Discrimination Decrement in an Auditory Task as a Function of Time during a Prolonged Vigil

Saeger
DISCRIMINATION DECREMENT IN AN AUDITORY TASK AS A FUNCTION OF TIME DURING A PROLONGED VIGIL

By

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INTRODUCTION

Recent technological advances have automated industrial manufacturing processes to a great extent. This has often resulted in the shift of man's function as an active operator of the equipment to the role of a relatively inactive monitor whose primary functions are detection and correction of infrequent malfunctions and maintenance of the machinery at a safe operating level. As technology improves further there will be even fewer breakdowns, and for those which do occur, rapid detection will be important. A missed signal may result in expensive repairs and may even endanger the life of the monitor, as in the case of astronauts orbiting in space.

As a result of this automation, the importance of adequately understanding monitoring and vigilance behavior is increasing. Vigilance tasks generally are said to have the following characteristics (Kibler, 1965, p. 93):

a. The signals to be detected are weak and brief.
b. The signals occur infrequently and at irregular intervals.
c. The observer is usually required to react only to the presence of the critical stimulus dimension. Interpretative identification is typically not required.
d. The tasks require sustained attention for protracted periods—usually one hour or longer.
e. Motor involvement is slight (e.g., pressing a button).
f. The decision functions are rarely more demanding than simply judging whether or not the specified signal is present.

These types of vigilance tasks are often incorporated in jobs which require monitoring involving the attending to a display panel or to other potential information sources for the purpose of identifying, sustaining, modifying, or interpreting the signals received from the information sources. Involved in all monitoring activities, as envisioned by Kibler (1965), are the functions of: (a) detection (receipt of information), (b) decision processes involving the interpretation, translation, and collection of sensory data, and (c) executive or control behaviors appropriate to the decisions.

Bakan (1955) has developed a vigilance technique using the ascending method of limits which appears to be very sensitive to visual discrimination decrements. He presented to the S a regular series of light flashes. Occasionally one of these flashes would be slightly brighter than the others, and the S had to report this. If he failed to do so, another flash with even greater brightness was successively inserted and so on until the S did report a difference in brightness. The change in threshold could then be used as an indication of the
discrimination decrement as a function of time. This type of measure gives more data from each experiment than do tasks in which a signal is simply reported present or absent. Bakan found a rise in the difference threshold as the task progressed in any one session. Bakan had previously (1952) used the term vigilance to refer to a central state. He regarded vigilance as a form of sustained attention, and it was in terms of vigilance, or attention, as an intervening variable, that he has described fluctuations or changes in detection performance. The increase in threshold he obtained was believed due to attempts by the S to ward off boredom by changing the situation psychologically in order to reduce the task monotony. This may have been done by means which reduced attentiveness to the discrimination task (e.g., daydreaming) and thus impaired discrimination performance.

Elliott (1957) used the same technique as Bakan, but with auditory signals. In his experiments a regularly repeated sound was present throughout the test, and the signal was inserted immediately after this sound. However, Broadbent (1958) points out that the interval between the regular, no-response stimuli was different from that of Bakan, and so also was the interval between repetitions of the signal if the latter was not immediately detected. Another feature of his experiments
which differed from Bakan's was that his Ss were allowed to read or write as they chose during the course of the experiment; but this aspect of the experiment had no effect on their performance. Elliott did not find a decline during a session, but this did not imply good performance throughout. Broadbent (1958) notes that Elliott's S's thresholds were far above those obtained in a normal situation when the S was expecting a signal (i.e., performance was poor throughout the session).

Elliott's experiments are the only examples of replications of Bakan's technique in the auditory modality, and they differ enough from Bakan's procedure so that they may be called systematic replications only in the loosest sense of the term. The present investigation is a more systematic replication of Bakan's technique and procedure using the auditory modality. However, before entering into a description of the hypotheses which will be tested and the procedures, it may be helpful to look at a brief history of vigilance research because there are several interpretations of the objective and subjective behaviors associated with vigilance situations.

The experimental analysis of human vigilance was pioneered by N. H. Mackworth in 1943. Mackworth's problem was to find the optimum length of watch for English airborne radar operators on anti-submarine patrol. To
determine this he devised the "Clock Test" to produce a visual situation within which the relevant variables could be investigated. In this task, the S was required to respond by pressing a key to irregularly and infrequently presented stimuli; i.e., double-length movements of a pointer in front of a flat white circular surface. The pointer jumped regularly once each second, making a single-length movement. The S was not required to make an overt response to these single-length stimuli, but was to respond as rapidly as possible to the so-called double-length stimuli. The S was instructed that "every now and again, at long and irregular intervals, instead of the pointer moving like so (single-length), it will move through double the usual distance... Press the response key as soon as you notice one of these double-length movements..." (Mackworth, 1948, p. 8).

The Clock Test was administered under a range of different conditions with some of the following results: (a) two-hour watches (control group)—Ss began to miss more signals after they had been working for half-an-hour at the task; (b) one-hour watches—Ss missed fewer signals during their first half-hour than on their second half-hour; (c) one-half hour watches—statistical analysis showed no significant difference between the average performance on the first half-hour of the test and that during any other period of the experiment;
(d) two-hour watches with interposed telephone message at the beginning of the third half-hour—the telephone message "dramatically" reduced the number of missed signals, raising the average level of efficiency for the third half-hour to a standard usually obtained only by fresh Ss; "the introduction of the telephone message produced an effect which lasted for 25 minutes, but this disappeared about 35 minutes after the application of the stimulus" (Mackworth, 1948, p. 114); and (e) the briefing experiment, a two-hour watch wherein Ss were given an extra display to view as well as the Clock hand—this procedure had no effect upon efficiency during any segment of the experiment.

Mackworth also investigated vigilance behavior in an auditory task. This was done by reproducing in an auditory form some of the features of the Clock Test. Preliminary listening tests were performed in order to assure that the auditory task would be of equivalent difficulty to the visual task, difficulty being operationally defined as the incidence of missed signals. The S sat in a sound-proof room listening through headphones to the tones emitted by the test apparatus which was in an adjoining room. The sound came on once every 18 seconds throughout the experiment. Usually it lasted for 2.0 seconds but occasionally it was lengthened to 2.25 seconds, these longer sounds being the signals that the
S had to detect. The signals were presented at the same intervals as were used in the Clock Test.

Mackworth found that the first half-hour of the first session showed a higher degree of accuracy than the rest of the session. This downward trend was not so definite during the second session as the first. The evidence obtained from the combined results on the main listening test also allowed a comparison between the vigilance deterioration found in auditory and visual tasks of equivalent difficulty. The overall incidence of mistakes was practically identical in the two types of vigilance tests. He concluded that this similarity in the two modalities indicated that the decrement in performance, was due to central factors, specifically internal inhibition, rather than to peripheral factors.

In the discussion of his findings, Mackworth analyzed much of his data within a classical Pavlovian conditioned response framework, but using instrumental responses (e.g., key pressing) instead of the involuntary responses studied by Pavlov. Mackworth was very favorably inclined to the Pavlovian formulation.

The Pavlovian framework of ideas is an extremely convenient systematic analysis of behavior, and without some theoretical guidance, followed by an immediate and rigorous check on the deductions, one would soon become lost amongst the countless facts related to fatigue . . . (Mackworth, 1948, p. 252).

Mackworth interpreted the main downward trend of
the data as being "an example of a state of inhibition—
in the sense of the decrease or absence of a response
which was the result of some form of positive stimulation
[Knowledge of results]" (Mackworth, 1948, p. 18). Since
this decrease was apparently due to the repeated presen-
tation of stimuli incorporated in the test situation
itself, it seemed reasonable to regard the lowered
efficiency as an example of internal inhibition. How-
ever, since internal inhibition was never total (i.e.,
Ss never stopped responding completely), the nature of
the condition had to be defined more fully. It was
probable that the exact form it took was that of ex-
perimental extinction, since this can usually be consid-
ered as the absence or weakening of a conditioned
response upon repeated application of the conditioned
stimulus without any of the reinforcement which was
present in the practice session. Under the circum-
stances in question, this was taken to be the repeated
presentation of the double-length signal without any
provision of knowledge of results.

In the discussion of minor fluctuations in effi-
ciency, Mackworth explained these as meaning that al-
though the E gave no information concerning the Ss' progress, the Ss may have had a "vague and uncertain" source of knowledge of results in their own experience of the test situation. This is believed to have been
why the experimental extinction was only partial and not complete; i.e., that to some extent the influence of expectancy and self-instructions replaced the initial reinforcing stimulus of knowledge of results so that the S was occasionally reinforced when he was expecting a signal or when he was engaging in covert self-instruction. This resulted in second-order fluctuations being superimposed on the main trend of the work efficiency curve.

From the standpoint of handling more recent results, Frankmann and Adams (1962) feel Mackworth's inhibition hypothesis is not adequate. For example, a high frequency of signals should result in a greater vigilance decrement than low frequency signals because, within the classical conditioning framework of the inhibition hypothesis, it represents a relatively high frequency of extinction trials. However, Deese and Ormond (1953) and Jenkins (1958) show the opposite to be true.

A few years later, another English researcher, D. E. Broadbent, explored vigilance behavior. However, instead of interpreting vigilance in terms of conditioning he interpreted both of these phenomena in terms of attention (1953, 1958). The theory he developed is known as the filter theory of vigilance. He reasoned that the operator would select stimulus subsets from the impinging stimuli because: (a) the nervous system cannot
adequately handle the total volume of stimulation at any given instant, and (b) adequate responding to one part of the stimulus situation is incompatible with adequate responding to another part. As a result of this, a selective operation is performed on all inputs of the system. The hypothetical construct of a filter, a neurophysiological process, is theorized to perform this operation and is hypothesized to be functional at an early time in the developmental history of the organism. The filter selects only part of the information available from the receptors and passes it on to the perceptual system.

Normally, the filter is theorized to select relevant information for the task at hand. However, the filter is said to have a permanent bias in favor of channels which have not recently been active. Therefore, after continuous observation of one source of information, the filter will select information from other sources. These breaks in attention are brief, but increase in frequency as the task is continued. The vigilance decrement may thus be explained as due to the fact that signals later in the task have a higher probability of falling in the brief periods when the filter is receiving irrelevant information and so are missed.

Broadbent (1958) also stated that at least three properties of stimuli are important in determining priority of selection. These properties are physical
intensity, biological importance, and novelty (i.e., novel stimuli are those differing more from immediately preceding stimuli). The repeated application of a stimulus results in reduced novelty, allowing other parts of the stimulating situation to gain priority. During a rest period different stimuli are selected allowing the original task stimuli to regain novelty. This corresponds to the observed improvement in detection following rest. In similar fashion, a new stimulus introduced between applications of the original stimulus will temporarily renew the novelty of the original one since it is then different from the immediately preceding stimulus.

Broadbent's model rests essentially on the assumption that selection of stimuli is necessarily in accordance with the three stimulus properties already mentioned. Frankmann and Adams (1962) have criticized Broadbent on the grounds that the results he considered seem more specific than the model can convincingly handle. For example, Broadbent had stated that when several sources must be monitored some of them have higher initial priority, specifically those displays with a central location, but as the watch progresses attention shifts towards previously neglected sources. In an experiment using 20 dials as signal sources, Broadbent (1950) found this to be the case. Jerison
and Wallis (1957) found that the detection level remained stable with a three clock display, but in a comparison with a one clock display found that the overall detection level was much lower for the three clocks, although the decrement was not as great. A fine-grain analysis indicated that a decrement may have occurred in just the first 3-4 minutes of the watch with three clocks, but this is quite a different order of phenomenon than the large decrement for the one clock test situation that develops over a relatively long time period. This example does not seem to be adequately explained by the use of the three stimulus properties. The physical intensity and biological importance of all three displays are the same, and it would seem that the overall level of performance should be higher because of their greater novelty in relation to a one clock display. A number of Broadbent's interpretations seemed more like ad hoc explanations of known results rather than predictions following logically from hypotheses derived from a theoretical model.

In his expectancy hypothesis, Deese (1955) has given some reasons for minimizing the importance of inhibition. He felt it to be uneconomical to introduce two opposing states in the nervous system without first examining other possible ways to explain changes in vigilance as alterations in a single positive state of
readiness to respond. Furthermore, there is a need to provide an explanation for the observation that performance does not merely decline—it may also improve (e.g., towards the end of a session) or may oscillate throughout the session.

Deese begins with the concept of an excitatory state of vigilance which determines the probability of detection for any observer. The expectancy hypothesis states that:

(a) 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 (b) the observer's level of expectancy determines his vigilance level and his probability of detection (Deese, 1955, p. 362).

The second part of the hypothesis does not, for Deese, imply that the level of vigilance is directly determined by the level of expectancy.

The level of vigilance of any observer is also subject to adjustment as a function of changes in his motivation state, whereas his extrapolation of future stimulus events might not be affected by such changes. Deese wanted to avoid the artificial situation where expectancy completely determined vigilance.

The failure of the reinforcement hypothesis suggests that it is not fruitful to regard the observer as a passive instrument that remembers only the time since the last signal. Rather, it seems more fruitful to regard the
observer as a detecting instrument that is continuously performing a kind of averaging of previous input in order to extrapolate the results to future behavior of the search field (Deese, 1955, p. 364).

These motivational states, according to Deese, are the basis of individual differences in vigilance and it is the psychologist's task to discover measures of behavior which predict levels of vigilance expected of an individual in a search task. Non-expectancy states determine a base level for an individual's vigilance. Expectancy, however, determines both the overall level and the short range of variations in probability of detection. It is assumed that the average level of expectancy, and thus detectability, is a positive function of signal rate, while the short range variations in expectancy are determined by the ongoing intersignal interval.

Gettys (1964) has interpreted the vigilance decrement in terms of the expectancy hypothesis. He thought a decrement in performance was caused by a progressively downward revision of the S's estimate of signal frequency caused by missing signals, or alternately, by an unrealistically high preliminary estimate of the frequency of the signals due to a lack of experience with the task. This account does not explain why there is a decline in performance within a session even after the S has had ample experience with the task (Buckner,
Harabedian, & McGrath, 1960). Gettys also does not take into account the effect of false-alarms (detections when the signal is not present) which would, according to the expectancy hypothesis, raise the S's level of expectancy.

About the only supportive evidence for the expectancy hypothesis is that probability of detection is a positive function of signal rate (Deese & Ormond, 1953; Jenkins, 1958). However, little or no evidence can be found in support of Deese's views of expectancy as a function of intersignal interval (Frankmann & Adams, 1962). Buckner, Harabedian, and McGrath (1960) emphasize that a communication problem will have to be overcome in arriving at a generally acceptable definition of intersignal interval before expectancy as a function of intersignal interval can be adequately handled. Presently the intersignal interval can be expressed in terms of (a) time between signals, whether the signal is detected or not; (b) time since the last detected signal; and (c) time since the last missed signal. Investigators will have to be more specific in stating which one of these definitions they are using so that other researchers will not draw erroneous conclusions as a result of wrongly interpreting the intersignal interval used.

Baker (1958, 1959a,b) has elaborated on Deese's expectancy hypothesis and has provided a body of
experimental evidence in support of his own views. A major portion of Baker's arguments in applying the expectancy model to experimental data rests on the single consideration that an operator's expectancy is based on how he perceives the actual series of stimulus events. Any variation which makes confirmation of expectancy more probable or which allows more accurate perception of the actual stimulus events should lead to better performance.

Operationally, Baker's expanded definition of expectancy involves five major classes of variables: (a) average signal rate—Baker agrees with Deese that detection probability is a positive function of average signal rate (Baker, 1959b); (b) regularity and range of the intersignal interval (i.e., difference between the longest and the shortest intersignal interval)—increase the probability that the expectancy state will be reinforced. The range of intersignal intervals was related to the occurrence of decrement, and apparently Baker has been the first to demonstrate this phenomenon (Baker, 1958, 1959a); (c) knowledge of results—prevents a decrement by allowing an accurate perception of the sequence of stimuli; (d) knowledge of signal location on a visual display—makes confirmation of expectancy more probable; and (e) signal intensity—expectancy is more likely verified with more intense signals.

Frankmann and Adams (1962) have pointed out that the
underlying assumptions of the expectancy hypothesis are set forth more clearly than was the case with Broadbent's attention hypothesis with the result that the former lends itself more readily to testing. The expectancy hypotheses do not deal explicitly with the classical vigilance issue of decrement occurring over observation time, which might be listed under long range effects as distinguished from short range effects where momentary determiners of response (intersignal interval, spatial location of the signal, etc.) are emphasized. These latter effects concern expectancy theorists. Other variables (e.g., rest periods and environmental factors such as the presence of the experimenter, interpolated messages, and noise) are known to be important, but have been largely neglected.

Other researchers have turned their attention to the neurophysiological correlates associated with vigilance behavior. Scott (1957) examined Hebb's (1955) thesis that stimuli serve a dual function: (a) they have a cue function in controlling goal responses, and (b) an arousal or vigilance role to which Hebb ascribes motivational properties. This latter function has lead to this hypothesis being termed the arousal or activationist hypothesis of vigilance. The arousal function is believed to be vital for organized cortical activity. The arousal function, in turn, is assumed to depend upon
the variability of the stimulus situation. When the stimulation is made repetitive, mental functioning is significantly affected, leading to lowered arousal, and thus to less efficient detection. Scott felt the arousal function of stimuli has been largely ignored and should be given more attention.

Given the nonspecific effect of stimuli on behavioral organization, Scott suggested that stimuli lose their nonspecific effects with continued exposure, the rate of such habituation increasing as the environment is more uniform. This process, termed "sensory habituation," results in a wide range of modifications in behavior of which the vigilance decrement is one of the earliest to appear.

The sensory habituation theory finds application to vigilance tasks in a number of ways. One would expect to find performance restored to or maintained at a higher level under conditions which increase the variety of either peripheral or relevant task stimuli. It appears that under some experimental conditions, not yet clearly defined, task complexity and variety eliminates vigilance decrement in most cases. Scott provided strong evidence for the presence of perceptual variation as a necessary condition in maintaining alertness. An impressive amount of facts about vigilance behavior superficially fit the general framework of the
activationist hypothesis; however, the absence of operational definitions for the type of stimuli, as well as the characteristics of each stimulus class, gives the hypothesis little predictive capability for measures of molar behavior (Frankmann & Adams, 1962).

Holland (1958) felt that investigators of vigilance should attempt to establish an appropriate behavioral datum rather than postulating subjective states. Toward this end, he has devised a technique for the analysis of observing behavior. Working in a dark room, Ss were required to observe and report deflections of a pointer on a dial that could only be seen after they had pressed a key which provided a brief (0.07 sec.) flash of light thereby illuminating the face of the dial. The pointer remained deflected until another key was pressed returning it to normal. Deflections of the pointer were scheduled in many different ways analogous to the scheduling of food reinforcement with animals. The advantage of this technique is the ability to show an increase in response rate even when the rate of signal detection is nearly 100 per cent.

Holland found that poor observers showed a sharp decline over the first half-hour in both pressing the illumination key and detections of pointer deflections, with a continued gradual drop until the last period where some recovery occurred. For the good observers
percentage of signals detected did not decline and ob-
serving rate increased according to a negatively accel-
erated function of time. Holland also analyzed observing 
behavior using the Mackworth schedule. He found high
detection Ss showed an increase in response rate as the 
session progressed. Their percentage-detection data 
could not reflect this rise because the Ss were already 
detecting nearly all of the signals. The vigilance 
decrement as earlier found by Mackworth was confirmed,
and a parallel decrement in observing rate was shown as well (Holland, 1958).

Frankmann and Adams (1962) have criticized on 
several grounds this method of studying vigilance be-
havior through observing responses. Requiring an overt
response such as key pressing introduces an element into 
the situation that is not present in free scanning 
vigilance tasks. Repetitive rapid pressing of a key may 
produce work inhibition or fatigue. Furthermore, there 
is the implicit assumption, not only that the viewer 
looks at the display every time he presses the key, but 
also that this is the same scanning response that would 
occur if the Ss were not required to press the key. 
Frankmann and Adams indicate an equally reasonable inter-
pretation is that the S presses the key rapidly in order 
to keep the display illuminated so he can scan when he 
wants to, and they note that the very high response
rates (Holland, 1957, 1958) suggest this as the case. However, the high response rates may very well be a function of the schedule of reinforcement the $S$ is on. The variable interval schedule, most typical of vigilance tasks, has been shown to produce a high rate of responding (Ferster & Skinner, 1957). Changes in the detection rate, under the interpretation of Frankmann and Adams, would not necessarily correlate with the observing rate if head and eye movements were to be measured directly and motor fatigue was trivial. This criticism has been supported by Baker (1960). By means of photography he has demonstrated that under conditions where a decrement in performance did not occur, the frequency of nonobserving behavior and general activity increased in time. Observing responses were defined by photographic records of eye-fixations toward the display. However, Jerison and Wing (1959) note that "rather than refuting Holland's arguments, this result of Baker seems to us to indicate that such eye-fixations cannot be observing responses" (Jerison & Wing, 1959, pp. 34-35).

Originally developed by electrical engineers in the early 1950's, the theory of signal detectability (TSD) has rapidly evolved into a new model for the interpretation of vigilance behavior. The application of mathematical models to a sensory process was initiated by Tanner and Swets in 1954. TSD is a combination of
decision theory along with a refinement of the theory of ideal observers.

Decision theory provides an analysis of the process which produces the division between stimuli that the S reports he does and does not hear. The theory recognizes that a priori probabilities, values and costs associated with correct and incorrect decisions, and the physical parameters of the signal play a decisive role in establishing the dichotomy. This dichotomy is determined by an adjustable criterion. The theory shows how a quantitative estimate of the criterion can be obtained from the data (Swets, 1964). Decision theory also emphasizes that the S's criterion in addition to the parameters already mentioned performs a major function in determining the S's responses. The theory indicates the class of variables which determines the level of the criterion, and suggests an analytic technique, using the parameter $d^*$, to account for this criterion level. The parameter $d^*$ is the difference between the means of the two distributions, noise minus signal-plus-noise, divided by the common standard deviation (Green & Swets, 1966). This gives equal weight to the units of the noise and signal-plus-noise. Under ideal conditions, the parameter $d^*$ measures the ability of S to detect a signal of whose existence he is unsure (Taylor, 1965). This technique leaves a relatively pure measure of the detectability.
of the signal. The invariance of the $d'$ measure over several psychophysical procedures has been demonstrated (Swets, 1959).

The second part of the detection theory is the theory of ideal observers. This theory supplies a collection of ideal mathematical models which relate the detectability of the signal to definite physical characteristics of the stimulus. There are a number of such models because one may make different restrictions on the nature of the detection device. The calculated results of the ideal observer are then compared with performance results for the purpose of suggesting a new model of the hearing mechanism, or new experiments to clarify the exact nature of the inequality (Swets, 1964).

As it relates to vigilance, the techniques of detection theory make possible the experimental determination of whether the observed vigilance decrement is due entirely to a decrement in perceptual sensitivity, the traditional interpretation, or in part to a change in the response criterion of the S. Green and Swets (1966) state it is "evident" from the data they studied that much of the decrement over time in the hit proportion is due to an increasing strictness in the response criterion, as indicated by the concomitant decrease in the number of false-alarms.

Jeronson (1967) voices the criticism that the
psychological interpretation of the TSD measure of
criterion (β) as an index of conservativeness during a
vigil does not appear to be valid. β is interpreted in
a psychophysical experiment as a measure of the obser-
ver's (psychological) conservativeness in calling a
sensory stimulus a signal or nonsignal event (Green &
Swets, 1966). When an observer adopts β = 1.0, he, in
effect, accepts an "even-money" bet (where p (signal +
noise) = p (noise) = p = 0.5) on his sensory information
that a particular stimulus which he reports as a signal
is, in fact, a signal. Jerison feels it is difficult
to give the higher numerical values of β obtained in
vigilance research using TSD some psychological meaning.
In psychophysical-TSD studies, values of β greater than
1.0 are unusual. It is therefore surprising to Jerison
that vigilance researchers in using TSD, report values
of 70 or more (Colquhoun & Baddeley, 1964). Jerison
feels measures such as these be regarded as psychologi-
cally meaningless because they are mainly artifacts due
to pooling observations made under different conditions
of attentiveness during a long vigil.

From this brief review it can be seen that no one
model adequately accounts for all the events associated
with vigilance behavior. Frankmann and Adams (1962)
attribute this in part to "... casualness of formu-
lation that makes the definitive testing of implications
rather difficult" (Frankmann & Adams, 1962, p. 268). All the models have certain areas in which they have more validity than other hypotheses, but as yet none of the models may truly be called a theory of vigilance. More empirical investigation is needed in order to develop a valid, comprehensive theory of vigilance. This theory may possibly be a synthesis of some of the formulations of the current models.

In the opinion of this investigator, the activationist hypothesis as proposed by Hebb (1955) and Scott (1957) holds the most promise in forming the foundation of the "ultimate" theory of vigilance. This hypothesis may also produce an "explanation" for the occurrence of a decrement in performance in some situations and not in others. It is necessary that the nature of the physiological changes in the nervous system as a function of time during a vigil be understood so that empirical research at the behavioral level can be conducted with a firmer foundation. However, at the present time the lack of valid operational definitions for the type of stimuli related to vigilance performance give this hypothesis little predictive power (Adams & Boulter, 1962). Another difficulty related to the development of this hypothesis is the deficiency in current neurophysiological techniques, but this problem is rapidly being overcome.
The purpose of this investigation is to empirically determine the nature of the vigilance decrement in the auditory modality using a systematic replication of the procedure of Bakan (1955). Bakan, working with a constantly observable patch of light, found that the difference threshold to slight increments in the brightness of this light increased with time on watch. The psychophysical procedure used by Bakan is closest to the single comparison standard studied by Pollack (1951). The first signal of the signal pair is the reference standard, and the second is the to-be-judged reference standard (either standard or test). The task of the S is to detect whether the second signal of the pair is higher than the standard or not.

Owing to the constraints of the apparatus, the psychophysical procedure employed in this experiment is most similar to the single standard procedure as described by Pollack (1951). Each signal is presented individually without an objective and concurrent signal serving as a comparison. The task of the S is to identify each signal as "high" or "the same" relative to an initial reference level produced at the beginning of the experimental session and maintained during the intertrial intervals or wait periods.

This investigation is necessary because researchers comparing vigilance performance in different modalities...
have obtained different results. Buckner and McGrath (1965) point out that "... even within the domain of vigilance tasks there is only a low positive correlation ($r=0.20$) between auditory and visual vigilance tasks" (Buckner & McGrath, 1963, p. 53). However, Mackworth (1948) has found that the character of the vigilance decrement was similar in both the auditory and the visual modalities. These discrepant reports may be due to the fact that Buckner and McGrath tested the same Ss on both a visual and an auditory vigilance task and correlated their results, whereas Mackworth used different groups of Ss in a task of equal difficulty in each modality and then compared the shape of the function obtained for each group.

The general supposition of this experiment is that the character of the vigilance decrement is similar in both the auditory and the visual modality. If this is correct, we can expect to find that: (1) differences in the difference threshold or limen for successive periods of time should be significant with the difference threshold at the end of the session being significantly higher than at the beginning; (2) differences in the number of errors of commission (false-alarms) for successive watch periods should be significant with the number of errors at the end of the session being fewer than at the beginning; (3) differences in
days should be significantly larger on the first day than on the second day of vigil; (4) differences in the number of errors for days should be significantly larger on the first day than on the second day of vigil; (5) a Days X Ss interaction for the difference threshold should be significant; and (6) a Days X Ss interaction for the number of errors should be significant.
METHOD

Subjects

Twenty male college students attending Western Michigan University participated in this experiment. They were paid $1.00 per hour and were obtained by responding to sign-up sheets.

Apparatus

A Beltone Model 15 C Clinical Audiometer with headphones was used. The headphones used were Claricon dynamic stereo model #85-295. In order to prevent the sound of the apparatus from serving as a possible cue for the S, a ten foot extension cord was used to separate the audiometer from the headphones. The apparatus was calibrated in 5 decibel increments. A hand-made set of one decibel calibrations was placed over the dial in order to make the intensity adjustment more reliable. Wait periods were timed on the sweep second-hand of the experiment's watch.

Procedure

The subject was seated in the experimental room. The experimenter and the apparatus were located behind the S about ten feet. After instructions (see
Instructions in Appendix A) to the S were given, his absolute threshold was determined by the method of limits as described by Chapanis (1959). Four sets of trials were used.

The signals were presented binaurally through a set of headphones. All of the signals had a duration of 1/2 second as did the intersignal interval. The signals ranged in intensity from 31 to 36 decibels above the absolute threshold of the individual S being tested. The standard signal remained constant throughout the experiment at 30 db above threshold. The frequency of both the standard and test signals was maintained at 1,000 cycles per second. These stimulus values were selected because it has been demonstrated that at a frequency of 1,000 cps and at an intensity of 30 db above threshold it is possible to detect a one db difference in intensity (Riesz, 1928).

In order to analyze the pattern of the threshold change as the vigil progresses, the intensity increment required to elicit a difference judgment was determined by the ascending method of limits on each trial. A trial began with a presentation of a test signal in place of the standard which was one db more intense than the standard signal. If the difference was not detected within the first five presentations, the intensity of the test signal was further increased by one db. A
trial ended when the S indicated that a difference had been detected by raising his right hand. The right arm remained flat on the desk when the S was not responding. This was done so that the S's arm moved the same distance each time a response was made, enabling E to be certain that the S had definitely made a response. If the S did not respond after the test signal had reached the 36 db level, the trial was scored as if a response had been evoked at the 36 db level. The test signal was then replaced by the standard signal of 30 db above threshold until the start of the next trial.

After instructions had been given and the absolute threshold of the S determined, various test signals ranging down to the standard signal were then demonstrated for him. This was followed by a practice period of approximately 7.5 minutes during which five trials (see Appendix C) were given under test conditions like those of the experimental session. At the end of the practice period the S was asked if he had any questions about the procedure of the experiment. A five minute rest period followed the practice period before the start of the actual session.

The trials were irregularly spaced and came after wait periods of 50, 60, 65, 140, 185, and 350 seconds between the beginning of one trial and the beginning of the next. This was done so that all Ss would spend an
approximately equal amount of time in the session. Additionally, Ss would not be able to predict the onset of test signals by using the passage of time as a cue. Six different 15 minute programs of wait periods were used on each day (see Appendix B). Testing was performed on two separate days, generally within the same week. These programs were used so that no two successive 15 minute periods had the same wait sequence, and so that the second would be different from those on the first day of testing for any individual S. Each session was approximately 1.5 hours long, consisting of six equivalent 15 minute blocks (the length of each block is the sum of the combined length of the six wait periods and the six trials), each block being made up of six trials (see Figure 1).

The Dependent Variables. One of the dependent variables in this experiment was the change in vigilance performance (discrimination alteration) as a function of time. This performance was measured by the mean intensity increment in db level required to evoke a response for each 15 minute period for each session; i.e., the mean difference limen. Another dependent variable was the number of errors of commission (false-alarms) as a function of time during the sessions. The errors of commission were tabulated for each 15 minute period; i.e., a record of responses made when no louder test signal was presented.
The Independent Variables. One of the independent variables in this investigation was the manipulation of the intensity of the test signal during a trial. Another independent variable was the division of the sessions into 15 minute periods in order to better observe the change in discrimination performance and in the number of errors of commission. A loosely controlled independent variable was the length of time between the two test days. However, it should be pointed out that this was in keeping with the procedure of Bakan (1955) whose Ss were "tested on two different days, generally during the same week" (Bakan, 1955, p. 387).
SESSION (1 1/2 Hours) - Composed of Six Blocks (Periods)

B = BLOCK (PERIOD)

BLOCK (15 Minutes) - Composed of Six Trials and Six Wait Periods

W₁ — T₁ — W₂ — T₂ — W₃ — T₃ — W₄ — T₄ — W₅ — T₅ — W₆ — T₆ (New Block)

W = WAIT PERIOD

T = TRIAL

Trials are irregularly spaced and come after waits of 50, 60, 65, 140, 185, and 350 seconds between the beginning of one trial and the beginning of the next.

TRIAL — Trial BEGINS with a presentation of a test signal in place of the standard.

STD | 1/2" | 1" | 1"" | 2 | 3 | 4 | 5 | TEST
----|------|----|----|---|---|---|---|------
30db| 30db | 31db| 31db| 31db| 31db| 31db| 31db| 32db

Above 36db S's Threshold

Trial ENDS upon response by S.

WAIT PERIOD

W₁ — T₁ — W₂

Figure 1—Schematic diagram of Procedure
RESULTS

Threshold Data

Table 1 shows the analysis of variance for the auditory threshold data. Significant main effects were noted for Periods at the .01 level, F(5, 95) = 29.47 and for Subjects also at the .01 level, F(19, 19) = 4.88. The significance of the variance for individual Ss indicated that, in terms of overall threshold scores, some Ss were good at the task and others were poor in spite of an attempt to make the task equally difficult for all Ss. The main effect for Days was not statistically significant. The interactions that were significant were for Periods X Days F(5, 95) = 2.30, p < .05 and for Days X Subjects F(19, 95) = 5.74, p < .01. The nature of the function between successive 15 minute periods and the difference threshold is illustrated in Figure 2 for each of the two test days. The general level of performance on Day 2 was slightly better than on Day 1 in four out of six periods; however, the variance contributed by was not statistically significant F(1, 19) = 0.08, p > .05. The Periods X Subjects interaction was the only interaction which was nonsignificant F(19, 95) = 1.14, p > .05.
False-alarm Data

Table 2 presents the analysis of variance for the false-alarm data. The only main effect found to be significant was for Periods $F(5, 95) = 19.14$, $p < .01$. Both the variance for Days, $F(1, 95) = 1.68$, $p > .05$ and for Subjects, $F(19, 95) = 1.30$, $p > .05$ were not statistically significant. The only interaction which was significant was that noted for Days X Subjects, $F(19, 95) = 11.15$, $p < .01$. Neither the interactions for Periods X Days, $F(5, 95) = 0.8$, nor for Periods X Subjects, $F(95, 95) = 0.7$, were statistically significant at the .05 level. Figure 3 shows the nature of the function between successive 15 minute periods and the number of false-alarms (errors of commission) for each of the two test days. For each day there was a decreasing number of false-alarms from the beginning to the end of the session. There were fewer false-alarms in all periods on Day 2 than on Day 1, but the differences between days was not statistically significant.
### TABLE 1

**ANALYSIS OF VARIANCE FOR THRESHOLD DATA**

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<thead>
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<th>Source</th>
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<th>MS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Periods (P)</td>
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<td>3.478</td>
<td>29.47</td>
<td>.01</td>
</tr>
<tr>
<td>Days (D)</td>
<td>1</td>
<td>.058</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ss</td>
<td>19</td>
<td>3.312</td>
<td>4.88</td>
<td>.01</td>
</tr>
<tr>
<td>Px D</td>
<td>5</td>
<td>.272</td>
<td>2.30</td>
<td>.05</td>
</tr>
<tr>
<td>Px Ss</td>
<td>95</td>
<td>.135</td>
<td>1.14</td>
<td></td>
</tr>
<tr>
<td>Dx Ss</td>
<td>19</td>
<td>.678</td>
<td>5.74</td>
<td>.01</td>
</tr>
<tr>
<td>Px Dx Ss</td>
<td>95</td>
<td>.118</td>
<td></td>
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</table>
Figure 2. The effect of time on the difference threshold for each day.
### TABLE 2

ANALYSIS OF VARIANCE FOR FALSE-ALARM DATA

<table>
<thead>
<tr>
<th>Source</th>
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<th>MS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Periods (P)</td>
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<td>19.14</td>
<td>.01</td>
</tr>
<tr>
<td>Days (D)</td>
<td>1</td>
<td>84.016</td>
<td>1.68</td>
<td></td>
</tr>
<tr>
<td>Ss</td>
<td>19</td>
<td>64.832</td>
<td>1.30</td>
<td></td>
</tr>
<tr>
<td>Px D</td>
<td>5</td>
<td>3.866</td>
<td>—</td>
<td></td>
</tr>
<tr>
<td>Px Ss</td>
<td>95</td>
<td>3.518</td>
<td>—</td>
<td></td>
</tr>
<tr>
<td>Dx Ss</td>
<td>19</td>
<td>49.850</td>
<td>11.15</td>
<td>.01</td>
</tr>
<tr>
<td>Px Dx Ss</td>
<td>95</td>
<td>4.468</td>
<td>—</td>
<td></td>
</tr>
</tbody>
</table>
Figure 3. The effect of time on the number of false-alarms for each day.
DISCUSSION

The general supposition of this experiment that the character of the vigilance decrement is similar in both the auditory and the visual modality was indirectly confirmed. This is depicted in Figure 1. The data confirmed hypothesis (1) which asserted that changes in the difference limen for successive periods of time should be significant with the difference threshold at the end of a session being higher than at the beginning. Hypothesis (2) was also confirmed. The differences in the number of false-alarms for successive watch periods were significant at the .01 level. The number of errors at the end of a session were fewer than at the beginning of a session, successively decreasing in each time period.

There was presumably a practice effect which improved the general level of performance on Day 2 as contrasted to Day 1, but this result did not seem to have significantly altered the gradual increase in the difference threshold over time which was found for both days. The variance contributed by days was not statistically significant which resulted in the rejection of hypothesis (3). Hypothesis (4) was also rejected as the variance contributed by days for the false-alarm data failed to reach the .05 level of significance. Both hypothesis (5) and
hypothesis (6) were accepted. The Days X Ss interactions for both the difference threshold and the number of false-alarms were significant at the .01 level. The significant Day X Ss interactions for both the false-alarm and the threshold data indicated that there was less variance between Ss' performance on these measures on the second test day as compared to their performance on the first test day.

The results of this investigation have partially demonstrated that, by using a systematic replication of Bakan's (1955) procedure, the character of the visual vigilance decrement was in some important respects similar in a different sensory modality. Although the results were comparable in terms of the form of the discrimination decrement obtained, there were some notable differences. It remains to be seen just how far one may generalize from the data of this study to Bakan's findings. Some of the differences between the results obtained in this investigation and those of Bakan's experiment will be examined and possible explanations offered. The findings of this study will then be briefly discussed in terms of Bakan's concept of attention.

It may be difficult to directly compare the results of this experiment with those of Bakan for several reasons. First, the tasks are conceivably of different difficulties. This is due in part to the fact that it is almost impossible
to empirically determine when a brightness increase is equivalent in discrimination difficulty to a loudness increase using the psychophysical procedure of this experiment. Also related was the difficulty of comparing two figures in which the units of measurement were non-equivalent. Second, the exact nature of Bakan's instructions were not known and could not be obtained. All the information available was that the "S was instructed to push a button whenever he detected a stimulus brighter than standard" (Bakan, 1955, p. 387). The instructions used in this study may have raised the S's criterion above that for S in Bakan's investigation. For example, in this experiment the S was cautioned against responding unless he was quite certain the signal he was listening to was actually the test signal.

A primary discrepancy between the results of this study and those of Bakan was the failure of differences in the variance associated with test days to reach statistical significance. This was the case with both the difference threshold data and the false-alarm data. These were the only instances in which the experimental hypotheses were not confirmed. This failure may have been due to differences in environmental conditions (i.e., heat, humidity, and ambient noise level) and/or the time (i.e., the hour of the day during which the S was tested). An additional possibility is that days should not be expected
to contribute significantly to variability. Performance on one day ought to be consistent with performance on another day after Ss learn the task and if the nature of the stimuli do not differ in character. Also to be considered is the "warm-up" effect noted during the first 15 minute period of the second day, especially during the first one or two trials of that period. This "warm-up" effect was primarily responsible for the difference threshold scores for the first period of the second day being higher than those for the first day. The Period X Days interaction was statistically significant for the threshold data. This indicated that discrimination performance during each 15 minute period for the first day was significantly different from the performance of the comparable 15 minute period for the second test day.

The similarity of the form of the discrimination decrements in both experiments gives support to the assumption that vigilance is a central state (Mackworth, 1948; Bakan, 1952, 1955). This also reemphasizes the need for an adequate neurophysiological explanation of vigilance performance. Most of the Ss began the task with a relatively high level of attention as indicated by the low difference threshold scores in the first period of the first day. This was also true for the second period of the second day after the "warm-up" effect found in the first period as shown in Figure 2. However, as
time on the task increased, the presumed level of attention became increasingly lower as inferred from the higher threshold scores, although there were some short between trial reversals of this tendency. Note should be made here of the fact that the Periods X Subjects interaction was not significant. This would indicate that individual differences tend to persist in about the same magnitude from period to period. Bakan (1955) has hypothesized that the monotony of the typical vigilance situation tended to lower the level of attention of the S and to bring about a state of drowsiness. In this experiment one S, as indicated by his response rate, was observed to fall asleep for a brief time towards the end of a session. If the S were motivated to perform well on the task, he might engage in thinking behaviors which were self-reinforcing and thereby raise or maintain his level of attention and decrease the probability of going to sleep. This type of thinking would commonly be known as daydreaming. However, daydreaming is usually incompatible with attending to certain discrimination tasks. If attention to the task at hand became progressively harder to maintain as the vigil progressed, the rate of daydreaming behaviors could be expected to increase. This would consequently lead to an increase in the proportion of time during which incompatible behaviors were engaged in and hence to an increase in the discrimination threshold. It would require a more
intense test stimulus to "break in" and bring the stimulus to the S's attention.

This increase in incompatible behavior may also explain why the false-alarm rate decreased with time. Initially the S paid close attention to the task. Any discrepant stimulus may have been interpreted as the test signal and responded to thusly. As the session progressed the S paid increasingly less attention to the signals and consequently made fewer false-alarms. This factor, combined with the effects of practice on the task and possibly a shift in the S's criterion, resulted in a decreasing number of false-alarms.

An interesting way to empirically observe the drop in the level of attention would be to employ some type of procedure similar to Holland (1958) which would separate out the variables of attention ("observing responses") and discrimination performance. However, it seems that an observable measure of attention in an auditory task would be difficult to obtain. Perhaps some physiological (heart rate) or neurophysiological (change in electrical potential measured at the auditory nerve) indices of behavior may be utilized.
SUMMARY

A systematic replication of Bakan's 1955 study was conducted to evaluate the nature of the vigilance decrement in a different sensory modality. Bakan, working with a constantly observable patch of light, found that the difference threshold to slight increments in the brightness of this light increased with time on watch.

An auditory vigilance task was used to investigate the change in the differential loudness threshold and the number of false-alarm responses as a function of successive periods of time. Measures of auditory difference threshold and false-alarm responses were obtained from twenty college students during the course of two day 1.5 hour vigils in which the S responded when they detected an intensity increase in the signal.

The general supposition of this experiment was that the character of the vigilance decrement was similar in both the auditory and the visual modality. If this were correct, we would expect to find that: (1) changes in the difference threshold or limen for successive periods of time should be significant with the difference threshold at the end of the session being significantly higher than at the beginning; (2) differences in the number of errors of commission (false-alarms) for
successive watch periods should be significant with the number of errors at the end of the session being fewer than at the beginning; (3) differences in the difference threshold for days should be significantly larger on the first day than on the second day of vigil; (4) differences in the number of errors for days should be significantly larger on the first day than on the second day of vigil; (5) a Days X Ss interaction for the difference threshold should be significant; and (6) a Days X Ss interaction for the number of errors should be significant.

Significant effects in the threshold data were found for Periods, Ss, Periods X Days, and Days X Ss. Significant effects in the false-alarm data were found for Periods and Days X Ss. The results were found to confirm hypotheses (1), (2), (5), and (6), thus supporting the supposition that visual and auditory vigilance phenomena are essentially similar.
REFERENCES


Baker, C. H. Attention to visual displays during a vigilance task: II. Maintaining the level of vigilance. British Journal of Psychology, 1959, 50, 30-36. (a)


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Appendix A

INSTRUCTIONS
INSTRUCTIONS

Thank you for your cooperation in this experiment. The experimental session will last approximately an hour and a half and will require another session to be completed later this week, if possible. You will receive your pay at the end of the second session. For this experiment it is necessary that you remove your watch.

The purpose of this experiment is to determine the ability of operators to detect intensity (loudness) differences between two auditory signals. Your task will be to listen to two signals which are the same except for intensity (loudness). One signal, the standard signal, will be constant in intensity throughout the session. No response is required when you hear this signal. Another signal, the test signal, will be presented at irregular intervals in place of the standard signal. When you judge that the test signal is present, that is, the signal you are listening to is louder than the "normal" standard signal, respond by raising your hand for 2-3 seconds. Do not raise your hand unless you are quite certain the signal you are listening to is actually the test signal. When you have made the response, you can consider the trial at an end. Another trial will begin shortly. Please keep your arm flat on the
desk when not responding. This is so your arm will move
the same distance each time you make your response and
so I will be certain when you are making a response.
This procedure will continue throughout the session.
Appendix B

ORDER OF PRESENTATION OF WAIT PERIODS FOR EACH DAY
ORDER OF PRESENTATION OF WAIT PERIODS FOR EACH DAY

<table>
<thead>
<tr>
<th>Period</th>
<th>Length of Wait Period in Seconds</th>
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</thead>
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<td><strong>DAY 1:</strong></td>
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<tr>
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<td>65 - 60 - (1_{10}0) - 350 - 185 - 50</td>
</tr>
<tr>
<td>2</td>
<td>50 - 350 - 185 - (1_{10}0) - 65 - 60</td>
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<tr>
<td>3</td>
<td>65 - 50 - 350 - 185 - 60 - (1_{10}0)</td>
</tr>
<tr>
<td>4</td>
<td>350 - 60 - 65 - 50 - (1_{10}0) - 185</td>
</tr>
<tr>
<td>5</td>
<td>350 - 60 - 50 - (1_{10}0) - 185 - 65</td>
</tr>
<tr>
<td>6</td>
<td>50 - (1_{10}0) - 350 - 185 - 60 - 65</td>
</tr>
<tr>
<td><strong>DAY 2:</strong></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>50 - 185 - 350 - (1_{10}0) - 60 - 65</td>
</tr>
<tr>
<td>2</td>
<td>65 - 350 - 50 - 60 - (1_{10}0) - 185</td>
</tr>
<tr>
<td>3</td>
<td>350 - 65 - 185 - 60 - (1_{10}0) - 50</td>
</tr>
<tr>
<td>4</td>
<td>65 - 60 - (1_{10}0) - 185 - 50 - 350</td>
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<td>5</td>
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</tr>
<tr>
<td>6</td>
<td>350 - 185 - 50 - 60 - 65 - (1_{10}0)</td>
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</tbody>
</table>
Appendix C

ORDER OF PRESENTATION OF PRACTICE TRIALS
ORDER OF PRESENTATION OF PRACTICE TRIALS

Length of Wait Period in Seconds

60 - 140 - 65 - 50 - 140