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COMBINED EFFECTS OF NOISE AND VIBRATION ON HUMAN TRACKING PERFORMANCE AND RESPONSE TIME

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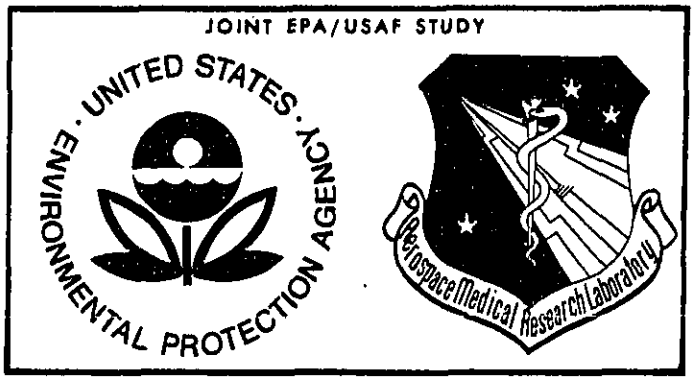

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Combined Effects of Noise and Vibration on Human Tracking Performance and Response Time

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In our laboratory vibration has been shown to be the primary cause of performance impairment in studies of the combined effects of noise and vibration on human tracking performance. Noise has had little consistent effect when presented alone, and has added little or not at all to the impairment produced by vibration. In two studies with heat included as a third stressor, vibration presented alone had a slightly more adverse effect on tracking performance than combined heat, noise and vibration. In the present experiment, 12 subjects were exposed to lower noise and vibration levels for a longer period of time than used previously. Subjects were tested under the following conditions: (1) no vibration—60 dB (dB re 20 $\mu N/m^2$) noise; (2) no vibration—100 dB noise; (3) 6 Hz vibration at 0.10 g_n (peak)—60 dB noise; and (4) 6 Hz vibration at 0.10 g_n—100 dB noise. Noise had no significant effects on tracking performance, while vibration adversely affected both dimensions of the tracking task. On both horizontal and vertical tracking, vibration combined with 60 dB noise produced greater impairment than vibration combined with 100 dB noise. These results parallel previous findings from studies of combined noise, heat, and vibration, and give support to a subtractive interaction interpretation of the combined effects of noise and vibration on human tracking performance.

IN OUR LABORATORY four studies have been conducted on the effects of combined stress on human tracking performance and response time. In two of the studies[5,6] the combined effects of noise and vibration were investigated, and in the remaining two, heat was included as an additional variable.[1,2] In all of these studies the major cause of performance decrement was vibration. In the first study[5] noise produced an adverse effect; however, the effect was small relative to the effect produced by vibration. Vibration clearly affected all task measures (red and green light response time, horizontal and vertical tracking) while noise affected only the vertical dimension of the tracking task, and on this measure, the error produced by vibration was more than three times as large as the error produced by noise. Since only 1 of the 4 task components was affected by noise, the validity of this finding seemed questionable. A followup study[6] confirmed our suspicions, since no effect of noise was found on any of the tasks, and high-level noise combined with vibration produced no greater effect on performance than vibration combined with low level noise.

In a study including heat as a variable, Grether, Harris, Mohr, Nixon, Ohlbaum, Sommer, Thaler, and Veghte[1] found that vibration presented with low level noise and a low ambient temperature produced more adverse effects on the two dimensions of the tracking task and green light reaction time than vibration combined with comparatively high levels of heat and noise. The authors of the study conclude: ". . . The direction of the differences suggested a small antagonistic interaction among the stresses. It seems more likely, however, that these differences were due to chance factors.—(Grether *et al*[1])."

A subsequent experiment by Grether, Harris, Ohlbaum, Sampson, and Guignard[2] using approximately the same procedures, compared ambient, vibration, vibration and heat, and vibration, heat, and noise conditions. The results generally confirmed the results of the previous experiment and demonstrated that vibration alone produced slightly more performance impairment than either combination of vibration and heat, or vibration, heat and noise. The authors state: "Generally, the differences between stress conditions were not statistically significant, but the findings are consistent in direction for two measures of tracking and two measures of reaction time. Thus, the direction of this relationship, in two separate experiments, could hardly have been a chance factor (Grether *et al*[2])."

There are a number of differences between the studies conducted by Grether *et al*[1], Grether *et al*,[2] and the studies conducted by Harris and Shoenberger,[3] and by Sommer and Harris.[5] In Grether's studies, the subjects performed a verbal task simultaneously with the tracking

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The voluntary informed consent of subjects used in this research was obtained as required by Air Force Regulation 80-33.

and reaction time tasks, while this task was not included in the other studies. Noise and vibration were not presented as separate experimental conditions, therefore, the results may be due to the interaction of vibration with heat rather than noise. Further, in Grether's studies, a 105 dB broadband noise was used while in the Harris and Shoenberger[3] and the Sommer and Harris[5] studies a 110 dB broadband noise was used. In spite of these differences, in all studies vibration was the prominent variable that produced impaired performance. From the results of these experiments, the most appropriate conclusion is that broadband noise (up to 110 dB) presented for short time periods (20 to 30 minutes) does not interact in any consistent manner with vibration (5 Hz, 0.25 to 0.30 g_x peak), in affecting psychomotor performance.

The purpose of the present study was to test subjects for a longer period of time with lower noise and vibration levels. The longer durations should allow the noise to have a better chance to "interact" with the lower level vibration.

MATERIALS AND METHODS

Subjects: Twelve male university students ranging in age from 19 to 23 years volunteered for participation in the experiment. As determined by standard audiometric methods, all subjects had normal hearing, within the frequency range of 500 to 6000 Hz, with no greater than 5 dB difference between ears at any frequency.

Apparatus: Vibration stimulation of 6 Hz at 0.10 g_x (peak) was presented by an MB Electronics Model C-3 electromagnetic exciter. Subjects sat in a chair with a wooden seat which was mounted on top of the shake table and were restrained by a lap belt. Peak acceleration was monitored continuously at the seat of the chair.

The noise exposure was produced by a Grason-Stadler type 455-B white-noise generator, amplified by an Altec 351-C solid-state amplifier and passed bilaterally to a military H-157 headset worn by the subject. The noise spectrum measured under the earphones for both overall levels of 60 dB and 100 dB (dB re 20 $\mu N/m^2$) can be seen in Figure 1. The tasks used for measuring tracking and response time performance will only be described briefly since a complete description of these tasks can be found elsewhere (Shoenberger[4]). Figure 2 shows a subject in place for an experimental run. On the tracking task, the subject was required to keep a dot in the center of a stationary circle by use of a displacement-type hand controller mounted at the end of the right arm rest. The circle was 3/8 inch in diameter and was presented in the center of the cathode ray tube (CRT) at a distance of 20 inches from the subject. The dot was moved randomly about the CRT by horizontal and vertical forcing functions recorded on magnetic tape. The separate forcing functions were composed of random noise filtered to bypass 0.075 to 0.75 radian per second. The subject's displacement of the control stick was proportional to the velocity of the dot movement. The error score for each channel was the integration of the sum of voltages for both the control stick and the program over a 4 minute period.

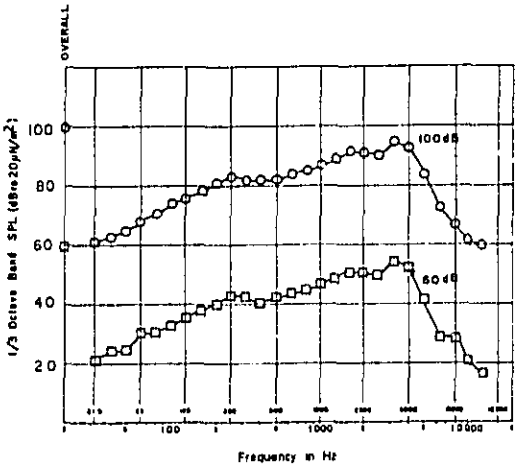

Fig. 1. Noise spectrum at 60 dB and 100 dB.

Two reaction time tasks, response to red lights coming on and green lights going off, were presented in conjunction with the tracking task. The subject's display panel was located to the left of the CRT and consisted of alternating red and green lights with a response button located directly below each light. Three red and three green lights were used. There was an average of 11 changes each of both red and green lights during the 4 minute test blocks. The time interval between lights varied between 7 and 15 seconds, and if the subject did not respond to a light change within 6 seconds, then the light automatically reset to the normal position. The number of misses, incorrects, and cumulative response time were recorded throughout each 4 minute block.

Procedure: All subjects were tested during 7 different test sessions—3 practice and 4 experimental sessions.

Fig. 2. Experimental arrangement for tracking and response time tasks.

TABLE I. RESULTS OF VARIANCE ANALYSES FOR EXPERIMENTAL MEASURES

Measure	Noise(N)	Vibration(V)	Trials(T)	N x V	N x T	V x T	N x V x T
Horizontal Tracking	NS	$p < 0.05$	NS	$p < 0.10$	NS	NS	NS
Vertical Tracking	NS	$p < 0.01$	$p < 0.05$	$p < 0.05$	NS	NS	NS
Red Lights	NS	NS	NS	NS	NS	NS	NS
Green Lights	NS	NS	NS	NS	NS	NS	$p < 0.05$

TABLE II. MEAN SCORES FOR PERFORMANCE MEASURES FOR EXPERIMENTAL CONDITIONS

Measure	60 dB—0 Hz	60 dB—6 Hz	100 dB—0 Hz	100 dB—6 Hz
Horizontal Tracking (error)	13.0	17.1	15.4	15.9
Vertical Tracking (error)	15.2	20.8	16.4	18.9
Red Lights (seconds)	1.33	1.30	1.28	1.25
Green Lights (seconds)	1.45	1.43	1.46	1.40

A session was 2-1/2 hours long and each subject completed all sessions within a 2 week period. Each session consisted of five 19 minute trials, which were further divided into four 4 minute blocks. After each 4 minute block of testing a 1 minute rest period was given, and at this time the subjects were informed of their scores on the tracking task. Between trials a 10 minute rest was given, and during the rest periods subjects were instructed to remain seated erect and keep alert. On each of the 4 days of experimental testing, one of the following conditions was presented: (1) no vibration—60 dB noise, (2) no vibration—100 dB noise; (3) 6 Hz vibration at 0.10 g_s—60 dB noise, and (4) 6Hz vibration at 0.10 g_s—100 dB noise. Different orders of presentation were used for administering the experimental conditions. Vibration and noise were administered continuously throughout the 2-1/2 hour test period.

RESULTS

The same analysis of variance technique, a three-way treatment × subject design, was applied to the data obtained from all four measures in the experiment (Tables I and II)). Significant effects were obtained for vibration for both horizontal and vertical tracking. In agreement with previous studies, vibration had a greater effect on the vertical part of the tracking task than it did on the horizontal as can be seen in Figure 3. Vertical tracking also showed a significant effect for trials and for the noise × vibration interaction. The effect for trials is shown in Figure 4. The figure indicates a slight learning or adaptation effect for both horizontal and vertical tracking scores. The lowest scores occurred on trial five for both horizontal and vertical tracking. This may have been an "endspurt" produced by awareness of the subjects that this was the last block of testing during the day. However,

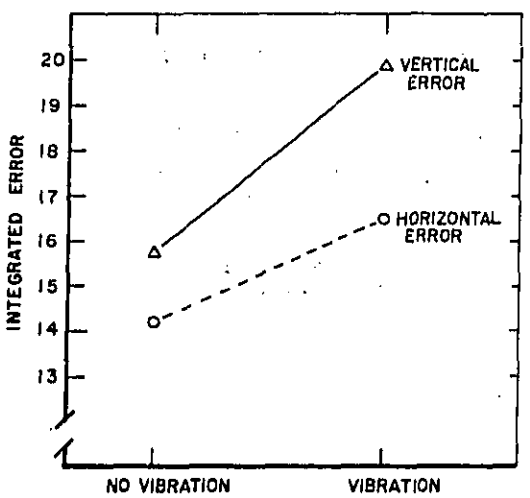

Fig. 3. Mean error for horizontal and vertical tracking during the no-vibration and vibration conditions.

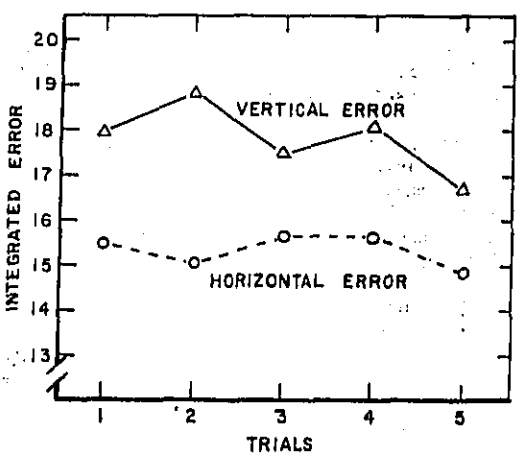

Fig. 4. Mean error for trials for both horizontal and vertical tracking.

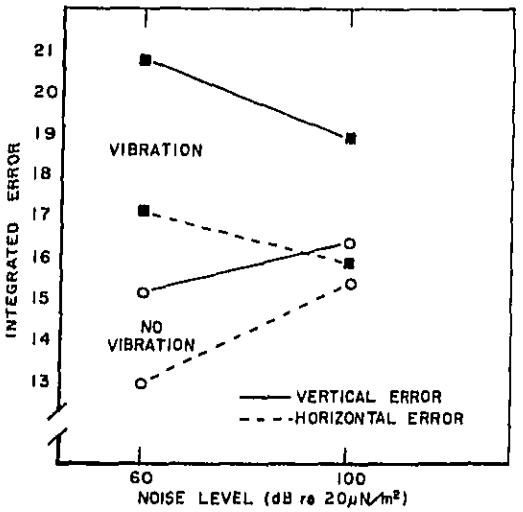

Fig. 5. Mean error for horizontal and vertical tracking at 60 dB and 100 dB with and without vibration.

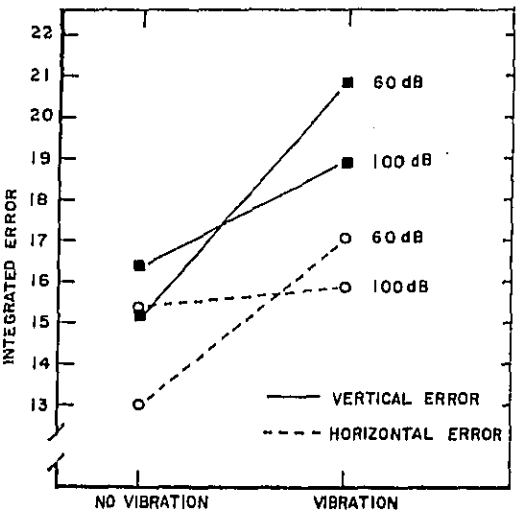

Fig. 6. Mean error for horizontal and vertical tracking at no-vibration and 6 Hz vibration with both noise levels.

the only significant difference between means was found for Trial 2 and Trial 5 of the vertical tracking scores.

The most interesting effect obtained in the experiment was the noise × vibration interaction which was statistically significant for vertical tracking and which approached significance for horizontal tracking. In Figures 5 and 6, it can be seen that the interaction occurred because without vibration 100 dB noise increased tracking error over 60 dB noise, and with vibration the tracking error at 100 dB was less than with 60 dB noise.

The differences between the noise condition means were not significant at either level of vibration for either horizontal or vertical tracking. For vertical tracking scores, vibration was statistically significant at the 60 dB level but not significant at the 100 dB level. Similarly, for horizontal tracking scores, vibration was significant at the 60 dB noise level and not significant at the 100 dB level.

The only statistically significant effect obtained in the analyses of variance for the response time measures was a three-way interaction of noise, vibration and trials for green light response time. The reason for this effect was that the response time was less during the first trial and the fourth and fifth trials for the 6 Hz—100 dB condition than for the other three conditions (Fig. 7). And this difference, of course, was reflected in the overall mean for conditions, where the fastest reaction time was obtained for both green and red lights. However, these differences are not statistically significant, and the response time data are probably not reliable since a large number of errors were obtained under all conditions. The errors were not orderly in terms of conditions or time. In previous experiments (Harris and Shoenberger[5]; Sommer and Harris[6]) errors were so few that they could safely be ignored in computing response time. This was not true in the present experiment, and the increase in errors occurred because subjects were not given knowledge of results concerning errors after each 4 minute block of testing, as was done in previous experiments. As a consequence, the response time tasks became truly secondary tasks, and the scores obtained in this experiment are not comparable to those obtained previously.

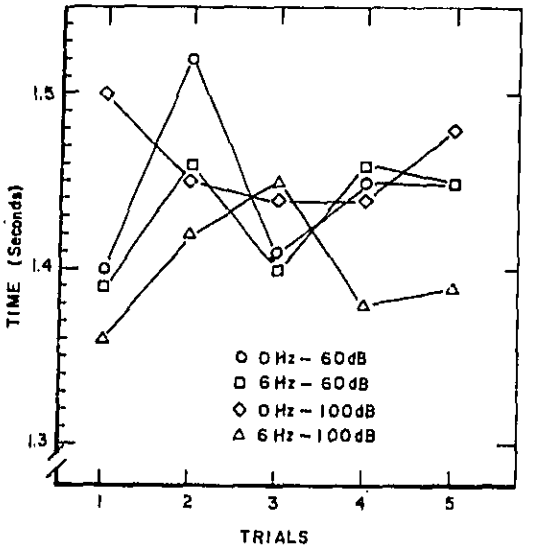

Fig. 7. Mean green light reaction time, per response, for trials for each experimental condition.

DISCUSSION

The results of the present experiment support those of Grether *et al.*[1,2] and add considerable generality to the findings. Approximately the same pattern of results was obtained even though the studies differed considerably in intensity levels of noise and vibration, and in testing time. Since heat was not included as a variable in the present study, this suggests that Grether's results were due primarily to the interaction of noise and vibration. This is partially supported in the second study (Grether *et al.*[2]) where all four performance tasks showed less adverse effect with combined heat, noise, and vibration than with vibration and heat. Grether *et al.*[2] tested two hypotheses concerning why such results occurred. The first hypothesis was that heat or noise reduced the vibration energy received by the man, either by relaxation or other alteration of body musculature. This was not confirmed when the amount of body transmission was measured by an accelerometer attached to the right shoulders of the subjects. Body transmission of the vibration was approximately equal during both conditions in which vibration was presented. The second hypothesis was that motivation was increased by the presence of an on-site medical monitor during the combined heat, noise, and vibration condition. By this means, the experimenters were inadvertently informing the subjects that this was the most important condition, consequently, the subjects exerted more effort and obtained better scores than they would ordinarily have obtained. In the second experiment, the medical monitor was not present and approximately the same results were obtained. The expectations of the subjects and their beliefs about the relative importance of the experimental conditions cannot be ruled out as a cause, since they could not be kept ignorant of the test conditions. Nevertheless, in both of Grether's studies as well as in the present one, attempts were made to insure that subjects did their best on each day of testing. They were repeatedly urged to do their best and were given knowledge of results after each 4 minute period of tracking.

An interpretation of the results in terms of "arousal" theory is not appropriate unless we assume a lulling or somnolent effect for vibration. Otherwise, one must explain why high level noise without vibration did not improve performance over low level noise without vibration. If a lulling effect is accepted then the explanation would be that low level noise does not alert the subjects while high level noise alerts the subjects and partially compensates for the lulling effect, which leads to superior performance with high intensity noise combined with vibration. This seems an unlikely interpretation because of the motivation controls mentioned above and because in the Grether *et al.*[1,2] studies a level of vibration (0.30 g_z peak acceleration) was used that was unlikely to produce a somnolent effect.

A better explanation for the subtractive interaction of noise and vibration is that high intensity noise inhibits input from the other sense modalities. If this is the case, the noise may make the individuals less sensitive to vibratory input from the receptors of the skin, muscles, and joints. Vibration, therefore, may be less distracting when presented with high level noise than when presented with low level noise. This, of course, is not an original suggestion, and is a *post hoc* explanation of the results of these studies, subject to experimental test.

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13. ABSTRACT

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