A STUDY OF THE EFFECTS OF ILLUMINATION AND NOISE ON SIMPLE MOTOR PERFORMANCE

RESEARCH REPORT

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By

Carol A. Gardinier

Approved by

Dr. Newton C. Ellis
Chairman

Dr. Paul N. Hale, Jr.

Dr. James Elliott

Dr. R. D. Huchingson

Texas A&M University
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13. ABSTRACT

This paper investigates the effects of two environmental parameters, illumination and noise, on human performance. While many single-factor studies have been made on both illumination and noise, relatively little research has been done to determine multi-factor environmental effects on performance. Studies of the combined effects of various environmental factors would be useful to both government and industry in the maintenance area. For example, the Army could use such information to determine more accurate estimates for maintenance task times and repair times. In an organization as large as the Army, with its huge investments in maintenance operations this could result in a significant cost reduction.

In this study, subjects perform a manual task under four conditions of illumination and noise. The results show an effect due to illumination but no effects due to noise or the noise-illumination interaction.

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The ideas, concepts and results herein presented are those of the author and do not necessarily reflect approval or acceptance by the Department of the Army.

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CHAPTER I

INTRODUCTION

General

There has been much research performed in the area of environmental testing to determine the effects of various environmental factors on human performance and activity. Most of this research has been confined to the study of a single factor, however, while little attention has been paid to multi-parameter tseting. Since man's normal environment includes the effects of more than one parameter it seems reasonable to attach greater importance to studies of two or more factors.

The knowledge gained from this type of research could be applied to many areas. Studies of multi-parameter effects on performance could be used by safety groups if reaction times were used as a data base. Organizations having large maintenance divisions such as the Army would also be aided by this research through information useful in determining maintenance task times and repair times. In general, studies of multi-parameter effects on performance would result in improved, more efficient designs for man-machine systems in addition to a better understanding of how man performs in his environment and what can be done to improve his performance.

Problem

The main purpose of the experiment is to determine the effect of a combination of two environmental parameters, illumination and noise, on simple motor performance. Both illumination and noise are also examined individually to determine the single-factor effects.

Research Hypotheses

The null hypotheses against which the research hypotheses will be tested are: 1. Illumination has no effect on performance; 2. Noise has no effect on performance; and 3. The interaction of illumination and noise has no effect on performance.

Summary

In this paper, a two-factor study of the effects of illumination and noise will be presented. Chapter II contains the results of a survey of the literature on noise and illumination. The experiment is described in Chapter III and an analysis of the data is given. Chapter IV is a discussion of the results of the experiment. The conclusions and recommendations for future research are presented in Chapter V.

CHAPTER II

LITERATURE REVIEW

Illumination

Many studies have been made to determine the adequate levels of illumination necessary for various human tasks and activities. The criteria used to establish these levels include visual acuity, heart rate, blink rate, muscular tension, opinions and preferences, and the critical level of illumination, which is described by Tinker (15)* as being the intensity beyond which there is no appreciable increase in the efficiency of performance as the illumination is increased. Equipment used to determine illumination levels includes optical systems for measuring visibility such as the Luckiesh-Moss visibility meter (1), and the Blackwell Visual Task Evaluator (11). There has been much controversy concerning the choice of criteria for use in setting standards and, as a result, there are no universally accepted standards. However, the trend in recent years has been directed toward the use of standards established by the Illuminating Engineering Society which

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*Numbers in parentheses refer to list of references at the end of the paper.

were obtained using the Blackwell Visual Task Evaluator.

Numerous laboratory studies have been made to determine the effect of varying levels of illumination on performance of a task. In a study conducted by Simonson and Brozek (13), subjects performed a letter recognition task for several two-hour periods, each of which having a different illumination level. The results of that study showed a marked increase in performance with illumination levels up to 15 footcandles, a smaller rate of increase from 15 to 50 footcandles, and practically no increase above 50 footcandles.

Another study by Tiffin (14) investigated the effects of three levels of illumination (5, 50, and 150 ft-c) on the performance of a manual task. Each subject performed the Purdue Hand Precision Test under each level of illumination. Again, a significant improvement in performance occurred from 5 to 50 footcandles but there was little change beyond the 50 footcandle illumination level.

These and other similar studies reveal a typical performance pattern of a noticeable increase in performance with increasing illumination up to a certain point above which the performance level remains constant.

In contrast to the large amount of laboratory research in illumination, very few studies have been carried out under actual work conditions. Most literature in this area consists of records of changes in performance after changes in illumination levels were made. These changes in illumination levels were not made primarily for the purpose of experimentation however, and other factors also might have changed since there were no controlled experiments. Several surveys in this area were taken by Luckiesh and Moss (9), Hess and Harrison (6), Viteles (16), Weston (17), and others in factory and assembly plant situations. Data were recorded in the form of old and new (higher) illumination levels and the per cent change in work output was measured. The majority of these surveys show varying increases in performance from 4 to 35 per cent.

The choice of an optimum level of illumination was simplified by the information found in the IES Lighting Handbook. In order to simulate a normal working environment, a level of 100 footcandles was selected since this is the level recommended by IES for various types of assembly, inspection, and manufacturing operations. It is also the recommended level for a regular office work environment.

The results of the literature survey indicated that a lower than optimum level of illumination should be used in the experiment because there would not be any appreciable change if a higher level were used. The nature of the task was such that it was suitable for use under very low illumination conditions. After several preliminary tests were made, a low level of 0.5 footcandles was selected.

Noise

Many references are available on the effects of noise on human performance; however, many of these are contrabelieve that when the work environment has been made quieter, they ought to be able to work faster and so do. This may or may not indicate any genuine effect on performance of a noisy environment. The opposite effect is also possible in which subjects perform better in a noisy environment because they feel they should.

Perhaps the only conclusion one can reach from reading reviews of the effects of noise on human performance is that there are effects. Whether these effects are detrimental or facilitative (or both), how they are related to intensity or frequency, what changes occur over time, etc., remain largely undetermined.

Thus, the choice of type and level of noise to be used in this experiment was somewhat difficult. The first decision made was to use ambient noise as the normal level and a high intensity noise as the adverse level. Although it has been shown by Fornwalt (5) that noise of random periodicity and by Broadbent (2) that noise of high frequency are more detrimental in their effect on performance, it was decided to use constant, broad-band, random (white) noise to present a more uniform, more easily controllable noise environment. Schoenberger and Harris (12) used white noise in their experiment, as have several others, because noise of this type contains all frequencies up to a specified maximum (20,000 hertz) at a fairly constant intensity. White noise can thus be used as an easily reproducible, readily available noise source, without concern for periodicity or spectrum.

The experiment for which these values of noise and illumination were required is discussed in Chapter III.

CHAPTER III

METHOD AND ANALYSES

In this chapter the method in which the experiment was conducted is described and an analysis of the data is given.

Apparatus

The experiment was conducted in the Human Factors Environmental Laboratory using the chamber in which a table, chair, and loudspeaker were placed. The illumination and noise levels were controlled from the panel instruments and other equipment located outside the chamber. The normal lighting facilities of the chamber were used to obtain the optimum and adverse illumination levels. A Gossen Luna-Pro light meter was used to measure the illumination.

A General Radio random-noise generator (Type 1390-B) was used to obtain the adverse noise level. The output of the generator was amplified by a McIntosh amplifier (Model 240) which was connected to a Knight loudspeaker. Sound level readings were made with a General Radio Type 1551-C Sound Level Meter.

The task used in the experiment was the Purdue Test of Manual Dexterity, which is a board containing two columns of equally-spaced holes into which a peg, washer, and sleeve combination is placed in a specified order (see Figs. 1 and 2). The two columns of holes, as well as the area of the board between them, were masked off with black tape to make the task somewhat more difficult. This particular test was selected as a performance task after considering such factors as task complexity, intelligence required to perform the task, time limitations, space limitations, and amount of training required to perform the task.

Subjects

Twelve subjects were selected from a group of male graduate students. Subjects enter into the experimental model as one of the fixed factors.

Procedure

The experiment consisted of having the subjects perform the task under various combinations of illumination and noise conditions while temperature remained constant at a level of 72° F. The optimum and adverse levels of the two parameters gave four treatment combinations:

1. I_0N_0
2. I_0N_1
3. I_1N_0
4. I_1N_1

where: I_0 is 100 footcandles; I_1 is 0.5 footcandles; N_0 is 55 decibels; and N_1 is 95 decibels.

Subjects were seated at the table on which the pegboard, loudspeaker, and a signal light were placed (see Fig. 3).

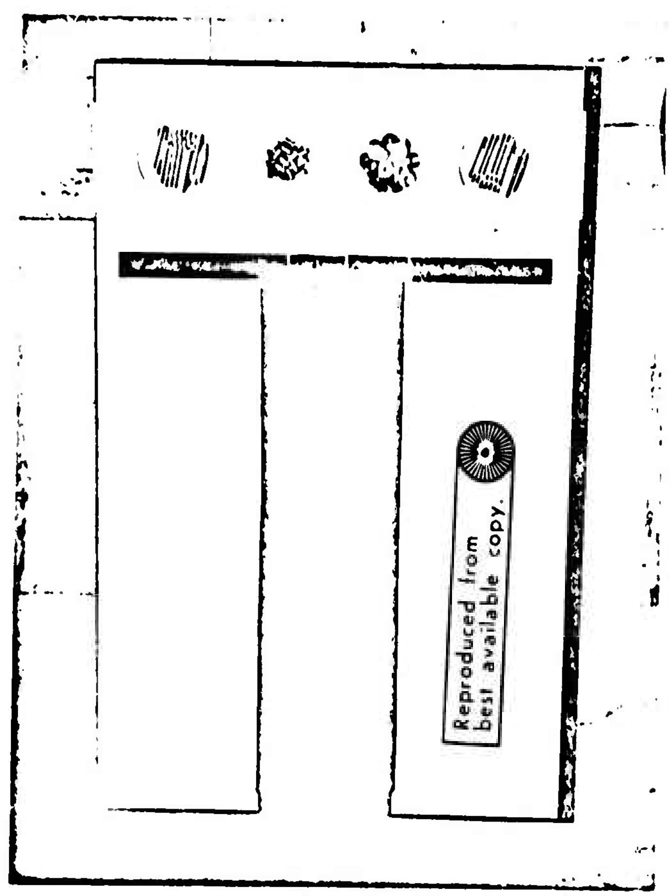

Figure 1. Pegboard and components.

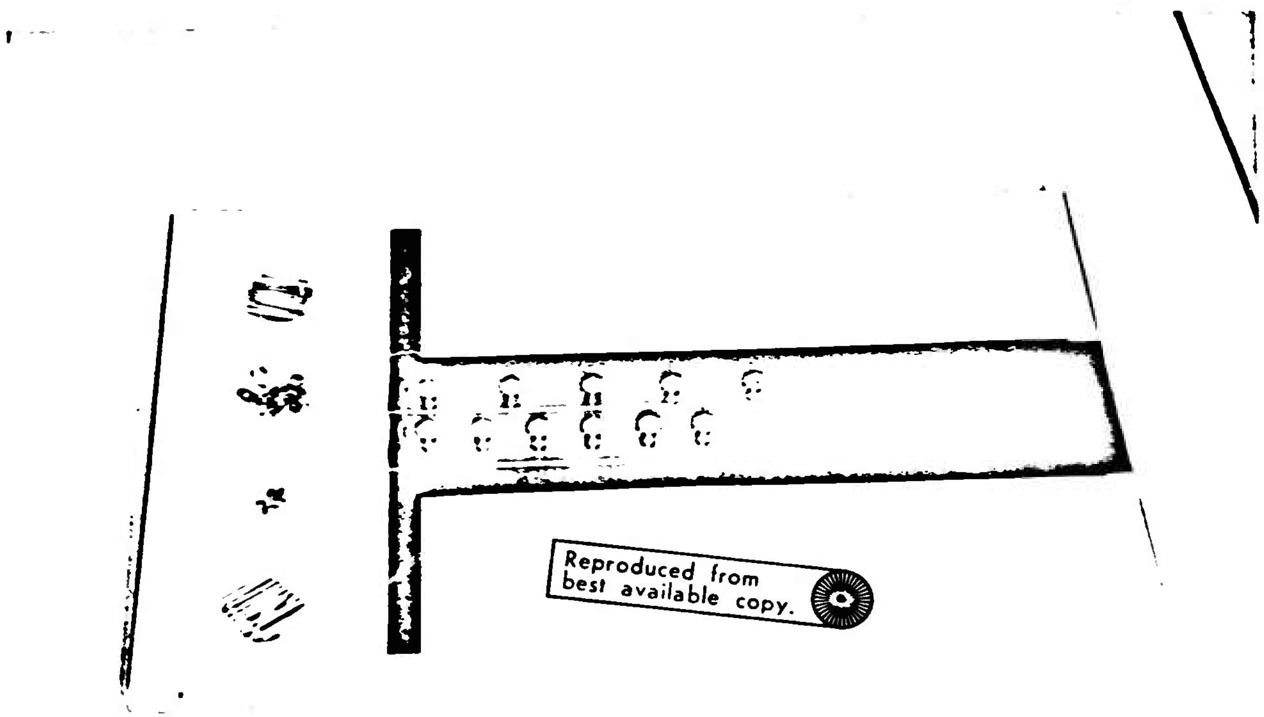

Figure 2. Pegboard and components assembled in required pattern.

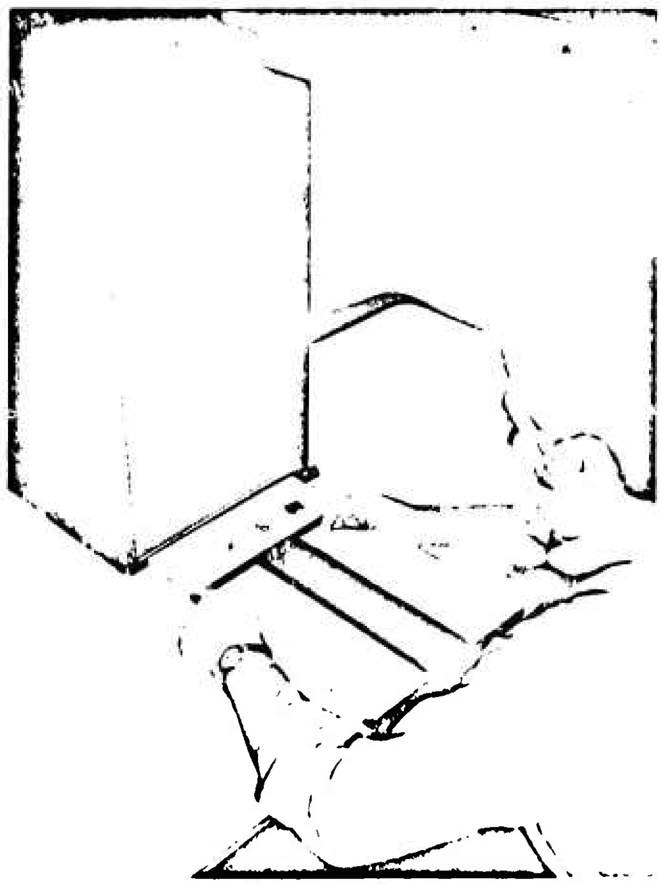

Figure 3. Subject performing the task.

Noise and illumination levels were adjusted at the beginning of each run. The subjects were given a sufficient amount of time to practice the task and establish a pattern for assembling the components. The subjects were instructed to begin assembly with the first hole in each column followed by a column pattern of every other hole on the left and every third hole on the right. This column pattern was to be established while alternating between the left and right columns. Upon a command from the experimenter relayed through the red signal light, each subject was given one minute in which to assemble as many components as possible. At the end of one minute the red light was flashed, signalling the end of the run. The number of correctly placed components was recorded and the board was disassembled for the next run. The subjects performed the task two times under each of the four conditions in random order.

Measures and Analyses

The experiment was not completely randomized due to the restriction that each subject had to perform the task eight times in one sitting. In this case, each replication was a block and the design was a randomized block design with a complete factorial experiment randomized within each block.

The expanded model for the factorial experiment in a randomized block design is given by the following equation:

$$X_{ijk} = \mu + S_i + N_j + I_k + SN_{ij} + SI_{ik} + NI_{jk} + SNI_{ijk} + \epsilon_{m(ijk)}$$

which includes the interactions of replications and treatments. The terms in the model are defined as follows:

X_{ijk} is the observation;

μ is the common effect for the whole experiment;

S_i is the effect due to subjects;

N_j is the effect due to noise;

I_k is the effect due to illumination;

SN_{ij} is the effect of the subject-noise interaction;

SI_{ik} is the effect of the subject-illumination interaction;

NI_{jk} is the effect of the noise-illumination interaction;

SNI_{ijk} is the effect of the subject-noise-illumination interaction; and

$\epsilon_{m(ijk)}$ is the error term.

The hypotheses to be tested are: H_1: $N_j = 0$; H_2: $I_k = 0$; and H_3: $NI_{jk} = 0$. These hypotheses are used to represent the assumptions that noise, illumination, and the interaction between noise and illumination have no effect on performance.

The independent variables in this experiment were noise and illumination. The dependent variable was the number of correctly placed components.

The data recorded during the experiment were analyzed using the methods outlined by Hicks (7) for a two-factor experiment in a randomized block design. Error mean square terms were calculated (Table 1) so that tests of significance could be determined and an analysis of variance table was developed (Table 2). The data recorded during the experiment may be found in the appendix.

The three hypotheses were tested at a five per cent significance level. The results of the experiment will be discussed in Chapter IV.

Table 1

ERROR MEAN SQUARE TERMS

Model	12 F i	2 F j	2 F k	2 R m	E M S
S_i	0	2	2	2	$\sigma^2_e + 8\sigma^2_s$
N_j	12	0	2	2	$\sigma^2_e + 48\sigma^2_n$
SN_{ij}	0	0	2	2	$\sigma^2_e + 4\sigma^2_{sn}$
I_k	12	2	0	2	$\sigma^2_e + 48\sigma^2_i$
SI_{ik}	0	2	0	2	$\sigma^2_e + 4\sigma^2_{si}$
NI_{jk}	12	0	0	2	$\sigma^2_e + 24\sigma^2_{ni}$
SNI_{ijk}	0	0	0	2	$\sigma^2_e + 2\sigma^2_{sni}$
$\epsilon_{m(ijk)}$	1	1	1	1	σ^2_e

Tests: Test all terms against error term.

(Note: The EMS Table was developed according to the methods outlined by Hicks (7).)

Table 2

ANALYSIS OF VARIANCE TABLE

Source	DF	SS	MS	F
Subjects	11	1264	115	6.24 *
Ncise	1	7	7	N.S.
Illumination	1	2981	2981	162 *
SN	11	195	17.7	N.S.
SI	11	696	63.3	3.44 *
NI	1	12	12	N.S.
SNI	11	91	8.27	N.S.
error	48	881	18.4	
Total	95	6127		

$F_{.95,\ 11,\ 48} = 2.0$

$F_{.95,\ 1,\ 48} = 4.04$

(* indicates significance)

CHAPTER IV

RESULTS AND DISCUSSION

The results of the experiment may be obtained from the tests of significance as shown in the Analysis of Variance Table. The purpose of the experiment was to determine the effects of illumination and noise on performance; therefore, the illumination term, the noise term, and the illumination-noise interaction term should be examined.

Illumination Effects

Illumination was found to be the only factor which produced an effect on performance in the experiment. It was expected that illumination would have an effect on performance since past studies have shown that low light levels produce decrements in performance.

Noise Effects

The second environmental parameter, noise, was found to have no effect on the simple motor performance tested in the experiment. The finding of no noise effects is compatible with past research. Perhaps some other type of noise such as a random signal would have an adverse effect on performance.

Illumination-Noise Interaction

The results of the experiment show that there are no effects due to the interaction of illumination and noise. This might be attributed to the lack of any effect due to noise alone. Or, the illumination level might have been sufficiently low so that the noise factor would not have produced a further decrement in performance. There may be interaction effects at other levels of the two parameters.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

The general conclusions which can be stated from the results of the experiment are that a low level of illumination will produce a decrement in performance, a constant, broad-band, random noise will not have an effect on performance, and the interaction of illumination and noise will not have an effect. These conclusions are limited by the levels of the parameters which were selected. If different combinations of illumination and noise levels were used, there might be an interaction effect. Different kinds of noise also might produce a decrement in performance.

Further research in the area of multi-parameter environmental testing should be done to determine the combined effects on performance of various factors such as temperature, humidity, vibration, and acceleration as well as noise and illumination. Several levels of these parameters should be used so that a complete analysis may be made. Not only should two-factor studies be made, but research should be extended to include the higher-order combinations also.

APPENDIX

APPENDIX

NUMBER OF COMPONENTS

	N_0		N_1	
Subject	I_0	I_1	I_0	I_1
1	46 46	35 37	45 50	38 38
2	45 53	36 45	45 49	39 46
3	59 67	46 46	54 66	41 46
4	39 50	40 49	43 45	31 39
5	46 59	24 23	48 53	29 30
6	49 46	30 38	45 46	29 36
7	53 49	44 42	55 45	40 42
8	48 48	36 30	46 52	36 41
9	41 42	29 37	47 44	40 42
10	48 47	38 39	48 50	42 42
11	48 51	35 45	50 51	46 39
12	48 54	40 34	46 56	34 42

REFERENCES

1. Boast, Warren. B. Illumination Engineering. New York: McGraw-Hill Book Co., Inc., 1953.

2. Broadbent, D. E. "Effects of Noises of High and Low Pitch on Behaviour," Applied Psychology Research Unit, Cambridge, England, September, 1954.

3. Broadbent, D. E. and W. Burns. "Effects of Noise on Hearing and Performance," Medical Research Council, London, England, April, 1965.

4. Chapanis, A. et al. "Lectures on Men and Machines," Systems Research Laboratory, Johns Hopkins University, Baltimore, Maryland, 1947.

5. Fornwalt, N. E. "Investigation into the Effect of Intermittent Noise of Constant Periodicity on the Performance of an Industrial Task," School of Engineering, Texas Technological College, Lubbock, Texas, May, 1965.

6. Hess, D. P. and W. Harrison. "The Relation of Illumination to Production," Transactions of the Illuminating Engineering Society, Vol. 18, 1923.

7. Hicks, C. R. Fundamental Concepts in the Design of Experiments. New York: Holt, Rinehart and Winston, Inc., 1964.

8. IES Lighting Handbook, 4th edition. New York: Illuminating Engineering Society, 1966.

9. Luckiesh, M. and F. K. Moss. Seeing. Baltimore: The Williams and Wilkins Co., Inc., 1931.

10. McCormick, Ernest J. Human Engineering. New York: McGraw-Hill Book Co., Inc., 1957.

11. McCormick, Ernest J. Human Factors Engineering. New York: McGraw-Hill Book Co., Inc., 1970.

12. Schoenberger, R. W. and C. S. Harris. "Human Performance as a Function of Changes in Acoustic Noise Levels," Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio, December, 1965.

13. Simonson, E. and J. Brozek. "Effects of Illumination Level on Visual Performance and Fatigue," Journal of the Optical Society of America, Vol. 38, 1948.

14. Tiffin, J. Industrial Psychology. Englewood Cliffs, N. J.: Prentice-Hall, Inc., 1952.

15. Tinker, M. A. "Trends in Illumination Standards," Transactions of the American Academy of Ophthalmology and Otolaryngology, March-April, 1949.

16. Viteles, M. S. The Science of Work. New York: W. W. Norton and Co., Inc., 1934.

17. Weston, H. C. "The Effects of Conditions of Artificial Lighting on the Performance of Worsted Weavers," Medical Research Council (Great Britain), Industrial Health Research Board, Report 81, 1938.