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THE COMBINED EFFECTS OF VIBRATION, NOISE, AND EXPOSURE DURATION ON AUDITORY TEMPORARY THRESHOLD SHIFT

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13. ABSTRACT

To determine the combined effects of noise and vibration on auditory function, the temporary threshold shifts (TTS) of two groups of 10 subjects each were measured as a function of intensity and duration of exposure. Combined noise and vibration was presented to one group for 5 minutes and to the other for 20 minutes. Both groups were exposed to vibration in the Z axis at frequencies of 9 Hz and 18 Hz at intensity levels of 0.475 g_z (peak) and 0.950 g_z, respectively. Noise levels of 90 dB and 100 dB (re 20 $\mu N/m^2$) were presented simultaneously with the vibration. TTS was measured at post exposure recovery times of 0.5, 2.0, 5.0, 10.0, and 20.0 minutes. Although the mean difference was small (0.72 dB), a significantly larger TTS was obtained at 9 Hz than 18 Hz vibration, and 100 dB produced a larger TTS than 90 dB. Significant differences in TTS were also obtained as a function of duration of exposure, and as a function of post exposure recovery time. The results indicate that whole body vibration alters noise induced TTS, however additional research is necessary to more accurately define TTS as a function of vibration frequency and level as well as to determine if the alteration is of practical consequence.

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Preface

This study was accomplished by the Biodynamics and Bionics Division of Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio. The research was conducted by Henry C. Sommer of the Biological Acoustics Branch, Biodynamics and Bionics Division. The research was accomplished under Project 7231, "Biomechanics of Air Force Operations," Task 723103, "Effects of Operational Noise on Air Force Personnel," and supported in part by the Environmental Protection Agency (EPA) under Interagency Agreement No. EPA-IAG-0181(D). Acknowledgement is made of the assistance provided by Dr. C. Stanley Harris and Mrs. Cora Partin of the Biological Acoustics Branch.

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INTRODUCTION

Structure borne vibrational and airborne acoustical energy are produced by much the same type motion, and for that reason often act on man simultaneously. A large amount of research has been conducted to determine the individual effects of these stimuli on human performance, physiological response, and sensory acuity. However, little information is available on the combined effects of whole body vibration and acoustic energy on human responsiveness. Of particular interest is the combined effects of these stimuli on auditory thresholds. Most of the studies conducted in this area have been inadequately controlled and have lacked appropriate statistical treatment of the data. A summary of the literature on the combined effects of whole body vibration and acoustic stimulation on temporary threshold shift (TTS) is presented in Table 1. Very few studies exist, as is evident from the table, and no systematic attempt has been made to explore interactive effects as a function of intensity and duration of exposure. The present experiment represents a first step in filling this gap.

The results of one study suggest that vibration presented alone increases hearing sensitivity, however, vibration (16.7 Hz) combined with 100 dB SPL* white noise produced more TTS at 4000 Hz than the noise presented alone (Morita, 1958). These results are difficult to evaluate since no statistical analyses were performed and the subjects were exposed to a pitching motion rather than sinusoidal vibration in one axis. Sinusoidal motion has been used in most vibration studies since a pitching motion complicates the situation by introducing an angular acceleration component. Nevertheless, Yokoyama, Yamamoto, and Fujii (1965) using Z axis vibration have subsequently reported results in agreement with those obtained by Morita (1958). These authors presented subjects with 5 and 16.7 Hz vibration at 0.3 and 0.9 g, respectively, in conjunction with white noise at 82 dB SPL for 20 minutes, and measured TTS at 4000 Hz beginning 0.2 minutes postexposure ($TTS_{0.2}$). Noise alone produced a 5 dB decrement at $TTS_{0.2}$ and a 2 dB decrement at TTS_{2}, while noise combined with 5Hz vibration produced a 12 dB decrement at $TTS_{0.2}$ and full recovery did not occur even 20 minutes postexposure. Noise combined with 16.7 Hz vibration produced shifts of 13 and 10 dB at $TTS_{0.2}$ and TTS_{2}, respectively. The 5 Hz vibration, presented alone, produced 3 dB enhancement at $TTS_{0.2}$. As in Morita's (1958) experiment, the data were not analyzed statistically, thus only tentative conclusions can be reached.

The findings that vibration when presented alone enhances hearing sensitivity has been challenged by Tease and Snyder (1963). These investigators used 15 vibration frequencies in the range of 1 to 27 Hz at four amplitudes and found no significant differences between preexposure and exposure audiograms. However, the question still remains as to whether whole body vibration interacts with noise to produce greater TTS than noise alone. In spite of the procedural problems and the fact that no statistical analyses were performed to determine if an interaction existed, the differences reported by Morita (1958) and Yokoyama et al (1965) seemed large enough to warrant further investigation. Therefore, in an exploratory study conducted in our laboratory (unpublished), four experimental conditions were presented: noise alone (earphones), noise plus whole body vibration at 6 Hz–0.25 g_z, at 18 Hz–0.83 g_z, and at 36 Hz–1.40 g_z. Subjects were seated in a chair with a wooden seat, and vibrated in the Z axis. Noise of 106 dB with the greatest energy concentrated in the 1000 to 2000 Hz range was presented for 4 minutes. TTS at

* SPL—Sound Pressure Level referenced to 20 $\mu N/m^2$.

TABLE 1

Summary of Available Literature

AUTHOR	VIBRATION		NOISE	DURATION	TEST TONE	RESULTS
	FREQUENCY	AMPLITUDE (gz peak)				
MORITA (1958)	16.7 Hz	1.5 g	White Noise (100 dB SPL)	30 min	4000 Hz	greater TTS with noise plus vibration than noise alone. (no statistical data)
	5.0 Hz	0.3 g	White Noise (82 dB SPL)	20 min	4000 Hz	7 dB shift (mean of 8 Ss) with noise plus vibration than noise alone, no full recovery at TTS_{20}. (no statistical data)
YOKOYAMA et al (1965)	16.7 Hz	0.9 g	White Noise (82 dB SPL)	20 min	4000 Hz	6–7 dB shift (mean of 8 Ss) with noise plus vibration than noise alone, no full recovery at TTS_{20}. (no statistical data)
6570 AMRL Exploratory Investigation (1968)	6.0 Hz 18.0 Hz 36.0 Hz	0.25 g 0.83 g 1.40 g	1000–2000 Hz band of noise (106 dB SPL)	4 min	2000 Hz and 4000 Hz	no significant differences, vibration at 18 Hz, combined with noise produces a 3 dB greater shift for TTS_{1-9} than noise alone.
PILOT STUDY (1969)	18.0 Hz 18.0 Hz 18.0 Hz	0.5 g 1.0 g 1.5 g	1414–2828 Hz band of noise (106 dB SPL)	4 min	2000 Hz and 4000 Hz	no significant differences
OKADA et al (1971)	2.0 Hz 5.0 Hz 10.0 Hz 20.0 Hz	0.1 g 0.1 g, 0.5 g 0.1 g, 0.5 g, 1.0 g 0.5 g, 1.0 g	Steady-State (101 dB SPL)	20 min and 60 min	1000 Hz and 4000 Hz	significant TTS for 5 Hz at 0.5 g significant TTS for 10 and 20 Hz at 1.0 g, significantly greater TTS for noise combined with 5 Hz–0.5 g than 5 Hz vibration or 101 dB noise alone.

2000 and 4000 Hz were measured for 30 seconds of each minute for a total of 9 minutes post-exposure. The results, although not statistically significant, indicated that 18 Hz with noise produced a greater change in TTS at 4000 Hz (a mean TTS for eight subjects of about 3 dB for TTS_{1-9}) than the other frequencies combined with noise.

Since 18 Hz whole body vibration produced the greatest TTS in our first study, this frequency was studied in a subsequent study at intensity levels of 0.5, 1.0, and 1.5 g_z. Narrow band noise, 1414 to 2828 Hz, at 106 dB was presented alone over earphones and in combination with whole body vibration at the three acceleration levels. Each exposure condition lasted for 4 minutes, with TTS determined at 2000 and 4000 Hz alternately every 30 seconds for 10 minutes post-exposure. No significant differences were found for either test frequency. We concluded that, within the constraints of the experiments, threshold hearing levels for 2000 and 4000 Hz were not affected by the vibration component. However, there are two major factors that could have influenced the outcome of these experiments. First, subjects tended to adjust their posture in the chair to minimize transmission of the vibratory motion to the head. Second, high level background noise in the test room may have produced some masking effects of the pre- and postexposure audiograms.

Subsequent to the experiments conducted in our laboratory, Okada, Miyake, Yamamura and Minami (1971) found evidence to support the additive effects of noise and vibration findings obtained by Morita (1958) and Yokoyama et al (1965). In their study, subjects were exposed to Z axis at frequencies of 2, 5, 10, and 20 Hz at intensity levels presented in Table 1. A "factory type noise" (peak energy in the 500–1000 Hz region) of 101 dB SPL was presented by itself and with the 5 Hz vibration condition. TTS_2 was measured at 1000 and 4000 Hz after 20 minutes and 60 minutes of exposure. For a 20 minute exposure to 5 Hz–0.5 g_z vibration (presented alone) a 5 dB TTS_2 was measured at both 1000 and 4000 Hz while a 60-minute exposure increased the TTS_2 to approximately 7.5 dB for both test frequencies. This effect was opposite in direction to that found by Yokoyama et al (1965), a decrement in hearing instead of increased sensitivity due to vibration. Significant TTS was also obtained after both exposure durations to the 10 Hz–1.0 g_z vibration. The noise presented alone for 20 minutes produced a 4 dB TTS_2 at 1000 Hz and an 18 dB TTS_2 at 4000 Hz. When vibration at 5 Hz–0.5 g_z was combined with the noise, the TTS_2 at 1000 and 4000 Hz was increased approximately 4 dB over that for the noise alone. This increase in TTS was statistically significant.

The various experiments concerning vibratory/auditory interaction used similar procedures for measuring TTS and the shift at 4000 Hz was a common measure in all. Also, the frequency and intensity of vibration used in our pilot studies were similar to those of the earlier studies. There were, however, wide differences in intensity and duration of noise exposures used in the experiments. This difference in duration and intensity of noise exposure may have been instrumental in producing the additive effects of noise and vibration on TTS obtained by Morita (1958), Yokoyama et al (1965) and Okada et al (1971). Possibly, in the pilot studies the vibration and noise were simply not presented for a long enough period of time to interact with each other. The maximum permissible vibration exposures allowable for nonhazardous experiments conducted in our laboratory are in compliance with or identical to those set forth by the International Standards Organization (ISO), Technical Committee 108, Working Group 7 "Guide for the Evaluation of Human Exposure to Whole-Body Vibration" (1972) and are considered to be maximum safe vibration exposure limits for the various exposure durations specified. Many of the vibration exposures used by Morita (1958), Yokoyama et al (1965), and Okada et al (1971) exceed those recommended by the ISO document and for that reason cannot be duplicated in our investigations.

The purpose of the present study was to evaluate the individual and the combined effects of vibration frequency, noise intensity level, and duration of exposure on magnitude of TTS and recovery. Vibratory stimuli of 9 Hz at 0.475 g_z and 18 Hz at 0.95 g_z were selected for study. These stimuli were selected on the basis of the ISO standard (1972), waveform distortion characteristics of the vibration excitor, and use in previous research. To test for the effect of exposure duration, 5 and 20 minute exposure were used. Noise intensity levels of 90 and 100 dB SPL were selected in the range where a small TTS could be measured for the lowest level at the shortest exposure duration, and where the higher level would not produce any undue discomfort. To determine the combined effects of the variable on TTS and the recovery function, TTS was measured at five postexposure times.

METHOD

SUBJECTS

Twenty male military members of the U. S. Air Force ranging in age from 23–40 years volunteered for participation in the experiment. The subjects were experienced in vibration exposure. As determined by standard audiometric methods, all subjects had normal hearing for test frequencies of 500, 1000, 2000, 3000, 4000, and 6000 Hz.

APPARATUS

A block diagram of the equipment used for presenting the vibratory and auditory stimuli is presented in Figure 1.

Vibration Stimulation

Vibration stimulation was accomplished by use of an MB Electronics model C-3 electromagnetic exciter. Uniaxial sinusoidal vibration in the Z axis was transmitted to the subject's chair. The load limit of the vibratory system was 210 pounds, with the differential between the subject's weight and 210 pounds compensated for by the use of additional weights. Vibration frequencies of 9 and 18 Hz at peak accelerations of 0.475 and 0.950 g_z, respectively, were obtained with little distortion of the waveform. Peak acceleration was monitored by an MB model M3 vibration meter from an accelerometer mounted under the subject's chair. A Brush model 220 line recorder connected to the output of the meter was used for obtaining a permanent record of the vibratory stimulus.

Noise Exposure

The signal generated by a Grason-Stadler type 455-B white noise generator was adjusted with a Spencer-Kennedy Laboratory model 302 variable filter to produce the desired noise spectrum. The filtered output was amplified by an Altec 351-C 50 watt audio amplifier and an attenuator (110 dB total, in 1 dB steps) controlled the gain of the amplified noise. The attenuated output passed to one channel of a Grason-Stadler model 829S51 electronic switch, which delivered a signal bilaterally to Koss Pro 600 earphones. At both 90 and 100 dB SPL the noise spectrum had its peak energy in the 2000 to 4000 Hz octave band with an approximate 6 dB per octave roll off.

Auditory Test Signal

A 4000 Hz pure tone, generated by a Hewlett-Packard 200 AB audio oscillator, was used in the hearing threshold detection portion of the experiment. The output was directed to a Grason-Stadler model 829 E electronic switch which pulsed the signal two times per second at a duty cycle of 50% to enhance signal detection. Each pulse had a rise and decay time of 50 ms (milliseconds) and an on duration of 175 ms. An operator's attenuator was placed prior to the subject's recording attenuator to allow a 1 dB control over the recorded response. The recording attenuator was a Grason-Stadler type E 3262 and was remotely adjusted by the subjects to provide a continuous threshold record. Gain of the recording attenuator was continuously

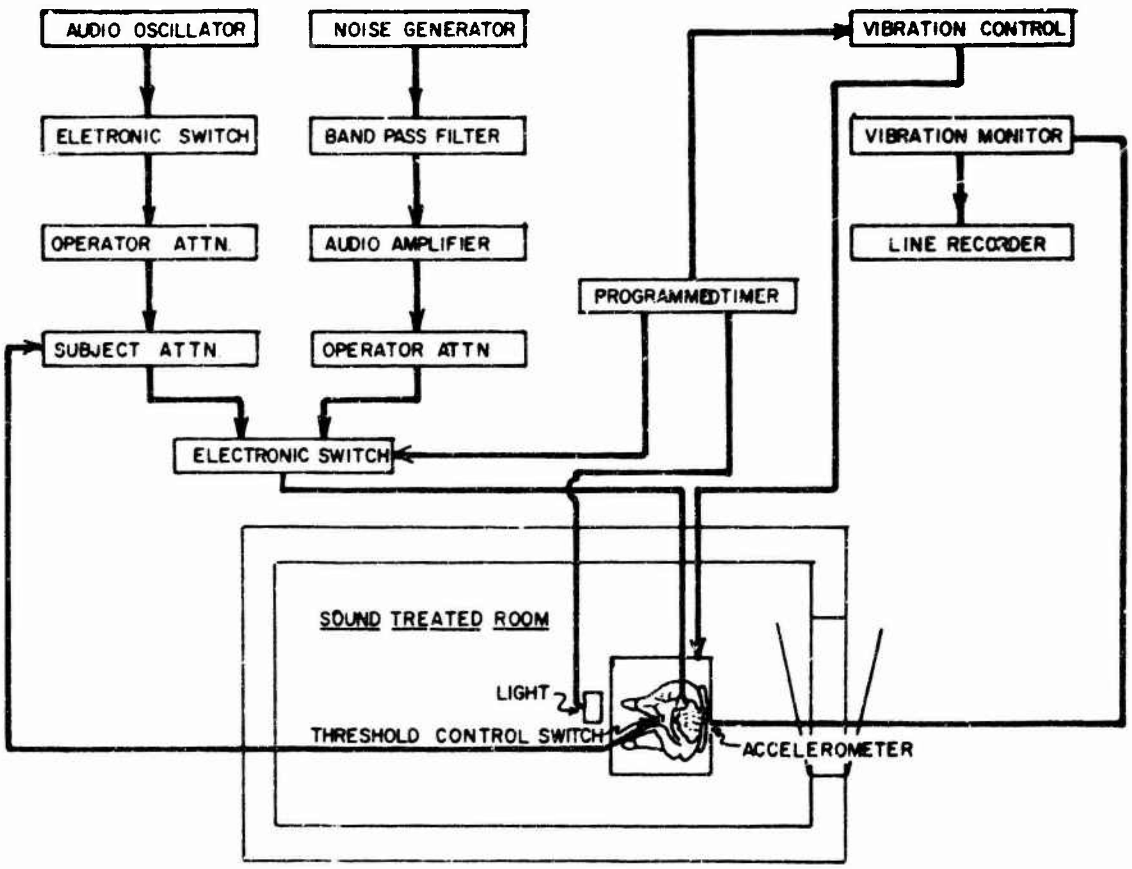

Figure 1. Block diagram of the equipment.

varied by the subject at the rate of 4 dB per second within the dynamic range of 100 dB. The signal then passed to a Grason-Stadler model 829S51 electronic switch which allowed switching between noise and pure tone to occur without producing an audible transient pulse in the earphones. This output, as with the noise generation portion, passed bilaterally to Koss Pro 600 earphones.

Presentation of exposure stimuli and collection of response data were automatically controlled by the use of a programmable timer. This timer also controlled a red, green, and yellow light which assisted the subjects in determining the correct sequence operation. The red light was used when when the threshold detection portion of the experiment was off. Fifteen seconds prior to the onset of the audible signal the yellow light was actuated to provide warning that the green light was coming on, indicating that the subject should begin plotting threshold.

PROCEDURE

A four factor design, repeated measures on three of the four factors, was used as the experimental design for this investigation. Subjects were randomly assigned to one of two groups of 10 subjects each. The groups differed in exposure duration, 5 minutes versus 20 minutes of exposure. All subjects were presented two levels of noise, 90 and 100 dB SPL, and two frequencies of vibration, 9 Hz at 0.475 g_z and 18 Hz at 0.950 g_z. Postexposure TTS was measured at 0.5, 2.0, 5.0, 10.0 and 20.0 minutes. The scores used for analysis were obtained by subtracting, for each subject, the TTS obtained at each recovery time from the average of four preexposure threshold level determinations.

Each subject was tested in a series of daily sessions for five consecutive days. This series was comprised of a preliminary session and four experimental sessions in which each of four combinations of noise and vibration were presented. These conditions were: (1) 9 Hz–90 dB, (2) 18 Hz–90 dB, (3) 9 Hz–100 dB, and (4) 18 Hz–100 dB. Each subject was presented the conditions in a different random order. During the first session, the subjects were instructed in test procedures and given practice in plotting hearing thresholds. To reduce any possible apprehension caused by the exposure conditions, subjects were briefly exposed to each condition, subsequently presented in the experiment proper. In the subsequent testing sessions a preexposure baseline hearing threshold level at 4000 Hz was obtained during the first 5 minutes. Thresholds were found by continuously varying the intensity of the test tone between audibility and inaudibility in a manner associated with the von Békésy procedure (von Békésy, 1960). A sample threshold record is presented in Figure 2. The threshold value was the mean of the excursions within a 30 second interval about the critical postexposure time. After each combined noise and vibration exposure, threshold was plotted continuously at 4000 Hz for a period of 5 minutes. The subjects then rested until 9 minutes, 30 seconds postexposure, at which time they again plotted hearing threshold for 1 minute. Finally, subjects were tested at 19 minutes 30 seconds postexposure for 1 minute. Subjects were tested in an acoustically treated room and reported that they were unable to hear any noise or conversation in adjacent rooms.

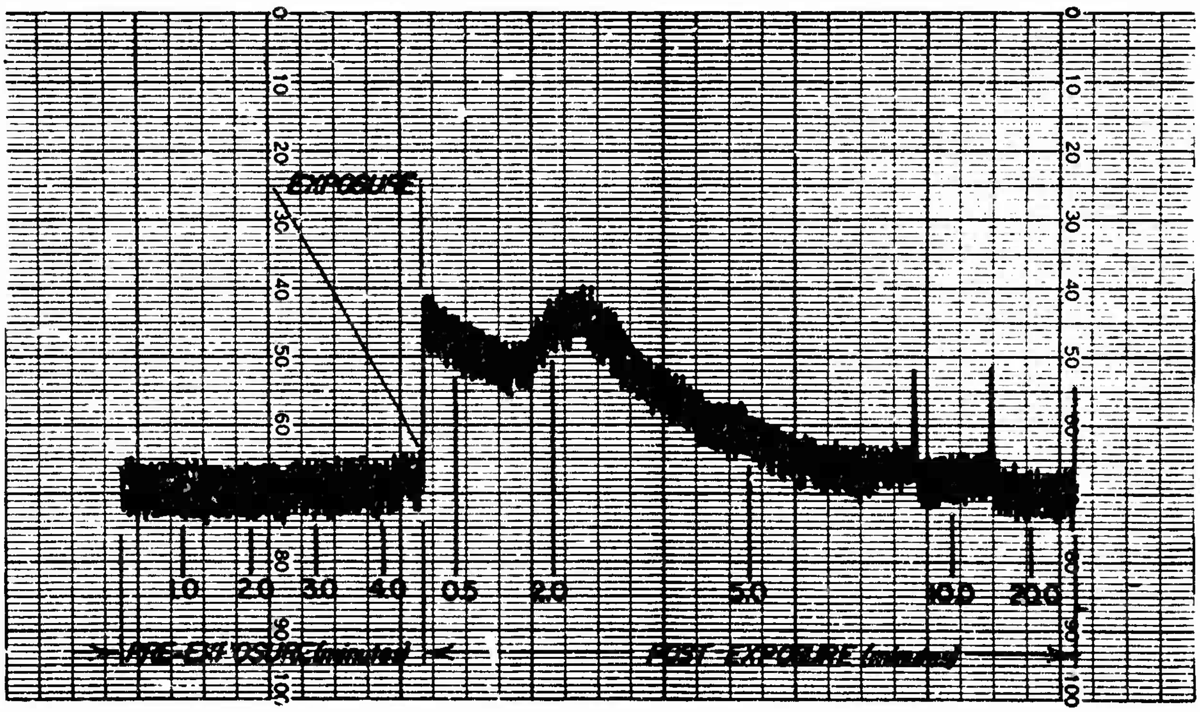

Figure 2. A typical threshold record for one subject. The threshold value was the mean of the excursions within a 30 second interval about the critical time.

RESULTS

An analysis of variance conducted on the data revealed that statistically significant effects were obtained for exposure time, noise level, vibration frequency, and recovery time (see Table II). Figure 3 depicts the effect of exposure time on TTS. The difference between the 5 and 20 minute exposure was expected since the "—increase in TTS with exposure time is found under almost all conditions (Ward, 1963)." Similarly, the effects for noise level (Figure 4), and recovery time (Figure 5) are in agreement with the previous literature (Ward, 1963).

Of particular interest is the effect obtained for vibration frequency. Although the effect was significant, 9 Hz vibration produced only a 0.72 dB greater TTS than 18 Hz (see Figure 6). The significant effect was produced mainly by the consistency of the shift; 16 of 20 subjects had a larger increase in TTS at 9 than at 18 Hz. Also vibration frequency did not interact with exposure time, noise level, or with recovery time.

The two significant interactions, Exposure Time x Noise Intensity (Figure 7) and Noise Intensity x Recovery Time (Figure 8) were expected and predictable from the experimental literature (Ward, Glorig, and Sklar, 1958; Ward, 1963).

TABLE II

Summary Analysis of Variance

Source of Variance	Sum of Squares	df	MS	F	
Between Subjects	*4908.69*	*19*			
A (exposure time)	1530.77	1	1530.77	8.1571	*
Sub w grps	3377.92	18	187.66		
Within Subjects	*9673.54*	*306*			
B (noise level)	4379.13	1	4379.13	55.4460	**
AB	379.27	1	379.24	4.8021	*
B x Sub w grps	1421.81	18	78.98		
C (vibration freq)	52.93	1	52.93	5.5892	*
AC	15.01	1	15.01	1.5850	
C x Sub w grps	170.47	18	9.47		
D (recovery time)	1253.82	4	313.45	41.9611	**
AD	54.40	4	13.60	1.8206	
D x Sub w grps	538.44	72	7.47		
BC	4.40	1	5.40	< 1.0000	†
ABC	70.15	1	70.15	3.4252	
BC x Sub w grps	368.67	18	20.48		
BD	279.99	4	69.99	17.5854	**
ABD	15.01	4	3.75	< 1.0000	†
BD x Sub w grps	287.04	72	3.98		
CD	2.27	4	0.56	< 1.0000	†
ACD	3.89	4	0.97	< 1.0000	†
CD x Sub w grps	128.81	72	1.78		
BCD	26.15	4	6.53	2.1766	
ABCD	4.71	4	1.17	< 1.0000	†
BCD x Sub w grps	216.17	72	3.00		

Note: Analysis based on raw data with 10 dB added.

* $p < .05$

** $p < .01$

† Not significantly less than 1.000

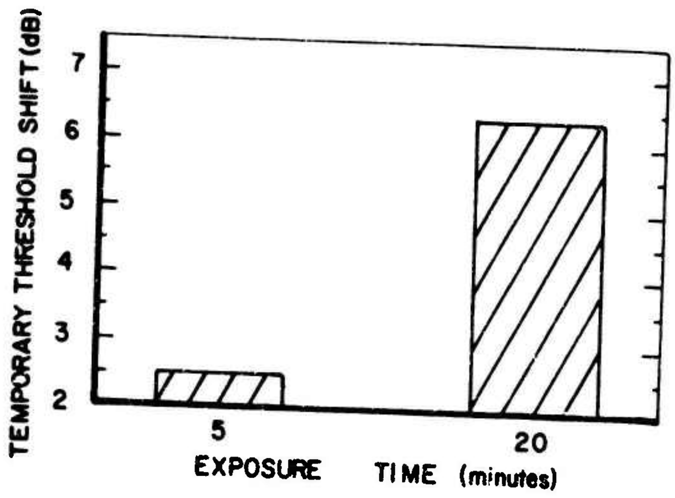

Figure 3. The main effect of exposure time on TTS.

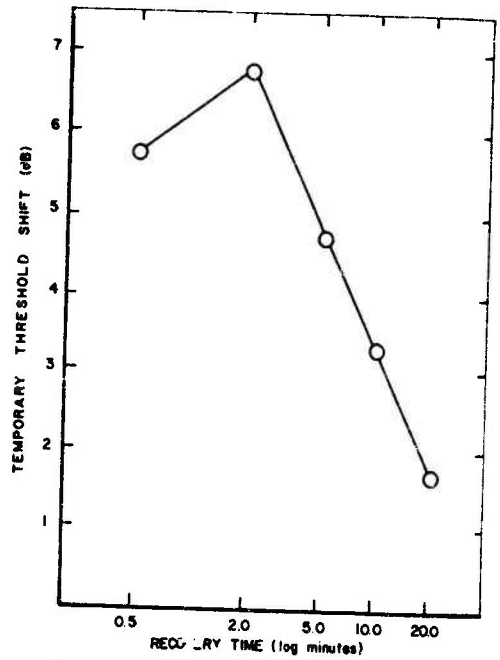

Figure 5. The main effect of recove time on TTS.

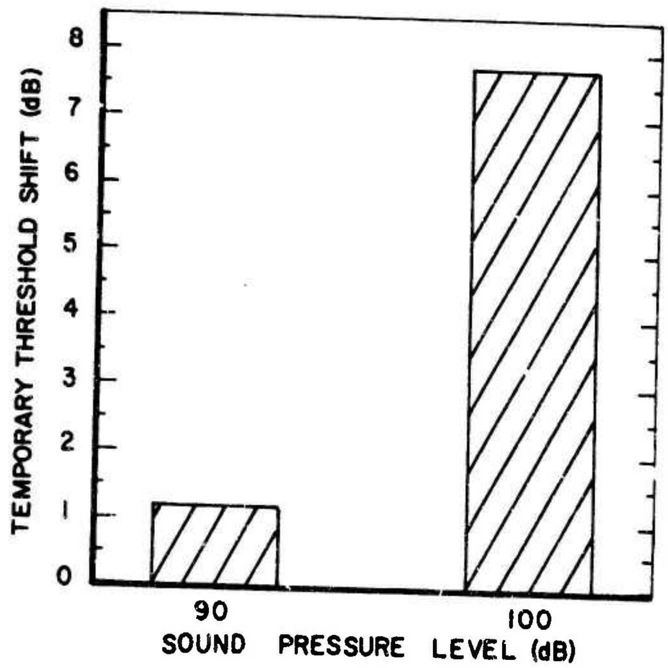

Figure 4. The main effect of noise intensity level on TTS.

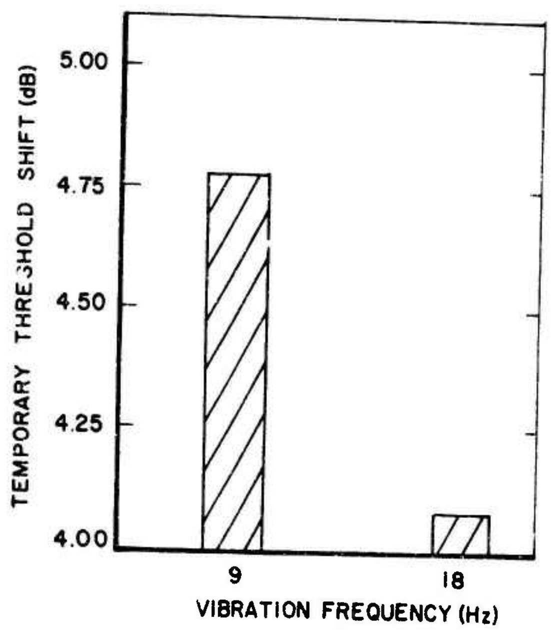

Figure 6. The main effect of vibration frequency on TTS.

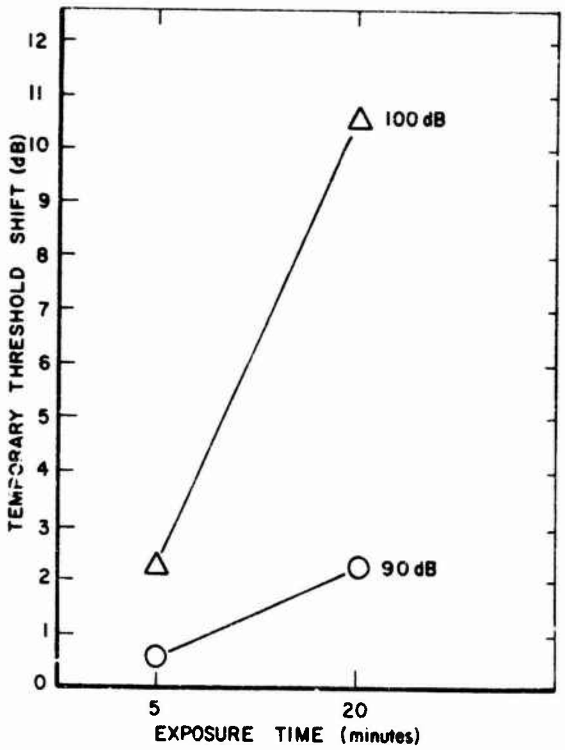

Figure 7. The interaction of exposure time with noise intensity level.

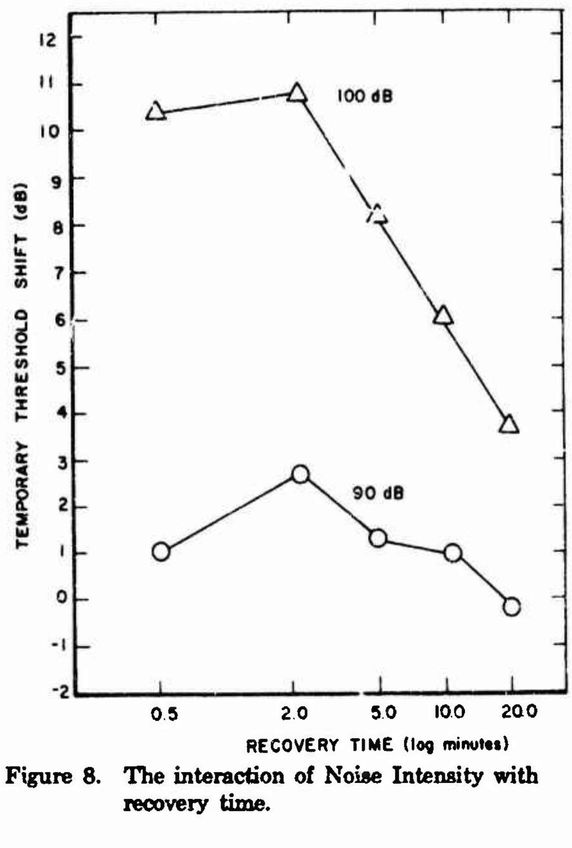

Figure 8. The interaction of Noise Intensity with recovery time.

DISCUSSION

The results demonstrate that the pattern of TTS was not significantly affected by the combination of vibration with noise. In fact, vibration did not interact with any of the variables used in the experiment. Since a significant effect was obtained for vibration frequency, the 9 Hz vibration produced a constant increase in TTS even when combined with noise. A clearer picture would have been obtained if a vibration alone condition had been included in the experiment. Nevertheless, the effect was constant across two levels of noise that produced a wide difference in TTS. As stated earlier, although the mean difference between 9 and 18 Hz was only 0.72 dB, it was fairly consistent across subjects with 16 of the 20 subjects showing greater TTS at 9 Hz. For the 5 minute exposure group, 7 of the 10 subjects had higher TTS at 9 Hz while nine subjects had higher TTS at 9 Hz in the 20 minute exposure group (see Figure 9).

The higher TTS for 9 Hz in comparison to 18 Hz was also consistent at each recording time during the postexposure recovery function as can be seen in Figure 10. Similarly, 9 Hz produced the greater TTS regardless of the duration of noise and vibration (Figure 11) or intensity of noise exposure (Figure 12). Since 9 Hz produced a consistently greater TTS than 18 Hz across all variables, the effect seems genuine, nevertheless, because of the size of the difference we must conclude that it is only of theoretical interest.

Since subjects practiced plotting hearing threshold with no vibration and were exposed to noise, the TTS caused by noise alone was available. However, practice only occurred on the first day; therefore, motivational factors in addition to task understanding may have influenced performance. A comparison of the practice data with each of the vibration conditions shows that noise alone produced a greater TTS than 9 Hz combined with noise. In other words, it appears as though the addition of vibration reduces the amount of noise induced TTS, which is in direct opposition to those findings reported by Morita (1958), Yokoyama et al (1965), and Okada (1971). These observations should be viewed with caution however, since the no vibration condition was not incorporated into the design of the present experiment. Nevertheless, if comparison with the practice data is appropriate then the meaning of the results is changed considerably. By ignoring the practice data one could conclude that 9 Hz adds to the effects of noise. On the other hand, considering the practice data one could estimate that 18 Hz vibration reduces TTS due to noise more than 9 Hz.

Although a significant auditory temporary threshold shift effect for vibration was found in the present study, the results are still ambiguous with respect to those of previous research. To fully understand the influence of whole body vibration on noise induced TTS and to determine if the amount is of any practical consequence, additional research is required. Future research should consider the effect of vibration frequency and intensity level on noise induced auditory temporary threshold shift. In addition, proper control conditions should be incorporated into the experimental design and exposures administered for longer durations.

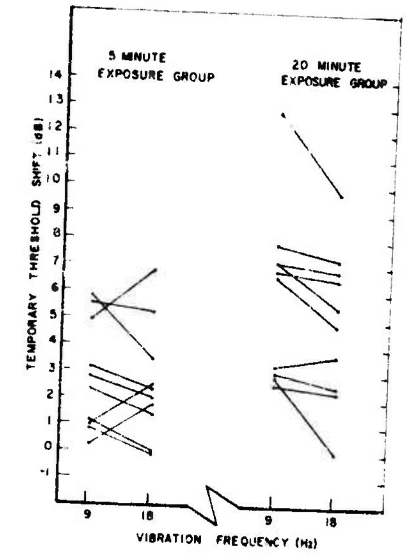

Figure 9. Individual differences in TTS between vibration conditions for the different

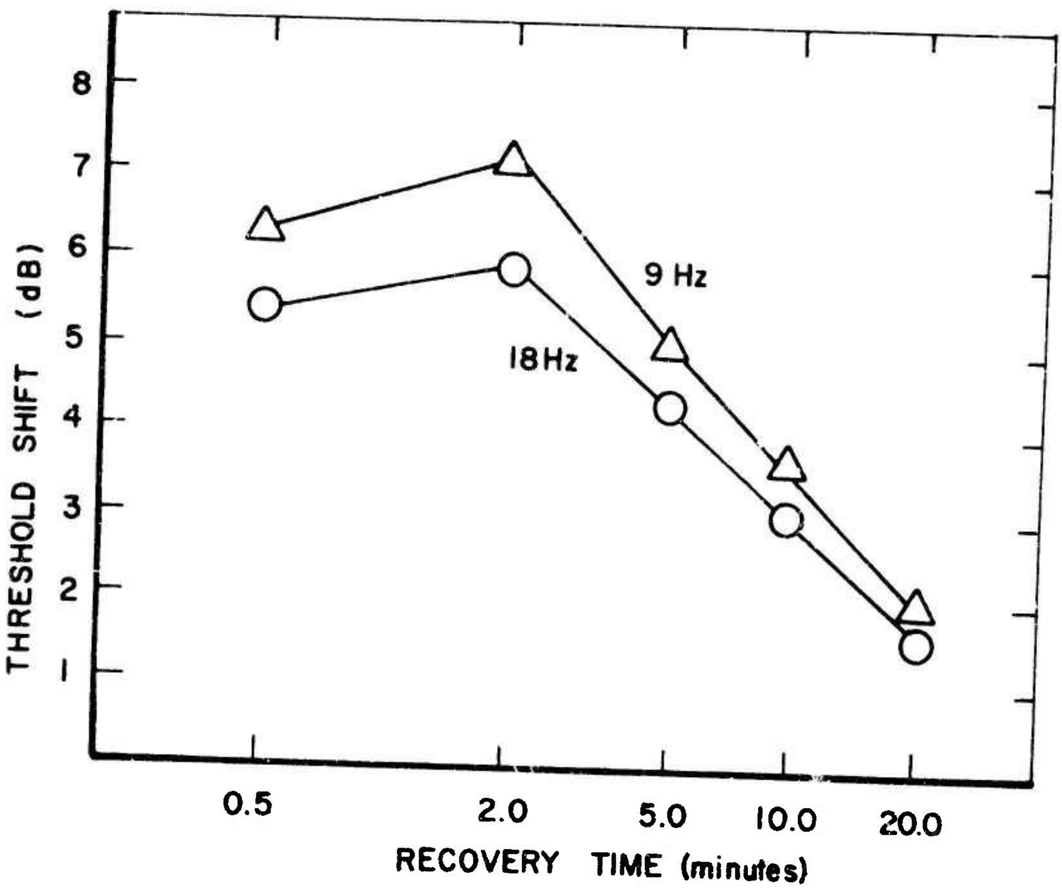

Figure 10. Graph of the TTS recovery time function for each vibration frequency.

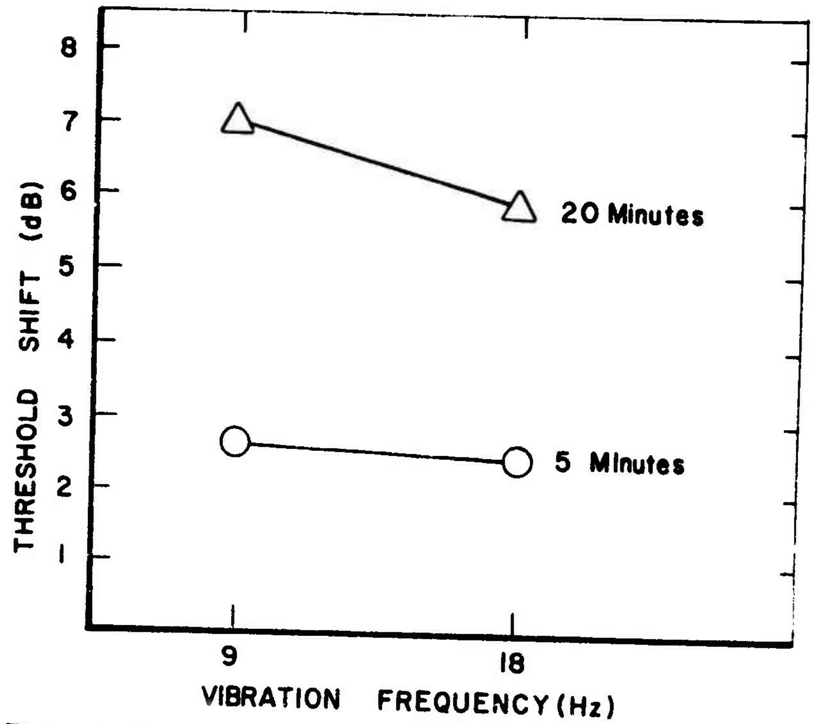

Figure 11. The effect of duration of exposure on TTS for each of the vibration frequencies.

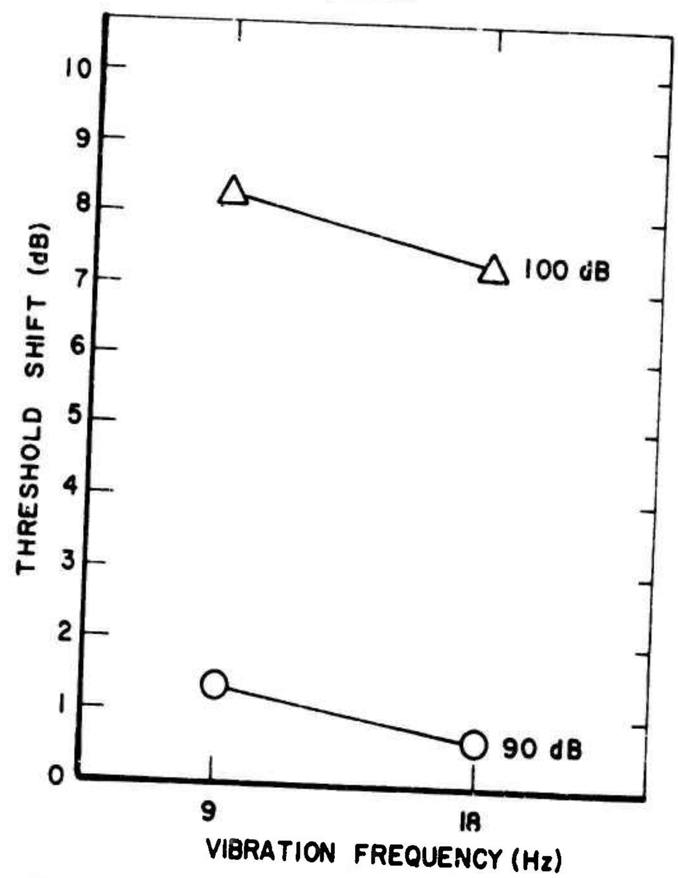

Figure 12. The effect of noise intensity on TTS for each of the vibration frequencies.

REFERENCES

Békésy, Georg von. *Experiments in Hearing*, New York: McGraw Hill, 1960.

International Standards Organization (ISO), Technical Committee (TC) 108, Working Group (WG) 7 revised draft, "Guide for the Evaluation of Human Exposure to Whole-Body Vibration," April 1972.

Morita, M. "Experimental Studies on the Acoustic Influence of Vibration and Noise." *Otologia Fukuoka*, 1958, 4, 327-331.

Okada, A., M. Hirotsugu, K. Yamamura and M. Minami. "Temporary Hearing Loss Induced by Noise and Vibration," *Journ. Acoust. Soc. Amer.*, 1971, 51, 1240-1248.

Teare, R. J., and F. W. Snyder. *Human Hearing and Speech During Whole Body Vibration*, Technical Report No. 3, the Boeing Company, Wichita Division, Contract Nonr 2994(00), "Research on Low Frequency Vibration Effects on Human Performance," 1963.

Ward, W. D. "Auditory fatigue and masking." *In* J. Jerger (Ed.), *Modern Developments in Audiology*, New York: Academic Press, 1963. Pp. 241-248.

Ward, W. D., A. Glorig, and D. Sklar. "Dependence of Temporary Threshold Shift at 4 Kc on Intensity and Time," *Journ. Acoust. Soc. Amer.*, 1958, 30, 944-954.

Winer, B. J. *Statistical Principles in Experimental Design*, New York: McGraw-Hill, 1962.

Yokoyama, T., K. Yamamoto and T. Fujii. "Effects of low frequency vibration on auditory fatigue." Paper presented at the meeting of the Second Extra-Ordinary Congress of International Society of Audiology, Oct. 1965.

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