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EFFECTS OF NOISE ON THE PERFORMANCE OF A MEMORY-DECISION-RESPONSE TASK

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16. Abstract

An investigation has been made to determine the effects of noise on human performance. Fourteen subjects performed a memory-decision-response task in relative quiet and while listening to tape recorded noises. Analysis of the data obtained indicates that performance was degraded in the presence of noise. Significant increases in problem solution times were found for impulsive noise conditions as compared with times found for the no-noise condition. Performance accuracy was also degraded. Significantly more error responses occurred at higher noise levels; a direct or positive relation was found between error responses and noise level experienced by the subjects.

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EFFECTS OF NOISE ON THE PERFORMANCE OF A MEMORY-DECISION-RESPONSE TASK

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SUMMARY

The present study investigated the effects of noise on the performance of a self-paced memory-decision-response task, primarily of a mental nature and requiring high subject concentration. Fourteen subjects performed the task in relative quiet and while listening to a variety of commonly heard noises, half of which were aircraft noises. Quality of work, as well as rate of work, was examined.

Analysis of the performance data showed that different subjects and noises had statistically significant effects upon mean task time. Performance degradation was caused by noises of impulsive character. A positive relation was found between error task responses and sound pressure level experienced by the subjects. Both speed and accuracy on the memory-decision-response task were degraded by the noises used in the testing situation.

INTRODUCTION

Noise has gained national attention as an unwanted byproduct of society's technological advances. This attention has resulted in increased research to determine the sources and transmission of noise and the effects of noise on both man and his environment. Research on the effects of noise on man (in particular, aircraft noise) has followed three different paths: somatic or physiological effects, subjective effects such as annoyance, and effects of noise on performance. The present study is directed toward the effects of noise on human task performance.

Noise present in a work situation may have some adverse effects which degrade performance from that under quiet conditions. Investigations have been made of the effects of many kinds of noises on the performance of primarily mental tasks. Broadbent (ref. 1) briefly outlined several early experiments; studies by Morgan in 1916 and Ford in 1929 showed task performance degradation with changes in the noise environment. Other studies cited in reference 1 showed no detrimental noise effects once the subjects became familiar with the task and noises. Broadbent (ref. 2) found that performance of an intellectual task deteriorated more in noise than in quiet. Woodhead (ref. 3) found that brief bursts of loud low-frequency noise caused an increase in the number of decisions omitted during a decision-making task. Teichner, Arees, and Reilly (ref. 4) concluded that change in noise level, regardless of the direction of change, has a distracting effect on task performance. Blau (ref. 5), Hoffman (ref. 6), and Slater (ref. 7) found no significant noise effects on student performance of relatively long-term intellectual tasks. Kryter (ref. 8) outlines an experiment made by Jerison in 1956 which showed that noise severely and uniformly depressed performance of a complex counting task. Reference 8 also cites a study made by Kovrigin and Mikheyev in 1965 which found that higher noise level in a room used by postal letter sorters increased the number of sorting errors.

The present study investigates the effects of noise on the performance of a self-paced memory-decision-response task, primarily of a mental nature and requiring a relatively high degree of subject concentration. Fourteen subjects performed the task in relative quiet and while listening to tape recordings of a variety of commonly heard noises. The subjects were unfamiliar with the task, and the noises were presented at varying intensities for relatively brief periods during the task. Data were taken in small units to detect fluctuations in quality of work, as well as rate of work.

EXPERIMENTAL SETUP

The subjects performed the memory-decision-response task under noise/no-noise stimuli conditions presented through earphones. A diagram of the experimental setup is presented in figure 1. The subjects were tested individually in a quiet office environment.

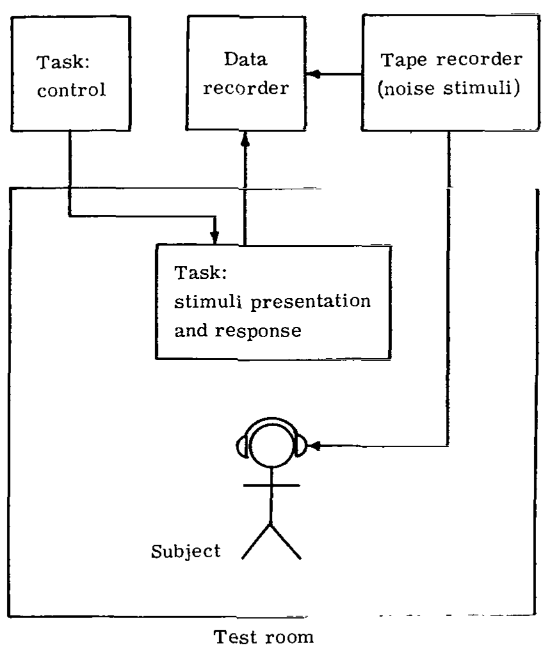


Figure 1.- Diagram of experimental setup.

The task was automatically programed by a remotely located machine and was presented to the subjects by a visual display. The subjects solved the task problems by pushing appropriate buttons on a hand grip. Records were made of the task parameters, the subjects' performance, and the noise conditions.

The smallest unit of the task was a problem which required that a stimulus be encoded to make the proper response. Twenty-five problems in a particular code were presented in a self-paced sequence; this formed one block. Each subject performed 16 problem blocks, randomized between 8 blocks in relative quiet and 8 blocks while listening to tape recorded noises. An example of subject task performance during noise and no-noise blocks is presented in figure 2. In the upper portion of the figure, the overall sound pressure level in decibels (re 2×10^{-5} newton/meter^2) is plotted as a function of time for representative noise and no-noise blocks. In the bottom portion of the figure, the varying problem solution times are indicated for the sequences of each block.

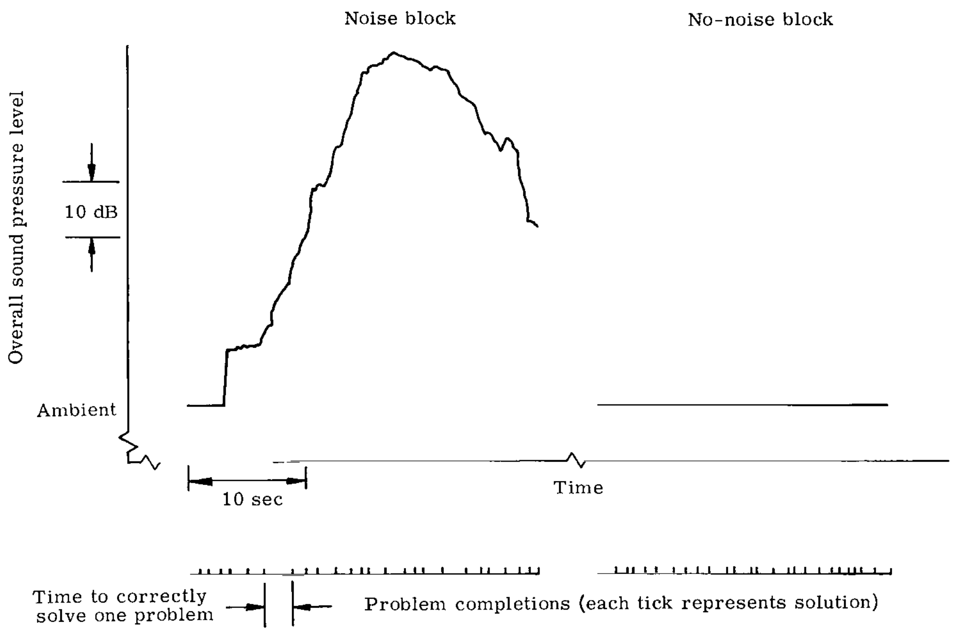


Figure 2.- Representative time histories of noise and no-noise conditions and problem completions.

Experimental Design

The experiment was planned so that each of the 14 subjects would perform 16 blocks of the memory-decision-response task. The noise/no-noise conditions were made subject-blind by randomizing the two conditions among the 16 task blocks of each subject. The sequence of the particular noises to be presented during the noise blocks was also randomized. In this way, an attempt was made to minimize any experimental bias due to ordering of the noise/no-noise conditions or due to ordering of the particular noise conditions. The sequences of presentation for each of the 14 subjects are listed in table I.

TABLE I.- ORDER OF NOISE AND NO-NOISE CONDITIONS FOR EACH SUBJECT

Subject \ Task block	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	0	6	0	0	7	0	2	5	0	0	8	0	0	3	1	4
2	0	8	2	0	1	0	0	0	3	6	0	5	7	4	0	0
3	0	0	3	0	8	0	0	0	7	1	0	4	5	0	6	2
4	0	5	0	2	7	0	0	0	1	0	3	8	4	0	0	6
5	0	6	5	0	4	0	0	0	7	8	0	3	0	0	1	2
6	0	1	0	0	5	6	3	0	8	0	0	2	0	7	4	0
7	0	0	1	5	6	0	3	0	0	8	0	0	2	4	0	7
8	0	4	5	0	0	7	3	1	0	2	0	0	6	0	8	0
9	4	0	0	0	5	0	3	2	0	0	7	6	8	0	0	1
10	2	0	5	0	0	3	8	0	0	0	6	7	0	1	0	4
11	0	5	0	0	4	2	0	0	0	6	1	0	8	3	0	7
12	0	6	0	0	8	7	0	4	5	0	0	3	0	0	1	2
13	0	7	0	0	1	0	4	0	0	6	8	0	0	3	2	5
14	0	0	3	0	5	2	8	0	0	6	0	0	7	4	0	1

Key:
0 No-noise
1 Cannon firing
2 Helicopter flyover
3 Nonsense noise
4 Textile machinery
5 Jack hammer
6 Propeller aircraft static runup
7 Jet aircraft flyover
8 Jet aircraft flyover

Subjects

Fourteen volunteer subjects, employed at the Langley Research Center, participated in this study. The subjects were engineers, technicians, secretaries, clerk-typists, and mathematicians. The subjects ranged in age from 17 to 30 years. All subjects had normal hearing, in their own estimation.

Noises

Eight different tape recorded noises were presented to the subjects through earphones. The noises were

(1) cannon firing
(2) helicopter flyover
(3) nonsense noise
(4) textile machinery
(5) pneumatic "jack hammer"
(6) propeller aircraft static runup

(7) jet aircraft flyover

(8) jet aircraft flyover

As may be noted from the list, the noises varied greatly in character. Some were impulsive; some had intensities and spectra which varied with time; some had constant intensities and spectra. The noises also varied in terms of meaning or recognizability. The spectral analysis of each noise at the points of maximum intensity is shown in figure 3. The levels shown in figure 3 are representative of those noises heard by the subjects; it was not possible to exactly reproduce maximum levels from one subject to the next. Each subject wore the earphones throughout all 16 blocks to attenuate the ambient noise of the experimentation site and to avoid introducing a no-earphone variable into the data.

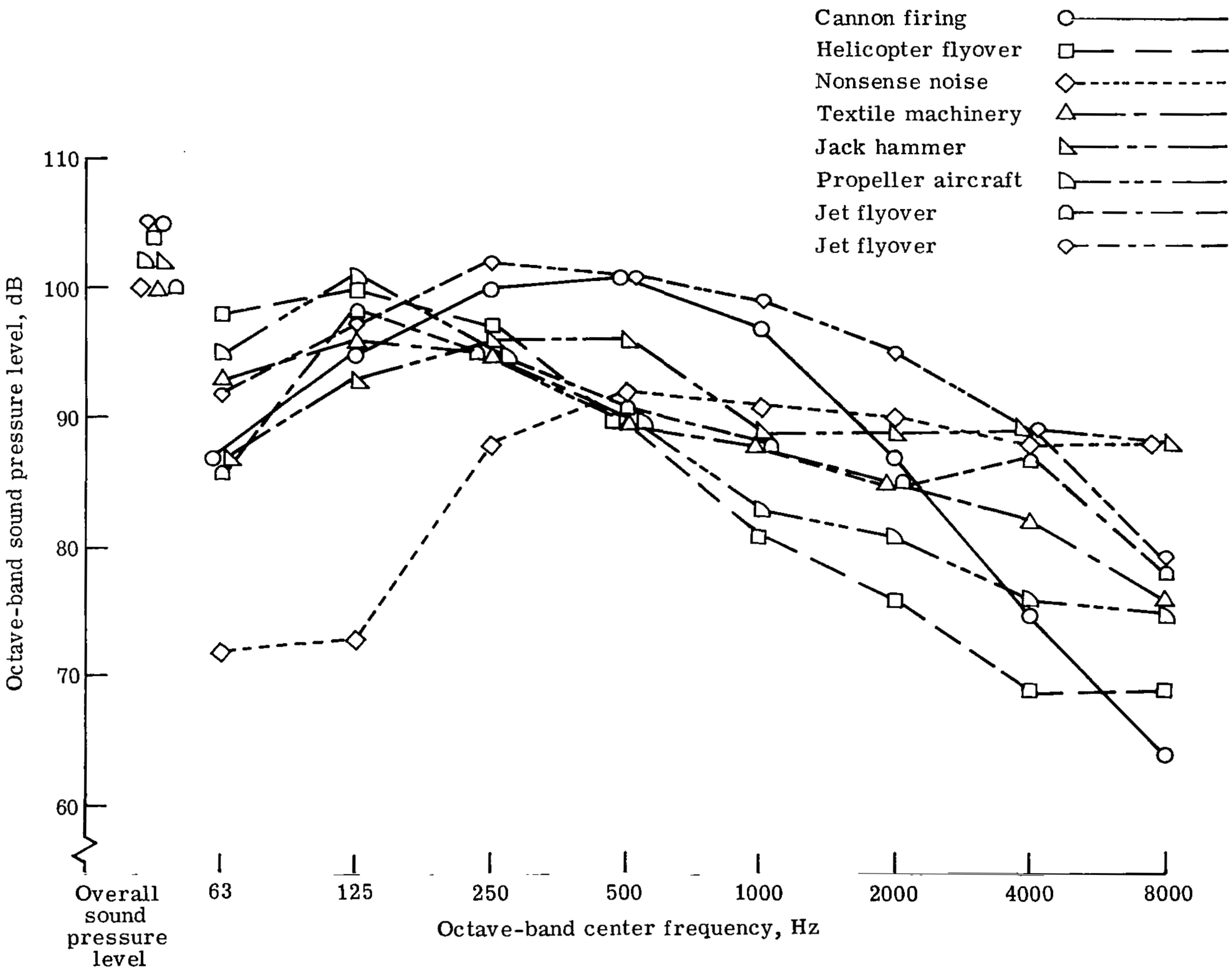


Figure 3.- Overall and octave-band levels of noises used.

Task

The memory-decision-response task used for this study required a relatively high degree of concentration and alertness on the part of the subjects. The self-paced task required that the subjects respond to the illumination of one of four stimulus lights. Response was made by pressing, with the fingers, one of four response buttons. The correspondence between stimulus lights and response buttons was determined by a four digit code which the subjects had to mentally retain from a brief display at the beginning of each block of 25 problems.

Apparatus.- The particular device used in this study was programed with six different codes and eight different sequences of 25 problems. Both codes and sequences were presented in such a manner as to appear random. The subjects' portion of the device, made up of the stimulus light bank and the response button grip, is sketched in figure 4. Use of a code is also illustrated in the figure. To correctly solve the problem shown, several encoding operations must be performed. The third stimulus light is illuminated; the third digit of the code is "1"; the first button must be depressed to correctly solve the problem. The problem illustrated in figure 4 is the first problem of a block of 25 problems. After this first problem is solved, the code ceases to be displayed and must be mentally retained by the subject for the remaining 24 problems of the block. However, the code could be reviewed, for as long as needed, by depressing the code review button. Such a code review would be recorded as an abnormal response.

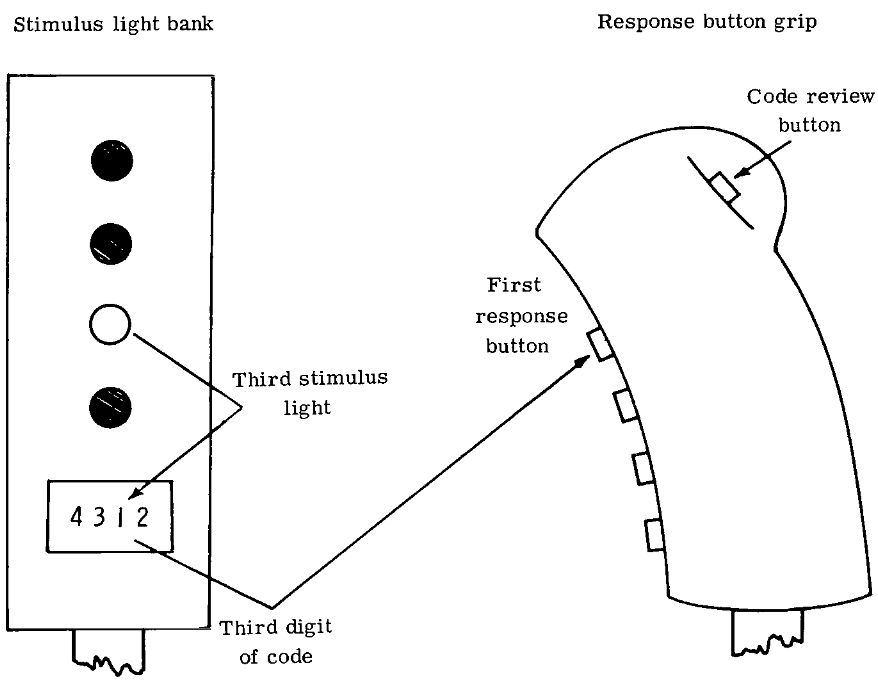


Figure 4.- Sketch of the stimulus light bank and response button grip, and illustration of the use of a code.

Data.- The subject performance data recorded were (1) time to correctly solve each problem, (2) incorrect responses and code reviews (if any) while solving each problem, and (3) sound pressure level experienced when the correct response button was depressed. Other data were recorded concerning the code, stimulus light sequence, response button sequence, and noise (or no-noise) presentation. All data were recorded on the basis of problems rather than blocks; individual problem data were combined, as appropriate, for block and subject statistics.

Test Procedures

Each subject was tested individually. Upon reporting for participation in the experiment, each subject was told that the study was an investigation of the effects of noise on performance of a memory-decision-response task. The subject was then instructed in the use of the device, fitted with earphones, and allowed two no-noise practice blocks to familiarize himself with the task device. During these practice blocks, an experimenter was available to answer questions concerning use of the device. When the subject could perform the task, the experimenter left the subject alone in the experimentation room to begin the experimental blocks.

The various noise and no-noise conditions were presented randomly during the 16 experimental blocks which lasted approximately half an hour. Rest periods or intervals between blocks lasted approximately 2 minutes. After completion of the 16 blocks, each subject was thanked for his participation and dismissed. The subjects were not paid for their participation but were excused from their normal duties for participation in the study.

EXPERIMENTAL RESULTS

For the purpose of analysis, each subject performed 192 problems during his eight no-noise blocks and an equal number during his eight noise blocks. All 14 subjects, taken as a group, performed 2688 problems during the no-noise blocks and an equal number during the noise blocks. To avoid introducing a memory variable, data for the first problem of each block are not considered. Recall from the section entitled "Task" that, while solving the first problem of each block, the subjects had to mentally retain the code from the display.

Frequency distributions of all problems worked during no-noise blocks and during noise blocks are presented in table II. Listed are the number of problems solved within the times indicated.

The means and standard deviations of problem solution times for no-noise and various noise conditions are listed in table III. The statistics are listed for each subject

TABLE II.- FREQUENCY DISTRIBUTION OF ALL PROBLEMS

Time, sec	Frequency of –		Time, sec	Frequency of –		Time, sec	Frequency of –	
	No-noise problems	Noise problems		No-noise problems	Noise problems		No-noise problems	Noise problems
0.2	2	2	2.3	18	19	4.4	2	2
.3	9	24	2.4	15	16	4.5	1	2
.4	58	48	2.5	21	14	4.6	2	4
.5	101	78	2.6	18	18	4.7	--	2
.6	106	89	2.7	10	10	4.8	1	2
.7	158	141	2.8	9	11	4.9	--	3
.8	228	223	2.9	10	4	5.1	--	2
.9	272	282	3.0	6	6	5.4	--	2
1.0	285	242	3.1	3	5	5.7	--	2
1.1	253	234	3.2	5	2	5.9	--	2
1.2	240	243	3.3	6	3	6.4	1	--
1.3	174	209	3.4	5	3	6.9	--	1
1.4	161	153	3.5	4	3	7.0	--	1
1.5	129	131	3.6	4	5	7.5	--	1
1.6	107	107	3.7	4	3	8.0	--	1
1.7	60	93	3.8	1	3	9.7	--	1
1.8	51	87	3.9	1	1	9.9	2	1
1.9	58	41	4.0	--	3	Total	2688	2688
2.0	35	36	4.1	2	1			
2.1	25	33	4.2	1	1			
2.2	22	32	4.3	2	--			

TABLE III.- MEANS AND STANDARD DEVIATIONS OF PROBLEM SOLUTION TIMES, IN SECONDS, FOR THE NO-NOISE AND VARIOUS NOISE CONDITIONS

Subject	Mean problem solution time, sec, for –					Standard deviation, sec, for –	
	No-noise	Noise	Noise ≧ 60 dB	Noise ≧ 70 dB	Noise ≧ 80 dB	No-noise	Noise
1	1.28	1.41	1.43	1.37	1.35	0.42	0.70
2	1.11	1.12	1.13	1.09	1.09	.51	.46
3	1.18	1.39	1.34	1.28	1.33	.53	.91
4	1.25	1.33	1.29	1.26	1.22	.59	.61
5	1.16	1.25	1.26	1.31	1.32	.65	.75
6	1.54	1.64	1.62	1.55	1.60	.89	.97
7	1.23	1.35	1.37	1.38	1.37	.49	.48
8	1.20	1.24	1.22	1.17	1.13	.51	.52
9	.95	1.00	1.02	1.01	.97	.43	.78
10	1.52	1.43	1.38	1.46	1.50	.85	.69
11	1.42	1.44	1.42	1.43	1.42	.52	.75
12	1.23	1.24	1.24	1.15	1.14	.68	.67
13	1.12	1.16	1.14	1.13	1.17	.55	.54
14	1.54	1.51	1.51	1.61	1.78	.66	.79
All subjects	1.27	1.32	1.31	1.30	1.31	0.63	0.72
t value		2.81	2.22	1.74	1.83		

and for all subjects as a group. The statistics listed for the noise condition were calculated by pooling all problem time data taken during the noise blocks. Represented in these data are all eight noises at all levels, with portions of the noise blocks when no noise was being presented to the subjects. Subsets of the noise data were used to calculate the mean times for problems worked under increasing noise levels.

DATA ANALYSIS

The data for each subject were examined for significant differences between the mean performance statistics. The mean times for all problems worked under the no-noise condition and all problems worked under noise conditions were examined by using a paired-t test. An analysis of variance procedure was used to examine the effects on mean problem time produced by different subjects, different noises, and increasing noise level. The Duncan multiple range test was used to determine which noises significantly affected the subjects' performance. A linear regression analysis was also used to show noise effects on performance.

Paired-t Test

One of the primary objectives of the present study was to determine whether there were differences in performance under the noise and no-noise conditions. For each subject, all no-noise problem times were pooled to make a no-noise mean problem time. The same procedure was used to determine mean problem times for all noise problems without regard to sound pressure level and for noise problems worked in sound pressure levels equal to and greater than 60 dB, 70 dB, and 80 dB. By using the paired-t test, the subject no-noise means were compared with mean problem times of all noise problems and with those of increasing dB levels. In other words, four paired-t tests were performed on the subject mean problem times: no-noise/noise, no-noise/noise $\geqq$ 60 dB, no-noise/noise $\geqq$ 70 dB, and no-noise/noise $\geqq$ 80 dB. The t values of these tests are listed in table III. Comparison of these t values with those in standard tables showed statistically significant differences (at the 0.05 level, which means that such differences could be expected to occur randomly only 5 percent of the time) between the no-noise and the noise and the noise $\geqq$ 60 dB cases. The differences between the mean times of the no-noise and the noise $\geqq$ 70 dB and noise $\geqq$ 80 dB were not significant (at the 0.05 level).

Analysis of Variance

The mean problem times by block were examined by using an analysis of variance procedure to discover whether the subjects, noises, noise levels, or any interactions thereof produced significant effects. The analysis of variance table is presented as table IV. This table includes the sources of variation and the statistical degrees of freedom associated with each source. The sum of squares and mean square calculated for each source are listed as well as the F ratio for each source $\left(F = \frac{\text{Source mean square}}{\text{Error mean square}}\right)$. Comparison of the calculated F ratio with values from standard F tables, for the appropriate significance level and statistical degrees of freedom, indicates the individual sources of variation which produced statistically significant changes in the mean problem times.

The significant sources of variation (at the 0.05 level) were subject, noise, and the subject-noise interaction. The sources containing noise level were not found to be statistically significant.

Duncan Multiple Range Test

After a significant performance effect due to individual noises was found, the mean statistics were examined to discover which of the eight noises produced the performance degradation. The Duncan multiple range test was used to rank the mean problem times and evaluate the least significant difference between these statistics. The mean problem times for each noise, summed over all subjects and noise levels, are listed in table V. The noises which produced significant effects on mean problem time (at the 0.05 level and in descending order) were the jack hammer, cannon firing, and static propeller aircraft. The other five noises were statistically indistinguishable (at the 0.05 level) in their effects on mean problem time.

TABLE IV.- ANALYSIS OF VARIANCE TABLE

Source	Degrees of freedom	Sum of squares	Mean square	[a] F
Subject, S	13	14.915	1.147	[b] 67.471
Noise, N	7	5.322	.760	[b] 44.706
Noise level, NL	3	.037	.012	.706
$S \times N$	91	25.468	.280	[b] 16.471
$S \times NL$	39	.967	.025	1.471
$N \times NL$	21	.195	.009	.529
Error	273	4.771	.017	
Total	447	51.675		

[a] $F = \frac{\text{Source mean square}}{\text{Error mean square}}$

[b] Significant at the 0.01 level.

TABLE V.- MEAN PROBLEM SOLUTION TIMES FOR EACH NOISE

[Summed over all subjects and noise levels]

Noise	Mean problem solution time, sec
1	[a] 1.41
2	1.28
3	1.30
4	1.25
5	[a] 1.59
6	[a] 1.33
7	1.23
8	1.32

[a] Significant at the 0.05 level.

Regression Analysis

A single linear regression analysis was performed on the no-noise and noise data. The analysis fits data to a straight line of the general equation

$$Y = a + bX$$

where Y is the dependent variable, X is the independent variable, and a and b are unknown constants. Block number was chosen as the independent variable. This choice gave an indication of increasing experience with the task. Dependent variables chosen were mean problem time by block, for each subject, and standard deviation of problem time by block.

Linear regressions were performed on the no-noise, noise, and noise $\geqq$ 60 dB block means and standard deviations. The regression curves of the block mean problem times and block standard deviations are shown in figures 5 and 6, respectively. The Pearson product-moment correlation coefficient r, which is a measure of goodness-of-fit, is listed for each curve.

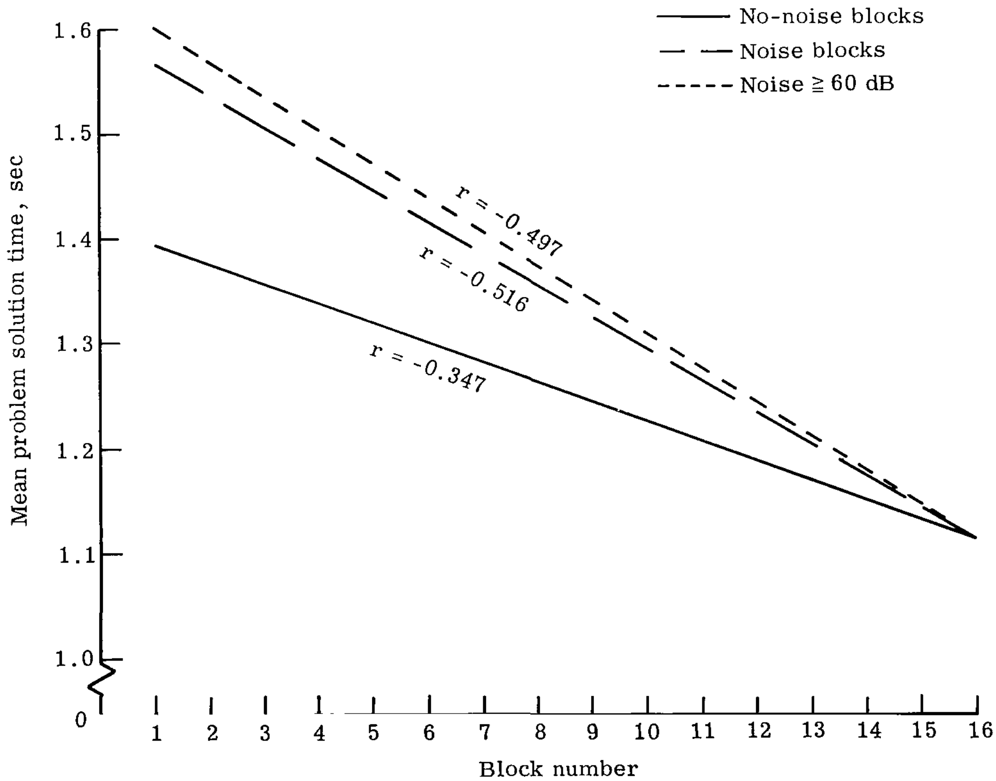


Figure 5.- Single regression analysis of subject mean problem times by block number.

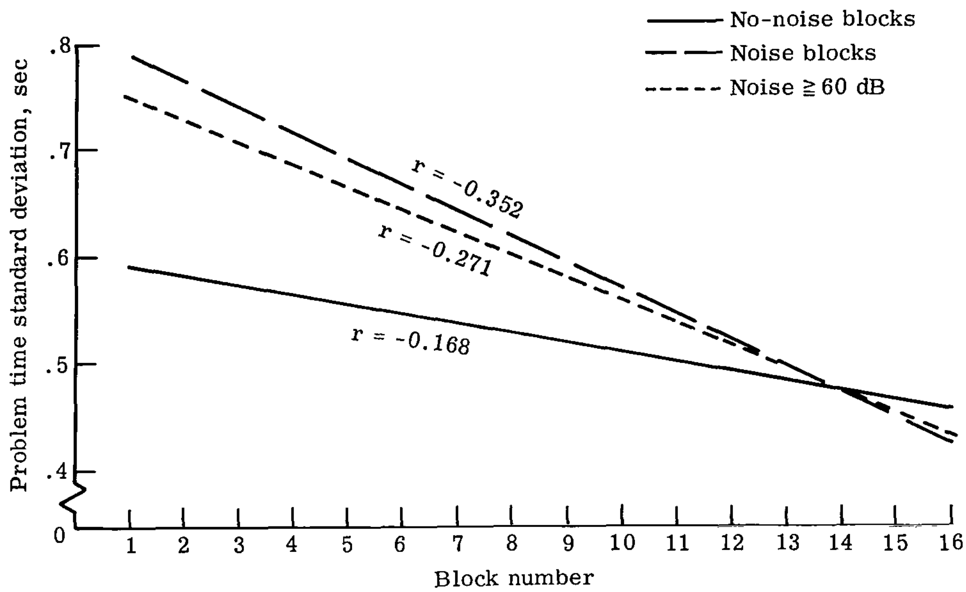


Figure 6.- Single regression analysis of subject problem time standard deviations by block number.

A single linear regression analysis was also performed on all error response data (incorrect responses and code reviews). The independent variable was sound pressure level (SPL) and the dependent variable was the error responses per problem. The resulting curves of this regression analysis are shown in figure 7 with the Pearson product-moment correlation coefficients.

DISCUSSION

In the present study, no attempt was made to direct the investigation toward specific effects, noises, or psychophysical factors. Rather, general treatments such as noise and no-noise were used. The noise conditions ranged widely in character, meaning, duration, frequency content, and intensity. It was expected that any results would have some applicability to quiet and noisy task situations.

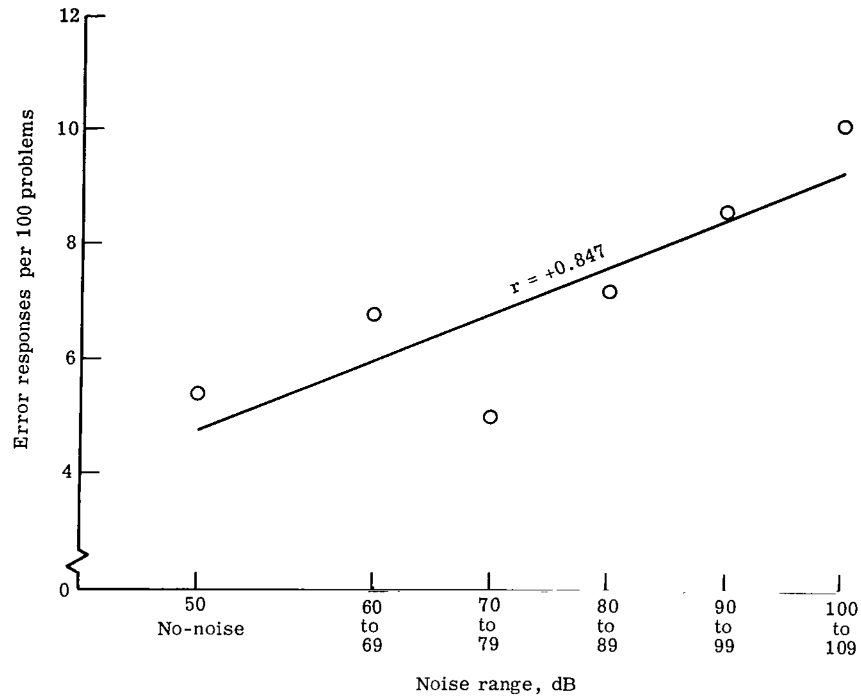
The analysis of variance results showed several factors affecting the task performance. The most significant effect on mean problem solution time was due to different subjects. This result was expected; different subjects should perform the memory-decision-response task with differing facility or dexterity. Similarly, different noises were expected to have different effects upon subject performance. The significant relation between the subject-noise conditions and task performance was also expected – that is, different effects on the performance due to different subjects reacting to different noises. The effect of levels of the various noises was, however, statistically indistinguishable; intensity level, over the range investigated, had no distinguishable effect on performance.

After having established that the different noises did affect the mean problem solution times, it was necessary to discover whether the effect was a degradation or improvement in performance. The paired-t test showed that the noise performance was degraded from the no-noise condition. Subsets of problems worked in increasing noise showed smaller effects as noise intensity increased, the effect becoming insignificant above a noise intensity of 70 dB. This finding supports the analysis of variance result which showed that noise level had no significant effect.

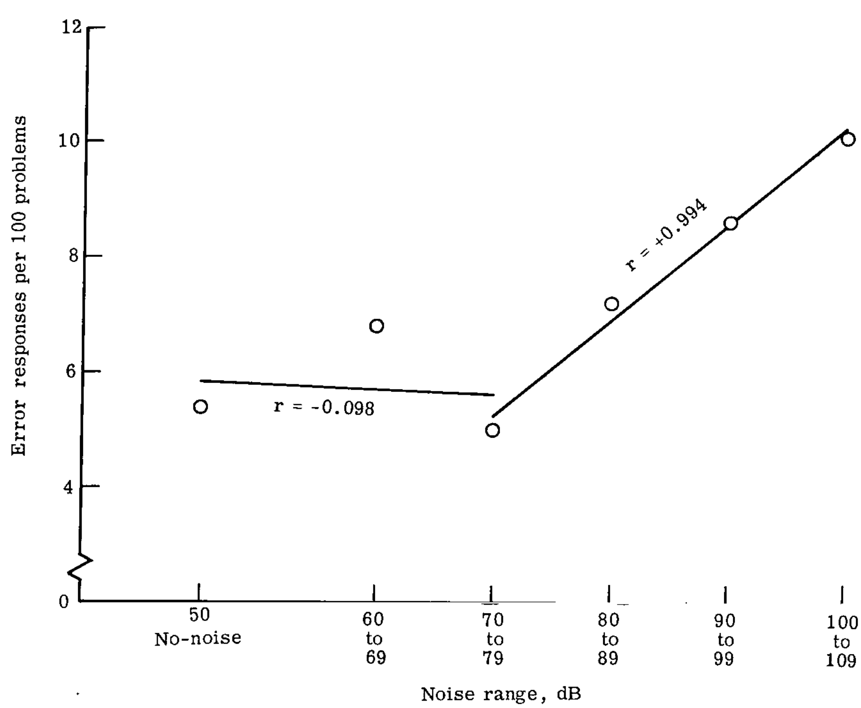
The analysis of variance and paired-t test showed that noise condition had a degrading effect upon the mean problem time. The Duncan multiple range test showed that the most significant performance degradations were due to the jack hammer and cannon firing (both of impulsive character), with a much less significant effect due to the propeller aircraft.

Linear regressions were performed of problem time means and standard deviation with increasing experience with the task. The linear regression curves are presented in figure 7. This analysis illustrates that noise exposure increased the time necessary to correctly solve the problems and increased the variability of these times. The slope of the regression curves indicates that as the subjects became more familiar with the task, the degrading effects of the noises diminished. It should be mentioned, however, that the Pearson product-moment correlation coefficients of these regressions are not high. The regressions show general trends but do not indicate strong functional relationships.

The regressions of error responses with increasing noise intensity show a possible factor in the performance degradation with noise. One possible interpretation of the data is a single least-squares line through the points, shown in figure 7(a). Another intuitively better approach is to set up two regimes of error responses, as shown in figure 7(b). One would expect a certain proportion of such responses to be committed during task performance under normal or usual conditions. This proportion of errors is estimated by the no-noise errors. One might also expect that a breaking point exists between quiet and noisy conditions and that above this point error responses are committed, due to the noise, in addition to those normally occurring. Such a two-regime approach is shown in figure 7(b). Error responses committed below approximately 80 dB show little relation to the noise level – that is, it is not possible to reject the hypothesis that, in this region, there is no relation between error responses and noise intensity.



(a) Single noise level regime.



(b) Two noise level regimes.

Figure 7.- Single regression analysis of error responses by range of noise level.

CONCLUDING REMARKS

An investigation has been made to determine the effects of noise on human performance. Fourteen subjects performed a memory-decision-response task in relative quiet and while listening to tape recorded noises. Analysis of the data indicates that performance was degraded by impulsive noises. Significant increases in problem solution times were found for the noise conditions, as compared with times found for the no-noise condition. Performance accuracy was also degraded. Significantly more error responses occurred at higher noise levels; a direct or positive relation was found between increasing noise level experienced by the subjects and number of error responses.

Langley Research Center,
National Aeronautics and Space Administration,
Hampton, Va., March 14, 1972.

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