San Fernando Valley State College

THE EFFECTS OF AMBIENT NOISE ON VIGILANCE PERFORMANCE

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by

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ABSTRACT

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The effects of continuous noise versus intermittent noise on subjects performing an audio-visual checking task were examined. It was found that intermittent noise reduced performance as predicted by the expectancy theorists. There were no differences in overall vigilance performance between male and female observers. There was a decrement in performance with time-at-work typically found in other vigilance studies. TSD (Theory of Signal Detectability) measures were relatively stable for all subjects and closely approximated the values which would be expected in a psychophysical setting. Due to the significant increase in omission errors in the last 20 minutes of the duty period, there was a corresponding increase in the subjects' response criterion.

INTRODUCTION

Experiments have been reported concerning the effects of noise on vigilance and on monitoring task performance. Broadbent (1954) found that subjects monitoring twenty dials performed less well in a 100db SPL noise field than in a field of 70db. A later study (Jerison and Wing, 1957) executed to check Broadbent's conclusions, indicated that subjects monitoring three Mackworth clocks for the occurrence of occasional double steps did about as well in a noise level of 114db as in a quieter 83db for the first $1\frac{1}{2}$ hours of work, but then when working in 114db noise, the subject's performance dropped significantly. Jerison and Arginteanu (1958) revealed that continuous high level noise does not affect time judgments, but an effect was demonstrated when a change occurred from high to low level noise, or vice versa, at a critical period in the task.

Teichner (1960) in a review of the "expectancy hypothesis" of vigilance behavior (Baker, 1959; Deese, 1955; Jenkins, 1953) questioned whether continuously high ambient noise levels are or are not distractors, or is it necessary that a change occur in the ambient noise level before distractors begin to function. Jerison and Arginteaunu's work lends support to Teichner's view.

The expectancy hypothesis of vigilance was

originally proposed by Deese (1955) and is thought to be a promising theoretical approach to vigilance study by Buckner and McGrath, 1963. Deese stated an excitatory state of vigilance exists which determines the probability of detection for any observer. He states that "the observer's expectancy or prediction about the search task is determined by the actual course of stimulus events during his previous experience with the task, and the observer's level of expectancy determines his vigilance level and probability of detection." Deese posits that expectancy depends upon an indeterminate number of signals preceding the signal in question.

Baker (1959a) expanded the expectancy hypothesis to posit that the signal detection probability in a vigilance task is greatest when the signal occurs after an interval equivalent to the mean of the intersignal intervals preceding the interval in question, and that detection probability is lowest immediately after a signal. The accuracy of the expectancy determines the probability of the S actually detecting the signal. Baker (1962) found observers' extrapolations based upon five to seven intervals preceding the signal in question.

Baker (1963) states that the accuracy of perceiving the temporal structure of a series of signals is a function of the degree of series regularity. The more accurate the perception, the more probable the confirmation of expectancy. The more variable the signal

presentation schedule, the lower the probability that the perceived mean interval will coincide with the next scheduled signal. The resultant lower detection probability leads to less frequent expectancy confirmation. Lack of confirmation lowers the apparent signal frequency.

The perception of lower frequency and corresponding greater variability produces further reductions in expectancy confirmation and performance gradually deteriorates. Baker believes that at some point in time enough past history has been accumulated by the observer to provide him with a "correct" expectancy a relatively small but stable proportion of the time. Eventually the decrement ceases and the level of performance parallels the time line but does not intersect it.

Baker (1963) states that noise effects on vigilance are not completely known and that he "does not know of a single vigilance study, for instance, in which the effects of intermittent noise have been studied." In terms of the expectancy position, Baker hypothesizes that a change in a high ambient noise level in the form of intermittent noise would produce a greater decrement in vigilance performance than continuous monotonic noise. Distractions such as intermittent noise or changes from high to low level noise, or vice versa, compete for attention to the vigilance task. Signals appear to occur less frequently due to a reduction in expectancy confirmation and deteriorated performance results (Baker,

1963). This intermittent noise serves to decrease the number of expectancy confirmations. The result of a subject's reduced expectancy accuracy is to cause him to overestimate the mean intersignal interval established by past stimulus events.

In view of the expectancy hypothesis, it is possible to operationally test the prediction that intermittent noise reduces vigilance performance significantly more than continuous noise. The factors which produce the difference between the two noise conditions, intermittent and continuous, are hypothesized to be:

- a. initial competition between signals and nonsignals,
- b. subsequent attention time sharing between signals and nonsignals.

A great deal of evidence has been amassed to suggest what is known as an "arousal," "activationist," or "varied sensory environment" hypothesis of vigilance behavior. Scott (1957) reviewed Hebb's thesis (1955) that stimuli serve a dual function. One is the cue function controlling goal responses and the other is the arousal or vigilance function which "tones up the cortex with a background supporting action that is completely necessary if the messages proper are to have their effect," (Hebb, 1955). Scott (1957) surveyed the literature concerned with performance deterioration in a variety of repetitive tasks, with particular attention to the uniformity of sensory environment that accompanied such

activities. He concluded "that loss of efficiency was directly related to reduction in stimulus variation. When background stimuli are at a minimum and only occasional and often low-key, critical stimuli are present, rapid deterioration should be expected. Extra-neous stimulation (such as intermittent noise) serves not only to focus attention on the stimulus in question, but also to make the organism more alert with respect to the whole environment."

McBain (1961) theorizes that the relation between effectiveness and the degree of arousal is not a linear one, but may be depicted as an inverted U when vigilance performance is plotted on the vertical axis and degree of arousal on the horizontal. For a specific individual, performing a particular task, a given degree of arousal should lead to optimal performance, while lower or higher arousal levels will reduce effectiveness. Conceivably less than optimal arousal would be most conducive to omission errors due to the observer's lack of alertness. Stimulation producing more than the optimal level of arousal may produce more commission errors due to the observer being overactive. McBain further states that since all sensory inputs are routed to the nonspecific arousal system, any environmental change, including changes in auditory stimulation, should result in increased arousal. He found that noise which is low in "intelligibility," or distraction value for the individual, while

at the same time being high in variability, should enhance performance in a monotonous task. It is conceivable that intermittent noise qualifies as a "varied sensory environment" which would prevent loss of efficiency due to a reduction in stimulus variation. If this is so, intermittent noise will serve to improve vigilance performance rather than decrease it.

A third approach to the study of noise effects on vigilance is offered through the theory of signal detectability (Swets, 1964). The theory of signal detectability (TSD) like decision theory is a general theory for it describes an ideal process which may be applied to various aspects of perceptual processes. TSD has recently been used to analyze vigilance performance (Broadbent and Gregory, 1963; Mackworth and Taylor, 1963; Jerison, Pickett and Stenson, 1965).

TSD provides a method for treating false alarm or commission data generated from vigilance tasks. Detection performance is considered as a judgment process in which stimuli are classed by the observers as signals or non-signals as a function of a criterion that the observer employs. The criterion is a statistical cutoff between two overlapping normal distributions which represent signal and non-signal stimulation. An observer will utilize a given criterion and will make errors of omission and commission at predictable frequencies. The observer's response criterion (" β ") and his discriminative efficiency

("d' ") may be computed as measures of vigilance performance. The value d' is the distance in standard scores between the mean of the non-signal distribution and the mean of the signal distribution. The percentage of detections, P_D , and percentage of commissions, P_C , represent areas of the signal and non-signal normal distributions respectively for which standard scores may be obtained from a table of normal curve functions. The distance in standard scores of P_D to the left of the signal distribution mean plus that of P_C to the right of the non-signal distribution mean equals d' . The response criterion, β , is the ratio of the ordinate of the P_D point on the signal distribution abscissa to the ordinate of the P_C point on the non-signal distribution abscissa. Ordinate values are available from a table of normal curve functions.

Depending upon which noise condition, intermittent or continuous, produces decreased vigilance performance and in turn upon whether the expectancy or arousal theory is operative, d' and β will vary accordingly. Discriminatory efficiency, d' , should increase and the response criterion, β , also may increase under the noise condition most conducive to signal detection.

The primary purpose of the present experiment is to compare vigilance, operationally defined as performance on the assigned experimental task, under ambient conditions of continuous and intermittent noise with the objective of providing support for either an expectancy or arousal

theory of vigilance behavior. As predicted by the expectancy theorists, vigilance performance, as measured by errors made on the assigned task, should be significantly better in continuous ambient noise than in intermittent noise. This result is to be expected due to initial competition for attention between signal and non-signal stimuli and subsequent time sharing of attention between signal and non-signal stimuli. Conversely, the arousal theorists might predict that intermittent noise provides the varied sensory environment necessary for prevention of efficiency loss due to reduction in stimulus variation. If this is true, then intermittent noise will facilitate rather than reduce performance. Secondly, the validity of Whittenburg, Ross, and Andrews (1956) findings that females perform better than males in vigilance tasks will be tested. The few other studies that have included females fail to report the effects of sex of observer as a factor (Bakan, 1955; Ross, Dardano, and Hackman, 1959).

METHOD

GENERAL DESIGN

An audio-visual checking task was used upon which Ss performance was measured. The task consisted of checking a list of seven digit numbers against an audio presentation of the numbers. The signal to be detected was a discrepancy between a number as it appeared on the checklist and the audio presentation of the number. The correct experimental response, or signal detection, consisted of striking out the digit which differed from that presented aurally, for example, 3 2 4 5 6 7 9 presented aurally versus 3 2 4 5 7 7 9 appearing on the checklist.

Ss performed for a one hour period. The hour duty period was divided into three twenty minute subperiods of signal presentations in which a quiet, continuous, or intermittent noise background was present.

Each of the seven digit numbers was presented in 1.5 seconds. The schedule of presenting numbers and signals (discrepancies) was the same for all three subperiods, see Appendix I. There were 100 number presentations during each subperiod consisting of 20 signals and 80 nonsignals.

Throughout the twenty minute subperiod of intermittent noise, background monotonies (520 cps and 50 db) of 1.5 second duration were interspersed between all number presentations. Intermittent tones were presented randomly

except for ten tones which occurred simultaneously with ten signal presentations. The pairing of ten signals, or 50%, and tones was done to determine if the noise frequency and intensity employed in the experiment produced a masking effect on signals. The other ten signals of this subperiod did not occur simultaneously with monotones.

During the twenty minute continuous noise subperiod, a steady monotone, 520 cps and 50 db, clearly distinguishable from the number presentations, was present.

Only the seven digit numbers were presented during the quiet control subperiod. The experimental room and immediate surrounding area were made free of disturbances.

Two tapes were recorded to partially counterbalance the order in which the three subperiods of the one hour duty were presented as follows: Quiet - Intermittent - Continuous, and Quiet - Continuous - Intermittent. Ss were divided equally to serve under the two orders of background conditions.

SUBJECTS

The Ss were ten males and ten females provided by the California State Employment Service at Van Nuys, California. Prior to the experiment period, two employment service interviewers recruited and screened all prospective subjects on the following criteria: Willingness to participate, 20 to 30 years of age, normal hearing and vision, and completion of high school. The Ss were paid

\$1.35 per hour for participating in the experiment.

APPARATUS

A stereo-tape recorder and audiometer were used to record the two tapes required. The ambient background conditions were a continuous monotone and intermittent monotones, 520 cps and 50 db, recorded from the audiometer, which were controlled to minimize distortion. Background conditions were recorded on one sound track of the recorder and the seven digit numbers on the remaining track. The presentation order of the intermittent and continuous conditions were counterbalanced by re-recording on the appropriate stereo-channel.

The checklist of seven digit numbers consisted of four pages of double spaced numbers, four columns per page. Only three pages were required for the one hour duty period, but an additional page was included so as not to influence Ss' expectancies nor produce increased S arousal manifested by an end spurt, see Appendix II. If the Ss expect a short duty period, the performance decrement is more gradual than if a long duty period is anticipated, Jerison, Pickett, and Stenson (1965). Twenty copies, one for each S, were provided for the testing. Each group received one of the two orders of background conditions (Q-I-C or Q-C-I).

PROCEDURE

The task was administered once each to two groups of

ten Ss. To eliminate collaboration between Ss, Ss were seated at individual cubicles in the test room with a pencil and the checklist. The audio stimuli were presented to Ss over loudspeakers. Prior to starting the experiment Ss were tested for normal hearing and vision. Ss were oriented on the task to be performed with oral and written instructions.

Ss were informed that they were about to take a test to measure numerical checking ability and the test purpose was explained. They were told that throughout the test period various background tones may be heard which should be ignored. A five minute trial period preceded the test to insure that Ss recognized and responded to discrepancies (signals) correctly.

In case S lost his place, he was instructed to indicate with a check (X) mark the last number he monitored and to indicate with a "B" the number at which he resumed his checking progress. Ss were required to give up their watches at the beginning of the test as the approximate length of the duty period may have been known to the S which could have possibly affected performance.

RESULTS

Data retrieval was complete since only three Ss momentarily lost their places and no omissive errors occurred. The number of errors for all Ss was computed for both the intermittent and continuous noise subperiods. Two types of errors occurred: errors of omission, that is, failure to detect a signal and errors of commission, or responding to stimuli which were not signals. Results were first analyzed in terms of total errors, which consisted of combined errors of omission and commission. The analysis of variance for total errors is summarized in Table 1, and there were no significant differences as measured by total errors.

It was thought that possibly the difference between noise conditions might become more evident if errors of omission and commission were analyzed separately. If an expectancy theory is operative, it may be that omission errors vary significantly between noise conditions due to poor estimation of the mean intersignal interval. If the arousal theory is operative, it may be that commissive errors vary significantly between noise conditions due to Ss being highly alerted and overactive in making commission errors.

The analysis of variance for errors of omission are presented in Table 2. The analysis of omission errors revealed a stronger tendency of continuous noise to affect

better vigilance performance than intermittent noise. The difference in this direction was significant at the 95% level of confidence.

To complete the analysis of variances commission errors were analyzed separately to determine if the lack of difference in noise effects revealed in the analysis of total error, Table 1, was due to a difference between intermittent and continuous noise subperiods in an opposite direction.

This analysis, summarized in Table 3, indicated that no significant differences between noise subperiods existed in terms of errors of commission. However, commission errors did have the effect of suppressing the greater difference in omission errors between the intermittent and continuous subperiods analyzed by total errors, omission and commission errors combined.

The significant difference in performance by Ss yielded a mean number of omission errors of 3.3 during the intermittent noise subperiod versus a mean of 1.9 omission errors in the continuous noise subperiod. The confidence interval, $C (0.01 < P_I - P_C < 0.14) = 0.95$ resulted where P_I = the probability of an S making an omission error during the intermittent noise subperiod, and P_C = the probability of an S making an omission error during the continuous noise subperiod.

There was lack of support for the Whittenburg, Ross, and Andrews (1956) finding that females perform better

Table 1

Analysis of Variance of Errors of Omission and Commission for Intermittent
and Continuous Noise Subperiods

<u>SOURCE</u>	<u>d. f.</u>	<u>MS</u>	<u>F</u>	<u>p</u>
Total	39			
Order	1	38.2	1.40	NS
Sex	1	27.4	1.00	NS
Order x Sex	1	10.8	<1	NS
Subjects within O & S	16	27.3		
Period	1	9.2	1.16	NS
Noise	1	18.5	2.34	NS
Period x Sex	1	4.0	<1	NS
Noise x Sex	1	2.7	<1	NS
Error	16	7.9		

Table 2

Analysis of Variance of Errors of Omission for Intermittent and Continuous Noise Subperiods

<u>SOURCE</u>	<u>d. f.</u>	<u>MS</u>	<u>F</u>	<u>p</u>
Total	39			
Order	1	36.1	1.91	NS
Sex	1	12.1	<1	NS
Order x Sex	1	3.6	<1	NS
Subjects within O & S	16	18.9		
Period	1	8.1	1.84	NS
Noise	1	19.6	4.55	<0.05
Period x Sex	1	1.6	<1	NS
Noise x Sex	1	0.1	<1	NS
Error	16	4.4		

Table 3

Analysis of Variance for Errors of Commission for Intermittent and Continuous Noise Subperiods

<u>SOURCE</u>	<u>d. f</u>	<u>MS</u>	<u>F</u>	<u>p</u>
Total	39			
Order	1	0.02	<1	NS
Sex	1	3.02	1.40	NS
Order x Sex	1	2.03	<1	NS
Subjects within O & S	16	2.15		
Period	1	0.02	<1	NS
Noise	1	0.02	<1	NS
Period x Sex	1	0.33	<1	NS
Noise x Sex	1	3.04	1.94	NS
Error	16	1.57		

than males as measured by all error types.

An initial analysis of errors of omission and commission for all 20 Ss for the one hour duty period revealed a high degree of dependence between the occurrence of omission and commission errors. A four-fold chi square table was constructed which resulted in a $\chi^2 = 8.22$, $p < .01$. A scatter plot of omission errors versus commission errors was prepared, Figure 1, from which the best line fit and Pearson product moment correlation coefficient was calculated to be, $r = 0.759$, $p < .01$.

The significant difference in errors of omission between the intermittent and continuous noise subperiods was plotted as in Figure 2. It is apparent from this figure that the difference in performance between the second 20 minutes subperiod (Period 1) and last 20 minute subperiod (Period 2) is greater than that revealed by the main effect "period" in the analysis of variances, Tables 1-3.

Winer (1962) points out that in a repeated-measures experimental design, the sum of squares within cells represents a pooling of what are often heterogeneous sources of variance. As a result the F test on the simple main effects for noise, which uses the mean square between subjects as a denominator will tend to be biased as follows:

Fig. 1 - Correlation Scatter Plot of Omission Errors Versus Commission Errors

Fig. 2 Cumulative Omission Errors for One Hour Duty Period

$$F(\text{noise in Period 2} = \frac{\text{MS noise in Period 2}}{\text{MS error bet. Ss}} = \frac{54.5}{18.9}$$

= 2.88 n. s., see Table 2.

However, if MS error within O x S and MS error within are pooled, the bias is minimized, and a more appropriate F test of the noise effect is possible:

$$F(\text{noise in Period 2} = \frac{\text{MS noise in Period 2}}{\text{MS error (pooled)}} =$$

$$\frac{54.5/302.8+71.6}{32} = \frac{54.5}{11.7} = 4.66, p < 0.05$$

The result is a significant performance decrement from Period 1 to Period 2. Expressed in terms of the probability of omission errors, the following confidence interval was calculated: $C(0.01 < P_2 - P_1 < 0.165) = 0.95$ where P_2 is the probability of an S making an omission error during Period 2, and P_1 the probability of an S making an omission error during Period 1. The difference from Period 1 to Period 2 is not as pronounced in terms of commission errors, Figure 3.

Ten signals, or 50%, were paired with ten tones during the intermittent noise subperiod. This was done to determine if the 520 cps - 50 db tone used intermittently masked signals when present throughout the continuous noise subperiod. If there were significantly more omission errors committed when both tone and signal occurred simultaneously as opposed to the remaining ten signals, or 50%, which were presented alone, then the difference between noise effects in the intermittent and continuous noise subperiods could

Fig. 3 Cumulative Commission Errors for One Hour Duty Period

be attributed to masking produced by the 520 cps-50db tone employed in the two subperiods.

Of a total of 91 errors, omission and commission, 48 were made on paired tone-signal stimuli for all 20 Ss in the intermittent noise subperiod. The hypothesis was set that there is a 50-50 split in the opportunity to make errors on simultaneous tone-signals. A binomial test and normal curve approximation led to the acceptance of the hypothesis of an equal chance for errors to occur on signal-tone stimuli and signal alone stimuli, $p < .01$. On this basis it is unlikely that the 520 cps-50db tone used in the intermittent and continuous noise subperiods, produced any masking or selective filtering of the seven digit number presentations.

Of the 20 Ss in this experiment, 12 in the intermittent subperiod, and 11 in the continuous subperiod emitted at least one false alarm and made fewer than 100 per cent detections. These are the only Ss for whom exact TSD (Theory of Signal Detectability) measures can be determined. The remaining Ss, however, are also important for the TSD analysis. There were four Ss in both the intermittent and continuous noise subperiods who detected all 20 signals correctly and made no commission errors in response to 100 non-signal stimuli. The TSD analysis is based on a total of 100 stimuli, 20 of which are signals, numbers with discrepant digits, and also non-signals because Ss had the opportunity to make an error of omission and

commission within the same stimulus number. The four "perfect" Ss of each subperiod make it possible to estimate a minimum d' and corresponding β .

The detection of all 20 signals can be treated as being at least as great as 19.5 of 20 detections. So the lower limit on the probability of detection is:

$$P_D = (19.5/20.0) = 0.975.$$

The absence of commission errors can be treated as the committing of fewer than 0.5 false positives, so the maximum commission error probability is:

$$P_C = (0.5/100) = 0.005$$

With these limiting probabilities d' and β may be defined and calculated. The variable d' is equal to the distance between the signal and non-signal distribution means, divided by the standard deviation of each distribution. The Ss response criterion, or β , is the ratio of the ordinate of the signal-present distribution to the ordinate of the signal-absent distribution, at the point where the criterion is placed.

For the limiting probabilities of P_D and P_C above:

$$d' = 4.535$$

$$\beta = 4.030.$$

The relationship between d' , β and the normal curves representing N and S + N are shown in Figure 4.

Figure 4 represents the TSD model for the four best Ss of the intermittent and continuous noise subperiods. It is important that β is theoretically independent of

$$P_D = 0.975$$

$$P_C = 0.005$$

$$\beta = \frac{\text{Ordinate at A (S+N)}}{\text{Ordinate at A (N)}} = 4.030$$

$$d' = \frac{\bar{X}_{S+N} - \bar{X}_N}{\sigma_N} = 4.535$$

$$\sigma = 1.0$$

Fig. 4 Probability Density Functions for Nonsignal Stimuli (N) and Signal Stimuli (S+N)

d' for rational behavior. It is only affected by the importance which the S places on detecting signals as opposed to avoiding commission errors, and by the probability which he assigns to the occurrence of a signal as opposed to a non-signal. A drop in detections alone can be due to a decrease in d' with constant β , or a rise in β with a constant d' .

The TSD measures obtained for Ss during the intermittent and continuous noise subperiods are presented in Table 4. The detectability index, d' , was not significantly greater for the continuous noise subperiod as measured by the Mann-Whitney U test. The response criterion, β , also was not significantly less for the continuous noise subperiod. Table 5 lists the d' and β values for Ss during Period 1 and Period 2 of the one hour duty period. The d' measure did not vary significantly between Period 1 and Period 2. However, β did increase significantly from Period 1 to Period 2, Mann-Whitney U test $p < .05$, indicating that Ss did become more cautious with time at work.

The fact that TSD measures could not be obtained on eight Ss in the intermittent noise subperiod and Period 1, and nine Ss in the continuous noise subperiod and Period 2, due to these Ss failure to make commission errors, probably biased the data in Tables 4 and 5 toward d' and β measures that are too low.

Table 4

Values of d' and β for Each Subject During the Intermittent and Continuous Noise Subperiods

Intermittent Noise Subperiod			Continuous Noise Subperiod		
Subject	d'	β	Subject	d'	β
1	3.96	3.91	2	3.00	12.07
2	3.33	3.60	4	3.96	3.91
4	3.60	6.66	5	3.36	8.80
7	3.60	6.66	7	3.96	3.91
8	2.68	2.25	8	3.60	6.66
9	2.89	5.74	11	2.56	4.68
11	1.08	3.69	13	2.14	4.28
12	3.36	8.80	14	3.33	3.60
13	2.70	14.00	15	3.96	3.91
14	3.96	3.91	16	3.33	3.60
15	3.36	8.80	17	3.96	3.91
16	2.92	3.41			
MEAN =	3.120	5.952		3.378	5.394

Table 5

Values of d' and β for Each Subject During Periods 1 and 2

Period 1			Period 2		
Subject	d'	β	Subject	d'	β
1	3.96	3.91	2	3.00	12.07
2	3.33	3.60	4	3.96	3.91
4	3.60	6.66	5	3.36	8.80
7	3.60	6.66	7	3.96	3.91
8	2.68	2.25	8	3.60	6.66
9	2.89	5.74	11	1.08	3.69
11	2.56	4.68	12	3.36	8.80
13	2.14	4.28	13	2.70	14.00
14	3.33	3.60	14	3.96	3.91
15	3.96	3.91	15	3.36	8.80
16	3.33	3.60	16	2.92	3.41
17	3.96	3.91			
MEAN =	3.278	4.400		3.205	7.087

DISCUSSION

The results indicate that intermittent noise is more detrimental to vigilance performance than continuous noise. This is most evident in terms of errors of omission. The expectancy hypothesis predicted the results which were obtained as measured by omission errors. It may be surmised that Ss do develop an expectancy or prediction of when signals will occur and that intermittent noise decreases the number of expectancy confirmations more so than continuous noise.

Baker (1959a, 1959c) believes that there is a point in time when Ss have enough past experience to provide them with a "correct" expectancy part of the time. Later Baker (1962) found that only five to seven intervals preceding a given signal were necessary before Ss could make accurate predictions of future signals. It is apparent from the present experiment that the expectancy formation process is disrupted by intermittent noise and consequently vigilance performance is retarded. Baker (1959a, 1959c) further maintains that eventually the decrement ceases and performance parallels the time line, but does not intersect it. Baker's predicted relationship of performance over time did not occur as shown by the increasing slope of cumulative omission and commission error plots with time, Figures 2 and 3.

Although errors of commission are highly correlated with omission errors, commission errors are frequently

a function of the Ss standard or criterion of what constitutes a signal for which he is looking. If the situation is ambiguous, some Ss "play it safe" by making many commission errors. This tendency was reflected by all Ss as commission errors were distributed homogeneously throughout both the intermittent and continuous noise subperiods, Figure 3. Therefore the difference between the two subperiods in terms of total errors (omissions and commissions) was nonsignificant, at $p < .05$, and could only be distinguished by omission errors.

Accepting the notion that the 520cps-50db intermittent tone served as an adequate varied sensory environment, leads to the rejection of arousal hypothesis of vigilance. McBain (1961) holds that since all sensory inputs are routed to the nonspecific arousal system, any environmental change, which certainly includes off-on intermittent noise, should result in increased arousal. Arousal, as reflected by commissive errors, did not vary significantly between noise conditions or Period 1 and Period 2. Conceivably the tone used in this study may not have been low enough in "intelligibility," or distracting enough, and also it may not have been variable enough in frequency to fairly test the arousal hypothesis as proposed by McBain (1961). However Ss reported to have been equally annoyed by the continuous tone as by the intermittent tone. At best, both noise conditions can be described as extremely noxious.

The Whittenburg, Ross, and Andrews (1956) finding that females perform better than males in vigilance tasks was not substantiated by this study. Few studies that have included females report the effects of subjects' sex (Bakan, 1955; Ross, Dardano, and Hackman, 1959). A recent study (Smith, Lucaccini, Groth, and Lyman, 1966) also revealed a lack of differences between sexes in vigilance performance. Differences in motivation, selection of Ss, and past monitoring task experience may account for the differences between studies. It is likely that sex differences are task specific, however, the sex variable deserves further study.

Jerison, Pickett, and Stenson (1965) have concluded that the shape of the vigilance decrement function is affected by the Ss advance knowledge about the vigilance task. If he expects a short vigil, the decrement is less sharp than if he expects a long duty period. If from past experience the subject knows that he can anticipate an unusually dull and monotonous duty period, the decrement will tend to be sharper. For these reasons, subjects in this experiment were chosen for their inexperience with vigilance tasks and were not allowed to keep their watches during the test period.

The performance decrement evidenced by differences between Ss performance in Period 1 and Period 2 is the most substantial result of this study. However, it can be seen from Figures 2 and 3 that subjects did not reach a performance

plateau as the slopes of the cumulative omission and commission error plots with time continued to rise throughout the one hour vigil. This indicates that a representative performance level for this task was not reached. The expectancy theorists maintain that lack of confirmation of signals present lowers apparent signal frequency. A lower perceived signal frequency and regularity results in further lack of signal verification, and performance deteriorates slowly. However, the expectancy theorists propose that at some point in time sufficient past history has been accumulated by the subject to enable him to have a "correct" expectancy, a relatively small, but stable proportion of the time (Baker, 1959c). Then performance supposedly parallels the time line but never intersects it. As this was not the case in the present experiment, it may be that a longer duty period would produce the typically found performance plateau following the work decrement.

Inspection of Table 4 reveals that the TSD measures, d' and β , are fairly stable across all Ss. The "true" d' of at least 4.535 was suggested by the data of the "perfect" Ss, Figure 4. This value should have been approximated by all Ss with most individual differences in β , however, the overall mean d' for Ss was 3.390, considerably less than that of our perfect Ss. Our obtained overall mean Beta value of 5.708 exceeds the β of 4.030 for our ideal Ss, Figure 4.

It is possible to estimate a "true" β for our perfect

Ss. Assume that the Ss who detected all 20 signals and made no commission errors were using an optimum strategy typical of psychophysical experiments. Also assume equal utilities of commission and omission errors; and of signal detections and not detecting non-signals. The theoretical optimum criterion, β_x , under these conditions in either noise subperiod would be the ratio of non-signal stimuli to signals (Swets, 1964):

$$\beta_x = 100/20 = 5.0,$$

which is approximated by the mean of the four Beta values, $\beta_{\bar{x}} = 5.708$, obtained in this study.

TSD measures are appropriate for the psychophysical experiment but fail to account for the different conditions existing in the vigilance situation (Jerison, Pickett, and Stenson, 1965). In the psychophysical experiment the S is constrained to maintain a consistent observing mode and his observing behavior is externally paced. In the vigilance setting the S is not under this constraint. In the psychophysical study the S not only maintains a consistent observing mode, but the situation is designed to facilitate his doing so. Trials may be delayed upon request and stimulus presentations may be controlled by the S so that they coincide with his readiness to respond. The value of β is constant throughout the psychophysical procedure while S discriminates between signals and non-signals.

The hypothesis that discriminatory efficiency, d' , would increase significantly in the noise condition most conducive to performance was rejected, see Table 4. The response criterion measure, β , was not significantly different between intermittent and continuous noise subperiods. The value d' varied in the predicted direction. The effect of time-at-work on TSD measures as reflected in change of d' and β from Period 1 to Period 2 showed a significant increase in β but no effect on d' . With this increase in β , it can be concluded that SS became more cautious with time-at-work. Discriminatory efficiency, d' , was relatively stable throughout the experiment from the intermittent noise to the continuous subperiod, and from Period 1 to Period 2. TSD measures do not reflect the drop in performance attributed to intermittent noise nor the vigilance decrement which was seen from a combination of conventional analyses of variances.

Of interest for further study would be the effect of different signal schedules on vigilance tasks performed in ambient noise. It is likely that intermittent noise would have a more detrimental effect on vigilance performance where a denser distribution of signals or a more varied schedule of signal presentation was used. Lengthening the duty period or using a simpler task may provide the leveled-off performance which the expectancy theorists found to typically occur. The study of intermittent noise

which varies both in duration and pitch typical of various industrial settings may well provide further insights into the effects of noise on performance.

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APPENDIX I

Presentation Schedule for Twenty Minute Subperiods

	<div style="border: 1px solid black; width: 60px; height: 15px; display: inline-block;"></div>	= a seven digit number.
	2,4,6,.....20	= interval in seconds between numbers (mean = 10.6 seconds).
	+	= a signal (discrepancy).
	<div style="border: 1px solid black; width: 150px; height: 100px; display: inline-block; vertical-align: middle;"></div>	<div style="display: inline-block; vertical-align: middle;"><div style="border: 1px solid black; border-radius: 50%; width: 15px; height: 15px; display: flex; align-items: center; justify-content: center; margin-bottom: 5px;">+</div>= a simultaneous occurrence of a signal and a tone during intermittent noise subperiod.</div>
Apply only to Intermittent Noise Subperiod	(1),(2),...(9)	= number of tones presented during intervals throughout the intermittent noise subperiod.

Appendix I (Continued)

Begin				
6 (2)	20 (9)	6 (2)	9 (4)	12 (5)
18 (8)	8 (3)	4 (1)	16 (7)	6 (2)
	2 (1)	7 (3)	9 (4)	9 (4)
2 (1)	12 (5)	8 (3)	20 (9)	4 (1)
20 (9)	16 (7)	12 (5)	2 (1)	18 (8)
12 (5)	8 (3)	8 (3)	18 (8)	14 (6)
16 (7)	12 (5)	16 (7)	4 (1)	2 (1)
6 (2)	20 (9)	8 (3)	20 (9)	18 (8)
9 (4)	6 (2)	7 (3)	6 (2)	14 (6)
8 (3)	4 (1)	18 (8)	9 (4)	16 (7)
14 (6)	18 (8)	2 (1)	7 (3)	7 (3)
7 (3)	8 (3)	6 (2)	12 (5)	4 (1)
18 (8)	7 (3)	12 (5)	2 (1)	20 (9)
4 (1)	16 (7)	8 (3)	9 (4)	9 (4)
6 (2)	14 (6)	16 (7)	14 (6)	2 (1)
14 (6)	4 (1)	7 (3)	4 (1)	20 (9)
20 (9)	2 (1)	9 (4)	18 (8)	7 (3)
2 (1)	14 (6)	14 (6)	6 (2)	14 (6)
12 (5)	9 (4)	20 (9)	7 (3)	12 (5)
9 (4)	18 (8)	4 (1)	16 (7)	6 (2)
16 (7)				

APPENDIX II
Numerical Checking Task

5446322	6808901	6738229	7437396
1538985	2041167	9066996	8768796
8594140	5821213	7803016	7699905
6114969	7057742	0363852	6769942
0521981	9452274	5988884	7916944
4141798	4262686	5094864	0325299
2835794	1605133	7501921	1903158
1778300	0824272	3646639	4671611
4095084	5949704	7032684	0489472
8299564	9715513	4175778	0141269
9675417	9840966	3483386	6152720
3435788	4547684	6633460	6679065
0631837	8930069	6737263	2316605
6211152	5005195	8476785	1227524
4753409	3175385	1274002	0230624
9861475	7915253	1492248	1876069
2485603	4456038	1864439	4212137
9688712	6832883	7828502	0561542
9080121	4693938	7676652	8586320
5516577	8354486	7021981	1378208
7588412	9162100	6462091	5530917
1677737	9189667	4391001	1184812
4623043	5575162	3299291	2930337
4290266	8515687	2347420	5501755
8100700	0752156	9542539	6231512

Appendix II (Continued)

5 2 0 9 8 8 2	4 2 4 5 1 1 5	9 0 4 6 4 2 9	1 6 2 5 5 1 7
7 7 2 0 4 0 4	1 0 2 3 7 3 9	8 3 9 9 1 5 1	7 3 5 7 9 9 2
5 1 4 0 0 2 5	4 4 7 8 5 6 8	0 6 2 3 5 3 3	4 6 7 0 3 9 8
6 4 4 3 2 1 6	3 0 1 0 1 7 8	1 5 2 9 7 2 8	7 2 7 8 1 7 2
3 6 8 6 3 5 5	6 9 7 2 7 9 4	8 0 9 7 2 0 8	5 0 3 2 6 5 9
3 5 9 1 1 1 4	8 6 5 3 8 2 7	3 4 3 3 4 6 4	3 9 2 8 5 6 5
7 3 8 0 0 9 1	0 8 4 7 8 9 6	6 0 5 1 8 3 7	5 9 0 6 4 0 7
5 7 4 1 2 1 3	4 7 7 5 0 6 7	8 2 8 0 2 8 4	2 7 0 5 8 4 0
7 6 5 9 3 9 1	9 5 4 6 6 7 4	0 1 0 8 7 6 6	0 5 4 9 7 3 3
3 5 6 8 2 4 0	4 8 7 3 7 5 4	3 4 4 7 1 7 4	0 3 1 3 4 7 0
8 4 9 8 9 2 3	4 4 3 0 0 7 3	1 7 2 1 7 7 4	0 5 1 9 2 4 8
6 5 1 7 8 9 0	9 8 1 4 7 3 4	8 4 1 4 1 4 8	5 0 7 7 1 8 3
5 1 2 6 9 6 9	9 3 6 4 3 5 8	4 3 2 6 9 5 6	6 5 9 3 8 8 1
7 1 6 8 1 9 8	0 3 0 6 2 5 8	4 7 9 8 5 4 6	5 5 9 0 3 4 4
7 8 7 8 3 7 5	2 1 5 8 0 5 1	8 5 4 8 9 6 9	2 3 6 0 8 1 5
9 9 9 4 3 9 1	7 7 0 3 3 1 2	0 5 3 7 5 1 5	9 6 0 7 1 0 5
9 8 2 1 5 8 2	1 6 3 5 9 8 9	6 9 3 7 3 4 0	0 5 3 8 3 3 9
6 2 1 7 3 0 2	9 6 2 7 9 1 4	8 6 3 5 2 0 0	7 2 7 4 4 8 8
9 8 1 9 1 8 4	0 7 4 2 5 6 2	2 0 1 6 8 0 9	2 1 3 1 5 0 0
0 2 1 4 6 0 5	4 5 7 5 1 1 5	6 6 7 6 2 1 7	6 5 1 2 8 1 4
1 0 4 2 1 0 5	2 9 8 4 5 6 0	4 7 6 7 6 3 3	6 7 5 9 8 8 2
3 4 4 3 4 8 8	4 9 9 3 9 3 3	7 9 9 4 9 8 5	7 0 7 4 9 3 5
7 0 7 6 9 6 4	2 9 1 8 1 0 9	8 2 7 5 8 6 6	9 1 0 7 7 4 0
0 9 1 3 4 5 9	4 5 3 8 6 3 6	2 4 0 5 7 7 4	6 0 6 5 1 9 1
9 6 6 5 7 5 7	2 3 3 7 7 5 1	0 9 5 7 7 9 1	4 6 6 6 0 4 2

Appendix II (Continued)

0 3 3 4 5 8 9	5 6 6 4 2 6 4	2 0 0 5 4 9 1	4 5 1 4 8 7 8
3 0 2 3 6 5 5	7 9 6 3 1 8 9	8 6 5 3 3 9 2	8 6 1 9 7 5 8
2 1 0 0 5 2 7	6 2 3 9 6 8 1	2 2 3 9 4 3 9	0 6 0 4 7 1 6
1 2 1 8 0 1 6	2 9 5 7 7 0 7	6 3 6 3 1 3 7	8 6 1 9 2 9 9
4 5 3 8 5 2 3	9 3 4 5 9 7 5	5 5 8 4 9 5 1	8 7 6 4 4 2 1
9 2 3 2 0 6 9	0 9 4 7 4 8 9	7 1 1 6 0 6 4	0 6 1 4 0 4 2
9 1 5 8 6 9 5	6 7 5 8 2 9 2	3 4 1 7 4 1 1	7 0 6 2 8 2 7
9 8 8 5 5 8 3	3 8 0 0 4 9 0	2 6 6 7 9 0 6	7 9 9 2 0 6 2
1 3 1 4 2 8 2	8 5 6 6 2 9 0	4 4 9 8 4 4 9	8 0 7 7 4 0 7
6 9 0 3 5 9 2	6 3 9 4 2 2 5	7 4 9 7 6 7 0	7 6 8 8 4 3 7
5 2 0 9 9 5 3	6 7 7 9 9 9 5	6 9 5 9 7 5 2	0 8 4 2 4 8 1
5 1 7 1 8 7 0	3 9 3 8 9 8 8	7 3 0 0 2 8 4	3 2 3 4 1 3 3
9 8 6 2 1 0 3	0 2 3 5 9 7 2	3 6 5 0 5 4 0	6 2 8 6 2 9 7
0 8 7 5 9 7 4	9 5 1 9 9 6 2	6 5 0 9 1 3 2	9 9 3 0 4 4 1
2 0 5 5 3 5 8	5 2 1 3 3 2 0	2 6 1 1 9 8 3	2 2 3 4 3 5 5
5 6 6 1 2 9 5	2 0 9 9 5 1 9	2 0 9 5 3 5 3	8 2 2 4 4 7 8
0 5 0 9 6 0 3	8 2 4 0 3 9 6	1 8 8 7 7 5 5	6 4 8 9 6 3 8
2 3 8 5 0 2 6	6 2 8 6 4 9 1	5 0 2 5 4 1 9	6 4 1 5 8 7 9
0 7 3 1 6 4 1	0 7 6 6 1 0 2	5 1 5 5 3 3 1	8 3 6 9 6 7 1
4 0 0 8 8 9 8	6 3 4 1 6 1 7	7 7 7 5 3 1 9	7 3 2 7 6 4 8
2 7 6 3 6 4 5	0 8 4 1 5 1 4	7 0 9 0 8 0 5	7 2 4 9 2 4 9
4 5 1 4 6 0 6	6 9 5 1 1 2 8	6 6 2 5 9 9 7	1 0 9 1 8 7 9
6 4 9 8 4 7 5	0 0 6 0 8 4 2	6 0 0 1 3 3 5	5 9 0 0 8 4 7
1 8 9 8 4 6 4	8 6 4 0 6 0 5	9 7 1 4 4 8 0	2 2 8 2 6 7 7
8 4 9 3 4 8 2	2 5 6 9 5 9 4	3 5 1 0 4 1 8	3 4 9 7 4 9 7

Appendix II (Continued)

6 4 2 4 9 6 3	3 8 9 1 6 5 5	3 1 7 4 1 0 7	7 9 4 2 2 8 0
2 6 5 3 8 4 4	6 4 2 8 8 1 9	4 4 0 7 2 4 0	2 8 8 2 0 5 9
0 5 8 4 5 0 0	8 6 8 0 9 5 1	6 9 2 9 6 9 1	1 9 0 0 0 5 8
7 4 8 9 7 6 8	9 9 8 0 0 9 9	8 3 0 4 8 1 7	9 4 8 8 9 5 3
2 0 8 7 2 5 4	9 2 3 4 5 3 1	2 2 6 2 6 8 6	9 4 0 6 8 4 9
3 1 4 3 2 9 6	9 0 3 6 3 6 5	2 4 4 8 0 7 7	8 0 8 3 4 0 6
6 6 8 9 0 6 1	6 4 4 3 7 3 2	1 3 5 6 8 7 6	5 9 7 0 2 3 1
4 8 1 9 4 5 7	9 1 7 1 4 5 3	4 8 1 1 9 5 2	7 4 7 5 8 5 1
1 1 3 0 3 8 7	2 0 9 0 2 1 7	2 8 4 2 0 4 9	0 3 4 4 4 5 5
5 4 3 7 4 5 7	1 2 2 1 7 8 6	1 0 5 6 3 9 7	7 6 0 9 4 9 6
6 4 8 5 2 3 4	4 5 1 7 7 0 2	3 9 8 1 0 4 2	7 4 9 2 1 1 7
1 6 3 0 9 2 0	2 8 3 2 5 9 0	8 9 8 4 6 3 0	5 4 5 7 7 4 7
4 2 5 8 7 3 7	2 9 0 1 9 2 8	9 8 1 3 1 3 7	0 8 8 1 5 4 6
4 0 1 7 7 9 8	8 4 9 7 9 8 1	6 7 5 8 8 6 2	8 2 5 6 7 3 3
8 2 3 0 9 7 6	5 0 3 7 1 2 6	0 4 8 3 8 4 0	2 5 5 6 3 9 1
7 9 7 8 8 6 8	5 3 4 2 2 0 6	1 4 7 4 3 1 7	1 8 0 0 3 4 9
4 0 5 3 8 7 9	6 7 4 5 3 3 5	2 3 4 8 9 3 4	7 0 2 2 5 4 7
6 4 0 1 6 7 3	0 7 2 9 4 8 5	3 3 1 0 2 4 5	0 7 2 0 2 9 9
4 9 7 5 7 1 2	7 9 5 4 4 0 0	7 9 1 0 9 0 9	8 8 9 6 8 1 4
7 6 9 7 4 5 5	6 4 1 4 4 8 5	0 0 4 9 7 5 1	3 9 5 0 0 8 7
2 3 8 5 4 0 8	9 0 9 1 9 1 1	6 4 6 1 0 9 9	2 8 2 1 0 3 4
6 8 9 7 3 7 0	0 6 6 7 0 5 7	7 9 8 4 8 3 1	4 6 9 2 4 6 0
3 6 4 4 4 9 3	3 6 6 3 4 9 3	0 0 4 2 7 5 2	6 0 9 4 8 1 8
0 3 0 0 3 8 7	7 5 1 0 1 7 2	0 0 7 8 1 3 2	6 2 1 0 7 6 0
1 7 5 4 0 2 6	0 5 1 1 2 7 1	6 1 4 6 3 5 7	6 2 0 5 6 5 7