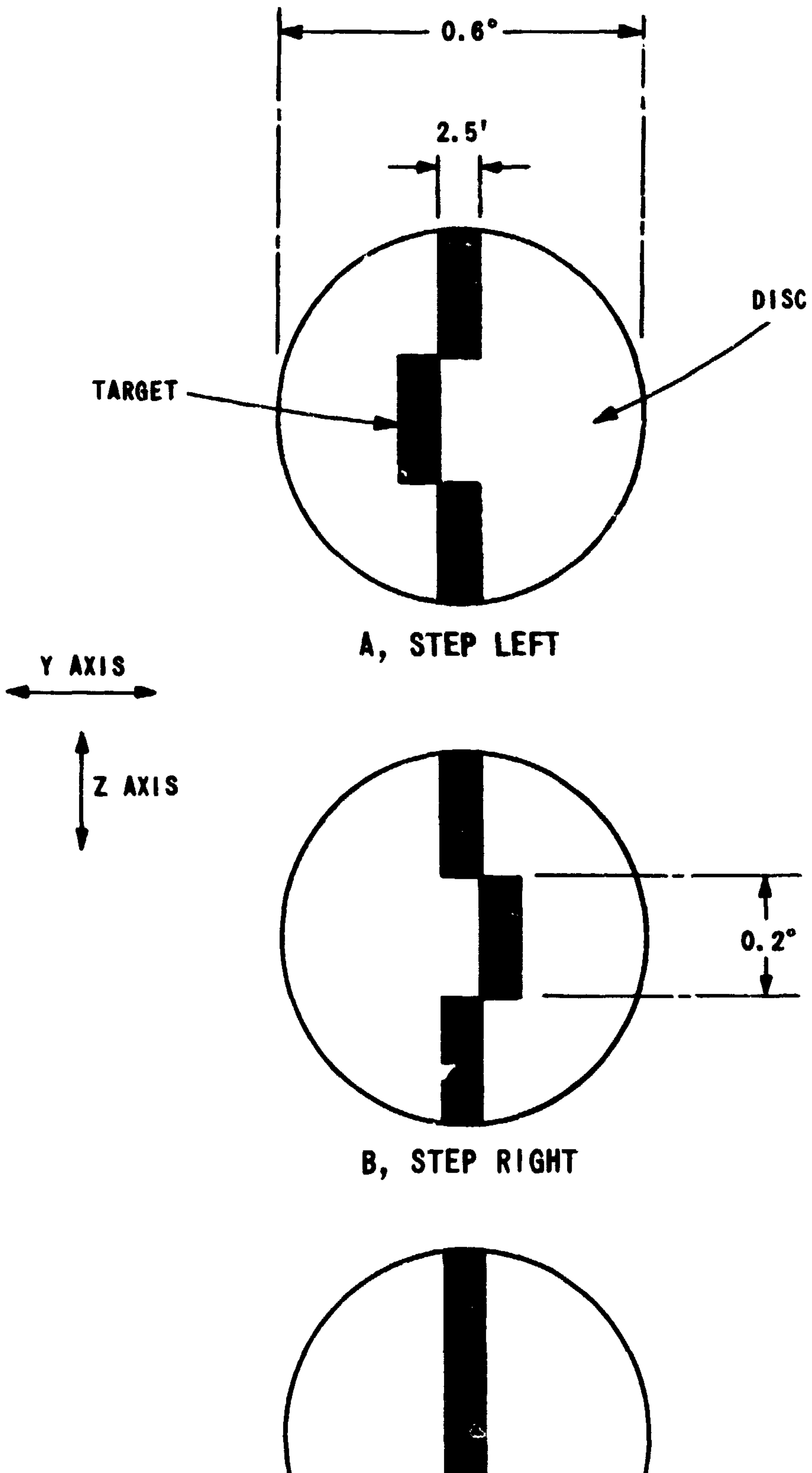

Figure 1 TARGETS AND DISCS FOR ACUITY MEASUREMENT WITH MEASUREMENTS OF THEIR PROJECTED ANGULAR SUBTENSE.

was .2 millilamberts. All luminance measurements were made with a Spectra brightness spot meter, Model U. The effects of the changes in overhead lighting are discussed in Section D.

Vibration Device

Sinusoidal vibration was produced with an electrodynamic shaker, capable of vibrating in either the horizontal or the vertical axis.

Restraint and Support

A photograph of the restraint device used is shown in Figure 2. It is essentially a cone plus a U-shaped frame. This head restraint was designed to assure accurate transmission of vibration from the shaker to the subject's head. A cone was chosen as the lightest, stiffest, axis-symmetric connection between the restraint frame and the shaker.

The restraint was designed to minimize the amount of cross-axis distortion in the x- and z-axes, while still permitting the subject to see beyond the restraint. To prevent the subject's head from rotating around the z-axis, he was fitted with two individually-molded, surgical plaster of Paris casts. These casts were fitted about the ears and supported the temporal and sphenoid areas of the head as well as the zygomatic arch. A steel plate was imbedded in the outside of each cast. The plates allowed the casts to be held in place by an adjustable pair of electromagnets mounted on the inside of the U-frame. The subject's head was fixed into place by applying current to the electromagnets from a d.c. power supply.

The subject was seated on a wooden platform, the height of which was adjustable from 1.25 to 20 cm.above the floor. This adjustment accommodated the differences in the sitting eye-heights of the subjects. His eyes were located 1.8 meters from the screen and he communicated to the experimenter by means of a push-button operated buzzer which he could hear, even during periods of vibration.

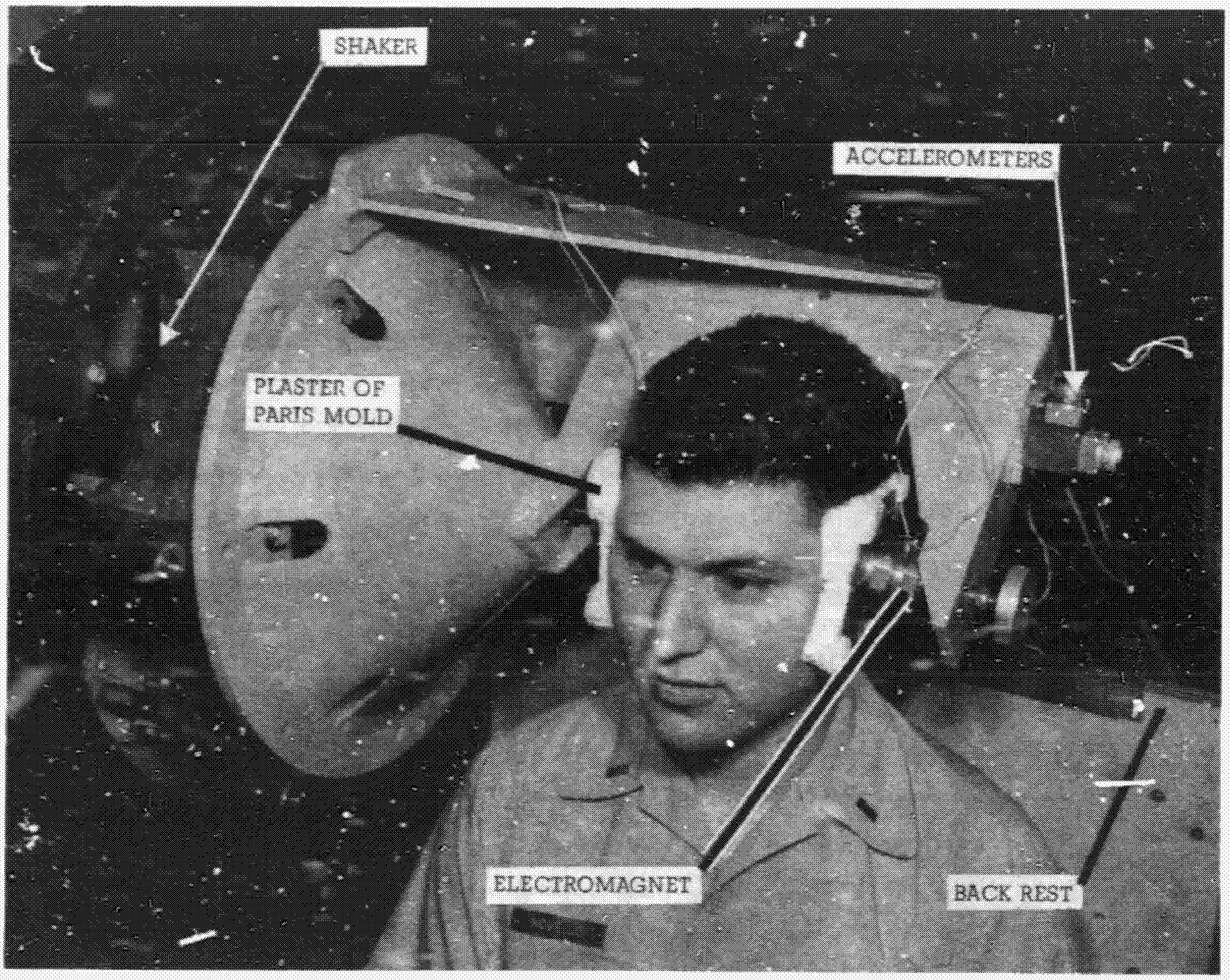

Figure 2 RESTRAINT SYSTEM FOR HEAD VIBRATION

Figure 2 RESTRAINT SYSTEM FOR HEAD VIBRATION

Vibrator Calibration

Three accelerometers were used to measure the vibration output in the x-, y-, and z-axes. The accelerometers were mounted on the part of the restraint frame most distant from the shaker. This is presumably the point at which this restraint is most susceptible to cross-axis vibration, and thus provides the worst case. The outputs from the three accelerometers were observed simultaneously on an oscilloscope.

GENERAL PROCEDURE

Four independent experiments were conducted. Details common to all experiments are given below. Aspects in which they differed are shown in Table 1 and discussed in the sections dealing with each experiment.

Subjects

Subjects were selected from among eight male Air Force personnel between 20 and 40 years of age, each with uncorrected 20/30 vision (near and far) or better.

Acuity Task

The method used for obtaining acuity thresholds was the ascending method of limits. The subject binocularly fixated the dim disc and watched the contrast between the target and disc increase progressively in a series of steps until he detected the direction of the offset (left or right) in the target line (see Figures 1a and 1b). At this point (threshold) the subject responded by squeezing a pushbutton. The experimenter, after recording the luminance at threshold, decreased the target luminance by resetting the filter magazine, and thus was ready for another measurement. Errors of anticipation were minimized by randomly substituting a straight line (Figure 1c) for the target, and by varying the initial luminance of the disc. Thresholds were recorded only for correct identification of the targets shown in Figures 1a and 1b.

Axis of Vibration

Input vibration was always in the y-axis. The amount of input in g_y units was determined from the readings of the y-axis accelerometer.

Session Design

Each test session was divided into two halves. In one half, acceleration was held constant at 1.0 g_y and frequency was varied. In the other half, displacement was held constant at .03 cm. and frequency was varied. In each experiment, half the subjects received constant-acceleration conditions first, and half received constant-displacement conditions first.

Table 1
EXPERIMENTAL CONDITIONS

				VIBRATION INPUT			
EXPERIMENT	VIBRATION MODE	NUMBER OF SUBJECTS	TARGET ORIENTATION	CONSTANT ACCELERATION g_y = 1.0		CONSTANT DISPLACEMENT DA = .03 CM.	
				F	DA	F	g_y
I	HEAD VIBRATION	8	VERTICAL	13	.295	13	.1
				26	.0750	26	.4
				44	.0250	44	1.2
				52	.0175	52	1.6
				58	.0150	58	2.0
II	HEAD VIBRATION	4	VERTICAL	18	.153	18	.2
				22	.103	22	.3
				30	.0550	30	.5
				34	.0425	34	.7
				78	.0075	78	3.6
III	TARGET VIBRATION	8	VERTICAL	13	.295	13	.1
				22	.103	22	.3
				26	.0750	26	.4
				34	.0425	34	.7
				52	.0175	52	1.6
IV	HEAD VIBRATION	4	HORIZONTAL	13	.295	13	.1
				22	.103	22	.3
				26	.0750	26	.4
				34	.0425	34	.7
				52	.0175	52	1.6

F - FREQUENCY OF VIBRATION IN HERTZ
DA - DOUBLE AMPLITUDE IN CENTIMETERS

Within each half session, each frequency-displacement combination occurred five times and followed every other frequency-displacement combination once.

Each session began with 10 minutes of adaptation to the ambient illumination. During this time adjustments in the fit of the restraint were made. Acuity was then measured without any vibration being administered, following which the vibration conditions were administered. A five minute rest was given after every 15 vibration runs. A run was one measurement of acuity at a particular frequency-displacement combination.

SECTION III

EXPERIMENTS

EXPERIMENTS I AND II: EFFECTS OF HEAD VIBRATION ON VISUAL ACUITY

Procedure

Experiment I

The particular vibration frequencies used in this experiment were selected because they yielded the least cross-axis distortion in the z- and x-axes, based on preliminary measurements on two dummy heads and one human subject (less than 30 percent in the z-axis and 50 percent in the x-axis). The mean cross-axis distortion obtained for the eight subjects for each frequency is shown in Table 2. It can be seen that the x-axis distortion was usually greater than that obtained in preliminary tests. For the z-axis, however, only at 13 Hz is the distortion greater than expected from the preliminary tests. The lowest frequency used was 13 Hz because this was the lowest frequency at which 1.0 g_y could be obtained from the shaker. The other frequencies sampled the range in which eyeball resonance might be encountered. Accelerations never exceeded 50 percent of the subjective tolerance levels determined during tolerance evaluations performed prior to the visual acuity experiments. Actual numerical values for frequency, displacement and acceleration, are given in Table 1. Data were collected for all eight subjects in this experiment.

Experiment II

Four subjects who made few errors or false responses in Experiment I (referred to henceforth as accurate subjects), were exposed to some additional vibration frequencies (also shown in Table 1) which would provide additional information about the relationship of acuity to vibrational parameters.

Results

The results of Experiments I and II are plotted in Figure 3. (Data for individual subjects are tabulated in the Appendix, Table A). The connected points refer to the data of four accurate subjects. The other points are data produced by the other four subjects. Note that frequency is plotted on a logarithmic axis.

Table 2

MEAN CROSS-AXIS DISTORTION (PER CENT)* FOR VIBRATION IN THE Y - AXIS; 8 SUBJECTS

FREQUENCY Hz	HEAD VIBRATION		TARGET VIBRATION	
	z- AXIS	x - AXIS	z- AXIS	x - AXIS
13	40	30	50	25
18	10	10		
22	10	10	10	10
26	20	20	25	25
30	20	100		
34	10	70	10	50
44	30	90		
52	10	40	10	50
58	10	100		
78	20	90		

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* PER CENT DISTORTION IS THE ACCELERATION OUTPUT IN THE z OR X-AXIS, DIVIDED BY THE ACCELERATION OUTPUT IN THE y-AXIS

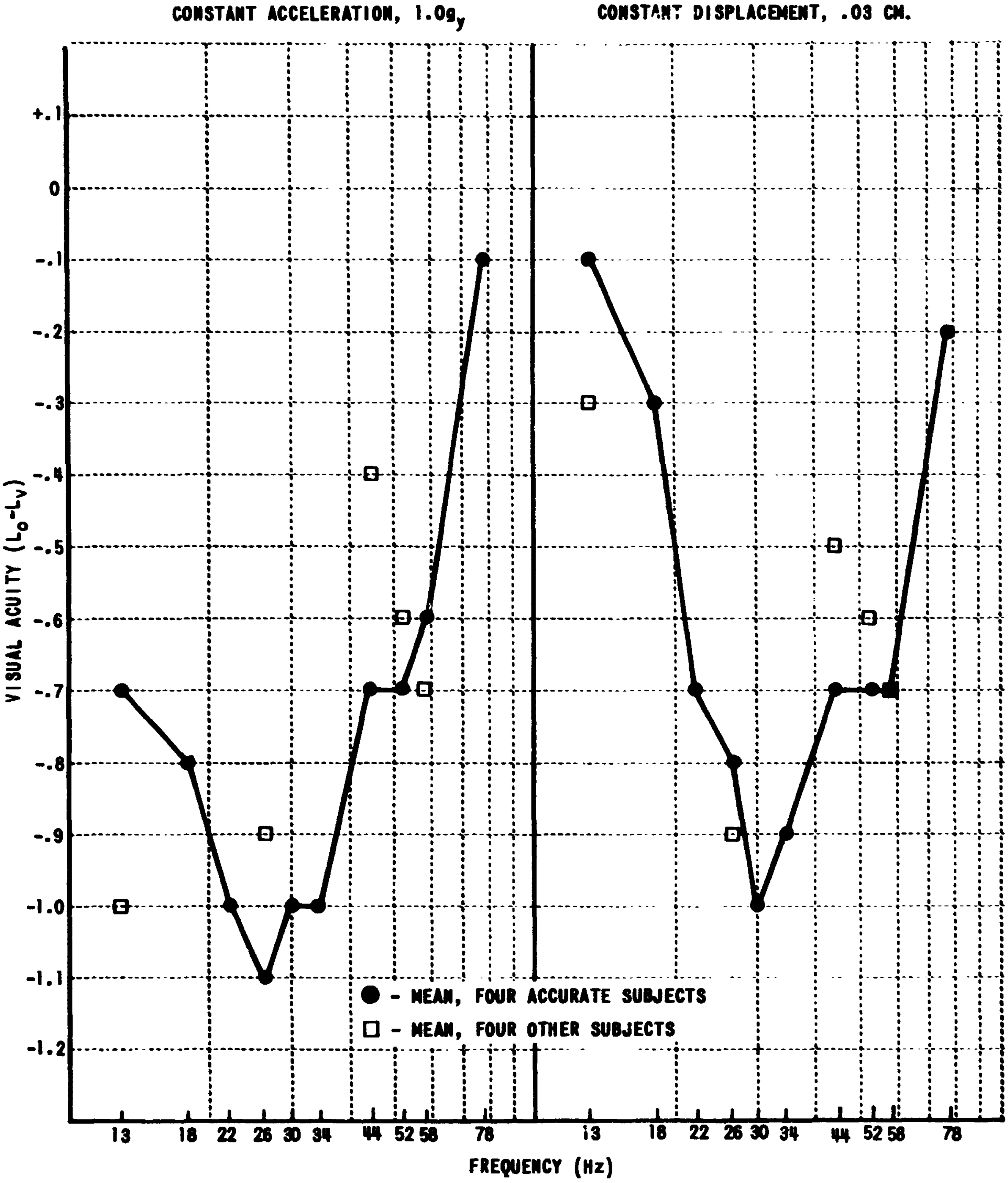

Figure 3 VISUAL ACUITY UNDER HEAD VIBRATION

The dependent variable is the log luminance (L_o) required to correctly identify the target without vibration minus the log luminance (L_v) required to correctly identify the target under the particular vibration condition. A negative difference indicates a decrement due to vibration. The significance of the difference between each vibration condition and the no vibration condition was determined by t-tests of the differences between the subject's mean acuity scores. Significance was at the .05 level, one-tailed test.

The data in Figure 3, for the four accurate subjects, show that for a constant acceleration of 1.0 g_y, acuity was minimal for frequencies between 22 and 34 Hz. As frequency was increased beyond 34 Hz, acuity improved. At 78 Hz, acuity was the same as without vibration. The minimum acuity in the present experiment occurred at a frequency of 26 Hz, where the difference in luminance required between acuity without vibration and acuity with vibration was more than 1 log unit. Thus, more than 10 times as much light was required to detect the target at 26 Hz than was required at zero Hz. Acuity under vibration was significantly poorer at all frequencies tested, except 78 Hz.

For a constant displacement of .03 cm., acuity was maximal at 13 Hz, declined with increased frequency up to 30 Hz and then improved from 30 to 78 Hz, returning almost to the 0 Hz or baseline level. As in the constant acceleration condition, acuity was poorest between 22 and 34 Hz, which produced .3 to .7 g. Acuity under vibration was significantly poorer at all frequencies except 13 and 78 Hz.

The data of the four less-accurate subjects (Figure 3) generally conform to the findings discussed above, although apparent disparities exist at 13 and at 44 Hz; these disparities, however, are not statistically significant. For these subjects, vibration produced significant decrements in acuity for all the vibration conditions under which they were tested.

When the data for all eight subjects are pooled, significant decrements in acuity are found at 13, 26, 44, 52 and 58 Hz for both constant-displacement and constant-acceleration conditions. The reader will recall that significant decrements in acuity were not obtained at 13 Hz under constant-displacement for the four accurate subjects. Note that a constant-displacement of .03 cm. at 13 Hz yields only 0.1 g in acceleration.

Discussion

The results partly conform to the expectations discussed in the Introduction. It was expected that in the constant-acceleration condition, acuity would improve with increasing vibration frequency. That expectation is only partially borne out, for acuity first decreases to a minimum at 26 Hz, but it then increases with increasing frequency. It was also expected that in the constant displacement condition, acuity would decrease with increasing frequency. This turned out to be true only between 13 and 34 Hz. Increases in frequency beyond 34 Hz usually produced increments in acuity, not decrements. It should be recalled that Oshima did not test acuity beyond 25 Hz. The present data agree with his findings, but for frequencies above 25 Hz, there is a discrepancy between the present data and the extrapolation from Oshima's data. Rather than speculate about the reason for these results, it was decided to examine first the relationship of acuity to vibration frequency when the target, rather than the subject, was vibrated.

EXPERIMENT III: EFFECT OF TARGET VIBRATION ON VISUAL ACUITY

Procedure

In Experiment III only the target was vibrated. This was accomplished by mounting a front surface mirror in the head restraint and reflecting the target off the vibrating mirror onto the screen. The subject was seated next to the restraint. The distance from eye to target and visual angle subtended by the target were the same as in Experiments I and II. The insertion of the mirror, rather than a head in the restraint, produced a slightly different cross-axis distortion profile. Frequencies selected for testing were those in which the cross-axis distortion profiles for the vibrating head were similar. These values are shown in Table 2. Data were collected on all eight subjects.

On the basis of Oshima's results, it was expected that acuity decrements produced by vibration of the target would be small. For constant acceleration, it was expected that acuity would be increasingly less affected as frequency increased; for a constant-displacement it was expected that acuity would be slightly reduced, owing to the amount of displacement, but unaffected by frequency. It should be recalled that Oshima observed that acuity fell to an asymptote beyond 12 Hz when displacement was constant.

Other than the changes noted above, the acuity testing procedure was like that used in Experiments I and II.

Results and Discussion

This experiment confirmed the reliability of the acuity measurements. An examination of Table B in the Appendix shows that 47 percent of the time the mean range of thresholds per condition, per subject, was .2 log units or less. The reader will recall that acuity was measurable in only .1 log unit steps.

Note that for the no-vibration runs (0 Hz), all subjects had poorer absolute acuity scores during the target vibration experiment than during the head vibration experiments. This was due to the loss of light introduced by reflecting the disc off the mirror and the increased illumination from the fluorescent lamps used for ambient illumination. The greater illumination from the fluorescent lighting brightened the screen and thus reduced the relative contrast between screen, disc, and target.

Because of the difference in background lighting between Experiments I and II vs. Experiment III, it is not meaningful to compare the absolute acuity scores obtained in these experiments. Instead, the difference scores, (L_o-L_v) obtained under each mode have been compared. The effect of the fluorescent lighting was corrected before Experiment IV, by screening off some of the fluorescent bulbs until each subject yielded approximately the same acuity score under no-vibration conditions that he yielded under these conditions in Experiments I and II.

The effect that vibrating the target has on visual acuity is depicted in Figure 4. The data for the effect of head vibration are included on the same graph for comparative purposes. Data for individual subjects are in Table B of the Appendix. The decrements in acuity due to target vibration are smaller than those due to head vibration. With one exception (13 Hz, with a displacement of .03 cm.) three times as much luminance (.5 log units) or more was required to attain the same acuity with head vibration than with target vibration. A series of *t*-tests of the difference between mean changes in acuity per subject under the two vibration modes showed that all differences in Figure 4 are significant, by a one-tailed test, at the .05 level, except the case at 13 Hz with constant displacement.

With target vibration under constant acceleration conditions a significant decrement in acuity occurs only at 13 Hz. Similarly, under constant displacement conditions acuity is constant and never significantly different from zero vibration. Thus, the expectations from Oshima's data are clearly confirmed.

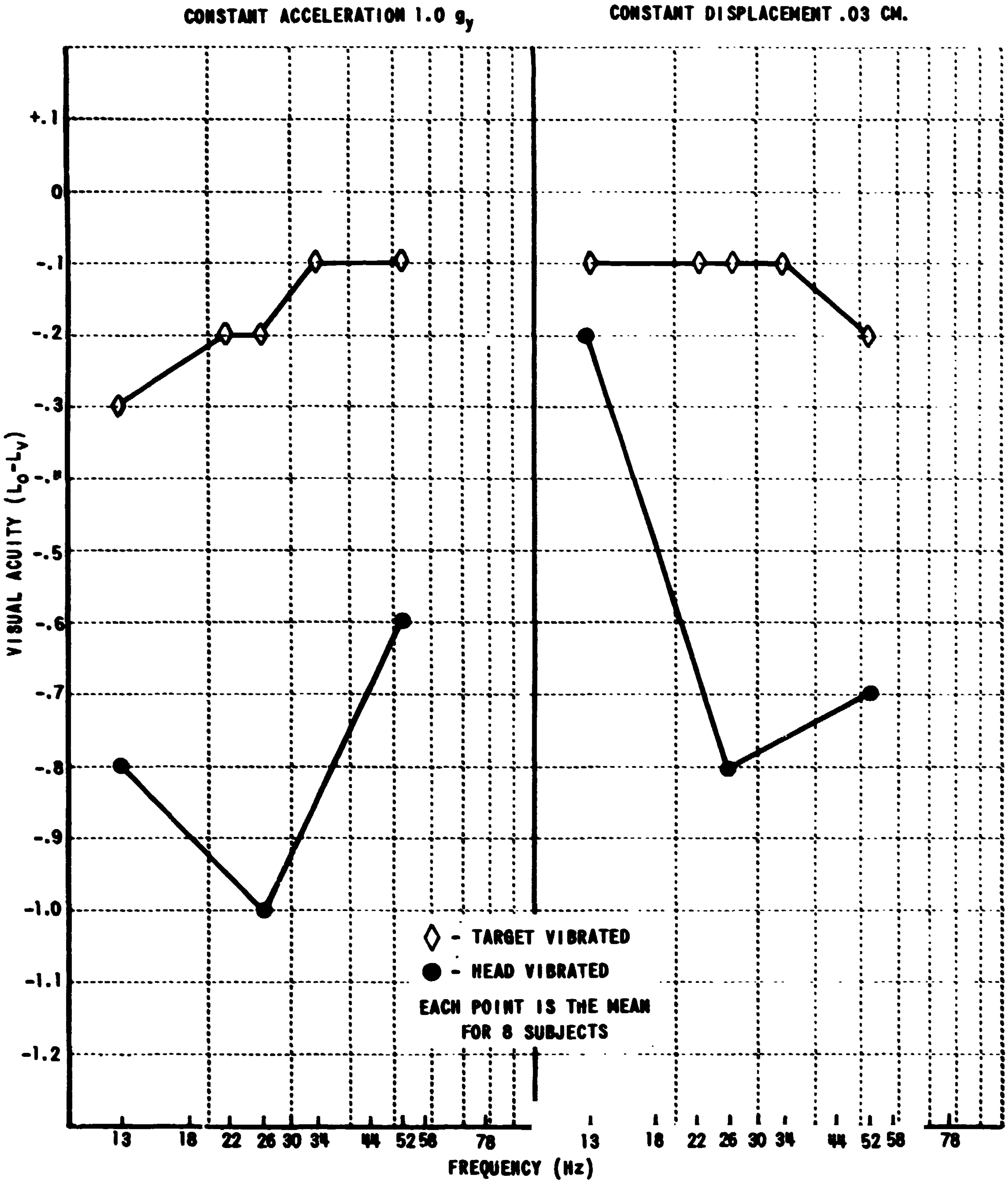

Figure 4 VISUAL ACUITY FOR A VERTICAL TARGET

EXPERIMENT IV: EFFECT OF HEAD VIBRATION ON VISUAL ACUITY: A COMPARISON OF TARGET ORIENTATION

Procedure

It was concluded from Experiments I and II that disturbance of visual functioning occurs at the frequencies around 26 Hz when vibration is applied by the technique used in those studies. It is possible that if the input vibration in the y-axis was the main cause of the decrement in acuity for a target oriented perpendicularly to that axis, then little decrement in acuity should occur for a target oriented parallel (in this case horizontal) to the axis of the vibration. The decrement that occurs should be related to the amount of cross-axis distortion in the axis (z) perpendicular to the new target orientation. Since z-axis distortion was always less than 40 percent, acuity scores should be considerably better for a horizontal orientation of the target. On the other hand, if visual functioning is generally disturbed by head vibration, or if angular head motion results(as has been observed from high speed movie records of previous prototype head restraint systems),the orientation of the target should make less difference in performance than might be expected, and the acuity scores using the vertical and horizontal targets should be similar.

Thus, in Experiment IV the target was oriented horizontally instead of vertically, as in the previous experiments. With the target oriented horizontally, the subject was asked to report the position of the step as up or down, instead of left or right. All other procedures were unchanged from Experiments I and II.

The four subjects who participated in Experiment II were tested. The vibration frequencies were selected so that they would be comparable to those used in the previous experiments: They are recorded in Table 1.

Results and Discussion

The results of Experiment IV are plotted in Figure 5. Comparable data from Experiments I and II are shown on the same graph. The most striking feature of the data is the general similarity between the acuities obtained with the target oriented vertically and the acuities obtained with the target oriented horizontally.

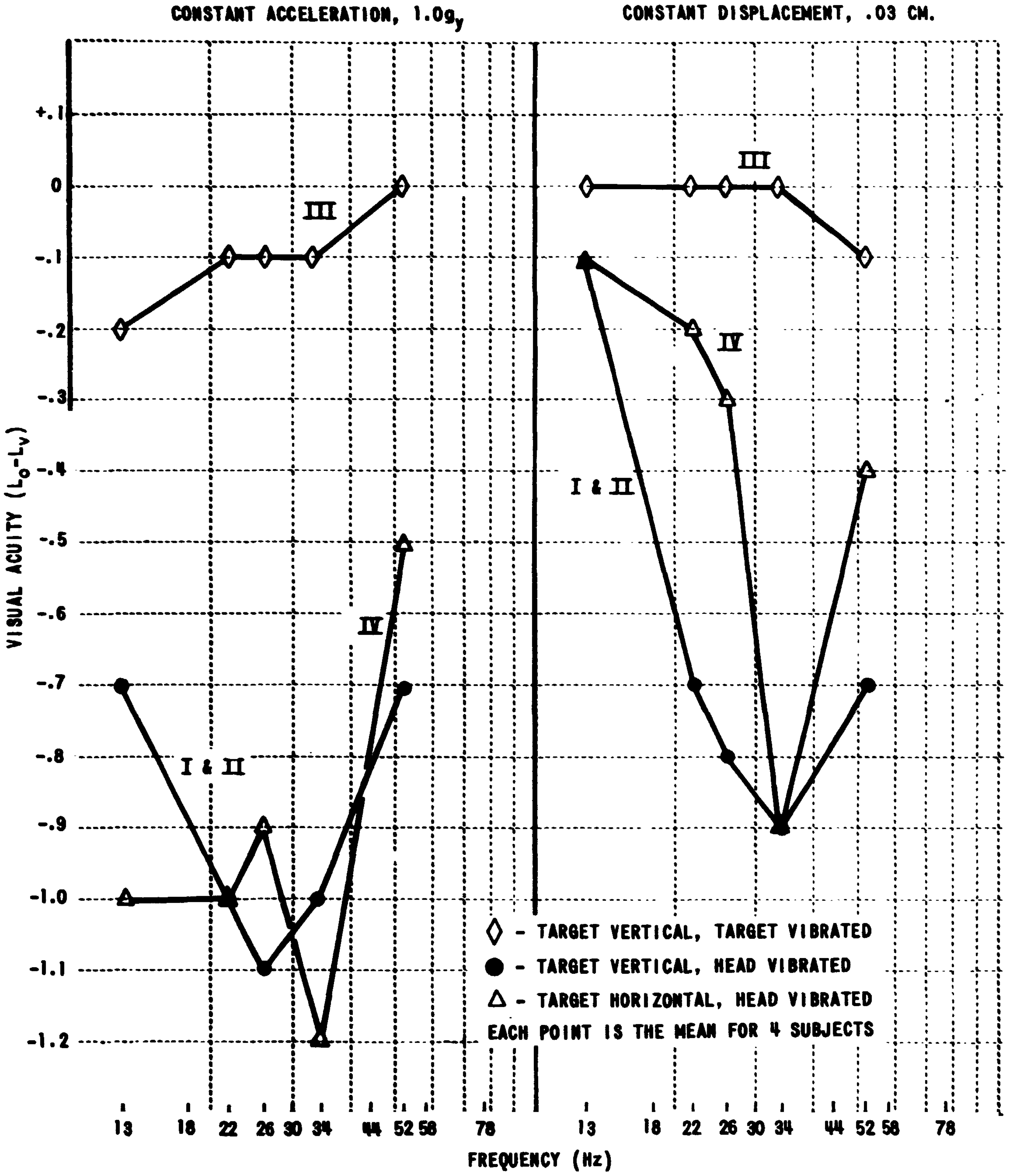

Figure 5 VISUAL ACUITY UNDER VIBRATION, (IDENTIFIED BY EXPERIMENT.)

For the experimental conditions used here, minimum acuity for the horizontal target occurred at 34 Hz in both the constant-displacement and the constant-acceleration conditions. For the vertical target the minima occur at the same frequency range, 26 Hz and 34 Hz (Figure 5), for constant-acceleration and constant-displacement, respectively. Data of individual subjects are in Table C of the Appendix. A series of _t_-tests of the difference between mean change in acuity per subject for the two conditions of target orientation indicated that there were no statistically significant differences in the effects of target orientation under head vibration in the y-axis.

With the target oriented vertically the relative movement (r. m.) of the target (r. m. = input displacement/step size) was 3.7 times greater than the r. m. with the target oriented horizontally, based on a step width of .17 cm. and a step length of .63 cm. (See Figure 1)

SECTION IV

CONCLUSIONS AND SUGGESTIONS FOR FURTHER RESEARCH

The experiments described above indicate that head vibration in the y-axis produces significant decrements (statistically as well as practically) in visual acuity, even at acceleration levels of less than .2 g_y, at frequencies of 13 and 18 Hz. For a constant displacement of .03 cm., the poorest acuity occurs on the average at 25-35 Hz. Acuity returns gradually to normal as frequency is increased above this range. At 78 Hz the same displacement which at 25-35 Hz produced substantial decrements in acuity, is no longer detrimental.

Vibration of the target only over the same frequency range never resulted in significant decrements in acuity, except at 13 Hz, with 1.0 g_y. Decrements with higher intensities, of course, could be expected. The differences in decrement of acuity produced by target vs. head vibration were significant under all conditions, except with 13 Hz at 0.1 g_y. It should be noted, however, that significant decrements in acuity were possible with target vibration when a target subtending a smaller visual angle was used in a small pilot study. But again, this target produced even larger decrements with head vibration.

Under head vibratory conditions, acuity vs. frequency functions obtained with a target whose distinctive feature (a stepped line) was perpendicular to the input axis were quite similar to those scores obtained with an identical target oriented parallel to the vibration axis. This implies a possible general disturbance of the visual system at frequencies of 25-35 Hz. Whether this disturbance is of the eyeball, its musculature, its blood supply, or whether the head underwent independent motions relative to the head restraint, can only be determined by further testing.

The measurement technique used here demonstrates that the effects of vibration on acuity can be counteracted by increasing the contrast between target and background, since in this method the angle subtended by the target is constant and the contrast is increased until the target is correctly identified. How much this can be extrapolated beyond the illumination and target conditions used here is a question for further research.

One final comment is in order. In the experiments reported here, the subjects viewed the acuity targets binocularly. To obtain a better understanding of the effect of vibration on visual functioning it is advisable to first obtain a substantial amount of information on the effects of vibration on monocular viewing. It is unreasonable to assume that the eyes are vibrating in phase until it has actually been demonstrated that they do so. Comparing the results from binocular and monocular experiments should give some clues about the type of visual disturbance that occurs under vibration.

APPENDIX

Note: Tables A, B, and C, are compilations of the acuity scores for individual subjects in Experiments I, II, III, and IV. Decimal points are omitted. They can be restored by dividing by 10. Restored values refer to the density of the neutral filter at the point of detection. To compute luminance (in log-millilamberts) required for detection, subtract filter density from 1.8. The value 1.8 is the luminance of the disc in log millilamberts. $L_o - L_v$ refers to the log-luminance required for detection at zero Hz minus the log luminance required for detection at a particular vibratory condition. Negative values imply decrements in acuity.

Table A
MEAN AND RANGE OF VISUAL ACUITY UNDER HEAD VIBRATION, TARGET VERTICAL; EXPERIMENTS I & II

CONSTANT ACCELERATION, 1.0 g_y

FREQ. Hz		INDIVIDUAL SUBJECTS								ALL SUBJECTS		4 ACCURATE* SUBJECTS		4 OTHER SUBJECTS	
		P	Z	N	W	M	R	B	K	MEAN	L_o-L_V	MEAN	L_o-L_V	MEAN	L_o-L_V
0	MEAN	29	28	27	29	27	28	28	29	28	—	28	—	28	—
	RANGE	3	0	5	6	3	2	2	2	3	—	4	—	2	—
13	MEAN	20	28	14	24	13	22	18	21	20	-8	21	-7	18	-10
	RANGE	3	2	6	3	5	6	1	5	4	—	4	—	4	—
18	MEAN	24	20	15	22							20	-8		
	RANGE	0	3	7	5							4	—		
22	MEAN	24	19	15	15							18	-10		
	RANGE	5	2	2	5							4	—		
26	MEAN	21	16	14	19	13	21	22	21	18	-10	17	-11	19	-9
	RANGE	10	3	3	5	2	2	2	2	4	—	5	—	2	—
30	MEAN	23	19	15	17							18	-10		
	RANGE	3	4	4	2							3	—		
34	MEAN	22	19	13	19							18	-10		
	RANGE	5	3	4	10							6	—		
44	MEAN	22	23	12	25	25	27	24	22	22	-6	21	-7	24	-4
	RANGE	4	3	5	5	6	3	0	4	4	—	4	—	4	—
52	MEAN	25	19	12	28	17	23	24	25	22	-6	21	-7	22	-6
	RANGE	2	4	7	3	3	6	4	2	4	—	4	—	4	—
58	MEAN	25	18	18	25	13	25	23	25	21	-5	22	-6	21	-7
	RANGE	4	3	5	4	4	3	10	2	4	—	4	—	5	—
78	MEAN	29	28	26	25							27	-1		
	RANGE	2	3	2	6							3	—		

* FOUR SUBJECTS WHO MADE FEW ERRORS OR FALSE RESPONSES IN EXPERIMENT I.

Table A
MEAN AND RANGE OF VISUAL ACUITY UNDER HEAD VIBRATION, TARGET VERTICAL (Cont.)

CONSTANT DISPLACEMENT, .03 CM.

FREQ. Hz		INDIVIDUAL SUBJECTS								ALL SUBJECTS		4 ACCURATE* SUBJECTS		4 OTHER SUBJECTS	
		P	Z	N	W	M	R	B	K	MEAN	L_o-L_V	MEAN	L_o-L_V	MEAN	L_o-L_V
0	MEAN	29	28	27	29	27	28	28	29	28	—	28	—	28	—
	RANGE	3	0	5	6	3	2	2	2	3	—	4	—	2	—
13	MEAN	27	28	26	29	22	24	27	25	26	-2	27	-1	25	-3
	RANGE	2	2	5	4	11	5	3	4	5	—	3	—	6	—
18	MEAN	28	24	20	27							25	-3		
	RANGE	4	3	2	2							3	—		
22	MEAN	27	19	13	26							21	-7		
	RANGE	2	4	5	3							4	—		
26	MEAN	23	16	14	28	11	22	25	20	20	-8	20	-8	19	-9
	RANGE	4	5	4	3	7	4	6	3	5	—	4	—	5	—
30	MEAN	23	17	9	24							18	-10		
	RANGE	8	7	5	3							6	—		
34	MEAN	28	19	12	19							19	-9		
	RANGE	6	4	3	6							5	—		
44	MEAN	23	24	14	24	20	26	25	23	22	-6	21	-7	23	-5
	RANGE	4	5	7	6	10	4	4	3	5	—	6	—	5	—
52	MEAN	25	19	14	26	17	25	22	25	21	-7	21	-7	22	-6
	RANGE	2	6	5	3	4	5	2	1	4	—	4	—	3	—
58	MEAN	22	20	17	26	14	26	22	24	21	-7	21	-7	21	-7
	RANGE	9	7	4	6	3	4	4	3	5	—	7	—	4	—
78	MEAN	30	24	25	25							26	-2		
	RANGE	2	8	2	4							4	—		

Table B

MEAN AND RANGE OF VISUAL ACUITY FOR TARGET VIBRATION; EXPERIMENT III

CONSTANT ACCELERATION 1.0 g_y

FREQ. Hz		INDIVIDUAL SUBJECTS								ALL SUBJECTS		4 ACCURATE* SUBJECTS	
		P	Z	N	W	M	R	B	K	MEAN	L_o-L_v	MEAN	L_o-L_v
0	MEAN	25	24	21	23	20	22	23	25	23	—	23	—
	RANGE	2	2	1	3	1	3	3	1	2	—	2	—
13	MEAN	20	23	18	22	21	15	20	21	20	-3	21	-2
	RANGE	3	1	5	3	4	3	1	4	3	—	3	—
22	MEAN	21	25	21	22	21	18	19	21	21	-2	22	-1
	RANGE	2	4	3	1	[illegible]	2	4	2	3	—	3	—
26	MEAN	21	25	21	21	22	20	19	22	21	-2	22	-1
	RANGE	4	0	2	5	3	4	7	1	3	—	3	—
34	MEAN	20	26	21	22	22	19	22	21	22	-1	22	-1
	RANGE	7	2	4	3	1	2	2	1	3	—	4	—
52	MEAN	21	25	21	23	22	19	19	22	22	-1	23	0
	RANGE	5	2	2	4	3	2	7	5	3	—	3	—

CONSTANT DISPLACEMENT .03 CM

FREQ. Hz		INDIVIDUAL SUBJECTS								ALL SUBJECTS		4 ACCURATE* SUBJECTS	
		P	Z	N	W	M	R	B	K	MEAN	L_o-L_v	MEAN	L_o-L_v
0	MEAN	25	24	22	23	21	22	23	25	23	—	23	—
	RANGE	2	2	1	3	1	3	3	1	2	—	2	—
13	MEAN	20	26	22	24	22	18	20	23	22	-1	23	0
	RANGE	1	3	3	3	1	5	1	3	3	—	3	—
22	MEAN	21	26	22	25	22	21	20	22	22	-1	23	0
	RANGE	3	2	1	2	2	0	2	3	2	—	2	—
26	MEAN	21	27	22	23	22	20	20	22	22	-1	23	0
	RANGE	3	3	2	3	1	3	5	4	3	—	3	—
34	MEAN	20	27	[illegible]	23	22	20	20	22	22	-1	23	0
	RANGE	2	2	2	2	1	2	3	5	2	—	2	—
52	MEAN	20	26	21	23	22	19	19	21	21	-2	22	-1
	RANGE	2	1	3	2	4	3	5	3	3	—	2	—

* THE SAME FOUR SUBJECTS WHO MADE FEW ERRORS OR FALSE RESPONSES IN EXPERIMENT I .

Table C

MEAN AND RANGE OF VISUAL ACUITY UNDER HEAD VIBRATION, TARGET HORIZONTAL FOR FOUR ACCURATE SUBJECTS* ; EXPERIMENT IV.

FREQ. Hz		CONSTANT DISPLACEMENT .03 CM.						CONSTANT ACCELERATION 1.0 g_y					
		P	Z	N	W	MEAN	L_o-L_v	P	Z	N	W	MEAN	L_o-L_v
0	MEAN	28	29	28	30	29	—	28	29	27	30	29	—
	RANGE	1	2	3	4	3	—	1	2	3	4	3	—
13	MEAN	27	28	27	30	28	-1	18	19	15	25	19	-10
	RANGE	1	2	1	2	2	—	6	4	6	5	5	—
22	MEAN	26	26	24	31	27	-2	16	19	18	21	19	-10
	RANGE	2	6	4	1	3	—	8	2	3	7	5	—
26	MEAN	26	24	23	30	26	-3	17	22	20	22	20	-9
	RANGE	3	3	5	3	4	—	4	4	2	8	4	—
34	MEAN	21	23	21	16	20	-9	14	22	18	13	17	-12
	RANGE	2	5	5	5	4	—	10	3	5	3	5	—
52	MEAN	24	22	25	27	25	-4	21	24	24	28	24	-5
	RANGE	9	3	3	7	6	—	3	5	6	4	5	—

* THE SAME FOUR SUBJECTS WHO MADE FEW ERRORS OR FALSE RESPONSES IN EXPERIMENT I.

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