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THE EFFECTS OF HIGH INTENSITY NOISE ON HUMAN EQUILIBRIUM

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13. ABSTRACT

Five experiments were conducted on the effects of broadband, high intensity noise on human equilibrium. The ability of subjects to balance on narrow rails was measured during exposure to the noise; and immediately after termination of the noise. Four different noise conditions were used in each experiment: control, 120, 130, and 140 dB (re. 0.0002 dyne/cm^2). In the first experiment subjects wore earmuffs and earplugs; in the second, only earplugs were worn; and in the third experiment, subjects wore earplugs and one earmuff to produce an asymmetrical exposure. At an ambient level of 140 dB, a detrimental effect was obtained in all three experiments. At lower intensities of noise, there were performance decrements only for the asymmetrical exposure. In the remaining two experiments, conducted after termination of the noise, detrimental effects were obtained for asymmetrical auditory exposure but not for equal auditory exposure. The results of these experiments are interpreted as a possible quantitative demonstration of the direct effect of high intensity noise on the vestibular system.

Key Words: Intense Noise, Balance, Rail Test, Stress, Biological Acoustics

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FOREWORD

This paper was given at the Aerospace Medical Association Meeting at Washington, DC, in April 1967. The research was conducted by C. S. Harris and H. E. von Gierke, Biodynamics and Bionics Division, Aerospace Medical Research Laboratory, Aerospace Medical Division, Wright-Patterson Air Force Base, Ohio 45433, under Project 7231, "Biomechanics of Aerospace Operations," and Task 723103, "Biological Acoustics in Aerospace Environments." Acknowledge is made of the assistance provided by Mr. H. C. Sommer and Staff Sergeant W. C. Knobloch of the Biomechanics and Bionics Division. Research covered herein is part of continuing research and was accomplished in 1966.

This technical report has been reviewed and is approved.

CLINTON L. HOLT, Colonel, USAF, MC
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SECTION I

INTRODUCTION

The effects on individuals working in the broadband high-intensity, low-frequency noise typical of jet aircraft have been discussed from many points of view. Davis points out:

> In the military situation the very loud noise which not only stimulates the ear very powerfully but also calls other sense organs such as touch into action, certainly adds to the total stress of what is already a difficult and perhaps dangerous overall situation. This is something that must be heard and felt to be appreciated (ref 2).

Investigators have also emphasized the possible effects of very loud noise on the vestibular system, since numerous reports of imbalance, nausea, and giddiness have been obtained (ref 1,3,9). Asymmetrical noise conditions, bilateral aural stimulation of unequal intensity, seem to produce the most disturbing effects (ref 1). Dickson and Chadwick conducted interviews with individuals working in the vicinity of operating jet engines to obtain their subjective experiences when standing in certain critical noise locations. They found that "descriptions varied and were vague," but were best described by "one of the engineers who said he experienced a momentary sensation of imbalance accompanied by a lack of power to think (ref 3)." Most studies up to the present time have been largely exploratory in nature and have used subjective measures with a very small sample of experimental subjects. It seems particularly important to use objective measures in future studies since a considerable decrement might occur in the ability of an individual to maintain his balance and orientation before he becomes consciously aware of dizziness, nausea, incoordination, etc. Particularly valuable would be a measure of nystagmus which would seem to give a direct indication of the involvement of the vestibular system. The major obstacle to this approach, since subjects with normal hearing are used, is the attainment of nystagmus at noise levels that do not produce a hazard to the hearing of the subjects. Our efforts in this direction have been discouraging. Numerous attempts have been made by using random noise, pure tones, and intermittent tones at levels and durations which were considered safe for our experimental subjects, and no nystagmus has been obtained. Although this program of research where direct measures of vestibular function are sought will be continued, we decided, in addition, to employ another more indirect measure since the failure to obtain nystagmus as a result of noise exposure is a distinct possibility. We decided to use a rail task battery developed by Graybiel and Fregley for measuring human equilibrium. These investigators (ref 5) have presented some evidence that this battery shows sensitivity to some variables that are primarily vestibular in nature. They have shown that individuals with little or no vestibular sensitivity performed on the rails at a level comparable with the lowest 1% of the labyrinthine normal population. Rail performance of labyrinthine defectives was unaffected by the consumption of alcohol while that of normal subjects was affected. They have also related performance on the rail test to canal sickness susceptibility, to threshold caloric responses, and to response to severe conditions. It would be naive to consider the rail test as being solely a vestibular measure since the vestibular system is so inextricably related to the visual system, the kinesthetic system, and the tactual system. Nevertheless, the evidence is convincing that the vestibular system at least plays a role in producing efficient performance on this task. Regardless of the causal relationship between rail test and vestibular function, performance on this task during exposure to intense noise is of practical interest.

In a previous study a decrement was obtained in the length of time subjects could balance on the rails in noise which was statistically significant (ref 7). However, the decrement was quite small, was obtained only when there was a different level of noise at each ear and by using a very difficult task. There was also the possibility that the decrement obtained in that study could have been due to either the intensity of the stimulus or due to the asymmetric stimulus presentation to the ears. Therefore, in the present series of experiments, we investigated primarily the variables of noise intensity and noise asymmetry with appropriate controls included to determine the relative importance of each of these variables. This was accomplished by using the same wideband noise with ambient intensity levels of quiet (control, about 70 dB), 120 dB, 130 dB, and 140 dB (re. 0.0002 dyne/cm^2) in all experiments, and by varying the amount and type of ear protection given the subjects. In addition to the rail test battery, a subjective rating scale was used to give us a standardized procedure for obtaining subjective information for comparison with the results of the rail measure.

SECTION II

METHOD

SUBJECTS

A total of 52 male university students served as subjects in the five experiments. They were paid volunteers and all were in their late teens or early twenties. When a subject first came to the laboratory he was given a pure-tone audiogram. In addition to normal hearing at audiometric test frequencies from 500 cps to 6,000 cps, subjects evidenced approximately equal sensitivity in both ears for each test frequency. Individuals with a threshold of hearing difference between the right and left ear of greater than 5 dB were not used as subjects in the experiment.

NOISE CHAMBER

The study was conducted in a large reverberation chamber, approximately 14.8 x 17.3 feet, which was vacant except for the experimenter, subject, rails, and the sound source. The location of the rails, experimenter, and sound source in the noise chamber have been described in a previous report (ref 7). The effective intensity of the noise in the ear canals of the subjects is shown in table 1 for each intensity of noise and each type of ear protection used in the experiments. These values were obtained by subtracting the average real ear attenuation at threshold of the ear protectors from the ambient noise levels in each band.

EXPERIMENTAL MEASURES

Rail Task - The instructions given the subjects and the detailed procedures for measuring performance on these rails were patterned after those used by Graybiel and Fregley (ref 5). Four fiber glass covered wooden rails were used to measure equilibrium. On two of these rails, 2 1/4 inch wide and 1 3/4 inch wide before covering with approximately 1/16 inch fiber glass, the subjects were required to stand with their eyes closed. On the other two rails, 1 1/4 inch wide and 3/4 inch wide plus their 1/16 inch fiber glass cover, the subjects were required to stand with their eyes open. The score for both the standing eyes closed task and the standing eyes open task was the time, to the nearest second, from when the subject assumed the correct position on the rail until he violated his position or fell off the rail. The maximum score for each trail was 60 seconds. If the subject was still balanced on the rail at the end of this time, the trail was discontinued. Subjects were given five trials on each rail in experiments I, IV, and V. The scores used for analysis were an eyes open measure and an eyes closed measure. The maximum possible scores for each measure was 600 seconds, that is, five trials x two rails x the maximum possible score per trial of 60 seconds.* In experiments II and III only three trials were administered on each rail because of the time limit imposed by the type of ear protection worn by the subjects in these experiments (ref 11). The same measures were obtained as in the other three experiments with a maximum possible score of 360 seconds for each measure; three trials x two rails x 60 seconds.

TABLE 1

Ambient Wideband Noise Spectra and Calculated Noise Levels in Ear Canal after Reduction of Noise by Ear Protectors

		Octave Band Pass Frequency						
Condition	Overall	75 150	150 300	300 600	600 1200	1200 2400	2400 4800	4800 9600
120 Ambient	120	108	117	114	109	106	100	87
Earmuffs and plugs	81	76	78	74	68	63	46	42
Earplugs	95	83	93	88	81	70	64	48
130 Ambient	130	117	127	123	116	111	104	92
Earmuffs and plugs	91	85	88	83	75	68	50	47
Earplugs	105	92	103	97	88	75	68	53
140 Ambient	140	129	137	133	126	119	111	100
Earmuffs and plugs	101	97	98	93	85	76	57	55
Earplugs	115	104	113	107	98	83	75	61

Table values in dB (re. 0.0002 dyne/cm^2)

* Graybiel and Fregley recommend that the scores for the best three out of five trials be used as the measure. However, in preliminary observations, we found that using all five trials increased the sensitivity of the measure to the experimental variable. The increased sensitivity was presumably due to an increase in the reliability of the measure brought about by the inclusion of the two additional trials.

SUBJECTIVE MEASURES

Attempts to obtain subjective rating of noise has proved disappointing in many previous experiments. The "annoyingness" of noise often disappears when it is brought into the Laboratory. Nevertheless, considering the potential importance of such a subjective rating scale, particularly if it relates to more objective measures, we decided to include a subjective measure. This measure was a Semantic Differential developed by Osgood, et al. (ref 8) for measuring meaning. It was administered after all experiments, except for Experiment I. The subjects were asked to rate "My Experience in the Noise Chamber" on 16 scales of "bipolar" adjectives. Four bipolar adjectives were chosen to assess each of four factors. The adjective scales of good-bad, nice-awful, valuable-worthless, and pleasant-unpleasant were used to assess an Evaluative factor (E). The scales of heavy-light, large-small, thick-thin, and strong-weak were used to assess a Potency factor (P). Sharp-dull, angular-rounded, active-passive, and fast-slow were used to assess an Activity factor (A). The scales of awkward-graceful, private-public, excitable-calm, and constricted-spacious were chosen to sample what Osgood, et al. (8), suggest may represent "some sort of anxiety factors" (Anx). Standard instructions were given for the Semantic Differential. The scoring was on a scale from 1 to 7. Four different scores were obtained for each subject corresponding to the mean of the four scales for each factor. These scores were then combined, and the mean for each subject determined. The E score was subtracted from seven to bring it into agreement with the P, A, and Anx scores. For example, if an individual had a mean E score of 5, his score used in determining the combined mean was 2 or 7 - 5. The formula for determining the score used in the analysis for each subject was

$$\frac{(7 - \text{Emean}) = \text{Pmean} + \text{Amean} + \text{Anx mean}}{4}$$

This measure was used after preliminary analysis revealed the four measures to be significantly correlated, and a more reliable measure could be obtained by using one score.

Our hypotheses were that the subjects would like (E factor) his experience in the noise chamber less, would feel it to be more powerful (P factor), more active (A factor) and would experience more anxiety (Anx factor) as the intensity of the noise was increased. In addition, we felt that the unbalanced noise conditions would be rated higher than the balanced noise conditions, that is Experiment III would be rated higher than Experiment II and Experiment V would be rated higher than Experiment IV.

EXPERIMENTAL DESIGN

In the first three experiments, the subject's performance was measured during exposure to the noise, and in the remaining two experiments, the subject's performance on the rail task was measured immediately on termination of the noise.* In all experiments, each subject received all four experimental conditions of noise intensities: A (control) (70 dB), B (120 dB), C (130 dB), and D (140 dB, re 0.0002 dyne/cm^2). The four experimental conditions were presented in four different orders, ABCD, BDAC, CADB, and DCBA. Two subjects were assigned to each of the orders of presentation in the experiments with eight subjects, three in the experiment with 12 subjects, and four in the experiment with 16 subjects. A summary of the experimental conditions is given in Table 2.

Table 2

SUMMARY TABLE OF EXPERIMENTAL CONDITIONS

Exp.	No. of Ss	Approx. Time of Exposure	Ear Protection	Task During Noise	After Noise	
I	8	13 min	Earplugs & Muffs	Rail		
II	12	8 min	Earplugs	Rail	SD	
III	16	8 min	Earplugs & 1 Muff	Rail	SD	
IV	8	10 min	Earplugs	Discrimination Task	Rail	SD
V	8	10 min	Earplugs & 1 Muff	Discrimination Task	Rail	SD

SD - Semantic Differential

* A discrimination test patterned after one used by Chiles (ref 4) was presented during exposure to the noise, and the results will be reported in a subsequent paper.

SECTION III

RESULTS

The same analysis of variance technique was applied to all data obtained in the experiments, since the same experimental design was used for all experiments. The technique was one described by Lindquist (ref 6) for use with a Type II experimental design. Table 3 presents a summary of the results of the analyses of variance performed on the eyes closed data obtained in all five experiments. It can be seen from this table that a significant effect for noise conditions was not obtained in any of the experiments. However, because of the large differences in means and because the probability level for the noise condition effect in three experiments was less than the 20%, and in another less than the 10% level of confidence, the mean differences were examined by use of a *t* test (see table 4). Significant mean differences were obtained in the four experiments in which the probability level was $p < 0.20$, while no significant mean differences were obtained in Experiment II whose noise condition effect did not reach the 20% level. Considering the significant mean differences obtained in these experiments, it would seem that the 140 dB noise condition had a detrimental effect on equilibrium in all experiments, with the exception of Experiment II.

TABLE 3

RESULTS OF VARIANCE ANALYSES FOR EYES CLOSED MEASURE

	Source of Variance			
Analysis	Groups (Order)	Noise Conditions (NC)	Sessions (S)	NC x S
Experiment I Earplugs & Muffs	n.s.	n.s. ($p < 0.20$)	n.s.	n.s.
Experiment II Earplugs	n.s.	n.s.	n.s.	n.s.
Experiment III Earplugs & 1 Muff	n.s.	n.s. ($p < 0.20$)	n.s.	n.s.
Aftereffects				
Experiment IV Earplugs	n.s.	n.s. ($p < 0.10$)	n.s.	n.s.
Experiment V Earplugs & 1 Muff	$p < 0.05$	n.s. ($p < 0.20$)	$p < 0.01$	n.s.

TABLE 4

MEANS AND MEAN DIFFERENCES FOR NOISE CONDITIONS FOR EYES CLOSED MEASURE

Noise Conditions	Mean	A	B	C	D
<u>During Exposure</u>					
Exp. I					
Earplugs & Muffs					
A (Control)	265.88		12.24	10.71	45.63*
B (120 dB)	278.12			23.00	57.87**
C (130 dB)	255.12				34.87
D (140 dB)	220.25				
Exp. II					
A (Control)	90.67		19.84	7.50	19.59
B (120 dB)	70.83			12.34	.25
C (130 dB)	83.17				12.09
D (140 dB)	71.08				
Exp. III					
Earplugs & 1 Muff					
A (Control)	74.62		9.07	5.38	17.87
B (120 dB)	83.62			3.69	26.94**
C (130 dB)	80.00				23.25**
D (140 dB)	56.75				
<u>Aftereffects</u>					
Exp. IV					
Earplugs					
A (Control)	194.50		27.75	11.75	55.50**
B (120 dB)	166.75			16.00	27.75
C (130 dB)	182.75				43.75**
D (140 dB)	139.00				
Exp. V					
A (Control)	130.38		5.12	12.63	22.00*
B (120 dB)	135.50			17.75	27.12
C (130 dB)	117.75				9.37
D (140 dB)	108.38				

*$p < 0.10$

**$p < 0.05$

However, there is little evidence that the asymmetrical exposure had more adverse effects than the symmetrical exposure, that is, decrements were obtained in two symmetrical exposure experiments, and two asymmetrical exposure experiments.

In contrast to the results obtained with the eyes closed measure, a significant effect in the analyses of variance for noise conditions was obtained in four of the five experiments using the eyes open measure (see table 5). Experiment IV, in which the subjects wore earplugs and performed on the rails after termination of the noise, was the only experiment in which a significant effect was not obtained for noise conditions. In the first three experiments in which the data was obtained from the subjects during exposure to the noise, it was found that the probability level associated with the significant noise conditions effect in Experiment I (earplugs and muffs) was $p < 0.05$, while in Experiment II (earplugs) the probability level was $p < 0.025$, and in Experiment III (earplugs and 1 muff) where the subjects received a different intensity of noise at each ear, the probability level was $p < 0.001$. In the last two experiments in which the data for the eyes open measure were obtained after termination of the noise, a significant effect for noise conditions ($p < 0.025$) was obtained for Experiment V (earplugs and 1 muff), while as mentioned above no significant effect was obtained for Experiment IV (earplugs). Table 6 presents the mean performance scores for the eyes open measure for noise conditions for all experiments, and the mean differences for the four experiments in which a significant effect was obtained for noise conditions. The differences between means was evaluated by use of a *t* test and the significant differences are noted in the table.

TABLE 5

RESULTS OF VARIANCE ANALYSES FOR EYES OPEN MEASURE

Analysis	Source of Variance: Groups (Order)	Noise Conditions	Sessions	NC x S
Experiment				
During Exposure				
I Earplugs & Muffs	n.s.	$p < 0.05$	n.s.	n.s.
II Earplugs	n.s.	$p < 0.025$	n.s.	n.s.
III Earplugs & 1 Muff	n.s.	$p < 0.001$	$p < 0.005$	n.s.
Aftereffects				
IV Earplugs	n.s.	n.s.	n.s.	n.s.
V Earplugs & 1 Muff	n.s.	$p < 0.025$	$p < 0.005$	n.s.

TABLE 6

MEANS AND MEAN DIFFERENCES FOR NOISE CONDITIONS FOR EYES OPEN MEASURE

Noise Conditions	Mean	A	B	C	D
During Exposure					
Experiment I					
Earplugs & Muffs					
A (Control)	264.62		31.63	17.50	48.50^{*}
B (120 dB)	296.25			14.13	79.13^{***}
C (130 dB)	282.12				66.00^{**}
D (140 dB)	216.12				
Experiment II					
Earplugs					
A (Control)	144.08		15.17	11.08	33.58^{**}
B (120 dB)	159.25			4.09	48.75^{***}
C (130 dB)	155.16				44.66^{***}
D (140 dB)	110.50				
Experiment III					
Earplugs & 1 Muff					
A (Control)	152.44		22.00^{**}	13.19	50.19^{***}
B (120 dB)	130.44			8.81	28.19^{***}
C (130 dB)	139.25				37.00^{***}
D (140 dB)	102.25				
Aftereffects					
Experiment V					
Earplugs & 1 Muff					
A (Control)	193.62		15.00	24.62^{*}	26.12^{*}
B (120 dB)	208.62			39.62	41.12^{**}
C (130 dB)	169.00				1.50
D (140 dB)	167.50				

Means for Experiment with Nonsignificant effect

Experiment IV

	Control	120 dB	130 dB	140 dB
Earplugs	168.00	176.75	215.62	184.25

$^{*}p < 0.10$

$^{**}p < 0.05$

$^{***}p < 0.01$

Figure 1 presents the results of the first three experiments in terms of the percent change of each of the noise conditions from their respective control condition. Figure 2 presents curves for Experiments II and III, in which noise conditions are plotted against the mean time in seconds that the subjects were able to balance on the rails. In both Experiments I and II, improvement over the control condition was obtained at 120 dB and 130 dB, although these differences were not statistically significant. At the 140 dB level a decrement was obtained in both experiments with the greater decrement obtained in Experiment II where the subjects wore only earplugs for protection. In Experiment III where the subjects had a different level of noise at each ear while performing the task, all noise conditions resulted in a decrement in performance over the control condition. The mean differences obtained at 120 dB, and 140 dB were statistically significant, $p < 0.05$ and $p < 0.01$, respectively. The decrement at 130 dB did not reach statistical significance ($p < 0.20$).

Figure 3 presents the percent change in mean performance of the noise conditions from their respective control groups for Experiments IV and V. Figure 4 presents the curves based directly on the experimental measure (time). In Experiment IV in which subjects wore earplugs during exposure to the noise and performed on the rails after termination of the noise, performance after the noise conditions was in every case superior to performance during the control session. There was a 28% improvement in performance at the 130 dB noise level, however, in spite of this large improvement in performance no significant effect was obtained for noise conditions in the Analysis of Variance. In contrast, in Experiment V (earplugs and 1 muff) significant decrements in performance were obtained at 130 dB and 140 dB. The difference between experiments IV and V at these two levels is striking; 28% improvement versus 13% decrement and 10% improvement versus 14% decrement for 130 dB and 140 dB, respectively. The difference between groups on the control measure was also quite large. However, the trend is clear-cut, one of improvement over the control for Experiment IV, and of decrement relative to the control in Experiment V. These differences should be viewed with caution since a significant effect was not obtained for noise conditions in the analysis of variance of the data for Experiment IV.

Subjective measurement using the Semantic Differential was not begun until after Experiment I was completed. Table 7 presents the results of the Analyses of Variance performed for Experiments II, III, IV, and V. Significant effects for noise conditions were obtained in Experiments II, III, and V. Table 8 presents the means and mean differences for the three experiments which yielded significant noise condition effects in their analyses of variance, and the means for Experiment IV in which a significant effect was not obtained. Figure 5 presents curves for the subjective measure plotted against noise conditions for the experiments. Scores in all experiments increased systematically with noise levels, and with the exception of the control period, the asymmetrical noise conditions (Experiments III & V) were rated higher than the symmetrical noise conditions (Experiment II & IV).

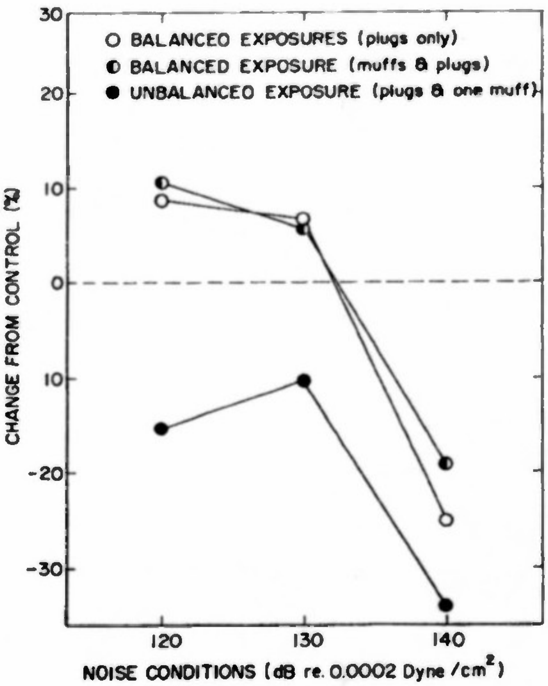

Figure 1. Percent change from control group means for means obtained at each noise level for eyes open measure in first three experiments.

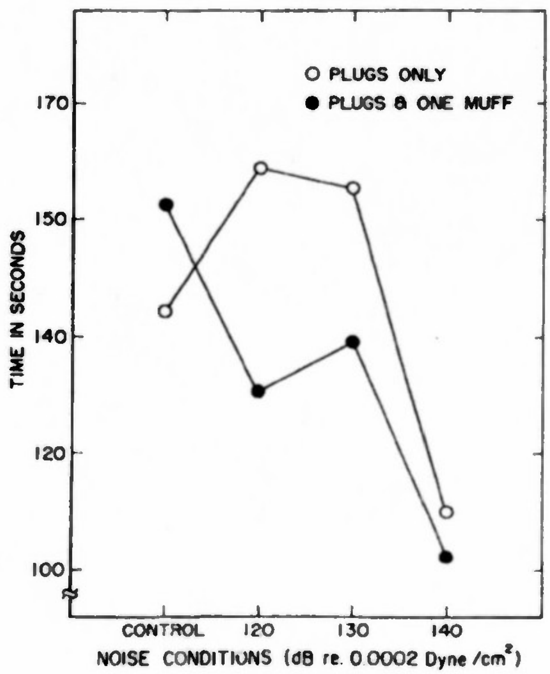

Figure 2. Means for eyes open measure for experiments II and III.

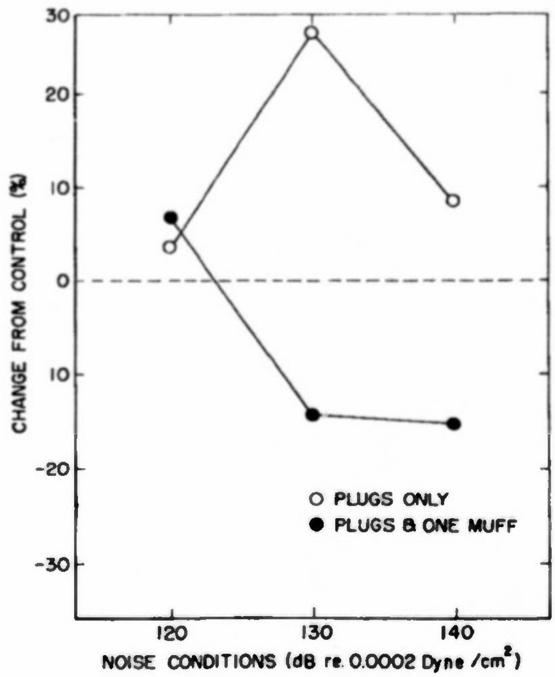

Figure 3. Percent change from control group means for means obtained at each noise level for eyes open measure in experiments IV and V.

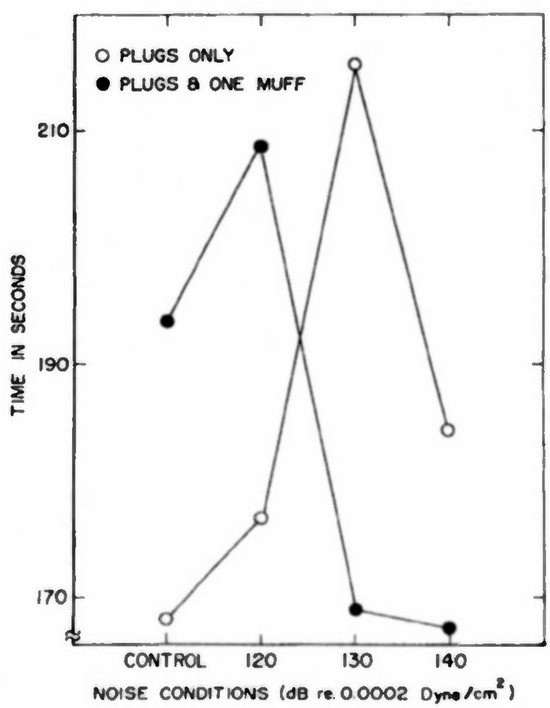

Figure 4. Means for eyes open measure for experiments IV and V.

TABLE 7

RESULTS OF VARIANCE ANALYSIS FOR SUBJECTIVE MEASURE

Analysis	Source of Variance: Groups (Order)	Noise Conditions	Sessions	NC x S
Experiment II Earplugs	n.s.	$p < 0.005$	n.s.	$p < 0.05$
Experiment III Earplugs & 1 Muff	$p < 0.025$	$p < 0.001$	n.s.	n.s.
During Mental Task				
Experiment IV Earplugs	n.s.	n.s.	n.s.	n.s.
Experiment V Earplugs & 1 Muff	n.s.	$p < 0.005$	n.s.	n.s.

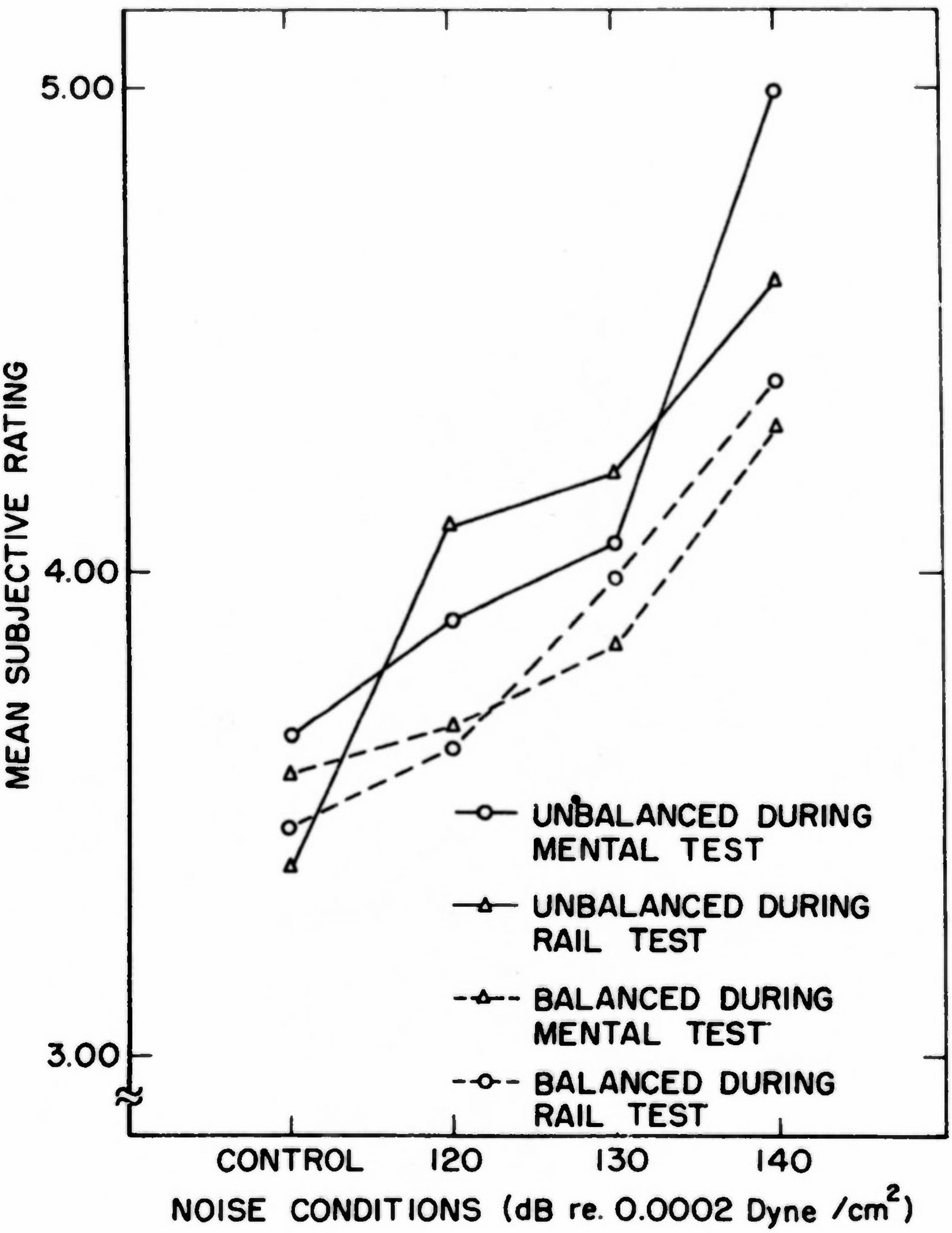

Figure 5. Mean subjective ratings for each noise level in experiments II, III, IV, and V.

TABLE 8

MEANS AND MEAN DIFFERENCES FOR NOISE CONDITIONS FOR SUBJECTIVE MEASURES

During Rail Task

Experiment II				
Earplugs				
A (Control)	3.46	.17	.52***	.95***
B (120 dB)	3.63		.35*	.77***
C (130 dB)	3.98			.42**
D (140 dB)	4.40			
Experiment III				
Earplugs & 1 Muff				
A (Control)	3.38	.72***	.83***	1.23***
B (120 dB)	4.10		.11	.51**
C (130 dB)	4.21			.40**
D (140 dB)	4.61			

During Mental Task

Experiment V				
Earplugs & 1 Muff				
A (Control)	3.67	.24	.39	1.32***
B (120 dB)	3.91		.15	1.08***
C (130 dB)	4.06			.93***
D (140 dB)	4.99			

Means for Nonsignificant Experiment

Experiment IV

	Control	120 dB	130 dB	140 dB
Earplugs	3.60	3.71	3.84	4.31

* $p < 0.10$

** $p < 0.05$

*** $p < 0.01$

SECTION IV

DISCUSSION

One would have expected that the eyes closed measure on the rails would be a more sensitive measure of the effects of noise on vestibular functioning since with this measure, with vision excluded, the vestibular system would seem to play a larger role in maintaining equilibrium. However, in our previous experiment (ref 7) and in the five experiments reported in the present paper, a significant effect did not occur in our analyses of variance for noise conditions. The means for the 140 dB noise condition were much smaller than the means for the control conditions in every case but because of large intra- and inter-subject variability no significant effect was obtained for noise conditions in the analyses of variance. Tests of mean differences, would lead to the conclusion that the 140 dB had an adverse effect on rail performance in most experiments. However, no differential effort was obtained for asymmetrical versus symmetrical exposure. By using more subjects than were used in the present studies, a more clearcut reaction to noise might be obtained using this measure if the problem is one of low reliability. However, another possibility exists, noise may interfere more with the task with open eyes because of some kind of yet to be determined interaction between the vestibular and visual systems.

The eyes open measure was quite sensitive to the effects of noise. Four of the five experiments, in the present report, yielded significant effects for noise conditions, and the extent of the differences clearly supports previous observations that asymmetrical noise has a more detrimental effect on human equilibrium than symmetrical noise. The difference was one, at the lower intensity levels, of improvement in performance over the control for the symmetrical noise exposure, and one of decrement in performance for the asymmetrical exposure. Nevertheless, it should be pointed out that in spite of the consistent improvements in performance found for symmetrical noise, none of these reached the level of statistical significance. The improvement occurred at the levels of 120 dB and 130 dB, while at 140 dB decrements were obtained in all of the first three experiments. As expected, more decrement was obtained in Experiment II (earplugs) than in Experiment I (earplugs and muffs), and more decrement obtained in Experiment III (earplugs and 1 muff) than in Experiment II. Decrements were also obtained at the 120 dB and 130 dB levels in Experiment III, where improvement occurred in the other two experiments.

Evidence was obtained from the results of Experiments IV and V that asymmetrical noise exposure produced measureable aftereffects on equilibrium whereas, symmetrical noise exposure did not. Further research is needed to determine how long this detrimental effect persists after the noise is terminated, and also, determine whether the size of the decrement is related to the length of the noise exposure.

Although there were no spontaneous reports of dizziness or vertigo in the present experiments, the results obtained with the Semantic Differential indicate that the asymmetrical noise was more severe subjectively than the symmetrical noise. The subjects' experience with the asymmetrical noise was rated higher at all three noise levels of 120, 130, and 140 dB than was the experience with symmetrical exposures. And, of course, the higher the score the more the subjects disliked the experience, thought it more powerful, more active, and felt more anxious about it. Thus, the hypothesis that a different intensity of noise at each ear produces more severe subjective ratings as well as more severe effects on equilibrium was well supported by the experimental data. This result was obtained even though the overall intensity of noise in Experiments II and IV, where the subjects wore earplugs, was higher than in Experiments III and V where the subjects wore earplugs and one earmuff.

These results are consistent with the subjective reports obtained in previous studies which led to the hypothesis that high intensity noise was acting directly on the vestibular system. The agreement of our objective measures with the previous subjective measures does not prove that noise was having a direct effect on the vestibular system in the present study. However, judging from the size and consistency of the decrements in the present study, and that at the 130 dB and 140 dB levels decrement is obtained as an aftereffect of noise exposure, it appears as a possible conclusion that the noise was directly affecting the vestibular system. This does not seem to be an unreasonable conclusion, since Ades (ref 1) concludes, after a survey of the effects of noise on human orientation in space, that the first sensory system after the auditory to be assaulted by intense noise is the vestibular. One of the more compelling arguments is the close anatomical link that exists between the auditory and vestibular systems; acoustic stimuli which activate the inner ear via the external auditory meatus may reach portions of the vestibular system as well. This effect might at high intensities not only result in direct mechanical stimulation but possibly in secondary stimulation due to increase in temperature sufficient to produce movement of the endolymph or through a direct effect of temperature on the vestibular receptors and nerves. An interpretation in terms of temperature elevation would seem to be particularly consistent with the results obtained with caloric stimulation studies, and would be clearly supported by the differential effects we obtained for symmetrical and asymmetrical exposures in the present experiments.

Many other explanations could be used to explain the results obtained in the present experiments, and indeed, these, alternate explanations cannot be ruled out at the present time. Studies in which various factors have been shown to increase body sway, such as fatigue, music, alcohol, etc., may be related to the results of the present study. Particularly, since it has been found that "Strongly illuminating one eye has also been found to increase sway to the same side," (ref 10). This would suggest that any asymmetrical stimulus, regardless of sense modality, may produce a decrement in the ability of subjects to maintain their equilibrium. Although, this is a possible explanation of our data, it seems unlikely considering the size of the decrements we obtained and the fact that decrements were obtained after exposure to the asymmetrical noise exposure. Additional research is needed to determine the causal factors involved in producing decrements on the rail test during exposure to noise.

Regardless of the hypothesis that is adopted about the particular sensory system most affected by high intensity noise, the results of the present study are important from both an applied and methodological point of view. Important from an applied point of view, since noise levels have been found to adversely affect human equilibrium at levels considerably below those that would be expected to damage hearing. And important from a methodological point of view, because a measure, eyes open measure on the rails, has been obtained which shows considerable sensitivity to noise. This is an important accomplishment, since it now allows us to explore the parameters of the noise stimulus to determine their relative effectiveness in producing decrements in equilibrium. The relative effects of different noise spectra, different frequencies, different lengths of exposure, and intermittent exposures can be explored.

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