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# DIFFERENTIAL EFFECTS OF NOISE AND FATIGUE ON A COMPLEX COUNTING TASK

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# FOREWORD

This report was prepared by the Psychology Branch of the Aero Medical Laboratory, Directorate of Research, Wright Air Development Center, under Research and Development Project No. 7193, Task No. 71614, "Operator Performance in High Energy Noise Fields," with Dr. Harry J. Jerison acting as Task Scientist. The experimental data were collected at Antioch College under Contract No. AF 18(600)-50 under the supervision of Dr. Virginia L. Senders. Mr. Arden K. Smith of Antioch College and Mr. Jules Arginteanu of the Psychology Branch assisted in data collection, reduction and statistical analysis. Special acknowledgment is due 1/Lt. W. D. Chiles of the Psychology Branch who provided extensive assistance in the statistical evaluation of the results. Whatever sophistication may appear in this evaluation is due to his unstinting education of the writer in these matters. Responsibility for the appropriateness of the analyses presented must rest, however, with the writer.



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## ABSTRACT

This report compares performance under the combined stress of noise and fatigue with that of fatigue alone. A complex mental counting test which involves mental work of a rather high order was the source of the performance measure. Although statistically significant differences between performance in noise and in quiet were found, these were not straightforward, and no simple relationship of the performance decrements and specific abilities could be established. It is therefore impossible to relate abilities involved in performance on the complex counting test to changes in performance under noise stress. Some indication was found of a direct relationship between susceptibility of individual subjects to auditory fatigue during a specific work period in noise and their ability to maintain performance in noise.

## PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

for JACK BOLLERUD
Colonel, USAF (MC)
Chief, Aero Medical Laboratory
Directorate of Research



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TABLE OF CONTENTS



LIST OF TABLES





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LIST OF FIGURES





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# INTRODUCTION

In a previous paper (7) a complex counting test was described, and effects of a combination of noise and fatigue on performance on that test were analyzed. This report is devoted to an experiment in which the effects of the combination of noise and fatigue were compared with the effect of fatigue alone on performance on that test. Research on human performance changes under noise stress was reviewed by Kryter (8) in 1950 who concluded that reports available to him had not been able to demonstrate any clear performance changes. More recently, Broadbent has reported poorer performance in noise than in quiet on a vigilance task (3) and on a paced performance task (1). Broadbent has concluded that performance decrements in noise occur when a task must be performed for a long uninterrupted work period, and when lapses of attention are readily reflected in the performance measure. More complete statements of his theoretical position have appeared in several sources (2, 4).

According to the analysis of the complex counting test developed in the previous report two kinds of abilities are involved. First, subjects are required to use their ability to remember the status of several counts at the same time, and second they are required to record the status of a change in one of the counts without confusing it with other counts. The abilities were, tentatively, described as "memory" and "ordering." For designing jobs for Air Force personnel, the previously reported results indicate that jobs in which such abilities are involved may be expected to show performance decrements if they are done continuously, without breaks, and are not intrinsically interesting.

The goal of this research program is to develop an understanding of the abilities - dimensions of performance - that are affected by noise or by a combination of noise and fatigue. It is designed, ultimately, to relate the effects that are found to the noise level and the duration of the work period; in this report the effect of one relatively high energy ambient noise level, 111.5 db re .0002 dynes/cm$^2$, is compared with the effect of relative quiet, 77.5 db, on performance. As in the case of all exploratory research, it should be recognized that conclusions are tentative and may be changed radically as more research on the problem develops.

# PROCEDURE

Fourteen paid male volunteer undergraduates worked individually on the complex counting test. Each subject went through a two-hour training session and then through a two-hour control session and a two-hour experimental session. The sessions were spread over a three week period, and the order of the control and experimental sessions was counterbalanced.

The first half-hour of the work in these two sessions was always in quiet (77.5 db). The final one and one-half hour of work was in a 111.5 db noise field in the experimental session and in quiet in the control session. It is therefore possible to use the first half hour as an anchor point to control intra-individual



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differences (differences in performance level of the same subject for the two sessions) by relating performance in subsequent half hours to that in the first half hour. The assumption is that day-to-day differences (in this case week-to-week differences) within a subject's base performance level are more variable than half-hour to half-hour differences. Or, put another way, the factors producing variations in half-hour to half-hour performance are under better experimental control than those producing intra-individual differences in performance during the first half-hour of work of two different sessions.

The Counting Test: This test as used in the present experiment was the same as that described in the previous report (7). In this test the subject sits alone in a small experimental room and observes a display of three 3/4 inch panel lights. Each of the lights flashes at a particular rate, and the subject is required to keep a mental count of the number of times each light has flashed. The flash rates were:

| | |
|---|---|
| Light I (Subject's right): | Once in 9.5 seconds |
| Light II (Center): | Once in 5 seconds |
| Light III (Left): | Once in 13 seconds |

When the count reached ten for any of the lights he was to press a button under that light and to begin that light's count again. The required count was ten for all three sessions. In addition to keeping his separate mental counts the subject was required to press a telegraph key at what he judged to be ten-minute intervals. This last activity was analyzed separately and the results of that analysis have appeared in another report (6). The exact instructions given the subject are presented in Appendix A. The subject worked without interruption for two hours. During the experimental session his work was not supposed to stop when the noise level was raised.

Audiometry: Audiograms were taken on every subject during all sessions, including control and training sessions. The subjects were screened prior to the experiment to be certain that none of those used had hearing losses exceeding 15 db at frequencies from 250 to 8000 cps as tested by a standard clinical audiometer (Maico Model H1). Post-session audiograms were taken after the experimental session to measure auditory fatigue.

Noise: Noise was generated by a P. A. L. Model 422 electronic noise generator. The noise level at the position of the subject's head was determined by a General Radio Sound Level Meter and Octave Band Analyzer. The energy distribution by octave band in this experiment during the high noise level period is indicated in Figure 1. The distribution for the low noise period was essentially the same though the entire curve is displaced downward. Figure 1 also presents averaged curves of hearing loss for the fourteen subjects in this experiment following the experimental session.

Experimental Design: The over-all experimental design is summarized in Table I. The fourteen subjects were divided into groups designated QN and NQ in order to counterbalance the order of taking the experimental and control



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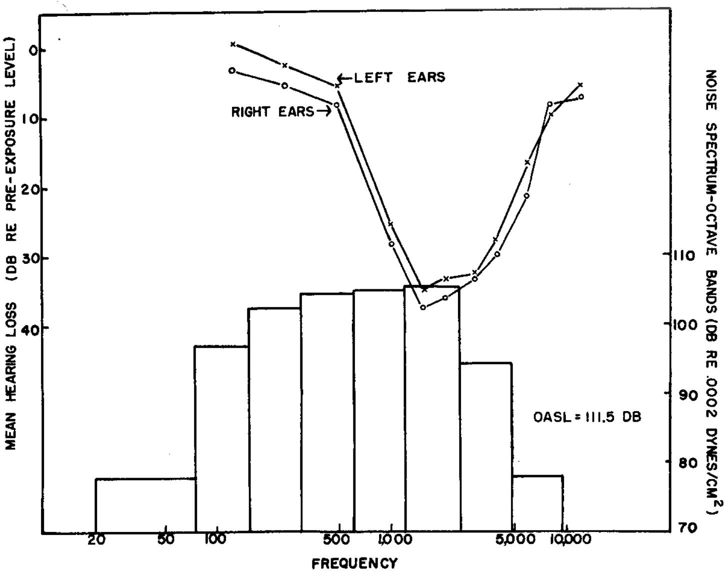


Figure 1. Energy distribution by octave bands when over-all noise level was 111.5 db. Upper curves show averaged hearing losses for the fourteen subjects.

TABLE I

Over-All Experimental Design

| | Session I | Session II | Session III |
|---|---|---|---|
| Group QN (7 subjects) | Training (Quiet throughout) | Control (Two hours quiet) | Experimental (1/2 hour quiet followed by 1-1/2 hours noise) |
| Group NQ (7 subjects) | Training (Quiet throughout) | Experimental (1/2 hour quiet followed by 1-1/2 hours noise) | Control (Two hours quiet) |

sessions. Both groups had a training session first. The high level 111.5 db noise occurred only during the final one and one-half hours of the experimental session.

Within each cell of Table I the independent variables intrinsic to the complex counting test were operating, namely: lights* and time at work. The dependent variable was always percent correct responses.

* In the previous report in this series (7) this variable was described as "flash-rates."



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The experimental design allows for two methods of analysis. First the similarity of noise condition during the first half hours of the experimental and control sessions (sessions II and III) can be used to control individual differences by relating scores in subsequent half hours to that of the first half hour. This, in effect, considers differences between the two sessions in the first half hour to result from fixed differences in performance level within an individual on a particular day. It takes into account the possibility of having a "good day" for a job such as this.

A second method of analysis does not use this technique for equating the control and experimental sessions. It compares performance in terms of the effect of sessions, noise programs, flash rates, and times (successive half hours). The difference between noise and quiet would appear in such an analysis as a noise programs by times interaction in an analysis of variance. The statistical procedure is that of an expanded Type VII "mixed" design as described by Lindquist (9). "Subjects" is a random variable, sessions and noise programs are confounded with groups of subjects, while lights and time are not confounded.

For both analyses the results of the training session are treated separately. When the first half hour of work during the experimental and control sessions is used as an anchor, the training session may be ignored. That session is important only for controlling individual differences in learning rates and for making sure that performance increments related to learning do not mask decrements due to fatigue and noise.

The training session takes on special importance for the second method of analysis. In that analysis the effects of groups, of sessions, and of experimental conditions are confounded, and an effect of one of these could not be discriminated from an effect of any of the others unless there were an independent reason for considering one of the effects as insignificant. The results of the training session can be used to compare the two groups of subjects, and to determine whether a significant bias was introduced in the selection of these groups. If no bias is found, that is, if effects of groups and the interactions of groups with other variables are not statistically significant, this would provide the independent reason for disregarding the contribution of groups to the confounded terms.

## RESULTS

The percent correct responses for all three sessions broken down by half hours of work, by lights and by subjects are presented in Appendix B. This appendix gives the raw data for all of the analyses presented in this report. The analyses suggested by the experimental design have all been performed. From a statistician's point of view the analysis which does not make use of the first half hour as an anchor point to control individual differences is somewhat more pure because all of the control of individual differences is then statistical, and also no arbitrary manipulation of data is involved. That analysis will be considered first.



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Analysis Using Statistical Control of Individual Differences: In this analysis the main effects to be considered are: session number, experimental conditions, lights, and time at work. An order effect is analyzed as the effect of groups which is identical with a session by experimental conditions interaction. For this analysis, it must first be determined that differences between the groups QN and NQ are not due to selection of good subjects in one group and poor subjects in the other group. This possibility can be tested by examining the performance of the two groups during the training session to see whether any systematic differences exist prior to the experimental and control sessions.

The first step is, therefore, to make a complete analysis of the performance during the training session. The required analysis is described exactly by Lindquist (9) as his Type VI design. In this case the "mixed" effect is groups, and the fixed effects are lights and times. The results of this analysis are presented in Table II.

TABLE II

Analysis of Variance in Performance During the Training Session

| Source | Error Term | df | Sum of Squares | Mean Square | F |
|---|---|---|---|---|---|
| Between Subjects (s) | | 13 | 61,131.58 | 4,702.43 | |
| Groups (G) | b | 1 | 4,024.67 | 4,024.67 | -- |
| Error Between (b) | | 12 | 57,106.91 | 4,758.91 | |
| Within Subjects | | 154 | 39,816.04 | | |
| Lights (L) | 1 (w) | 2 | 4,475.62 | 2,237.81 | 3.80* |
| Times (T) | 2 (w) | 3 | 1,268.50 | 422.83 | 1.40 |
| L x T | 3 (w) | 6 | 266.34 | 44.39 | -- |
| L x G | 1 (w) | 2 | 239.22 | 119.61 | -- |
| T x G | 2 (w) | 3 | 1,428.33 | 476.11 | 1.57 |
| L x T x G | 3 (w) | 6 | 755.52 | 125.92 | 1.43 |
| Error Within | | 132 | 31,382.51 | 237.75 | |
| $Error_1$ (w) | | 24 | 14,127.31 | 588.64 | |
| $Error_2$ (w) | | 36 | 10,895.06 | 302.64 | |
| $Error_3$ (w) | | 72 | 6,360.14 | 88.34 | |
| Total | | 167 | 100,947.62 | | |

* Significant at the .05 level.

It is clear from Table II that the effect of groups is not significant. On the basis of previous work we expect both lights and time to be significant. As may be seen in Table II, only lights proved to be significant. The absence of significance of an effect of time can be accounted for rather simply and in a way which is in agreement with previous results. The first session - a training session - is required with the complex counting test precisely because a long learning period occurs. During the learning session the learning effect and a



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"fatigue" effect more or less balance one another out. This has been noted in the first report on the complex counting test (7), and the data summarized in Appendix C confirm the first report's results.

The analysis of performance during the second and third sessions, after learning was complete and when effects of noise and fatigue were balanced against effects of quiet and fatigue is summarized in Table 3*. From that analysis it is clear that the test features which stand out most clearly are the effect of time at work and the effect of lights. Experimental conditions - that is, the experimental versus control session effect - should not necessarily be expected to be significant because the common noise levels during the first half hours of these sessions would systematically depress differences. On the other hand, the interaction of this effect with time (the E x T interaction) should be significant if noise has a straightforward effect on performance between the experimental and control sessions. This interaction is not significant, and we must, therefore, conclude that if noise has any effect on performance on the complex counting test it does not arise simply from its presence or absence.

A higher order interaction in which the "experimental conditions by time" interaction is represented would also be an indicator of an effect of noise. Table III indicates that the experimental conditions by sessions by times (E x S x T) interaction is significant, and the interpretation of this interaction provides a clue as to a possible effect of noise on performance on the counting test. Figure 2 graphs that interaction by presenting the composite effect of

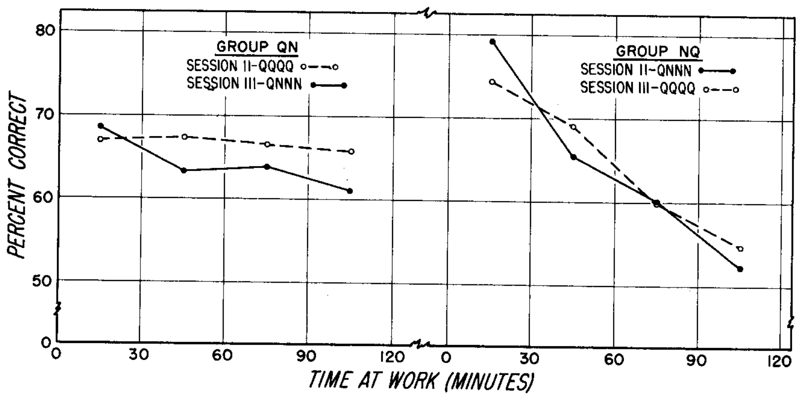


Figure 2. Performance as a function of time compared for the experimental (QNNN) and control (QQQQ) sessions for the two groups of subjects. The QN and NQ labels for the groups refer, as in Table I, to the order of taking the experimental (N) and control (Q) sessions.

three variables - noise programs, session number, and time at work. The interpretation of the interaction might be that the order in which subjects undergo noise in the successive sessions of this procedure has a critical effect on their subsequent performance. If they undergo a quiet session after having completed

* The analysis summarized in Table III was developed by Dr. Joseph B. Sidowski of the Psychology Branch and was modified by Mrs. Mary Lum of the Applied Mathematics Branch, WADC. It is essentially the same as Lindquist's Type VII design expanded to permit a single analysis to include two fixed effects and two "mixed" effects.



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TABLE III

Analysis of Variance in Performance During the Experimental and Control Sessions

| Source | Error Term | df | Sum of Squares | Mean Square | F |
|---|---|---|---|---|---|
| Experimental Conditions (E) | E x s/G | 1 | 141.48 | 141.48 | -- |
| Sessions (S) | S x s/G | 1 | 110.27 | 110.27 | -- |
| Groups[1] (G) | s/G | 1 | 108.14 | 108.14 | -- |
| Lights (L) | L x s/G | 2 | 13,521.76 | 6,760.88 | 3.93* |
| Time (T) | T x s/G | 3 | 8,522.00 | 2,840.67 | 8.69** |
| E x L | E x L x s/G | 2 | 1,649.88 | 824.94 | 3.29 |
| S x L | S x L x s/G | 2 | 1,736.37 | 868.18 | 3.46* |
| E x T | E x T x s/G | 3 | 651.01 | 217.00 | -- |
| S x T | S x T x s/G | 3 | 25.49 | 8.50 | -- |
| L x T | Res. | 6 | 1,047.63 | 174.60 | 2.09 |
| E x S x L | E x L x s/G | 2 | 192.22 | 96.11 | -- |
| E x S x T | E x T x s/G | 3 | 4,393.07 | 1,464.36 | 4.83** |
| E x L x T | Res. | 6 | 512.71 | 85.45 | 1.03 |
| S x L x T | Res. | 6 | 406.82 | 67.80 | -- |
| E x S x L x T | Res. | 6 | 356.37 | 59.40 | -- |

Error Terms

| Source | df | Sum of Squares | Mean Square | Comments |
|---|---|---|---|---|
| Subjects within Groups (s/G) | 12 | 72,423.22 | 6,035.27 | |
| E x s/G | 12 | 7,972.98 | 664.42 | Identical with S x s/G |
| L x s/G | 24 | 41,262.76 | 1,719.28 | |
| T x s/G | 36 | 11,763.73 | 326.77 | |
| E x L x s/G | 24 | 6,021.58 | 250.89 | Identical with S x L x s/G |
| E x T x s/G | 36 | 10,903.17 | 302.87 | Identical with S x T x s/G |
| Res. | 144 | 12,002.52 | 83.35 | Combines L x T x s/G and L x T x E x s/G |

[1]The effect of Groups is identical with an E x S interaction.
*Significant at the .05 level
**Significant at the .01 level



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their training session the introduction of noise during the third session has little effect on their performance level. On the other hand, if their second session is a noise session, their performance declines precipitously, and in a subsequent session the same kind of fast decline is found despite the fact that the work is now performed in quiet.

This interpretation is possible because the first session did not differentiate the groups at a statistically significant level (cf. Table II). However, it should be recognized that the groups may nevertheless have been different, because there is no obvious reason for the high level of performance of subjects in the NQ group as compared to the lower level of performance of the QN group during the first half hours which were always in quiet. This suggests that despite the data presented earlier in Table II there may have been systematic differences between the groups, and that the significant second-order interactions cannot be interpreted with confidence, because an unsuspected bias may have appeared in selecting the subjects for the NQ and QN groups.

Analysis Using Experimental As Well As Statistical Control of Individual Differences: The results of the following analysis formed the basis of a preliminary report (5) on the research reported here. The analysis is based on the fact that the first half hours of the experimental and control sessions were in identical noise conditions. Performance during the first half hour can, therefore, provide an anchor for controlling differences within an individual's performance level on two separate days.

To do this analysis a new set of data for sessions II and III was derived by disregarding the session number and comparing only experimental conditions, lights, times, and subjects. The new table was derived from the data of sessions II and III in Appendix B by using the average performance on each light during the first half hour of the experimental session for all fourteen subjects as a divisor for all of the individual scores in subsequent half hours of the experimental session for that flash rate. This was done separately for the three flash rates and for the experimental and control sessions. The result is that performance during the first half hour for each light is always 100 percent, and performance in subsequent half hours can go either up or down. In other words, all performance measures are relative to that during the first half hour.

An analysis following this procedure assumes that an order effect, if present, was overcome by the use of the first half hour's performance as a weighting factor. The experimental and control sessions are completely differentiated on the basis of noise level, and the variables for analysis are noise level, lights, time, and subjects. This is a factorial design in which the data are ratios of performance to the base level for a particular noise level. Only three time periods are involved, and performance during these time periods is expressed as a ratio to the performance level during the first half hour.

The results treated by this transformation are presented in Figure 3, and the statistical analysis is presented in Table IV. The F ratio is obtained by taking each effect's interaction with subjects as the proper estimate of its error variance. It will be noted that the main noise effect is not significant, nor are the interactions of noise with lights or with time significant. However all interactions of noise with subjects are significant. The interpretation



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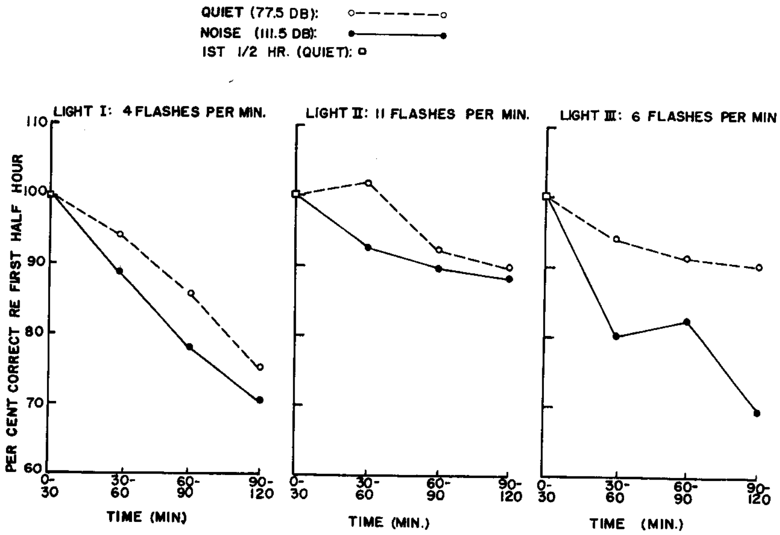


Figure 3. Performance as a function of time during the experimental and control sessions presented separately for each light. All performance is considered relative to that during the first half hour which was in "quiet."

TABLE IV

Analysis of Variance in Performance Relative to the First Half Hour in the Experimental and Control Sessions

| Source | Error Term | df | Sum of Squares | Mean Square | F |
|---|---|---|---|---|---|
| Subjects (s) | Res. | 13 | 12.4596 | .9584 | 74.29** |
| Noise Levels (N) | N x s | 1 | .4350 | .4350 | 2.94 |
| Lights (L) | L x s | 2 | .4906 | .2453 | -- |
| Time (T) | T x s | 2 | .5358 | .2679 | 5.72** |
| N x L | N x L x s | 2 | .1273 | .0636 | 1.09 |
| N x T | N x T x s | 2 | .0121 | .0060 | -- |
| N x s | Res. | 13 | 1.9253 | .1481 | 11.48** |
| L x T | L x T x s | 4 | .1371 | .0343 | 2.37 |
| L x s | Res. | 26 | 6.5976 | .2538 | 19.67** |
| T x s | Res. | 26 | 1.2159 | .0468 | 3.63** |
| N x L x T | Res. | 4 | .0651 | .0163 | 1.26 |
| N x L x s | Res. | 26 | 1.5202 | .0585 | 4.53** |
| N x T x s | Res. | 26 | .8867 | .0341 | 2.64** |
| L x T x s | Res. | 52 | .7544 | .0145 | 1.12 |
| Res. | | 52 | .6719 | .0129 | |
| Total | | 251 | 27.8346 | | |

** Significant at the .01 level.



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suggested is that there are important individual differences in performance on this test which are reflected also in the reactivity of individual subjects to the noise.

A closer examination of Table IV will make this interpretation more understandable. The variance estimate based on noise levels is .4350; this is the largest estimate for any of the main effects excepting subjects. It is tested for statistical significance by its interaction with subjects. That interaction, however, is quite large, and the effect of noise levels would have to be large indeed to be significant. The interactions in which a noise levels by subjects (N x s) term appears: N x s, N x L x s, and N x T x s, are all significant. One reason for this could be that subjects were, in fact, affected by noise levels, but the effect varied from subject to subject. This would be reflected in a significant noise levels by subjects interaction, and the net result would be that a large sample of subjects would be needed to raise the presumed effect of noise levels to "statistical" significance. Figure 3, it may be noted, shows a definite trend in favor of quiet as a work environment.

If the individual differences are the result of an orderly mechanism which makes some subjects more sensitive than others to noise, it might be possible to examine the subjects and differentiate those affected from those less affected or not affected by noise. On theoretical grounds, it seemed possible that such a mechanism might involve resistance to temporary deafness or auditory fatigue. This possibility makes sense in terms of the argument that temporary deafness, though presumably a peripheral phenomenon, would act to shield the central nervous mechanisms in which auditory stimuli are involved from the full effect of the massive stimulation of noise.

To examine this possibility, the fourteen subjects of this experiment were ranked in terms of their over-all hearing loss which followed the experimental session. The four subjects with the most severe hearing losses and the four with the mildest losses were then treated as two subgroups. The average hearing losses of these two subgroups are presented in Figure 4. It will be noted that the subgroups are differentiated mainly in the speech frequencies. Their hearing losses overlap in the high and low frequencies. The performance of the two subgroups was then examined exactly as the over-all performance was examined in Figure 3. The analogous breakdown of the results with the performance of the subgroups differentiated is presented in Figure 5. It is apparent that subjects with severe hearing losses either maintained or improved their performance, on the average, during the noise session relative to the quiet session. On the other hand, those with mild hearing losses fell off in their performance more rapidly in noise than in quiet.

A statistical analysis of this result can be performed by first comparing the groups in quiet, and then comparing them again in noise. Two analyses of variance were performed,* both of the Type VI design of Lindquist used in the previous section. Both analyses involved subgroups as a "mixed" effect and lights and time as "fixed" effects with subjects as a random variable. The results of these analyses are presented in Table V.

* The subjects with mild hearing losses were Nos. 1, 3, 6, and 11; those with severe losses were Nos. 8, 12, 13, and 14, and the raw data for these analyses are available in Appendix B. For these analyses an arc sin transformation was performed on each score to reduce the effect of extreme scores.



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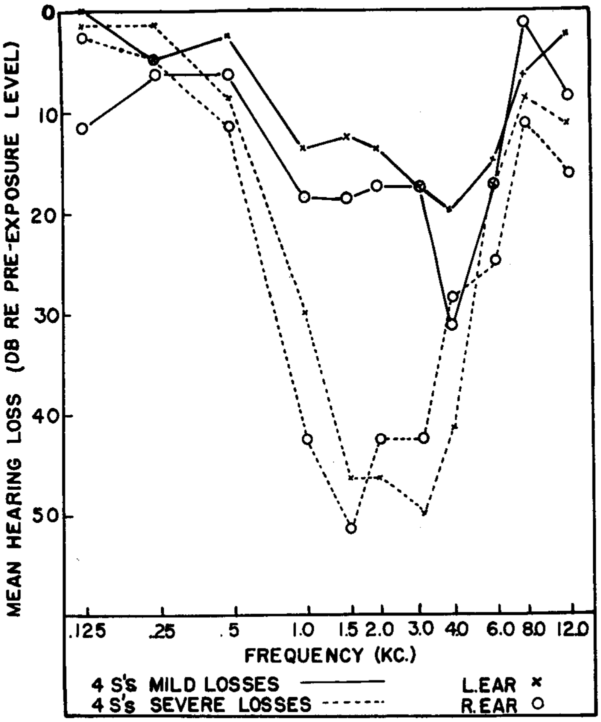


Figure 4. Average audiograms for the four subjects with hearing losses designated "mild" and of four designated "severe."

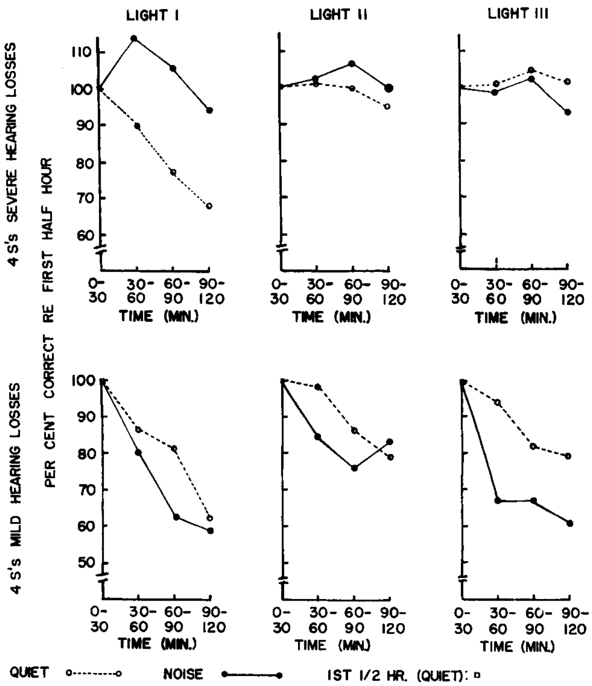


Figure 5. Performance as a function of time graphed as in Figure 3, but taken separately for the subgroup with "mild" and the subgroup with "severe" hearing losses.



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TABLE V

Analyses of Variance in Experimental and Control Sessions:
Subgroups Differentiated in Terms of Hearing Loss Following Noise Session

| | | | CONTROL SESSION | | | EXPERIMENTAL SESSION | | |
|---|---|---|---|---|---|---|---|---|
| Source | Error Term | df | Sum of Squares | Mean Square | F | Sum of Squares | Mean Square | F |
| Between Subjects | | 7 | 4,589.22 | | | 8,026.74 | | |
| Subgroups (G) | b | 1 | 15.00 | 15.00 | — | 127.97 | 127.97 | — |
| Error (b) | | 6 | 4,574.22 | 762.37 | | 7,898.77 | 1,316.46 | |
| Within Subjects | | 88 | 10,657.38 | | | 24,823.97 | | |
| Lights (L) | 1 (w) | 2 | 256.84 | 128.42 | — | 2,363.61 | 1,181.80 | 1.18 |
| Times (T) | 2 (w) | 3 | 1,452.49 | 484.16 | 2.77 | 1,626.84 | 542.28 | 3.21* |
| L x T | 3 (w) | 6 | 511.35 | 85.22 | 1.72 | 398.26 | 66.38 | 1.49 |
| L x G | 1 (w) | 2 | 331.67 | 165.84 | — | 1,846.77 | 923.38 | — |
| T x G | 2 (w) | 3 | 227.02 | 75.67 | — | 1,878.95 | 626.32 | 3.71* |
| L x T x G | 3 (w) | 6 | 141.68 | 23.61 | — | 64.47 | 10.74 | — |
| Error Within | | 66 | 7,763.34 | | | 16,645.07 | | |
| $Error_1$ (w) | | 12 | 2,809.27 | 234.10 | | 12,006.83 | 1,000.57 | |
| $Error_2$ (w) | | 18 | 3,148.40 | 174.91 | | 3,036.82 | 168.71 | |
| $Error_3$ (w) | | 36 | 1,778.67 | 49.41 | | 1,601.43 | 44.48 | |
| Total | | 95 | 15,246.60 | | | 32,850.71 | | |

* Significant at the .05 level



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It was not considered necessary to use the first half hour as an anchor in the statistical analysis because the subgroups x time interaction provided information equivalent to that of the effect of the noise levels variable in Table IV. It is apparent from Table V that the subgroups x time interaction is not significant for the quiet session and is significant for the noise session. This supports the differentiation indicated in Figure 5 between the effect of noise on the performance of the subjects suffering mild hearing losses compared with that of the subgroup suffering severe hearing losses.

This result is made less impressive when the subgroups x time interactions of the two sessions are plotted without the use of the first half hour as an anchor. Figure 6 shows that there is, indeed, a marked difference in rate of

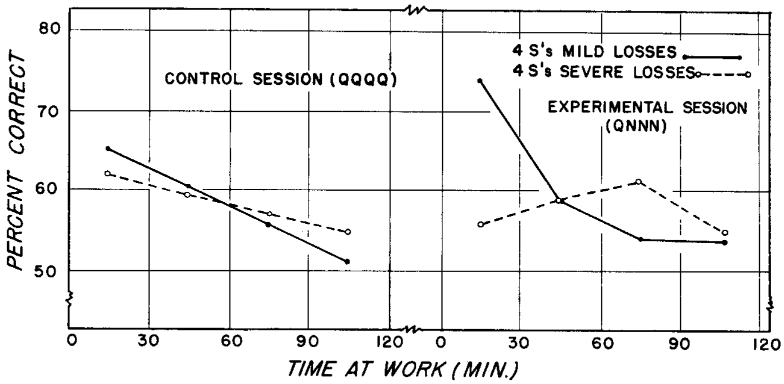


Figure 6. Performance as a function of time during the experimental and control sessions taken separately for the subgroups with "mild" and "severe" hearing losses.

change of performance between the two subgroups during the noise session. But this difference results mainly from the high performance level during the first half hour of the subjects who were later to suffer mild hearing losses. In order for the hearing loss criterion to be appropriate it is necessary to assume that performance level of the mild hearing loss subgroup during the first half hour of the noise session was a harbinger of continued high performance during that session. Actually this subgroup returned to the performance level it maintained during the quiet session, and it seems just as valid to interpret the significant interaction as resulting from the unusually high starting level of performance. On the other hand, no explanation is available for the high starting level, whereas the performance drop can be attributed to the noise.

## DISCUSSION

The over-all picture presented by these results is that of diverse performance changes which cannot be assigned to a simple effect of noise or a combination of noise and fatigue on performance. The situation is perhaps best appreciated if we recognize that noise may be expected to affect mainly rather complex



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behavior. But to explore complex behavior we must start with complex tests, and a complex test tends to be an unreliable test in the sense that correlation between successive performances by the same individual will not be high. In order to measure an effect we are forced, paradoxically, to use unreliable tests, and unreliable tests are poor measuring devices. The present test does not completely achieve its purpose perhaps because it is too unreliable. This would be reflected in high variance estimates from interactions with subjects (cf Tables II - V). On the other hand it may be that the abilities involved in the test are not affected to any marked degree by the fact that they must be used in a relatively high energy noise field.

It was only by means of a very detailed analysis of the results of this experiment that effects attributable to noise were teased out of the situation. Because such effects are not simple,we tend to be wary when we assign a meaning to them. Here, again, we are faced with a problem analogous to that posed by the nature of the effect we seek. We accept, almost a priori, the notion that any effects we can obtain will be complex. We cannot ignore the absence of a statistically significant effect of experimental conditions or of an interaction between experimental conditions and time in the general analysis presented first in the results section. That finding casts doubt on any interpretation developed in the second analysis of the results which attributes an effect to the presence or absence of noise.

The significant interaction, in the first analysis, of sessions by noise conditions by time (E x S x T) which was presented graphically in Figure 2 can be interpreted as indicating the following: When subjects are exposed to noise at a point when they have just learned a task their performance on the task suffers from the combined effects of noise and fatigue. This becomes manifested in a rapid decline in performance during a two-hour work session. Such subjects, if they are again exposed to the task will show a similar decline with fatigue and without any additional noise. On the other hand, subjects who have an opportunity to perform the task after they have reached essentially maximum efficiency (after clearly completing their learning period) and do this in relative quiet are essentially unaffected by fatigue. Such subjects, if they subsequently perform the task in a noise field, remain unaffected by the combined effects of noise and fatigue, as far as performance on that task is concerned.

This is the rather complex interpretation required by the first analysis if an effect is to be attributed to noise.

The second analysis shows somewhat more apparent effects. An over-all performance decrement, somewhat greater in noise than in quiet, is shown for the average of all the subjects over a two-hour work period. Statistically this effect is not significant, though it contributes a large portion of the total variance. It fails of statistical significance because the error estimate for this source, the interaction between subjects and noise levels, also contributes heavily to the total variance. Two tentative conclusions are dictated by the results of the second analysis. First, there is a trend in the direction of poorer performance on this test in noise than in quiet. Second, if this trend is real, there are significant differences among men in their susceptibility to this effect.



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It was to investigate the second conclusion that the data were broken down in terms of susceptibility of subjects to auditory fatigue. As indicated in the presentation of the results on this breakdown, there were statistically significant differences between subjects who suffered severe hearing losses and subjects who suffered mild hearing losses in terms of performance decrements. However, it was not clear that this difference resulted from an effect of noise. If, in fact, it did, this result would support the hypothesis that auditory fatigue acted to protect the subject from the full severity of noise as a source of performance decrement. Further consideration of this aspect of the problem should be deferred until experiments designed specifically to test this approach are completed.

## SUMMARY AND CONCLUSIONS

1. The complex counting test described in a previous report (7) was given to fourteen subjects. The subjects worked in a series of 3 two-hour sessions, a training session followed, in counterbalanced order, by experimental and control sessions. The experimental session involved working in a 111.5 db noise during the final one and one-half hours of the session after working in quiet (77.5 db) during the first half hour. The training and control sessions were both in the presence of a 77.5 db masking noise.

2. The interaction of learning and fatigue found in the previous experiment (7) was found again and is reported in Appendix C.

3. Performance on the complex counting test with the flash rates and count used in this experiment is not affected in a simple way by noise. A complex performance decrement related to the order of undergoing noise appears to be present. A suggestive result not anticipated in the original design of this experiment is that subjects who later showed auditory fatigue tended to perform at the same level in noise as in quiet, whereas subjects with only mild hearing losses tended to fall off from their starting performance level.



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# APPENDIX A

The subject was handed the instruction sheet and the material and was asked to read it. He was reminded of the fact that he had two tasks, the counting and the time judgment. These instructions (double-spaced) were read by the subject at the start of each session.

## INSTRUCTIONS

Before you is a panel of three lights and three buttons, one button for each light.
Your task is to press each light's button every tenth time that light goes on.
To do this you will have to keep a mental count which will tell you how many times each light has come on.
Don't be afraid to guess if you lose the exact count.
Occasionally a light may seem to blink twice in rapid succession - out of beat with its usual rhythm. Such apparent blinks are really part of a single flash, and you should count them as one flash.
Don't be afraid to guess if you lose the exact count.
Do not talk out loud during the session. Think your count; don't count out loud.
Remember: PRESS EACH LIGHT'S BUTTON EVERY TENTH TIME THAT LIGHT GOES ON!
As soon as the lights start flashing, tap the telegraph key once. Then, during the experiment, while you are keeping count of the flashing lights, tap the telegraph key once every ten minutes. This will determine how well you can keep track of the passing of time during the experiment.
Kindly remove watch before experiment.



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APPENDIX B

PER CENT CORRECT RESPONSES FOR EACH SUBJECT IN EACH COMBINATION OF CONDITIONS

FIRST SESSION

| Group | Subject No. | Light | Time Period 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|---|
| GROUP NQ | 1 | I | 71.43 | 80.00 | 84.21 | 88.89 |
| | | II | 81.08 | 89.74 | 85.71 | 94.12 |
| | | III | 92.31 | 66.67 | 84.62 | 66.67 |
| | 2 | I | 47.37 | 16.67 | 27.78 | 11.76 |
| | | II | 50.00 | 38.89 | 40.62 | 35.48 |
| | | III | 30.77 | 36.36 | 45.45 | 00.00 |
| | 3 | I | 83.33 | 84.21 | 78.95 | 78.95 |
| | | II | 63.89 | 89.19 | 84.21 | 94.59 |
| | | III | 76.92 | 83.33 | 100.00 | 84.62 |
| | 4 | I | 52.63 | 55.00 | 52.63 | 57.89 |
| | | II | 72.22 | 67.57 | 67.65 | 57.14 |
| | | III | 61.54 | 84.62 | 69.23 | 58.33 |
| | 5 | I | 26.67 | 43.75 | 82.35 | 62.50 |
| | | II | 55.88 | 71.88 | 93.75 | 78.79 |
| | | III | 00.00 | 00.00 | 00.00 | 9.09 |
| | 6 | I | 72.22 | 94.74 | 89.47 | 52.94 |
| | | II | 81.58 | 88.89 | 79.41 | 44.83 |
| | | III | 63.64 | 100.00 | 75.00 | 63.64 |
| | 7 | I | 94.12 | 83.33 | 61.11 | 77.78 |
| | | II | 94.12 | 91.18 | 78.79 | 87.88 |
| | | III | 100.00 | 83.33 | 90.91 | 76.92 |
| GROUP QN | 8 | I | 100.00 | 83.33 | 82.35 | 82.35 |
| | | II | 86.11 | 82.35 | 84.85 | 84.85 |
| | | III | 91.67 | 84.62 | 76.92 | 72.73 |
| | 9 | I | 25.00 | 57.89 | 52.63 | 72.22 |
| | | II | 48.65 | 63.16 | 72.22 | 69.44 |
| | | III | 21.43 | 38.46 | 53.85 | 58.33 |
| | 10 | I | 30.00 | 21.74 | 15.79 | 36.84 |
| | | II | 33.33 | 30.95 | 21.05 | 38.46 |
| | | III | 18.75 | 15.38 | 14.28 | 50.00 |
| | 11 | I | 68.42 | 61.11 | 83.33 | 61.11 |
| | | II | 73.68 | 69.44 | 82.86 | 68.57 |
| | | III | 61.54 | 83.33 | 83.33 | 76.92 |
| | 12 | I | 28.57 | 43.75 | 33.33 | 47.06 |
| | | II | 37.50 | 70.59 | 97.06 | 74.28 |
| | | III | 18.18 | 30.77 | 45.45 | 41.67 |
| | 13 | I | 55.56 | 57.89 | 55.00 | 68.75 |
| | | II | 57.89 | 78.38 | 71.43 | 55.88 |
| | | III | 75.00 | 58.33 | 41.67 | 64.28 |
| | 14 | I | 17.65 | 47.37 | 36.84 | 27.78 |
| | | II | 37.50 | 72.22 | 72.97 | 55.88 |
| | | III | 45.45 | 66.67 | 50.00 | 69.23 |



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SECOND SESSION

| Time Period | | | |
|---|---|---|---|
| 1 | 2 | 3 | 4 |
| 80.00 | 57.89 | 52.94 | 50.00 |
| 89.19 | 78.95 | 69.44 | 86.11 |
| 76.92 | 75.00 | 61.54 | 46.15 |
| 61.11 | 44.44 | 52.94 | 12.50 |
| 81.58 | 59.46 | 58.82 | 25.81 |
| 100.00 | 54.54 | 45.45 | 11.11 |
| 100.00 | 78.95 | 88.89 | 83.33 |
| 88.89 | 88.89 | 97.30 | 91.43 |
| 91.67 | 100.00 | 100.00 | 100.00 |
| 63.16 | 20.00 | 18.75 | 14.28 |
| 71.05 | 41.18 | 42.86 | 36.36 |
| 60.00 | 30.77 | 38.46 | 53.85 |
| 61.11 | 61.11 | 58.82 | 40.00 |
| 81.58 | 89.19 | 78.95 | 73.53 |
| 15.38 | 30.77 | 28.57 | 16.67 |
| 88.89 | 52.94 | 44.44 | 33.33 |
| 97.14 | 75.00 | 43.75 | 45.16 |
| 100.00 | 58.33 | 25.00 | 30.77 |
| 77.78 | 89.47 | 83.33 | 77.78 |
| 89.19 | 91.89 | 91.43 | 88.89 |
| 84.62 | 100.00 | 78.57 | 76.92 |
| | | | |
| 72.22 | 72.22 | 77.78 | 81.25 |
| 74.36 | 63.64 | 82.86 | 54.54 |
| 92.31 | 61.54 | 76.92 | 41.67 |
| 9.09 | 9.09 | 45.45 | 42.86 |
| 48.00 | 56.00 | 53.57 | 53.12 |
| 28.57 | 14.28 | 30.00 | 36.36 |
| 58.82 | 63.16 | 61.11 | 66.67 |
| 53,85 | 66.67 | 52.63 | 52.78 |
| 85.71 | 84.62 | 69.23 | 69.23 |
| 83.33 | 85.00 | 73.68 | 83.33 |
| 58.33 | 82.86 | 75.68 | 86.49 |
| 66.67 | 64.28 | 84.62 | 91.67 |
| 82.35 | 82.35 | 70.59 | 58.82 |
| 97.06 | 91.43 | 81.82 | 90.91 |
| 63.64 | 63.64 | 18.18 | 18.18 |
| 70.59 | 55.56 | 77.78 | 88.89 |
| 82.86 | 83.33 | 68.57 | 73.53 |
| 72.73 | 83.33 | 69.23 | 75.00 |
| 50.00 | 68.42 | 63.16 | 52.63 |
| 60.53 | 78.95 | 81.58 | 80.56 |
| 92.31 | 83.33 | 83.33 | 83.33 |

THIRD SESSION

| Time Period | | | |
|---|---|---|---|
| 1 | 2 | 3 | 4 |
| 73.68 | 88.89 | 77.78 | 61.11 |
| 76.32 | 86.49 | 75.00 | 66.67 |
| 84.62 | 76.92 | 66.67 | 18.75 |
| 50.00 | 52.63 | 47.06 | 47.06 |
| 66.67 | 58.33 | 50.00 | 54.54 |
| 25.00 | 45.45 | 38.46 | 71.43 |
| 94.44 | 94.12 | 88.89 | 88.24 |
| 91.67 | 85.71 | 77.14 | 67.65 |
| 100.00 | 76.92 | 75.00 | 76.92 |
| 76.47 | 70.59 | 43.75 | 52.94 |
| 78.38 | 72.73 | 65.71 | 82.35 |
| 64.28 | 53.85 | 61.54 | 57.14 |
| 61.11 | 37.50 | 41.18 | 31.25 |
| 78.38 | 86.49 | 81.82 | 69.70 |
| 23.08 | 46.15 | 41.67 | 8.33 |
| 81.25 | 44.44 | 26.67 | 30.77 |
| 78.79 | 45.16 | 33.33 | 20.00 |
| 72.73 | 61.54 | 38.46 | 15.38 |
| 94.74 | 77.78 | 76.47 | 78.95 |
| 91.89 | 94.44 | 76.47 | 82.86 |
| 92.31 | 92.31 | 71.43 | 64.28 |
| | | | |
| 94.44 | 88.89 | 100.00 | 81.82 |
| 75.00 | 97.14 | 93.94 | 82.61 |
| 66.67 | 84.62 | 84.62 | 54.54 |
| 14.28 | 00.00 | 00.00 | 00.00 |
| 67.57 | 83.33 | 82.86 | 94.12 |
| 6.67 | 5.88 | 6.25 | 6.25 |
| 77.78 | 61.11 | 70.59 | 58.82 |
| 75.00 | 71.05 | 62.86 | 75.00 |
| 84.62 | 71.43 | 61.54 | 76.92 |
| 88.89 | 50.00 | 57.89 | 52.94 |
| 91.89 | 63.89 | 69.44 | 80.00 |
| 91.67 | 57.14 | 46.15 | 35.71 |
| 56.25 | 64.70 | 75.00 | 82.35 |
| 96.97 | 93.10 | 100.00 | 96.97 |
| 00.00 | 00.00 | 00.00 | 00.00 |
| 94.74 | 68.42 | 66.67 | 68.42 |
| 77.78 | 61.76 | 64.70 | 63.64 |
| 69.23 | 70.00 | 66.67 | 66.67 |
| 58.82 | 77.78 | 72.22 | 50.00 |
| 64.70 | 70.59 | 77.14 | 71.43 |
| 81.82 | 92.31 | 83.33 | 83.33 |



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APPENDIX C

## The Interaction of Learning and Fatigue

The results section completed the presentation of results on effect of noise combined with fatigue versus effect of fatigue alone. This appendix section is devoted to a problem on the nature of the counting task raised in the previous report on this test (7). The conclusion in that report was, essentially, that learning occurred during a one or two hour period of one session, but that before it was completed fatigue set in so that performance drops off during a first session. It was indicated, however, that learning progressed beyond the level indicated by performance scores of the first session, because during the first half hour of the second session performance was at a level far superior to that attained at any time during the first session. During the second session performance immediately dropped off, and there was a steady decline over the two-hour work period. Again at the start of the third session performance returned to a level approximately the same as that during the first half hour of the second session, and again performance dropped off steadily during the two-hour work period. This result was illustrated in Figure 5 of the previous report.

Although the present experiment involved somewhat different noise programs and only one count (instead of three as in the previous experiment), the results are surprisingly similar to those presented previously. The averaged performance during successive half hours of all three sessions of the present experiment, including the training session, and with flash rates combined, is presented in Figure 7. These results are in the same direction and are quite similar in other

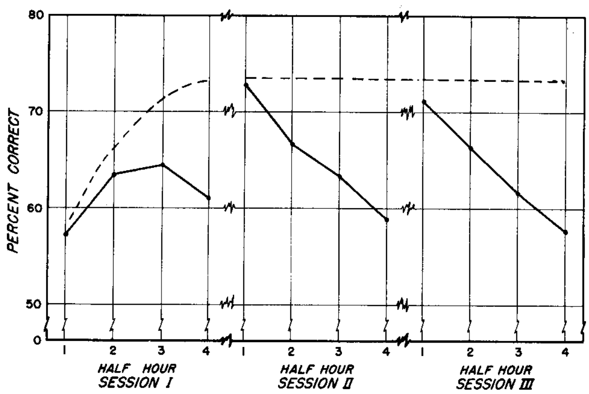


Figure 7. Performance (solid lines) as a function of time during the learning session (Session I) and subsequent sessions. Successive half-hours of a session are labeled 1, 2, ... The dashed line is a hypothetical learning function, and the performance curves can be thought of as a combination of the learning function with a fatigue function. (Compare with Fig. 5 in ref. 7.)

respects to the previously reported results. They are presented here to indicate the probable nature of the test. No statistical analysis is presented because this experiment was not designed to provide efficient tests of the problem posed by these results. It should be clear, however, that when two completely different experiments produce such similar results that we very likely are faced with a real phenomenon.



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