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COGNITIVE PERFORMANCE DURING LONG-DURATION VIBRATION

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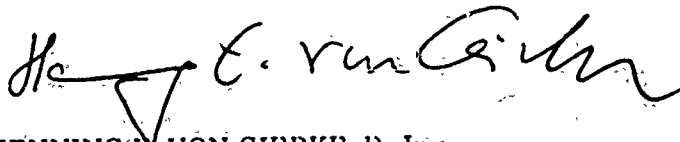
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FOR THE COMMANDER



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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) To evaluate the effects of vibration exposure duration on cognitive performance, the performance of 16 subjects was measured on a Complex Counting Task (CCT) and a reading task during a three-hour exposure to each of two whole-body vibration conditions. Quasi-random vibrations with frequencies from 2.6 through 16 Hz were presented at two intensities, 0.164 R.M.S. Gz and 0.03 R.M.S. Gz. During each of the two three-hour sessions the subjects performed the reading task for the first 45 minutes of each hour, and the CCT for the last 15 minutes of each hour. Performance on the CCT showed no effect of exposure duration;		

however, the reading task did provide evidence of such an effect. For the reading task, the high-level vibration condition showed a relative decrement in the amount read that increased with exposure duration. During low-level vibration there was a significant increase in reading rate that did not occur during high-level vibration.

PREFACE

The research presented here was conducted by personnel of the Biological Acoustics Branch and Biodynamic Effects Branch, Biodynamics and Bioengineering Division, Air Force Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio, under work unit 72310914 "Human Capabilities in Acoustic and Vibration Environments." Instrumentation and operation of the vibration machine; and production, analysis, and calibration of the vibration stimuli were accomplished by personnel of the University of Dayton Research Institute, under Contract F33615-79-0509.

INTRODUCTION

Performance decrements related to mechanical force environments may be classified into two primary categories — those produced directly, by interference with an essential sensory or motor aspect of the task, and those produced indirectly, by a generalized stress effect that in some way affects central nervous system processes. Vibration induced relative movement between the hand and a control, or masking speech by noise are examples of direct interference effects; while degradation of intellectual or cognitive functions, like problem solving or mental arithmetic, are examples of generalized stress effects. Since it is unlikely that mechanical force environments directly affect central nervous processes (in the same sense that they affect sensory and motor functions), one must hypothesize some sort of intervening mechanism; for example a greater than optimum arousal level, a reduction in available information processing capacity, or a reduction in motivation.

Studies indicating whole-body vibration effects on cognitive performance are relatively few. Tasks involving simple cognitive functions, such as pattern recognition or monitoring of dials or warning lights, are essentially unaffected by vibration (see Shoenberger (1972) for a review). However, a few experiments using more demanding "intellectual" tasks have shown significant vibration effects. Huddleston (1964) used a "rolling arithmetic" task, combining mental addition and recent memory, and found that performance on this task was significantly slower for 0.5 G_z (peak) sinusoidal vibration at 4.8, 6.7, 9.5 and 16 Hz than for a static control condition. A subsequent experiment with this task (Huddleston, 1965), using the same acceleration level at 4.8 and 6.7 Hz, provided confirmation of these results. A mental arithmetic task was also used by Harris and Sommer (1971) in a study of the combined effects of noise and vibration. Their task involved short-term memory and mental subtraction and was performed during exposure to broadband noise (80, 90, 100 and 110 dBA), both with and without 5 Hz vibration at 0.25 G_z (peak). Noise alone and vibration plus 80 or 90 dBA noise did not affect performance; however, vibration combined with 100 or 110 dBA noise significantly reduced the number of correctly solved problems.

Investigations of the combined effects of noise and vibration have also shown that noise, depending on its intensity, can either increase or decrease the effects of vibration on tracking performance. When noise levels of 100 to 105 dBA were combined with vibration, tracking error was less than with vibration acting alone (Grether et al., 1971; Grether et al., 1972; Sommer and Harris, 1973). However, when a noise level of 110 dBA was used, the interaction was reversed and tracking error increased when the noise was added to the vibration (Harris and Shoenberger, 1970; Harris and Sommer, 1973). Since noise effects on tracking performance are probably caused by interference with central processes, these interactions suggest that some of the effect of vibration on tracking is related to cognitive factors.

The effect of duration of exposure is another topic that has been relatively neglected in vibration research. In the performance area there is little evidence that decrements related to vibration duration are any different from time-dependent changes during static conditions (Maslen, 1972; Shoenberger, 1972). Very few studies have been conducted with exposure duration as a primary variable, and those (Gray et al., 1976; Holland, 1967; Hornick and Lefritz, 1966) have not included measures of complex cognitive performance. Since time-dependent effects should logically be related to the central processing mechanisms mentioned above, cognitive tasks should be more likely to show decrements as a function of vibration duration.

In a recent study of the effects of noise and vibration (Harris and Shoenberger, 1980) performance was measured for 30 min on a Complex Counting Task (CCT), during exposure to each of four experimental conditions. Two levels of noise, 65 dBA and 100 dBA, were presented both with and without a 0.36 R.M.S. G_z complex waveform vibration, made up of five sinusoids from 2.6 to 16 Hz. The CCT proved to be sensitive to the effects of both noise and vibration, showing a decrement in performance during vibration and during 100 dBA noise. However, vibration plus 100 dBA noise produced less decrement than either of these conditions alone. This subtractive interaction is like that found previously with tracking performance when vibration and 100 dBA noise were combined (Grether et al., 1971; Grether et al., 1972; Sommer and Harris, 1973). This experiment (Harris and Shoenberger, 1980) also suggested that the CCT was sensitive to duration of vibration exposure. Scores for three 10-min trials were obtained during the 30-min testing period, and the vibration by trials interaction showed a greater decrement as a function of time when the

vibration was present. Although this interaction did not reach the conventional 5% level of significance ($p < .10$), the trend of the data suggested that if testing had continued for a longer period of time a significant effect would have been produced. The present experiment was conducted to further explore this possibility by testing cognitive performance during exposure to a similar sum-of-sines vibration environment for a duration of 3 hours.

MATERIALS AND METHODS

SUBJECTS

Sixteen male Air Force military personnel served as subjects. They were physically qualified volunteer members of a vibration panel, and received incentive pay for participation in vibration experiments.

TEST FACILITY

Vibration was produced by an Unholtz-Dickie electromagnetic vibrator (Model MA 250D). The subjects sat in an aluminum seat rigidly mounted to the moving element of the shaker. They were restrained by a lap belt and shoulder harness. The seat pan was fitted with a 2.54-cm (1 in) temperfoam pad, to provide somewhat greater comfort during the 3-hour exposure. Previous research (Allen et al., 1973) has shown that a similar pad had a negligible effect on vibration transmission to the subject over the frequency range from 2-10 Hz. An evaluation of the pad used in the Unholtz-Dickie seat showed that, for the frequencies used in this experiment, vibration-table to shoulder transmissibilities for each of the frequencies individually and for all five combined were essentially identical with and without the pad.

During each vibration run the intensity of the vibration was monitored continuously from an accelerometer attached to the vibration table. The accelerometer signals were amplified and fed to a strip chart recorder and a true R.M.S. meter.

TASKS

The Complex Counting Task (CCT) was again used to measure cognitive performance. On the subject's console (figure 1) there were three small lights mounted on a vertical panel, and three buttons on a horizontal panel. Each of the lights flashed at a different rate. The light on the subject's left flashed once every 13 seconds, the middle one every 5 seconds, and the one on the right flashed every 9 seconds. The task was to keep a simultaneous count of the number of flashes of each light. The subject was instructed to press the button for each light every sixth time the light flashed. On an experimenter's panel, separate measures were obtained for the subject's responses to each light. For each light, scores for total responses, early responses, and late responses were obtained. An early response occurred when the subject responded before a light flashed six times, and a late response when the subject responded after a light flashed more than six times.

Our previous experience with the CCT (Harris and Shoenberger, 1980) indicated that the subjects felt that performing this task continuously for 30 min was very difficult and demanded unusual effort and concentration. Therefore, it seemed unreasonable to require the subjects to perform the CCT continuously during 3-hour testing sessions. We decided to administer the CCT during the last 15 min of each hour of testing and to fill the remaining 45 min with some less demanding activity.



Figure 1. Complex counting task, subject's console.

There are anecdotal reports that, even when one can see the letters without difficulty, reading while traveling seems to require an increase in effort, compared to a static environment, so that at some point the effort becomes too great and one just stops reading. Thus, a reading task might also show duration effects during vibration. Simply allowing the subjects to read or not, as they desired, and observing the effects of vibration was felt to be too uncontrolled and very susceptible to variability from extraneous factors. Therefore, the subjects were required to read during the first 45 min of each hour, to see if the amount read was affected by vibration. A high-school senior level, programmed English text (Blumenthal, 1972) was chosen as the reading material, with the expectation that the subjects' earlier training and experience with English would minimize individual differences and learning effects. The programmed book format facilitated measurement of the amount read during each 45-min period. Each subject was instructed to work at his own pace and the number of frames read was recorded at the end of each period. At the start of the next period, the subject began reading at the frame he reached in the preceding period.

VIBRATION CONDITIONS

Vibration was in the vertical direction (z-axis) and was continuous throughout each of the two 3-hour test sessions. The waveform was quasi-random and was produced by combining five sinusoidal frequencies, 2.6, 4.1, 6.3, 10 and 16 Hz. These are approximately the preferred center frequencies of every other third-octave band from 2.5 to 16 Hz. However, slight departures from two center frequencies were made to avoid harmonic relationships between frequencies. For one test session, the intensity of each frequency was set at the ISO 4-hour Fatigue-Decreased Proficiency Level (International Organization for Standardization, 1978). This produced an overall acceleration level of 0.164 R.M.S. G_z . When this vibration input was evaluated by the ISO weighting method (IOS, 1978) it yielded a value (0.121 R.M.S. G_{zw}) slightly less than the 3-hour Exposure Limit (0.128 R.M.S. G_{zw}). For the other test session, the intensity of each frequency was set at the ISO 8-hour Reduced Comfort Boundary, which produced an overall acceleration level of 0.03 R.M.S. G_z . Evaluation of this input by the weighting method gave a value (0.022 R.M.S. G_{zw}) approximately equal to the 3-hour Reduced Comfort Boundary (0.020 R.M.S. G_{zw}).

PROCEDURE

The experiment was carried out during four sessions — two training sessions and two formal testing sessions. In the first training session each subject had two 15-min periods of practice on the CCT, without vibration. During the second practice session each subject again had two 15-min periods of practice on the CCT, the first without vibration and the second with vibration at the high level. Also included in the second practice session was a brief indoctrination on the reading task.

During each of the two formal test sessions the subjects received a static 5-min warmup trial on the CCT and then were exposed to 3 hours of continuous vibration. In one session the intensity of vibration was set at the high level (0.164 R.M.S. G_z), and in the other session it was set at the low level (0.03 R.M.S. G_z). This very low-intensity vibration was used as a "control" condition, rather than a complete absence of vibration, in an attempt to minimize motivational differences between performing the tasks during a 3-hour exposure to a stressful environment and performing them for 3 hours in a completely static environment. Half of the subjects received the two vibration levels in the order high-low, and the other half in the order low-high. In both test sessions, the subjects were required to read the programmed English text during the first 45 min of each hour, and to perform the CCT during the last 15 min of each hour. Subjects were informed of their scores on the CCT at the end of the 5-min warmup trial and at the end of the 3-hour test session.

RESULTS AND DISCUSSION

For each of the two vibration levels, performance scores were tabulated for each subject for the first 45 min of each hour for the reading task, and for the last 15 min of each hour for the CCT. The score for the reading task was the number of frames of the programmed English text read during each 45-min period, and the score for the CCT was the percentage of correct responses during each 15-min period. Table 1 presents the mean number of frames (averaged across subjects) completed on the reading task during each experimental condition, and table 2 gives the mean percent correct on the CCT for each experimental condition.

TABLE 1
MEAN NUMBER OF FRAMES READ ON READING TASK
FOR EACH EXPERIMENTAL CONDITION

Vibration Level	1	Hours 2	3
Low (0.030 R.M.S. G_z)	168.3	181.3	201.9
High (0.164 R.M.S. G_z)	168.5	162.6	179.4
Both Levels	168.4	171.9	190.6

TABLE 2
MEAN PERCENT CORRECT ON COMPLEX COUNTING TASK
FOR EACH EXPERIMENTAL CONDITION

Vibration Level	1	Hours 2	3
Low (0.030 R.M.S. G_z)	90.1	92.1	91.2
High (0.164 R.M.S. G_z)	87.9	89.9	92.1
Both Levels	89.0	91.0	91.7

Each of the two sets of data was evaluated for significant effects, using an analysis of variance (ANOVA) for repeated measurements. The variables included in each analysis were subjects (S), vibration levels (V), and hours (H). Results of the ANOVA for the reading data are given in table 3. The ANOVA showed that the main effect of hours was significant beyond the .005 level. This effect is presented graphically in figure 2 (and is also given in the bottom row of Table 1). The number of frames read during the first 45 min of each hour increased during the 3-hour testing session, especially from the second to the third hour. This result indicates that, despite the familiarity of the subjects with the English language, some learning took place during the 3 hours of testing.

TABLE 3
ANALYSIS OF VARIANCE FOR READING TASK

Source	df	Sums of Squares	Mean Squares	F	p
Subjects (S)	15	296752.41			
Vibration Level (V)	1	4469.01	4469.01	1.09	NS
Hours (H)	2	9151.19	4575.60	7.88	<.005
V X H	2	2385.27	1192.64	1.71	<.20
V X S	15	61733.49	4115.57		
H X S	30	17412.81	580.43		
V X H X S	30	20914.73	697.16		
Total	95	412818.91			

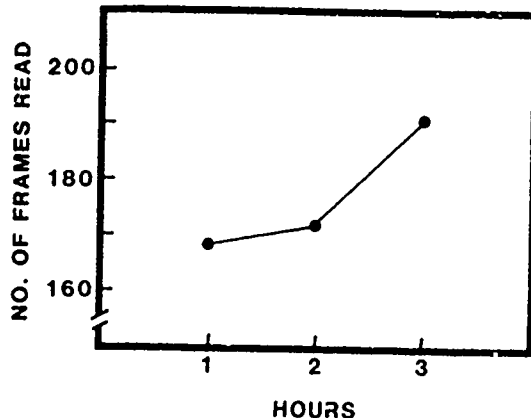


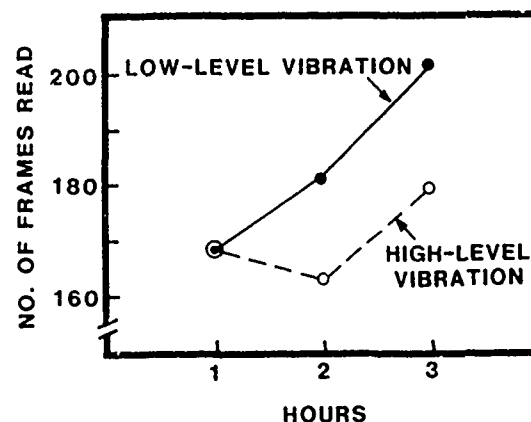
Figure 2

Mean number of frames read on reading task during each hour.

Since the purpose of the experiment was to look for possible effects related to the duration of the vibration exposure, the V x H interaction is of greatest interest. This interaction is depicted in figure 3 and shows that performance on the reading task was virtually identical for the two vibration intensities during the first hour, but differed considerably during the last 2 hours. For low-level vibration the mean number of frames read increased steadily over the 3-hour testing period, but for high-level vibration the number of frames read decreased during the second hour and then

Figure 3.

Mean number of frames read on reading task during each hour for each vibration condition.



increased during the third hour. In view of the importance of the V x H interaction, and the fact that it reached the 20% level of confidence in the overall ANOVA, the simple effects of hours were analyzed at each vibration intensity. The analyses showed that the effect of hours was significant only for the low-level vibration condition ($F_{2, 30} = 5.49, p < .001$). These results indicate that during low-level vibration the subjects were able to continue learning and increase their reading rate throughout the 3-hour test session, and that high-level vibration interfered with this effect and resulted in poor reading performance. Thus, the major effect of the high-level vibration was to slow down the rate of learning. This interpretation is reinforced by t-tests of the differences between the two vibration levels during each hour. Of course there was no difference during the first hour, but significantly more frames were read under the low-level vibration during both the second ($p < .10$) and third ($p < .05$) hours.

Table 4 presents the results of the ANOVA for the CCT data. The analysis demonstrated that the only effect that approached conventional levels of significance was the main effect of hours ($p < .20$). This effect is shown in figure 4 and in the bottom row of table 2, which indicate that the mean percent correct on the CCT during the last 15 min of each hour increased slightly (less than 3%) over the 3 hours of testing.

TABLE 4

Analysis of Variance for Counting Task

Source	df	Sums of Squares	Mean Squares	F	p
Subjects (S)	15	3716.41			
Vibration Level (V)	1	31.51	31.51	1.11	NS
Hours (H)	2	124.75	62.38	1.90	<.20
V x H	2	52.09	26.05	0.80	NS
V x S	15	425.99	28.40		
H x S	30	985.25	32.84		
V x H x S	30	981.91	32.73		
Total	95	6317.91			

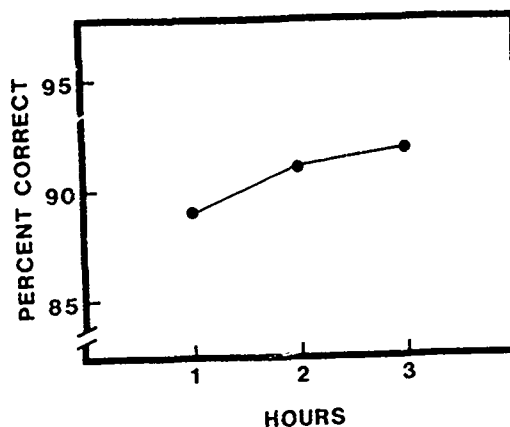


Figure 4. Mean percent correct on complex counting task during each hour.

The ANOVA (table 4) showed that the $V \times H$ interaction for the CCT was not significant, and it is evident from figure 5 that only minor differences in performance on the CCT were produced by the interaction of vibration level and hours. Additional tests to further evaluate the $V \times H$ interaction, parallel to those performed on the reading data, did not reveal any significant differences.

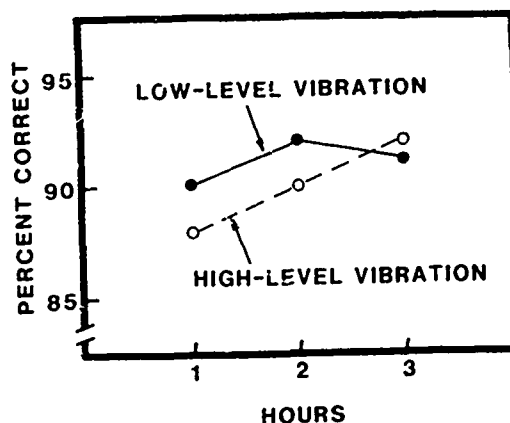


Figure 5. Mean percent correct on complex counting task during each hour for each vibration condition.

Our previous study (Harris and Shoenberger, 1980) suggested that an exposure longer than 30 min would show a significant time effect on the CCT; however, the results of the present experiment failed to support this suggestion. Although the total vibration exposure was for 3 hours and performance on the CCT was tested for a total of 45 min, each block of testing lasted for only 15 min and followed 45-min of performance on the reading task. Evidently this experimental paradigm made the CCT less demanding (and possibly less sensitive to the vibration). A comparison of the overall level of performance on the CCT in this experiment with that in the previous study gives some support to this contention. When averaged across all experimental conditions the mean percent correct in this study was 90.6 (a very high level of performance for this task), while in the previous experiment it was 82.7, a difference of almost 8 percent. In addition, most of the subjects felt that reading the programmed English text was rather boring, and were actually looking forward to performing on the CCT since it gave them a break from the reading task.

Although this experiment did not confirm a duration effect of vibration on the CCT, the results with the reading task provide evidence of such an effect. The $V \times H$ interaction in figure 3 and table 1 does not show an absolute decrement as a function of time, but shows a relative decrement in the number of frames read for the high-level vibration condition that is definitely time dependent. The tests for the simple effects of hours and the increasing difference in amount read at the two vibration levels from the first to the third hour both indicate a time dependent effect.

Switching from task to task in this experiment may have improved performance on both tasks. Performance on the CCT was something of a novelty, because it was only required for 15 min of each hour, and at that time it also provided a welcome relief from the reading task. A better approach might have been to measure performance continuously on the same task. However, prolonged testing on a single task also involves other factors, such as boredom, loss of motivation, and task-related fatigue, which may reduce the reliability of the task and its sensitivity to the effects of a stressor. Unfortunately, the ideal experimental paradigm for investigating time-related effects probably does not exist.

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