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A Survey and Analysis

of

Vigilance Research

by

Bruce O. Bergum and I. Charles Klein

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OF
VIGILANCE RESEARCH

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COMPOSITION OF RESEARCH TEAM

This study of vigilance research was initiated by SP 4 I. Charles Klein, who reviewed the psychological literature and completed the initial draft of this report. After SP 4 Klein was separated from the Army in June 1960, the study was completed by Dr. Bruce O. Bergum, who expanded the theoretical discussion, reviewed the research needs, and prepared the final version of this report.

This study was conducted under the supervision of Dr. Robert D. Baldwin, VIGIL Task Leader.

ORGANIZATIONAL NOTE

The sheer bulk of the information assembled for this report presented a major organizational problem. The difficulty was due in part to the desire of the authors to present the most comprehensive possible treatment of the subject matter, and in part to the diversity of the work accomplished in this area. The rationale on which the present organization is based is summarized below.

The report consists of five chapters and a bibliography. Chapter 1 contains three sections: a brief note on the background of vigilance research, a statement of the military problems posed for advanced weapon systems by vigilance phenomena, and a statement on the specific nature of the psychological problems involved in vigilance performance. These sections are oriented toward different audiences and are essentially introductory in nature.

A detailed survey of the empirical literature on vigilance is presented in Chapter 2, under three major groupings: task factors, environmental factors, and motivational factors. The effects of variables relating to these major classes of factors are summarized briefly at the end of the Chapter.

Following this presentation of the known facts relating to vigilance, the relevance and adequacy of current theoretical interpretations of these data are considered in Chapter 3. The theories are grouped under three major categories: conditioning theory, expectancy theory, and motivation theory.

The implications for action growing out of the facts and hypotheses presented in the preceding two chapters are discussed in Chapter 4. Three approaches to solution of the vigilance problem are discussed in terms of anticipated technological developments.

The final chapter is a summary of the report and of the suggestions for vigilance research growing out of the survey.

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A SURVEY AND ANALYSIS
OF
VIGILANCE RESEARCH

Chapter 1

THE VIGILANCE PROBLEM

INTRODUCTION

The current widespread military interest in vigilance behavior began during World War II when the generally low level of performance of lookouts, aerial observers, and sonar operators became a critical military problem. The need for immediate and practical solutions to these problems led to a considerable amount of research covering a broad range of "vigilance" behaviors, and such research continues today. With the trend toward increasingly automated system functions that has developed in recent years, however, the emphasis and interest in vigilance research has shifted to consideration of the problem of man as a monitor of automatic equipment. Because future and presently near-operational Army Air Defense systems reflect this trend toward automated functions, the Air Defense Human Research Unit is concerned specifically with the solutions to the human monitoring problems which will almost certainly be associated with these systems.

This report presents an assessment of the current empirical and theoretical "state of the art" in the area of vigilance behavior. The purpose of this effort is to develop a program of research specifically designed to study monitoring problems associated with advanced Army Air Defense systems.

THE MILITARY PROBLEM

That vigilance phenomena constitute an important problem for the maximum efficiency of complex weapon systems can be easily demonstrated. Man is typically an integral component of most weapon systems, and system effectiveness is a multiplicative function of the individual efficiencies of the total complex of components. Therefore, total system effectiveness will be radically affected by the low level of effectiveness typically found for the human component of the system. Where man makes continuous inputs to the system, this relationship is fairly obvious. Where manual inputs are infrequent, as in vigilance situations, the relationship is less apparent but nonetheless real.

This relationship is demonstrated in Table 1, in which an efficiency of 99 per cent is assumed for the electromechanical components of the system, and human efficiencies on the order of those typically found in psychological studies are assumed for the operator. It is apparent that the human inputs, while infrequent, contribute disproportionately to total system effectiveness as vigilance performance deteriorates.

Table 1

**Relationship of Machine and Operator Efficiency
to Total System Effectiveness**

Time at Task	Group [a]	Machine Efficiency (Per Cent)	Operator Efficiency (Per Cent)	Total System Effectiveness (Per Cent)
1/2 hour	M_1	99	84.3	83.5
	M_2	99	82.8	82.0
	J_1	99	65.0	64.4
	J_2	99	27.6	27.3
1 hour	M_1	99	74.2	73.5
	M_2	99	70.7	70.0
	J_1	99	53.3	52.8
	J_2	99	27.0	26.7

[a]Data for the M groups are from Mackworth (1950), and data for the J groups are from Jerison and Wallis (1957).

If military needs demand that total system effectiveness approach 100 per cent, and if vigilance tasks are required for operation of the system, then the military problem reduces to the question: What can be done to maintain vigilance performance at a level that will not reduce total system effectiveness? The answer to this question must grow out of the solutions to the psychological problems described in succeeding portions of this report.

THE PSYCHOLOGICAL PROBLEM

Definition of Vigilance

Current operational definitions of vigilance are in general agreement on its essential characteristics, although at an operational level there is some ambiguity regarding the precise range of values for these conditions. In general, the essential defining characteristic of vigilance phenomena is a systematic change in the probability of detection of a signal over time. Additional limiting conditions include changes in performance, over prolonged periods of time, in detection of infrequent signals, at near-threshold levels, which are temporally and spatially random in character.

Part of the problem of defining vigilance is that of specifying the terms "prolonged" and "infrequent." The duration of vigilance tests reported in the literature ranges from 30 minutes (Hickey and Blair, 1959) to as long as several days (Katz and Landis, 1935). Signal presentation rates have varied from a frequency of eight signals/min. (Jenkins, 1958) to as few as one signal/2 hrs. (Garvey et al., 1958). It should be noted, however, that in general the adequate definition of psychological concepts includes measurable changes in response as a function of variations of the stimulus; where variations in two or more stimulus dimensions result in similar response changes, these functional relations are subsumed under the same conceptual term. Thus,

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if similar decrements occur in the detection response over 30 minutes or over several days (time dimension), or with signals at eight/min. or one/2 hrs. (frequency dimension), all of these conditions are defining conditions for the same behavioral phenomenon. In short, inclusion of a description of the response changes is a necessary, and the limiting, condition for defining the phenomenon of vigilance, and insofar as any stimulus variations lead to similar changes in response these variations represent different aspects of the same psychological concept.

The psychological research problem, then, is really one of determining the full range of stimulus conditions that delimit the phenomena of vigilance, and of describing, in as precise terms as possible, the lawful relationship that exists between these stimulus variations and reliable variations in the detection response.
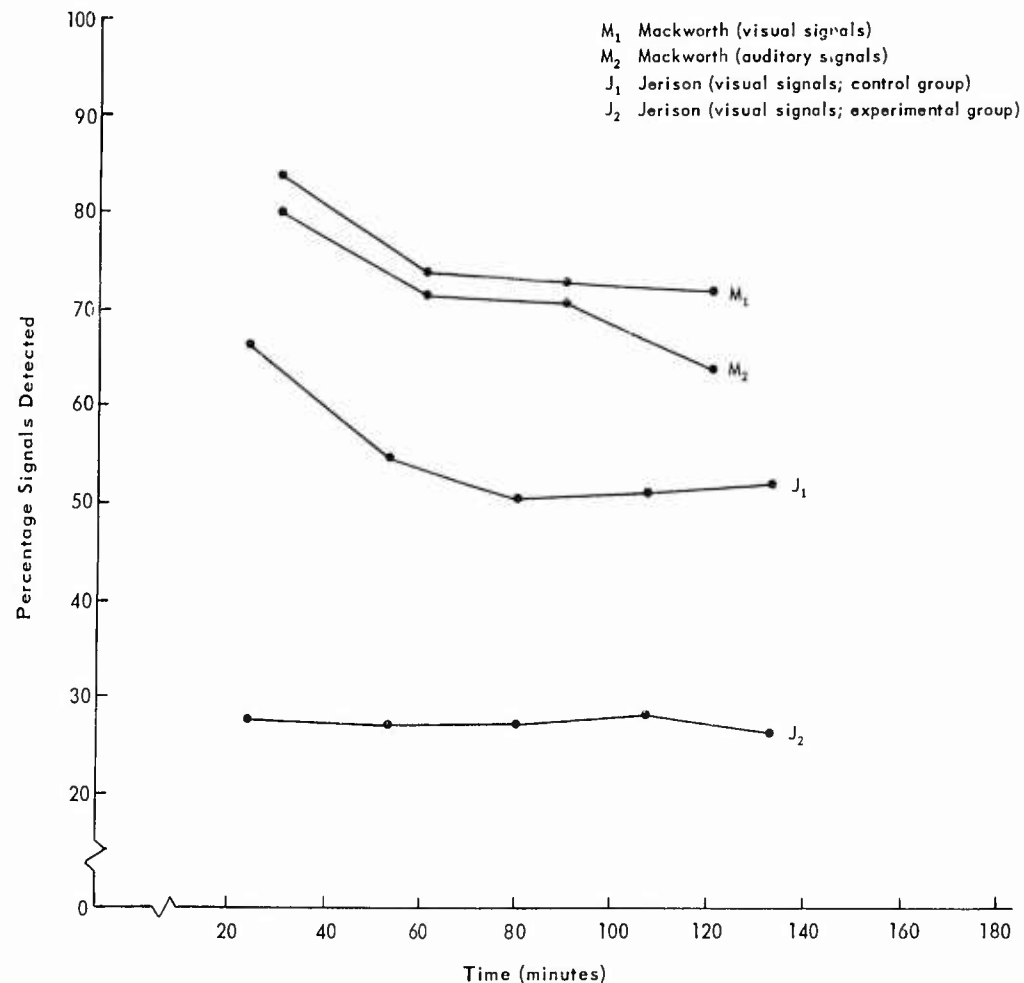
General Vigilance Phenomena

In the definition of vigilance emphasis is placed upon systematic and consistent changes in the effectiveness of the detection response over time. However, some of the problems of defining vigilance at the operational level have grown out of the use of performance measures that in some cases do not correlate with one another at a sufficiently high level to warrant the conclusion that the same psychological phenomenon is being measured. In addition, because of differences in procedures used in taking these measures, what appear to be the same measures are sometimes in fact quite different. For example, Adams (1956) determined the mean number of stimuli detected within five seconds of onset, while other workers (Lindsley, 1944; Monty et al., 1958) placed no time limits or different time limits on the detection.

Among those responses which have been used to measure vigilance are (1) errors of omission, (2) errors of commission, (3) response latencies, and (4) changes in threshold sensitivities. Of these, the most commonly used measure has been errors of omission, and these have typically been described in terms of the percentage of signals detected. Which of the measures "really" represents vigilance is a nonscientific question and is a function of the human performance requirements of the weapon system. In general, errors of omission appear to come nearest to describing the problem of vigilance performance for most systems, since these systems clearly cannot function against targets which have not been detected. However, errors of commission and response latencies could be of considerable significance to system performance under some circumstances, so the question of which measure should be emphasized depends primarily upon the system objectives and the nature of the particular research.

Despite the problems resulting from the use of different response measures and different operational procedures, there is sufficient consistency in the data to suggest that a decrease in the efficiency of detection is a widely encountered phenomenon. Typically, this phenomenon begins soon after the task is started and becomes greater as the vigil continues, with the greatest drop occurring within the first 30 minutes of the task.

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Examples of this decrement are presented in Figure 1. Curve M_1 describes performance on a visual task, and curve M_2 performance on an auditory task (Mackworth, 1950). The pattern of performance on the auditory task is similar in form to that of the visual task but is more depressed.

Percentage of Signals Detected as a Function of Time

M_1 Mackworth (visual signals)
M_2 Mackworth (auditory signals)
J_1 Jerison (visual signals; control group)
J_2 Jerison (visual signals; experimental group)

NOTE: Data from Mackworth (1950) and Jerison and Wallis (1957).

Figure 1

Curves J_1 and J_2 in Figure 1 are from a study by Jerison and Wallis (1957) in which they used Mackworth's visual condition (one-clock display) for their control group and employed a three-clock display for their experimental group. The form of the curve for the control group (J_1) generally follows the Mackworth data, although the curve is considerably below either of Mackworth's curves. The curve for the experimental group shows none of the initial decrement ordinarily found in vigilance tasks, but performance is at an efficiency level of less than 30 per cent throughout the task. Jerison and Wallis report that a decrement probably did occur very early in the task but was subsequently lost when the data were grouped.

In a somewhat different kind of task, employing a simulated radar screen, Baker (1958a) found that the percentage of missed signals varied from 21 to 46 per cent as a function of his experimental conditions, but he found little decrement in performance over time.

The data from the Baker and the Jerison and Wallis studies point up the kinds of problems encountered in vigilance research. There is a strong need for a description of the conditions under which decrements will and will not occur, both as a function of stimulus conditions and of the response measures employed. In addition, a need exists for precise determination of the conditions under which increments in performance occur at or near the end of the vigil.

A number of studies suggest that individuals are differentially affected by the conditions of vigilance to an extent greater than that ordinarily found in psychological studies. The fact that some individuals do not show a performance decrement during prolonged vigilance tasks suggests that variables other than those related to task and environment play a significant role in vigilance behavior (e.g., subject variables such as motivation, personality, perceptual, experiential). The implication is that an important part of the psychological problem is the isolation of parameters of individual differences, which contribute significantly to successful vigilance performances. It is quite possible that this class of variables may contribute at least as heavily to performance as do independent environmental variables. If this is the case, this fact should have important implications for the direction that vigilance research might take.

Chapter 2

FACTORS AFFECTING VIGILANCE PERFORMANCE

A broad range of variables related to vigilance performance has been investigated. They are discussed here in three general categories: (1) task factors, (2) environmental factors, and (3) motivational factors. This grouping is similar to that employed by Mackworth (1957).

TASK FACTORS

The first group of factors is concerned with characteristics of the task itself. Generally speaking, these factors are either human engineering variables or variables inherent in the over-all task. Both types tend to be predetermined by the objectives of the weapon system, the nature of the tactical problem, and the particular hardware implementation of the system.

Length of Vigil

Several studies have dealt with the effects of length of vigil upon detection performance. In general, performance decrement has been shown to increase as length of vigil increases. However, this is not inevitably the case. Katz and Landis (1935), for example, measured the effects of a 10-day vigil on the physical, chemical, and psychological responses of a subject and found no evidence of performance decrement resulting from a lack of sleep.

More recently, Williams et al. (1959) conducted a series of studies in which subjects were deprived of sleep for 72 to 98 hours and were required to perform visual, auditory, and tactual vigilance tasks. They found that "lapses" in attention tended to increase over time and that these lapses were sufficient to account for all decrements in performance. They also found that the performance decrements were similar for all sense modalities and, as anticipated, there were more errors of omission than of commission.

Employing the Mackworth clock test, Jerison (1958) examined the effects of two lengths of vigil and two sets of expectations of the subjects concerning the length of vigil. He found a decrement under both lengths, but it was less pronounced for the group expecting a short vigil than for the group expecting a long vigil.

Lindsley (1944) was concerned with the relationship between decrement and the length and frequency of repetition of operating periods. Using eight trained operators performing with a radar scope for periods of 4 hours per day, 6 days a week, for 17 days, they found

a progressive loss in detection proficiency which became significant after about the third day. For all days combined, a significant decrement occurred after the first hour of watch, with a slight recovery appearing in the fourth hour.

In a somewhat earlier study of factory workers performing an inspection task, Wyatt and Langdon (1932) found that the decrement function became significant after 30 to 45 minutes and continued for about 90 minutes, followed by irregular recovery. The accuracy of inspection varied considerably throughout the work session, but was lowest at about midsession.

In terms of the evidence, then, the general statement that decrement increases as length of vigil increases is only partially correct. In a number of studies the data appear to be confounded toward the end of the watch period, with indication of varying degrees of "end-spurt" improvement in performance. This is a phenomenon of some theoretical importance and will be touched upon in later discussions.

Signal Intensity and Duration

The Bunsen-Roscoe law $(I \times T = C)$, reflecting temporal summation effects in the retina, implies that increases in either stimulus intensity (I) or duration (T) should lead to increases in the probability of detection. However, this relationship is valid only through fairly limited ranges for both variables and implies nothing about performance decrements over extended time periods.

In line with the above prediction, however, Adams (1956) found that over-all performance in a visual task was positively related to both the intensity and the duration of the stimulus, but that the decrement function was independent of either variable within the range studied. Adams employed two levels of duration (one and two seconds) and two levels of intensity (.016 and .019 foot-candle). Of the two variables, signal duration appeared to be the more important.

Wherry and Webb (1951), using intensities of 10 and 20 decibels in an auditory vigilance task, found a tendency toward longer response latencies with the low-intensity signals.

The results for these variables are generally as expected. Both intensity and duration significantly affect detection performance. However, the effect is to raise or lower performance level in general without affecting the form of the performance decrement.

Position of Display and Signal

The position of the display relative to the observer's line of sight, and the position of the target signal on the display both appear to be significantly related to detection performance. Fraser (1950), for example, tested the effects of different display angles on vigilance performance with the clock test. He found that a vertical display was superior to either a horizontal display or a 45° angle display, but he found no difference between the horizontal and the 45° displays.

With regard to signal position, it is commonly observed that incoming target pips are ordinarily not detected until they are well in toward midradius of the radar. In an effort to evaluate possible ways of biasing scanning behavior toward the periphery, Baker (1958b) found that a "box sweep" technique, in which the observer was directed to scan within a prescribed area, was the most effective. The possible implications of these scanning, or observing, responses will be considered in more detail later.

Nicely and Miller (1957) studied the effects of unequal spatial distribution on the detectability of targets. A rate of 72 pips/hr. was presented in one quadrant of a simulated radar display, while 12 pips/hr. were introduced in another quadrant. In the quadrant of high occurrence 71 per cent of the signals were detected, as compared with 63 per cent for the quadrant of low occurrence. Of special interest was the finding that a decrement occurred in the low-frequency area, but not in the high-frequency area.

Frequency of Signal

In general, studies concerned specifically with detection/vigilance tasks are in agreement on the effects of signal frequency. Performance decreases as signal rate decreases. Kappauf and Powe (1959), for example, employed signal rates of 8, 20, 40, and 80 signals/hr. and found progressively poorer performance levels as signal rates were lowered.

As noted in the previous section, Nicely and Miller (1957) varied signal rate for different quadrants of a radar scope and found a significantly greater percentage of detected signals in the high occurrence quadrant. In addition, they noted that after 15 minutes of the 90-minute watch no further decrement occurred in the high frequency quadrant, but decrement did continue in the low frequency quadrant.

Deese and Ormand (1953) found confirming results in a series of detectability studies employing a simulated radar display. In one study they presented signal rates of 10, 20, 30, and 40 signals/hr. for three hours on each of four days and found a systematic increase in percentage of detected signals with increases in signal rate. The form of the relationship approximated a growth function. An observation of particular interest was that performance generally improved daily for the higher rates. These results were confirmed in a second study by the same authors. Large individual differences were noted for the within-watch and day-to-day performances in this study.

Jenkins (1958) used signal rates of 7.5, 30, 60, and 480 signals/hr. on a task requiring detection of larger than normal movements of a meter pointer. Jenkins' finding was similar to results obtained by Deese and Ormand. He found that percentage of detection increased as signal rate increased and that performance was nearly proportional to the logarithm of the signal rate, rather than to the rate itself. In addition, the effect of signal rate was independent of intersignal interval. Of some interest was the finding that more false detections occurred at higher signal rates. This is contrary to the usual finding. Jenkins found, also, that latency of response decreased as signal rate increased.

Bakan (1957) introduced a second task into an auditory vigilance situation, which in effect increased the number of signals requiring a response, and found an increase in the detection of the primary signals. Similarly, Garvey et al. (1959) found that the use of "artificial" signals benefited vigilance performance. Using eight dials, they introduced artificial pointer deflections at the rate of 48/hr. which were added to the "real" signals presented at predetermined random intervals. With the artificial signals present, no change was noted either in detections or in response latencies. In the absence of artificial signals, response latencies increased from 2.5 seconds in the first half-hour to 8.7 seconds in the third half-hour. The percentage of missed signals increased to a maximum of 39 per cent during the 2-hour watch.

The results for studies on frequency of signals are quite consistent with two exceptions. Wherry and Webb (1951) found no significant differences in performance on an auditory task as a function of signal rates of 12 and 30 signals/hr. However, only three subjects were employed in this study. Jerison (1957) found a lower general level of performance when signal frequency was increased by increasing the number of displays to be monitored.

Sense Mode of Signal

Research results for this variable appear to be in unanimous agreement. The pattern of vigilance performance is similar whether the signals are presented auditorily, visually, or tactually.

Buckner et al. (1960) compared visual and auditory tasks and found no differences in the form of the performance curves. Williams et al. (1959) compared tactual, visual, and auditory vigilance performance and found similar decrements for all three sense modalities. As noted earlier, Mackworth (1950) also found similar results.

The implication of these results is that the factors operating to cause the decrement in vigilance performance probably are central in origin. This suggests that the mechanics underlying the vigilance decrement are not associated specifically with characteristics of the receptors themselves, but rather are to be found in neural centers common to all modes of sensing.

Interpolated Rest

The introduction of rest periods consistently yields better vigilance performance. The only study that comes near to being an exception to this generalization is that of Taylor et al. (1937), who found a decrement in output immediately preceding a rest pause when the subjects knew a rest pause was imminent.

In an auditory vigilance task, Solandt and Partridge (1946) found that interpolated rest periods greatly reduced performance decrements and that the introduction of short intervals of listening to hydrophone sounds during a period of listening to "mock" signals tended to reduce performance to some extent, but not significantly. Saldanha (1957) found that, on an exacting visual task, rest periods resulted in the

. elimination of the decrement in the initial post-rest period, with accuracy then decreasing. He found, also, that rest resulted in increased speed in the post-rest period. Similarly, McCormack (1958) found that latency of response was reduced by interpolated rest, the amount of improvement being related to the length of the rest period.

Much the same results were obtained by Jenkins (1958). His subjects showed very little performance decrement when given a 30-second rest pause every 4.5 minutes. Some of his subjects were allowed to leave the room during the break, but their performance did not differ from that of subjects who remained in the room.

A study of particular interest in this area is that of McFarland et al. (1942), on a task involving the judgment of brightness differences over an extended period of time. The results indicated that observers who were not allowed to move during the entire watch demonstrated a marked decrease in sensitivity to brightness differences, whereas those who were permitted to shift position every 30 seconds (a form of interpolated rest) showed a recovery of difference limens (DL's) concomitant with the shift.

Probably the most dramatic effects of rest-intervals are those presented by Mackworth (1948), who found that when he alternated half-hour watches with half-hour rest periods, uniform detection performance occurred; in fact, performance after the rest period was even slightly improved over that for the first half-hour.

As noted earlier, the effects of interpolated rest are among the most consistent in the literature and raise a number of significant theoretical questions.

Intersignal Interval

The data for this variable are among the most confusing and contradictory in the vigilance literature. Both positive and negative results have been reported, and these in turn have been cited as evidence for or against contrasting theoretical positions. Because a number of writers have considered the theoretical implications to be so important, extensive discussion of this variable has been reserved for the theoretical section of this report.

Briefly, among those writers who have reported no relationship between intersignal interval and probability of detection are Deese and Ormand (1953) and Jerison (1957). McCormack (1958) found no relationship between intersignal interval and response latencies. These writers, however, defined intersignal interval as the time between presentation of the signals, without reference to whether they were detected.

Harabedian et al. (1960) found similar results when defining the intersignal interval in this manner, but when they defined the interval as the time from one detection to the next, they found significant differences as a function of interval length. Similarly, Jenkins (1958) found that when a signal was detected, the probability of detecting the succeeding signal was initially high and then decreased rapidly as the intersignal interval increased. In two different studies, Baker (1959, 1958a)

found much the same results. Intervals ranging from 36 to 196 seconds resulted in no decrement in detection performance, but intervals ranging from 45 to 600 seconds (a replication of Mackworth's conditions) showed a marked decrement. In contrast, Mackworth (1950) reported that subjects were definitely less alert at detecting signals presented only one minute after the previous signal.

On the basis of a somewhat involved and tenuous analysis of their data, Kappauf and Powe (1959) suggested that the probability of detection in relation to time between trials may be a U-shaped function.

As will be noted in the theoretical discussion, however, when differences in defining operations are accounted for, among other things, the effects of intersignal interval are probably not quite so confused as they appear to be superficially.

GENERAL ENVIRONMENTAL FACTORS

Whereas the task factors just discussed are closely associated with characteristics of the apparatus and the tactical environment and are essentially unalterable, the environmental factors are more amenable to control and manipulation in the operational setting. The variables listed under this section are few and the data relatively sparse.

Auditory Noise

A considerable amount of work has been done on the effect of noise on general performance, and a few studies have been concerned specifically with vigilance tasks. An example of the more general type study is that of Laird (1933) who considered the relationship between type of noise and production. Laird found that a complex, varying noise resulted in the greatest decrement in production, and that a complex steady noise was more detrimental than a relatively pure tone. For the same intensity, he found that a pitch above 812 cps was more detrimental than a lower pitch and that increases in frequency above 512 cps yielded systematically larger production decrements. In addition, he found that regardless of the original intensity, a reduction in a complex noise was accompanied by an increase in production.

Employing a "mental" work task, Smith (1951) tested the effects of intermittent noise (100 ± 2 db) over a 30-minute period and found no significant effects on performance. What trends there were, however, suggested that output rose but quality decreased under noise of this type.

In specifically vigilance tasks, the effects of noise are also inconsistent. Broadbent (1953) studied the effects of noise on paced and unpaced performance in a visual vigilance task and found that noise increased the number of errors in both conditions. Noise was defined as 100 db and quiet as 70 db.

In a second study, Broadbent (1954) tested the effects of noise on a vigilance task involving 20 dials, and one involving 20 lights. The noise and quiet conditions were 100 db and 70 db, respectively. Broadbent found that (1) noise did not affect the number of "seens" (signals detected

when the operator was attending a dial or light when the signal occurred);
(2) the number of "founds" (dials or lights discovered to have a signal
without actually having seen it occur) was significantly less under noise
conditions on the dial task; (3) noise did not affect performance on the
light task; and (4) individuals showing the greatest practice effect between
quiet runs showed the greatest decrement under noise. In a study bear-
ing on the latter finding, Jerison and Wing (1957) examined a complex
counting task under noise conditions and found that individuals differed
significantly in their responses to noise. Some individuals were able to
compensate for the noise, while others were unable to do so.

Using the Clock Test in another study, Jerison (1957) employed
112.5 db and 114 db noise conditions vs. no-noise conditions and found
performance decrements in all conditions, but no significant differences
between performance under noise and quiet.

As noted earlier, the results for the noise variable are not con-
sistent. This lack of consistency is probably a function of the specific
characteristics of the task and possibly of sampling errors, that is,
disproportionate selection for a sample of individuals who are differ-
entially affected by noise.

Temperature and Humidity

The evidence for these variables is scanty, but suggestive. Varying
ambient environmental temperature alone, Loeb and Jeantheau (1958)
tested response latency on a test of vigilance involving 20 dials, with
temperatures ranging from about 70° F during the night to about 118° F
during the day. Their results indicated that heat alone had no signifi-
cant effect on performance.

Apparently the combined effects of heat and humidity, however, do
affect vigilance performance. Mackworth (1946) studied the effects of
hot, humid atmospheric conditions on performance as measured by the
clock test. Eighty-nine subjects were divided into four groups which
performed, after a period of acclimatization, at temperatures of 70° F,
79° F, 87° F, and 97° F. At higher temperatures performance was poor
and declined at a more rapid rate. Latency of response was longest
for both the coolest condition (70° F) and the warmest condition (97° F).
No relationship was found between body temperature and performance.

Illumination

It is reasonable to expect that the level of ambient illumination
might be related to vigilance performance for a number of reasons. A
later section of this report discusses the relationship between sensory
thresholds and vigilance performance, and between muscular tension
level and vigilance performance. Both of these factors are related to
illumination level.

Luckiesh and Moss (1937), for example, found that the nervous
muscular tension resulting from visual effort was inversely propor-
tional to the level of illumination. Pressure on a key exerted by the
index and second finger of the left hand was measured for three light

intensities. The results indicated that for 1 foot-candle, 63.2 grams of pressure were exerted, for 10 foot-candles, 54.1 grams, and for 100 foot-candles, 43.0 grams.

Simonson et al. (1948) tested the effects of three types of illumination sources on visual performance. These included natural, frosted-glass lamp, and "Verd-A-Ray" lamp illumination. The results indicated a decline in performance over time under all conditions. Reaction time in the recognition of threshold-sized dots was retarded significantly more (1) under natural lighting than under Verd-A-Ray lighting, and (2) under frosted lamp lighting than under Verd-A-Ray lighting.

While these studies are not definitive, they suggest that illumination factors may be of some significance and are worthy of consideration in any given operational setting involving vigilance performance.

Isolation

The term "isolation" can be construed in a variety of ways, ranging from sheer deprivation of simple sensory stimulation, to the presence or absence of meaningful stimuli, human company, or special classes of human companions. These variables are closely related to the motivational factors discussed in the following section but are included here because, in a sense, they constitute aspects of the general operational environment for the operator.

Conditions of total isolation are referred to as "sensory deprivation" in the literature. Little research has been done in this relatively new area, but the evidence (Wheaton, 1959; Monty et al., 1958) indicates that performance under sensory deprivation conditions decreases in a manner similar to that in typical vigilance tasks. That the decrement occurs in other than sensory deprivation situations, however, suggests that the vigilance effect per se is probably dependent more upon the presence or absence of meaningful stimuli.

One class of relevant meaningful stimuli, signal rate, has been discussed earlier. Another form of meaningful stimulation is the presence of other human beings in the operational situation. This variable can be considered in terms of the effects of the presence of (1) other participating individuals, and (2) special classes of nonparticipating individuals. The data are sparse for both types of situation.

In group monitoring situations (presence of participating individuals), the results from the two available studies are conflicting. Taylor et al. (1937) report that output was better when their subjects worked alone rather than in a group. Schafer (1949), on the other hand, employing detection on audio-visual sonar displays, reported that two individuals working together made from 11 to 20 per cent more detections than an individual working alone, and that three individuals made from 6 to 15 per cent more detections than two individuals. Groups larger than three apparently added little to the detection score, but groups of two were always better than a single individual, and groups of three were always better than groups of two.

With regard to the presence of nonparticipating individuals, Pollack and Knaff (1958) reported no differences in performance between

individuals working in isolation in a darkened booth and those working in the company of other operators in a brightly lighted room, with a radio playing and conversation permitted (except about signals).

Apparently, however, when the nonparticipating individuals represent some form of authority, performance is affected. Fraser (1953), for example, found that when the experimenter remained in the room in a prolonged vigilance experiment, the operators performed significantly better than when he was not present.

Generally, the work in this area is promising but inadequate. A need exists for more specification of the stimulus parameters involved and for the systematic study of the effects of these parameters and their interactions on performance. The results from such studies could be of considerable practical and theoretical value.

MOTIVATIONAL FACTORS

The third group of factors is concerned with characteristics of the human operator. The choice of the term "motivational" is arbitrary since diverse variables are included under this heading. However, all of the variables have in common the fact that they reflect either the effects of various parameters on the motivational responses of the human operator, or the effects of motivational characteristics of the operator on his own performance. The effects of drugs, for example, are representative of the first type of variable, and the effects of per-- sonality variables are representative of the second type.

Drugs

The use of drugs probably does not represent a practical solution to the vigilance problem, but the effects of drugs are of considerable theoretical interest and the results of the few studies in this area are highly suggestive.

Solandt and Partridge (1946) included the oral administration of 10 mg of benzedrine sulfate and moderate amounts of alcohol as two of the independent variables in an auditory vigilance task. The results indicated that benzedrine sulfate reduced the decrement significantly for a minimum of eight hours. Alcohol was not found to lessen the decrement.

The most relevant and significant evidence comes from a study by Mackworth (1950). Three groups of subjects performed on a visual search task after taking (1) 10 mg of benzedrine sulfate, (2) dummy tablets, and (3) no tablets. The results of this study are presented in Figure 2. With benzedrine, the decrement was eliminated; also, more signals were detected, and response time was shortened. No undesirable side effects from the use of benzedrine were noted in this study.

Barmack (1939) administered 15 mg of benzedrine sulfate and 60 mg of ephedrine hydrochloride to subjects working on a pursuit task. The response measures were accuracy of pursuit, reports of boredom, sleepiness, fatigue, inattention, heart rate, and blood pressure. The

Percentage of Missed Signals as a Function of Time on Watch Under Benzedrine and No-Benzedrine Conditions

NOTE: Data from Mackworth (1950).

Figure 2

results indicated that with either drug, performance tended to remain constant, that is, no decrement occurred for about one and a half hours. In addition, benzedrine sulfate retarded the frequency of reports of boredom, fatigue, and inattention; ephedrine hydrochloride had a similar but somewhat weaker effect. Both drugs increased systolic blood pressure, but only the benzedrine increased heart rate. These results are suggestive; however, Barmack's task was not a typical vigilance task although it was performed for a rather long period of time.

Similarly, Somerville (1946) employed a nonvigilance task that was performed for a long period of time. Benzedrine was administered to a group of military subjects who were asked to work on staff problems over a 72-hour period. This group's efficiency in solving problems was no different from that of another group who took placebos. However, it is reasonable to expect that problem-solving tasks are sufficiently self-motivating to maintain high performance levels over extended periods of time, and these effects might obscure the possible facilitating effects of the drug.

In general, the effects of benzedrine and similar pharmaceuticals appear to facilitate performance but further work is needed in this area to define the limits of the conditions under which benefits are derived. The effects of this variable are of considerable theoretical interest and

the results obtained by Mackworth are sufficiently dramatic to justify further research in this area.

Diet

As with drugs, diet could conceivably have some effect upon the responsiveness of the operator. This possibility has been considered in two separate studies.

Simonson et al. (1948) studied the effects of diet on a visual task that demanded constant attention but involved little expenditure of energy. Fatigue trends of several visual functions including vertical divergence, convergence near point, and abduction and adduction powers were measured before and after the task. Four diet schedules were compared: (1) balanced, (2) high fat, (3) high carbohydrate, and (4) no meals. While statistically significant performance differences between diets were obtained, no one meal was superior or inferior for all visual functions measured. The results did indicate, however, that balanced or high fat diets were preferable for strenuous visual work.

In the second study (Tuttle et al., 1949) four types of breakfast were used: (1) heavy, (2) light, (3) coffee only, and (4) none. Response measures were taken in terms of work output, simple and choice reaction time, and neuromuscular tremor. The results showed performance decrements for all measures under the no-breakfast and coffee-only condition.

While the results indicate some effect from extreme dietary conditions, this variable is probably secondary in vigilance performance.

Sleep

Several studies have been conducted to examine the relationship between prolonged wakefulness and various psychological functions. Generally, the results indicate that when performance is measured for short periods of time (i.e., less than 15 minutes), the expected effects from sleeplessness are not observable.

In an early study conducted by Robinson and Richardson-Robinson (1922), the effects of sleep loss on performance on the alpha intelligence examination were observed. The experimental group had no sleep during the first day and night of the experiment, and until completion of the second testing, whereas the control group had no restrictions on sleeping. The results showed a performance improvement for both groups, with no significant difference in the amount of improvement shown by the two groups in what was essentially a problem-solving task. The authors hypothesized that the experimental group compensated for the sleep loss through increased effort and interest in the experimental situation. As noted earlier, problem-solving tasks typically do not yield decrements like those found in the usual vigilance tasks.

Chiles (1955) required subjects to be alert at varying intervals for 56 hours. These subjects performed on the Clock Test and a reaction time test. The results were inconclusive but did indicate a wide range of variability in the attentiveness of the subjects.

In an early study, Warren and Clark (1937) observed the effects of a 65-hour sleepless period upon "blocking," which was defined as a failure to respond for a period equal in time to two or more responses of modal length. Three tests of blocking were employed: (1) alternate addition and subtraction, (2) color naming, and (3) tapping. Three subjects completed 65 hours of the vigil, and the fourth subject 48 hours. The four control subjects were not required to go without sleep. Results of the study indicated that "blocking" increased with sleeplessness, particularly on the mental work, but decreased in the control group. Again, however, the similarity between this task and typical vigilance tasks is not very great.

In another study, again employing four subjects, Clark and Warren (1940) photographed horizontal and vertical ocular fixation movements during a 65-hour vigil. Their results indicated no uniform changes in eye movements as sleeplessness increased. Binocular adjustment showed no consistent trend, although there was a tendency toward decrement.

In general, the rather minor and ambiguous results for this variable suggest that loss of sleep is not a particularly significant variable in vigilance performance.

Individual Differences

Irvine (1957) conducted a study of a visual inspection task in industry and found large individual differences in the rejection rates of operators. Rejection rate, he found, was dependent upon batch size (number of ampules to be inspected), which affected individuals differently. Also, individuals who took a long time to inspect were no better than those who performed rapidly.

A number of investigators have taken up this cue and have attempted to isolate a variety of parameters of individual differences related to vigilance performance. Bakan (1957), for example, investigated personality variables and found that extroverts benefited more from the introduction of a second task in a vigilance situation than did introverts.

In studies involving subjective reports of feelings of boredom, tiredness, and monotony, several writers (Pollack, 1929; Poffenberger, 1938; Taylor et al., 1937) report that such feelings are negatively related to performance: that is, performance decreases as boredom increases. Poffenberger also reports that the individuals with the highest performance had the greatest changes in feelings of tiredness. It is not unreasonable to suspect that such subjective reports are related to personality differences. Barmack (1939) suggests that many of the physiological changes associated with prolonged work are a function of the attitude of the individual, and it is reasonable to expect that such attitudes might also be associated with personality characteristics.

Along other lines, Baker (1959) found a relationship between motor activity and performance on a vigilance task. Motor activity generally increased with increasing time on watch, with the less active individuals tending to be superior in performance.

Kappauf and Powe (1959) divided their subjects into four groups on the basis of their AFQT scores (ranging from the 10th to the 99th percentiles of the general military population), and found that in general the men with low AFQT scores showed greater decrements in performance on an audio-visual checking task.

Both age and sex differences in vigilance performance have also been demonstrated. Botwinick and Shock (1952), for example, measured the speed of response in a continuous task and found higher over-all performance in the younger group (20 to 29 years) as compared with that of an older group (60 to 69 years), but there was also a greater performance decrement for the younger group. Wittenburg et al. (1956) replicated the Mackworth clock test using both males and females and found that females were superior to males during the last half hour of a two-hour watch.

The studies cited are suggestive but largely unsystematic. For the most part, they have not been designed specifically to study parameters of individual differences despite the fact that a wide range of such variables are known to affect vigilance performance. In addition, with a few notable exceptions, little effort has been made to determine to what extent such characteristics are modifiable.

Along these lines, Garvey et al. (1958) employed a group of pre-trained individuals in a two-hour satellite tracking task and found large individual differences in detection thresholds. Of particular interest was their finding that the pretraining experience significantly decreased these differences.

Blair (1958) found individual differences in the rate of "observing responses," that is, responses that in turn make the detections possible. Some individuals maintained continuous observing responses while others tended to observe only when the signal was due. In a second study (Hickey and Blair, 1959) the observing rate was demonstrated to be unrelated to the probability of signal occurrence. In contrast, Holland (1958) found that the observing rates of individuals varied directly with the number of signals they detected. Holland's work is particularly interesting in that it implies that the development of effective techniques for increasing individual observing rates may be feasible and could lead to significant reductions in differences among individual operators.

Further evidence that some individual differences can be modified comes from a study by Dowd (1925) on the extent to which rate of work is an individual characteristic for different tasks. Her results indicated that an individual who is fast at some tasks has only a slight tendency to be fast at other tasks, and that the high correlations that do occur appear to result from similarities in task content rather than from a general speed factor. Transfer of training is implicit in these results and they suggest that learning may be a factor in some of the individual differences noted in vigilance studies.

The work of Holland and of Dowd points up a need for systematic studies of vigilance performance employing individual differences parameters as the primary variables. This possibility will be discussed further in the chapter on implications for research action.

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Threshold Responses

The primary vigilance research effort has been concerned with the effects of stimulus variables, both external and internal to the individual, on performance measured in terms of the efficiency of work output. However, there has also been a sizable body of research in which attempts were made to relate changes in work-output responses (e.g., detection) to non-work-output, or mediational, responses in the individual. The demonstration of such relationships would presumably push the explanation of vigilance performance back one level in the causal chain and possibly lead to more "fundamental" laws. The study of the effects of vigilance conditions upon various sensory thresholds is one example of this type of research.

The results for visual acuity are ambiguous. Saldanha (1957), for example, found that visual acuity remained unchanged after an exacting two-hour visual task, whereas Berger and Mahneke (1954) found a loss of acuity ranging from 18 to 30 per cent over a period of approximately one hour.

In a third study, Adams et al. (1944) found no deterioration in acuity. However, these writers tested the visual acuity of their subjects before and after 16 weeks of fire control training employing various optical instruments and radar oscilloscopes. The conditions are probably sufficiently different from the usual vigilance conditions to make these results somewhat irrelevant.

The differences in results between the Saldanha and the Berger and Mahneke studies remain to be resolved, before any definitive statement can be made regarding the effects of vigilance tasks on acuity.

The results for the critical fusion frequency (CFF) response are contradictory, but possibly resolvable. Of three studies, one found a decrement, one did not find a decrement, and the third found a decrement under one condition but not under another.

Brozek et al. (1947) found that after two hours of intensive inspection work at 2 foot-candles of illumination, visual functions such as blink rate and CFF did not change significantly, but speed of voluntary eye movements and precision of fixating deteriorated significantly. On the other hand, Berger and Mahneke (1954) also measured the CFF in two simple visual tasks and found a decline in CFF over time.

Wittenburg et al. (1956) measured the CFF response in relation to performance on the clock test and found that individuals who responded to all stimuli (both single and double pointer movements) showed no decrement in CFF. In contrast, individuals who responded only to the signal (double pointer movement) showed a significant decrement in the CFF response from the beginning to the end of the watch. A significant correlation was also found between detection performance and CFF. These data suggest that signal rate may be the important factor in determining whether CFF will change; this may account for the failure of Brozek et al. to find a decrement in CFF.

The evidence for absolute thresholds suggests no relationship to vigilance performance. Wertheimer (1955) found that auditory and visual absolute thresholds varied markedly throughout a vigilance task

but that no consistent trends were discernible in the data. In addition, the correlations between thresholds for the different sense modes tended to be low.

Similarly, Deese and Ormand (1953) found no change in visual thresholds as a function of time on watch, using an ascending method of limits.

In a study of auditory thresholds, Elliott (1957) found that, rather than becoming higher, thresholds became lower for his subjects over time. This suggests that either practice effects or transfer of training was operating to improve performance, although improvement was generally confined to the detection of weaker signals.

The evidence for changes in difference limens (DL's) as a function of vigilance conditions is straightforward. In the two reported studies, significant changes in DL's were found.

Using the method of limits, Bakan (1955) studied the change in differential brightness threshold as a function of time in a prolonged visual vigilance task and found that the threshold increased as a function of time on watch. On the basis of this evidence he suggested that the vigilance decrement function be thought of as a threshold change. This point is considered in some detail in the subsequent discussion of theory.

In the other study, McFarland et al. (1942) found that individuals who were instructed not to move during the entire watch demonstrated a marked decrease in their sensitivity to brightness differences. In a group that was allowed to shift position every 30 seconds, however, there was a parallel recovery of DL's.

In general, the data suggest that acuity and absolute thresholds are not related to vigilance performance. The CFF appears to be related under some conditions (possibly low signal rates only), and difference limens are quite clearly related to vigilance performance.

Related Responses

Some writers have concerned themselves with the effects of vigilance conditions upon mediating or peripheral responses other than perceptual responses.

One group of researchers has studied motor responses associated with the eyes. Clark and Warren (1940), for example, recorded eye movements during an extended visual vigil and found some temporary and sporadic changes in fixation time, binocular adjustment, and saccadic movement, but no uniform changes in any response over time.

Carpenter (1948) measured the number of blinks per minute in a replication of Mackworth's clock test and found that the mean blink rate per minute increased systematically with time. He found, also, that the variation in blink rate between subjects was as large as that within subjects. This is in contrast to the study by Brozek et al. (1947), mentioned earlier, in which no significant changes in blink rate were noted. These results suggest that, in general, the motor responses associated with the eyes are not very reliable indices of vigilance performance effects.

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Responses of the frontalis muscle over the eyebrow, on the other hand, do appear to be related to vigilance performance. Kennedy and Travis (1948) measured the action potential of this muscle and found that response latency and variability increased as action potentials decreased. Large individual differences in muscle action potentials were also found. Possibly related to this is the finding of McFarland et al. (1942) that forced maintenance of the same rigid posture yielded poorer vigilance performance. In contrast, Baker (1959), using no physical restraints, found better performance for the less active subjects.

A variety of autonomic responses have also been studied in relation to vigilance performance. Geldreich (1953) found that average rate of respiration, heartbeat, relative blood pressure, and level of palmar skin conductance all increased significantly in the course of a prolonged color-naming task. In line with the latter finding, Dardano and Mower (1959) utilized skin conductance as a response measure in a visual vigilance task to determine its value as an index of vigilance effects. Skin conductance was sampled once every 15 seconds during a one-hour vigil. The results showed a decline in conductance parallel to the deterioration in vigilance performance, and this effect was present for all subjects. The authors suggested that skin conductance be used to activate devices which would alert a drowsy observer.

SUMMARY OF FACTORS

A considerable amount of data has been presented on factors affecting vigilance performance. The effects of the major empirical variables are summarized briefly at this point before the current theoretical interpretations are presented in Chapter 3.

Task Factors. Seven groups of variables were considered under this heading. Of these, the most effective variables appeared to be interpolated rest and frequency of signal. The results for both variables are quite consistent. Although performance level increases as the signal rate increases, some decrement generally does occur over time. Interpolated rest periods, on the other hand, have been demonstrated to maintain uniform detection performance; in one study performance improved after rest.

Similar decrements have been demonstrated for all the sense modalities studied, including visual, auditory, and tactual.

Both intensity and duration of the signal affect vigilance performance. However, the effect is to generally raise or lower the performance level without altering the form of the decrement curve.

Display and signal position both significantly affect vigilance performance. Vertical mounting of the display yields performance superior to that with either horizontal or angular mounting. Significant response biases have been demonstrated for the position of the signal on the display.

Performance generally declines over time, but in some cases the effect is confounded by end-spurt improvements in performance. It is probable that length of vigil per se is of minor significance.

The effects of intersignal interval are conflicting and appear to depend upon the method by which the interval is defined.

General Environmental Factors. Four factors were considered in this section. The first factor, noise, showed inconsistent results. It appears that the effects from this variable are specific to the task and the individuals tested.

High ambient temperature alone appears to have little effect on performance, but in combination with high humidity reduces efficiency of vigilance performance.

General performance levels are significantly related to the type of ambient illumination, with superior performance occurring under artificial as opposed to natural lighting. Also, muscular tension, which is related to vigilance performance, has been demonstrated to be inversely related to illumination level.

While the vigilance decrement is intimately associated with the effects of sensory deprivation on the operator, the data suggest that sensory deprivation per se is not the basic causal factor for the decrement. Rather, the decrement appears to be related to the absence of meaningful stimulation since the effect also occurs under conditions without sensory deprivation. In vigilance situations involving the presence of other humans, the effects of group monitoring are inconsistent, but monitoring in the presence of persons who represent authority improves individual performance.

Motivational Factors. Six groups of factors were considered in this section. Of these, two appear to be unrelated or secondary in their effects. The effects of diet are secondary and probably irrelevant to most operational situations. Similarly, sleeplessness does not, except possibly under extreme conditions, significantly affect vigilance performance.

The most clear-cut and consistent results have been obtained with the administration of benzedrine and related drugs. Use of this group of drugs totally eliminates the performance decrement.

Among threshold responses, acuity and absolute threshold responses do not appear to be related to vigilance performance. The CFF appears to be related to performance when low signal rates are involved, and difference limens are significantly related to vigilance performance.

Motor responses associated with eye movements are not related to vigilance performance, but activity of the frontalis muscles is. So are general postural responses, respiration rate, pulse rate, blood pressure, and palmar skin conductance.

With regard to individual differences, work rate is significantly different for individuals on specific tasks but the trait is not general to other tasks and can probably be trained. Both initial detection thresholds and observing response rates, in which individuals are significantly different in performance effectiveness, can be altered through training. Other individual differences parameters which have been demonstrated to be significantly related to vigilance performance are age, sex, intelligence, and susceptibility to boredom.

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Chapter 3

THEORIES OF VIGILANCE

The variety of theoretical and quasi-theoretical interpretations that have been applied to vigilance phenomena encompasses most of the major theories in psychology. These include several variations of conditioning, expectancy, and drive (physiological) theories of behavior. Some of the "theories" are not theories at all, or at best are only suggestive analogies which might or might not be related to the phenomena of vigilance. None of the systems are sufficiently comprehensive, or at least, attempts to apply them have not been sufficiently comprehensive, to include all relevant aspects of the problem.

A theory, if it is to be called a theory, must satisfy at least two requirements: (1) It must integrate all, or a major portion, of the relevant empirical data, and (2) it should lead to the prediction of new relationships. In addition, it should show a high degree of internal consistency. Generally speaking, theories are evaluated in terms of the degree to which they meet these criteria and are flexible enough to apply to new information without altering their core assumptions. Theoretical interpretations of vigilance have all failed to some extent to meet one or all of these criteria. The purpose of this discussion is to point out where this has been true and to suggest how the current interpretations might be improved where they apply to vigilance behavior.

The previous discussion of the data indicated three broad classes of variables that significantly affect vigilance performance. Ideally, a theory would present a weighted accounting of these and possibly other variables and "explain" at a more primitive level (i.e., in terms of physiological or physical laws) the causal factors underlying effects. For present purposes, however, a "theory" that simply describes all of the S-R relationships in a moderately well integrated form would be quite adequate. Our purpose is to come as close as current theories permit to achieving this objective.

A final prefatory remark is in order. It is sometimes the case that a partial, or "miniature," theory will explain certain aspects of a general phenomenon quite adequately. It is also sometimes the case that such theories could be subsumed under more general theories of behavior, but because of differences in terminology (and sometimes the libidinal investments of their proponents) they are not so integrated. It is hoped that one product of this discussion will be to point out where this has been the case.

CONDITIONING THEORY

It has been suggested—and at a superficial level the data appear to some extent to support the belief—that learning is of little consequence

in vigilance behavior. This is not a universal belief, however, and it is notable that, with the exception of physiologically based theories, the major emphasis has been upon theories developed initially to explain learning behavior.

Conditioning theory has become highly complex and sophisticated in the years since Pavlov's early experiments, and a variety of conditioning interpretations of vigilance performance have been suggested. Probably the least successful interpretations have been those derived from classical conditioning theory.

The primary shortcoming of this approach as represented by its chief proponents (Mackworth, 1950; Broadbent, 1957) is that it fails to treat all of the relevant data. The most significant omission is any attempt to consider motivational variables. The result has been that effects that might more economically be explained in terms of these variables are "explained" instead by classical conditioning concepts without any accompanying validation data. Thus, in explaining the effect of an interpolated telephone call on performance in his clock test experiments, Mackworth (1950) attributed the increase in performance to disinhibition. This is not an unreasonable hypothesis, but Mackworth presents no supporting evidence. Bakan (1952) points out that an equally reasonable interpretation is that the telephone message, conveyed by an authority figure, implied that the recipient was not doing as well as he should, and this constituted a "threat" or motivating factor. These are both testable hypotheses, but without further evidence there is no logical basis for choice between them.
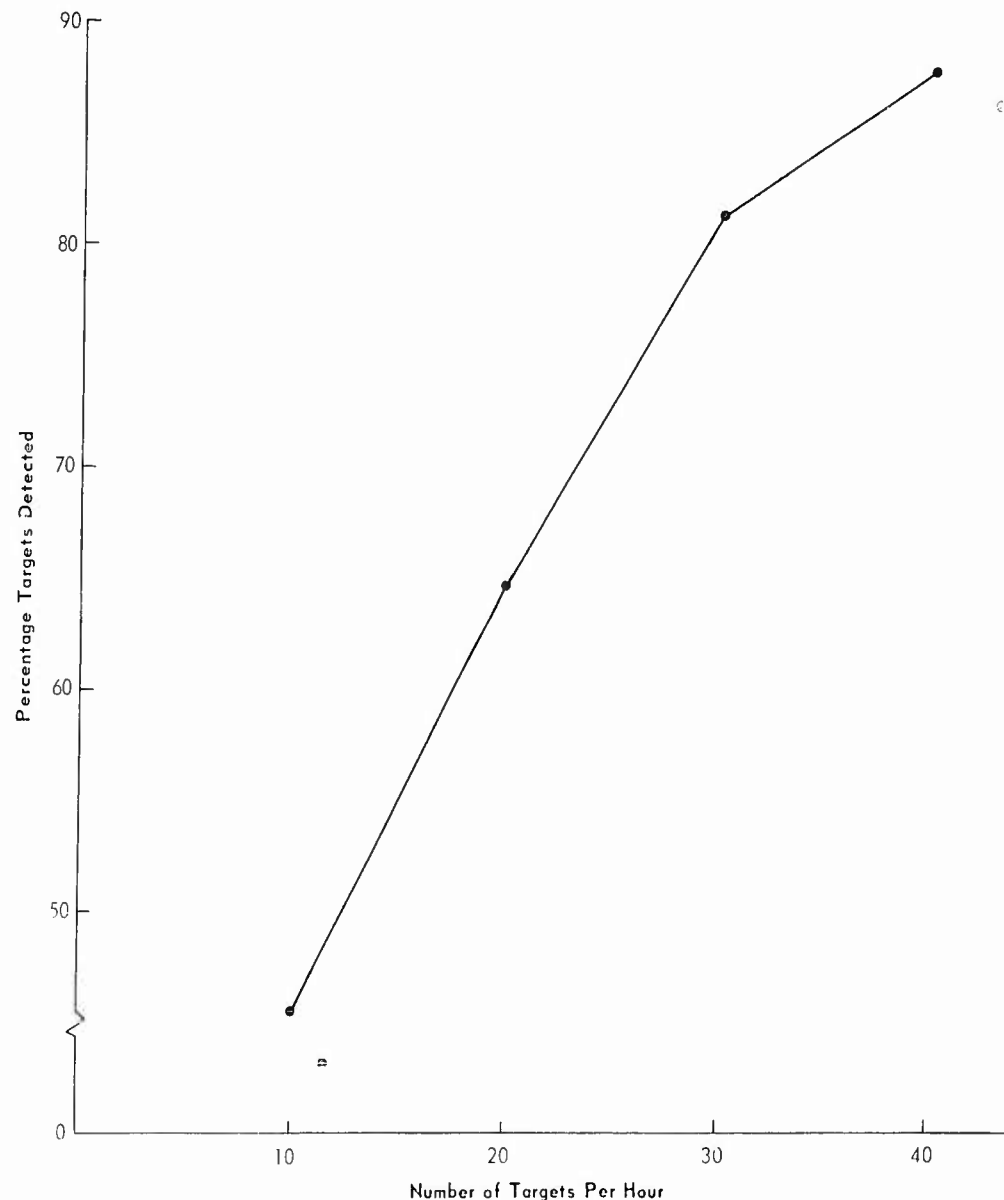
Mackworth also proposed the hypothesis that the decrement in vigilance is due to partial extinction arising from the absence of reinforcement during the course of the task. He attempted to account for the partial extinction in terms of secondary extinction in one instance, and conditioned inhibition in another. He later rejected these explanations, however, on the basis that if secondary extinction or conditioned inhibition did account for the vigilance decrement, then the decrement should not disappear with knowledge of results. Unfortunately, this logic is invalid on the ground that knowledge of results is probably a form of reinforcement and should effectively counter the inhibitory effects.

Bakan (1952) took issue with the Mackworth interpretation on other grounds and suggested an alternative expectancy hypothesis to explain the data. He maintained that the decrement in Mackworth's study resulted from (1) the transfer of expectancies, established during initial training, to the early part of the test period, and (2) the gradual extinction of these expectancies through nonconfirmation in the course of the task.

McGrath et al. (1960) offered the criticism that with high signal rates and nonreinforced responses, conditioning theory would predict an increase in inhibition, yet in some studies this has not been the case. As suggested earlier, however, the assumption that reinforcement is lacking in the vigilance situation is probably incorrect; as Holland (1957) points out, the detection of the signal may itself be reinforcing. If this were the case, then lack of decrement with high signal rates would be consistent with conditioning theory predictions.

Holland's notion was anticipated by Deese (1955) who hypothesized that the occurrence, or detection, of a signal would be reinforcing and thus maintain the state of vigilance at its initial high level. On the basis of this hypothesis, Deese (1957) predicted that signals presented at a higher rate would be detected more efficiently than signals presented at a lower rate (presumably because of the temporal gradient of reinforcement). Deese's data, described in Figure 3, support this prediction; a number of other studies cited earlier have yielded similar results.

Percentage of Targets Detected as a Function of the Number of Targets Per Hour

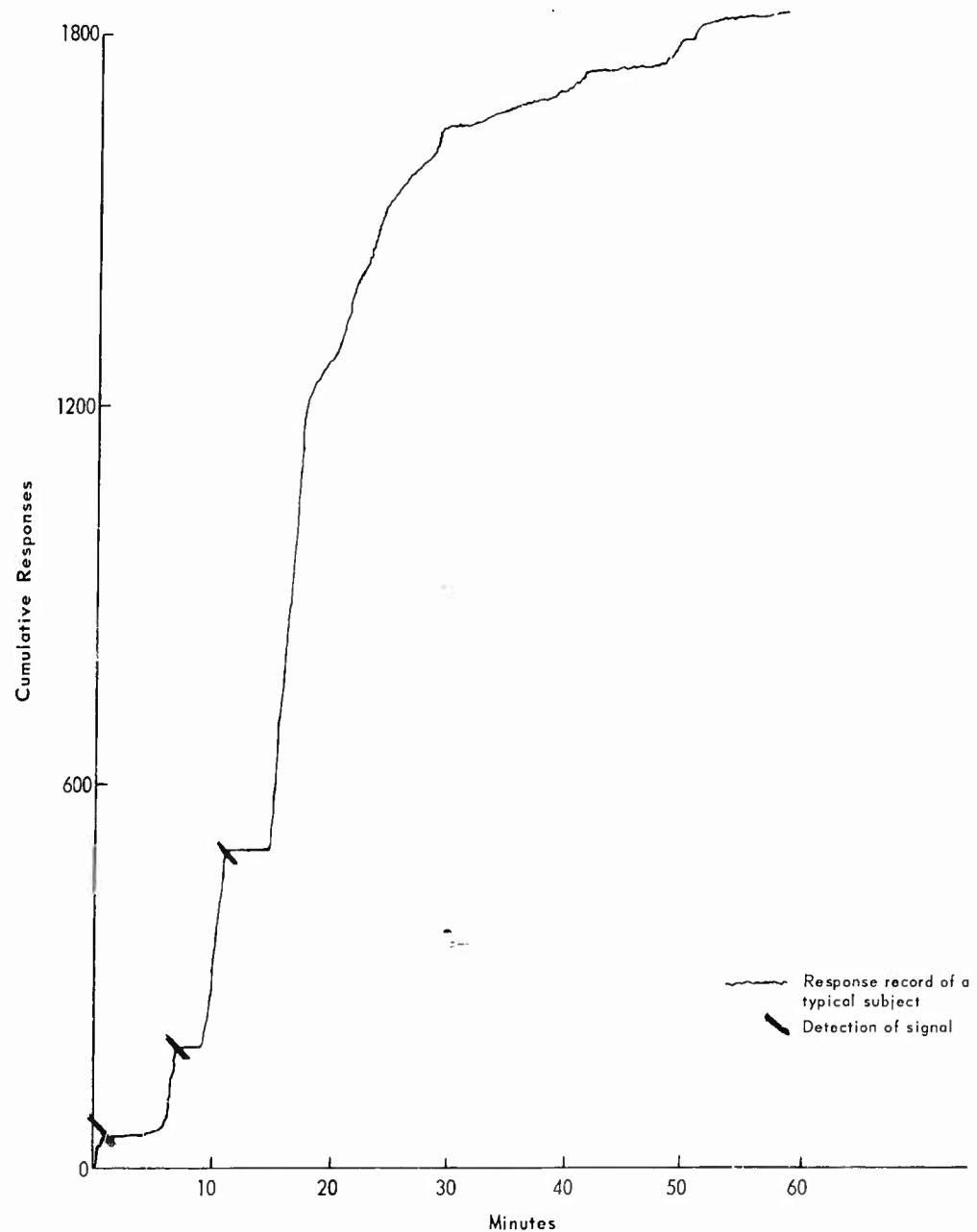NOTE: Data from Deese (1957).

Figure 3

Deese carried his analyses a step further, however, and considered detectability in terms of length of intersignal interval rather than rate of signal appearance. In this case the reinforcement hypothesis would predict that the shorter the time interval between two signals, the greater the probability of detecting the second signal. In contrast to his earlier work with Ormand (1953), Deese analyzed the data for this study in terms of the time between the second signal and (1) the occurrence of the first signal, and (2) the detection of the first signal. Neither analysis supported the reinforcement prediction. However, a recent similar study by Harabedian et al. (1960) provided supporting evidence for the reinforcement hypothesis.

Holland (1958) presents evidence which suggests a solution to the dilemma presented by Deese's negative results. He suggests that the probability of detecting signals depends upon making responses which, in turn, make the detections possible. Such responses, for example, might include correct orientation to particular portions of the display, and scanning or fixating the display. Holland terms these behaviors "observing responses" and suggests that they conform to the principles of operant conditioning. He suggests that the reinforcement for these responses is the detection of a signal, and that the rate of responding is controlled by the scheduling of signals in much the same way as reinforcement with food controls the rate of responding in animals.

In support of this notion, Holland devised a situation in which the subject pressed a key that in turn briefly flashed a light permitting him to observe a dial on which he was to detect pointer deflections. In his first study he found that when signals were presented according to a fixed-interval, or fixed-ratio, schedule, the subjects' observing responses were distributed over time in patterns similar to those of animals working for food on similar schedules of reinforcement. Data for a typical subject in a one-hour session are shown in Figure 4, illustrating the abrupt decrease in observing responses immediately after detection of a signal, followed by an accelerated rate of responding. Also shown is the extinction curve for the responses, resulting from termination of the signals after three signals were presented on a 4-minute fixed-interval schedule. Additional studies utilizing variable schedules of random signals showed that as the signal rate decreased, the rate of observing responses decreased. A finding of particular interest was that individuals who showed no decrement in detection performance showed an increase in observing responses over time, whereas individuals with lower detection performance showed lower observing rates over time. These results support the hypothesis that the detection of the signal reinforces the observing responses. It follows that increased observing would increase the probability of detection on a purely chance basis, and this might account for the reinforcing effects described by Deese and others.

The most comprehensive (and controversial) conditioning theories are those associated with Hull (1943) and Spence (1956), and a number of writers have attempted to apply their concepts to vigilance performance. Hull's basic paradigm, $H \times D - I - \bar{E} - - \to R$, marks a fundamental improvement over earlier conditioning theory in that an attempt is

Extinction of Observing Responses
as a Result of Withholding Signals

NOTE: Data from Holland (1958).

Figure 4

made to take into account the effects of motivational variables (D) on performance. This is significant in terms of the present discussion, since failure to consider this class of variables has been a major criticism of most theories when applied to vigilance performance.

In applying this paradigm to vigilance tasks, Baker (1959) assumed that the drive (D) and inhibition (I) components were the critical factors in vigilance tasks, since habit strength (II) could be assumed to be at, or near, asymptote at the onset of the task. The assumption is based on the further assumption that the S-R events in a vigilance task have already been developed in the past experience of the observer.

In contrast, Baker maintained that motivational factors such as temperature, special instructions, and drugs should, because of the multiplicative relation between H and D, greatly influence vigilance performance. Likewise, inhibitory factors arising from nonreinforced responses or from work being done (reactive inhibition, I_r) should also significantly influence vigilance performance.

Baker, however, appears to be most concerned with the inhibition factor. He cites studies that show a rise in performance following interpolated rest as evidence for an inhibitory factor which accumulates during work and dissipates in the absence of stimulation. If inhibition dissipates over time, a simple prediction would be that the longer the interval between signals, the better performance would be, yet there are studies indicating that the opposite is more likely true. Both Baker (1959) and McCormack (1958) present evidence for a lack of relationship between vigilance performance and length of intersignal interval.

It should be noted, however, that in rejecting the reactive inhibition concept, Baker has neglected a body of relevant data which might explain the failure to observe I_r in the vigilance situation. The occurrence of I_r in psychomotor tasks is a firmly established construct, whereas in verbal learning tasks this is not the case. Consideration of the kinds of responses ordinarily involved in most vigilance tasks suggests that the amount of motor involvement is negligible. The Hull and Spence theories, it should be remembered, are based upon behaviors with considerable motor involvement and it is probable that reactive inhibition is not particularly relevant to vigilance behavior.

The variety of inhibition involved in nonreinforcement (i.e., non-motor-response-generated), on the other hand, is directly applicable in view of the earlier discussion of Holland's (1958) work. In line with this thinking, the work of Berlyne (1951) and of McGrath et al. (1959) is suggestive.

Vigilance behavior can be conceived as consisting of chains of serially dependent r_g's (fractional responses) and R's such as observing (R), detection (r_g), judging the stimulus (r_g), tensing the finger to press the response key (r_g), pressing the response key (R), and so on, with each r_g and R acting as a stimulus for the next response in the sequence. In this interpretation, nonreinforced occurrences of these anticipatory responses should have a cumulative inhibiting effect upon the r_g's, which would tend to decrease their probability of occurrence. This could have two possible effects on the detection and key-pressing responses: (1) in a serially dependent chain, if the probability of r_g's (or "expectancies") was reduced, then the probability of R's would be reduced; and (2) depending upon their similarity, the inhibition might generalize from the r_g's to the overt R's. McGrath et al. (1959) make the additional suggestion that the inhibition of responses accruing from nonsignal sources might also generalize to signal responses, again depending upon the similarity between the signal and nonsignal sources of stimulation.

It should be noted that there is evidence that where learning is not involved (i.e., in relatively pure performance tasks) the effect of amount of reinforcement (W_g) and frequency of reinforcement is to directly raise or lower performance level. As Holland found, individuals

showing no decrement in detection performance showed an increase in observing responses as a function of high levels of reinforcement (detection r_g's), whereas individuals with lower detection rates (less reinforcement) yielded decreasing observing rates (extinction of observing R's). This would, in turn, lower the probability of detection, and in such a situation chance detections could be expected to maintain performance at some minimum level.

In general, the broader conditioning theories appear to be sufficiently comprehensive and flexible to satisfy many of the objections raised against them. The most common criticism of learning-based theories has been their inadequate treatment of motivational (performance) variables. The Hull-Spence theories are least subject to this criticism; as will be noted in the section on motivation theory, many of the motivational phenomena are adequately accounted for within this framework. The most significant deficiency in this approach appears to be with respect to individual differences, although Holland's work is highly suggestive in this area.
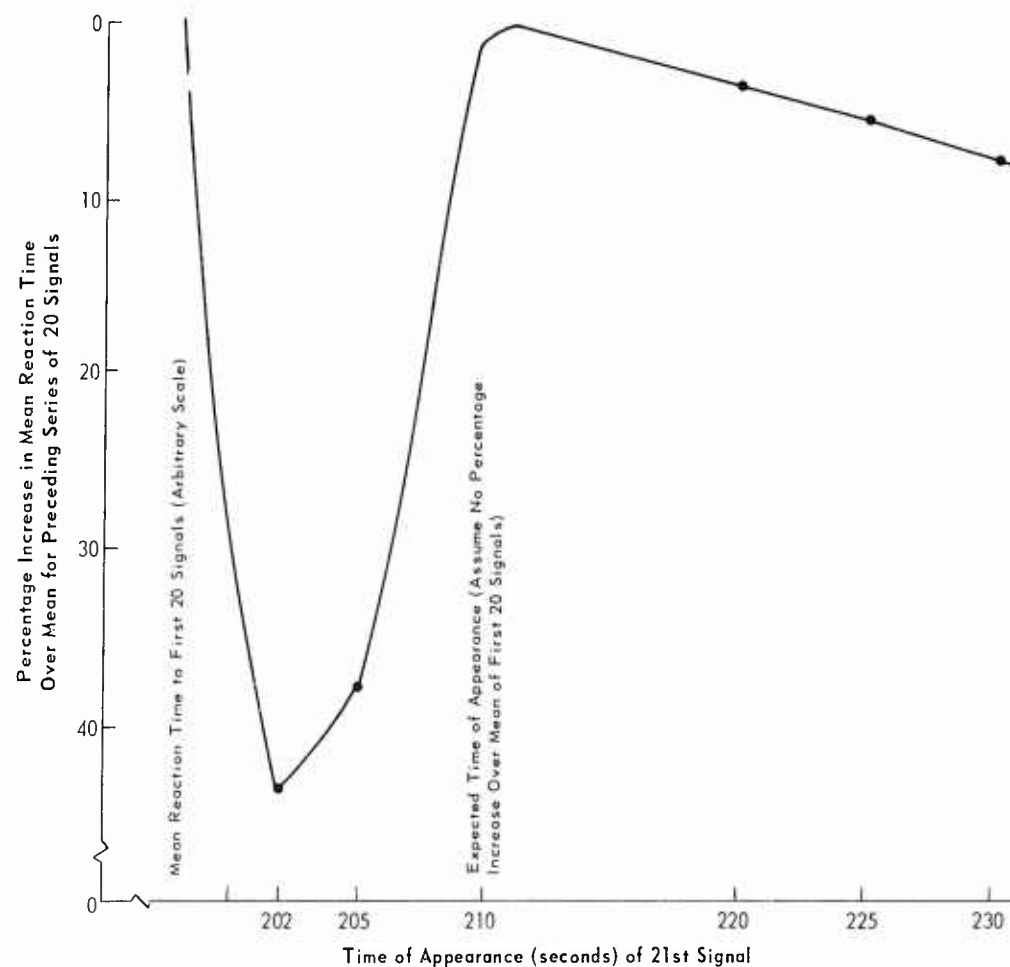
EXPECTANCY THEORY

Among learning-based theories, the major alternative to generalized conditioning theories of the Hull-Spence type is expectancy theory. A number of writers have subscribed to this position in recent years. In his definition of expectancy, Deese (1955) 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 hence his probability of detection."

This implies that the probability of detecting a signal is some function of the preceding rate of signal presentation, which is, however, a statement of a verifiable empirical law and not an operational definition for a theoretical construct. Expectancy level and vigilance level are superfluous terms in the definitional chain and, without additional independent defining operations, contribute nothing to an understanding of the empirical relationship.

Deese does, however, go on to attribute additional properties to the intervening variable, expectancy. Thus, expectancy should be low immediately after a signal and should increase as the mean intersignal interval is approached, becoming quite high as the intersignal interval passes beyond the mean. Baker (1958b) modified this conception, stating that expectancy again falls as the intersignal interval extends beyond the mean. In support of this notion, Baker cites a reaction time study by Mowrer (1940). The subjects responded to a tone appearing regularly at 12-second intervals, with occasional irregular intervals interpolated at periods ranging from 3 to 24 seconds, to test the effects on the subjects' reaction times. Mowrer found that response time decreases as the test interval approaches the standard 12-second interval and increases as the test interval goes beyond 12 seconds.

Baker (1958b) repeated the Mowrer study using 20 unvarying 10-second intervals, followed by a 21st interval of either 2, 5, 20, 25, or 30 seconds on separate trials. Mean reaction times to the 21st signal as a function of time of appearance of that signal are shown in Figure 5. Baker viewed the results as a demonstration of the expectancy curve, although the downward trend of the three "late" signals, while tending to support his hypothesized properties, was found not to be significant.

Percentage Increase in Mean Reaction Time
for 21st Signal Over Mean for Preceding 20 Signals
as a Function of Time of Appearance of 21st Signal

NOTE: Data from Baker (1959).

Figure 5

It should be noted, however, that the use of latencies to describe properties of an "expectancy," while legitimate in itself, is not a valid basis for explaining vigilance phenomena involving errors of omission, unless it can be demonstrated that response latencies are in some way related to the vigilance decrement. Of the two available studies in this area, one (Mackworth, 1950) indicates no relationship between latencies and detections, and one (Garvey et al., 1959) finds a systematic increase in response latencies over time.

Baker has attempted to relate a number of variables to predictions derived from expectancy theory. The evidence he cites suggests a direct relationship between signal frequency and percentage of detections, although more recent work (e.g., Harabedian et al., 1960) indicates some exceptions. Baker regards the relationship as being in accordance with the expectancy hypothesis: The greater the signal frequency, the larger the sample of data upon which observers are able to base their expectancies and, hence, the higher the proportion of detections. In addition, Baker cites evidence (Woodrow, 1951) to indicate that observers can estimate shorter intervals with greater precision than longer intervals. It is worth noting, however, that the relationship between signal frequency and percentage of detections could be predicted on a simple statistical basis without calling upon the additional concept of expectancy.

Integral to the expectancy concept is the notion of stimulus averaging. By means of this process the observer arrives at estimates of mean frequency and mean intersignal interval, these estimates presumably constituting the expectancy. This implies that expectancies are characterized by a regularity that is superimposed on the stimulus population. This is an additional hypothetical property of an expectancy which leads to the testable hypothesis that the more regular the intersignal interval is, the higher the probability of detection. In more sophisticated terms, since the probability of detecting a signal is based on the mean of prior signal frequencies, then it follows that to the extent that signals are more regularly presented the perception of the temporal structure of the series will be more accurate, and the likelihood that expectancies will be confirmed will be greater. Signals appearing at less regular intervals provide less confirmation of expectancies and subsequently lead to over-all performance decrement. In general, the experimental evidence (Deese and Ormand, 1953; Baker, 1958b) appears to support this position and thus provides support for the expectancy concept.

Two points are in order. The first is concerned with stimulus averaging. If the expectancy is based on a process of averaging previous stimuli, do all prior stimuli enter into this average, or only those within some preceding time period? Are the stimuli differentially weighted, and what is the mechanism for averaging? Clarification of these points would permit a number of testable deductions.

The second point is that these results are equally explicable in terms of general conditioning theory. Recurring r_g-s_g chains would result in the same prediction and this interpretation has the additional advantage that questions of the preceding kind do not occur. It should be noted, too, that the r_g-s_g paradigm displays many of the hypothetical characteristics of expectancies (Osgood, 1953) and that a very good possibility exists for subsuming expectancy theory under the heading of more general conditioning type theories. As the term implies, an expectancy is, by definition, an anticipatory response; therefore, it may be considered synonymous with the fractional anticipatory goal response mechanism, r_g-s_g, proposed by Hull.

In addition to the points already considered, Baker (1959) suggests that the direct relationship of percentage of detection to magnitude of

signal further supports the expectancy hypothesis, since signals of large magnitude make the confirmation (or nonconfirmation) of expectancies more probable because of the increased probability of perception. Rather than constituting supportive evidence, however, these data simply suggest a possible relationship between probability of detection and hypothetical expectancies. In this instance, the notion of expectancies is superfluous to an understanding of the relationship between signal magnitude and probability of detection per se.

When there is uncertainty about signal location, Baker states that an expectancy may be temporally "correct," but the signal may appear at an unscanned location at that moment, resulting in unconfirmed expectancies which would serve to lower the apparent signal frequency. He cites evidence (Garvey, 1957) that performance in vigilance tasks is poorer when the location of the signal is unpredictable. This is a reasonable deduction and is adequately supported by the evidence. It is also a reasonable deduction from either conditioning theory or simple statistical probability theory.

Expectancy theory is most hard pressed in explaining the effects of motivational variables. Knowledge of results, which most writers agree is a motivational variable, has been firmly established in a wide variety of tasks (Holland, 1958; Annett and Kay, 1957; Gibbs and Brown, 1956). Baker suggests, however, that rather than being motivational in character, knowledge of results provides information to the observer concerning the "true temporal nature" of a series of signals. This in turn, increases the probability of confirmation of expectancies. Thus, knowledge of results merely tells the observer when a signal has occurred and whether it has been detected. This information allows the observer to learn the true temporal nature of the series.

In general, Baker's position (1959, p. 40) is that the expectancy approach should hold for any level of motivation on the part of the observer. Even a highly motivated observer will lose efficiency with brief, small, irregularly spaced, infrequent signals. On the other hand, even poorly motivated observers will perform acceptably if signals are large, prolonged, frequent, and regularly spaced. In light of the considerable body of evidence pertaining to the effects of motivation on performance in vigilance situations (such as studies on drugs, end-spurt effects, extraneous stimulation, reinforcement, and knowledge of results), Baker's statement places expectation theory in a somewhat tenuous position.

Perhaps the most significant criticism of expectancy theory, however, is the fatalistic implication inherent in this position that no possibility exists of ever achieving perfect or near-perfect performance in most vigilance situations. If we accept the position that detection is dependent upon expectancies of regularly fluctuating probabilities, then with relatively infrequent and maximally random signals the coincidence of actual signals with the regularly spaced mean intertrial intervals could not possibly be perfect over an extended period of time. In short, if the expectancy position is correct, there is little hope for improvement in many critical vigilance activities. The very high levels of performance that have been demonstrated under conditions employing

rest periods or the use of drugs, for example, are concrete evidence that the vigilance decrement is not inevitable. Expectation theorists appear to be faced with the problem of continuing to deny clearly contrary evidence, or modifying and expanding their hypotheses to accommodate such evidence.

MOTIVATION THEORY

A broad range of variables known to significantly alter vigilance performance can be conceived of in terms of their motivational effects on the observer. Included among these are the effects of knowledge of results, end spurt, drugs, extraneous stimulation, special instructions, rest periods, and even possibly the frequency of stimulation. In addition, the often noted large individual differences in susceptibility to vigilance decrement suggest that personality (i.e., motivational) variables are of considerable significance in vigilance performance.

The preponderance of variables leading to improved performance are either motivational in character, invariant, or inherent to a given operational situation. Theories which are capable of integrating these diverse effects and which lead to testable predictions and to the isolation of new variables should be of considerable value in the general area of vigilance.

As noted in the preceding section, expectancy theory does not include motivational considerations within its framework. It is, in fact, a miniature or partial theory. In contrast, and as a result of its recognition of the basic learning-performance dichotomy, general conditioning theory devotes considerable attention to the effects of motivation on performance. The concepts of primary and secondary motivation, primary and secondary reinforcement, r_g and s_g, and the effects of observable antecedent conditions upon these constructs, such as amount of reinforcement (W_g) and deprivation time (t_d), are all concerned directly with describing, predicting, and explaining the role of motivation in performance.

As pointed out earlier, conditioning theory also considers a variety of inhibition concepts as they relate both to learning and to performance. Unfortunately, most applications of conditioning theory to vigilance have been concerned primarily with disproving the validity of inhibition concepts where such applications are probably not relevant in the first place (e.g., reactive inhibition) or with demonstrating the ineffectiveness of reinforcement (where such applications are relevant). In both instances, as discussed earlier, conditioning theory has been adequate to explain and predict. In terms of such phenomena as end-spurt effects, extraneous stimulation, signal frequency, and rest pauses, the integrative and explanatory power of conditioning theory can be equally well demonstrated.

For end-spurt phenomena, for example, conditioning theory might predict that the discriminating antecedent conditions determining the occurrence or nonoccurrence of end spurts would be knowledge (gained either through practice or through instructions) of the length of the

vigil, that is, goal gradient effects explained in terms of r_g and s_g and the gradient of reinforcement (termination of the task serving as the reinforcement). A number of testable predictions can be derived from this interpretation: (1) knowledge vs. no-knowledge of length of and present point in the vigil should yield different results (Jerison, 1958 provides suggestive evidence in this area); (2) the end-spurt effect resulting from a knowledge of vigil length should become more pronounced in successive sessions if the knowledge is based on previous experience; and (3) practice at one length of vigil and testing at different lengths should yield differently shaped curves.

As for extraneous stimulation, the literature on conditioning provides numerous examples of the effects of variations in drive level upon performance (as opposed to learning) and the related anxiety-arousing characteristics of either strange and unusual, or threatening (i.e., intense) stimulation on performance. In addition, the disinhibiting effects of Mackworth's phone call have by no means been disproved and, contrary to Deese's contention (1955), the defintion of disinhibiting stimuli is not difficult nor is the design of relevant studies impossible. Thus, the interpolation of irrelevant intense stimuli at various points in the vigil (using independent groups) is quite feasible and the results clearly predictable from conditioning theory.

With regard to signal rate, one means of objectively manipulating motivation in humans is a technique called "task-induced stress" (Garvey, 1957) which involves increasing the response rate requirements of the task: that is, the more responses required per unit time, the greater the "stress" or task-induced anxiety. Variations in signal rate and task complexity are a clear example of this type of manipulation. Several studies in the literature on conditioning demonstrate that the effect of increased drive is to increase performance up to some maximum (probably determined by the maximum possible responding rate of the individual) with further increases in drive resulting in performance decrements. Applying this information to the effects of signal rate, the prediction would be that increases in signal rate should increase performance up to some point, and that further increases in signal rate should result in decrements in performance. This is a testable proposition.

In general, conditioning theory appears adequate for predicting much of the data from vigilance studies. The area where this approach has little to offer, however, is that where frankly physiological and personality variables are involved. A case in point is the dramatic effect of drugs such as benzedrine on vigilance performance. Behavioristic theories in general, because of their very nature, either fail completely to consider both effects of drugs and the effects of personality, or relegate these factors to little considered aspects of the theory. Thus, Hull would relegate such factors to inherent response characteristics of the organism $(_sU_r)$ or to alterations in the effective reaction threshold $(_sL_r)$, for example. Such treatment restricts the possibility of increasing our understanding of many significant factors controlling human performance and, like the early instinctivism of McDougall and the modern nativism of the ethologists, precludes any possibility for increasing our control over behavior.

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It is in this area that physiologically oriented theories can make a significant contribution. It should be noted, parenthetically, that physiological theories are not contradictory nor antagonistic to behavioristic theories, but rather consider the data of behaviorism at lower (more fine-grained, more fundamentally "causal") levels of discourse. In short, the two levels of theory should be compatible and mutually supportive.

Recent years have witnessed a growing integration of a mass of physiological data relating to motivation and emotion from which has emerged what has come to be known as "activation" theory. In view of the significance of motivation for vigilance performance, it seems reasonable to expect that this type of theory might prove fruitful in increasing our insights into this form of behavior. This is essentially the position Deese (1955) has taken. He suggests that changes in vigilance performance be attributed to changes in some normal excitatory state of the individual. The vigilance decrement thus represents a dissipation in the initial excitatory state of vigilance.

The basic concept of the activation theory is straightforward, and has implications for the problems of vigilance. Briefly, the neurophysiological evidence indicates that one of the several hypothalamic centers, the waking center, exerts control over the wakeful-sleeping behavior of higher organisms, and that activity in this center is maintained in part, at least, by continued sensory input. Presumably, when such input falls below some minimum level, wakeful activity ceases and the organism "falls asleep." According to Deese, then, the decline in vigilance performance can be attributed to a decline in the level of sensory input resulting from monotonous aspects of the task. What some writers call "inhibition" would, according to this interpretation, be nothing more than a level of external stimulation lower than that required to maintain the individual at his "normal" excitatory level. At a behavioral level, it might be noted, there is considerable similarity between the "excitatory level" of activation theory and Hull's notion of generalized drive state. An attempt to integrate or coordinate the two levels of theorizing might prove both feasible and profitable.

Inherent in Deese's use of the phrase "decline . . . resulting from monotonous aspects of the task" (1955) is the notion of sensory adaptation. If stimulation in the environment continues at the same level, a reduction of stimulation at the waking center must be the result of changes in the intervening receptor mechanisms or connecting pathways: that is, adaptation. What Deese appears to mean by "monotonous," then, is repetitious stimulation leading to increased receptor thresholds. Among the earlier physiological works in support of this theory are Kleitman's (1939) studies of sleep in which he demonstrated that when an organism is deprived of sensory input, or when sensory input declines, the organism sleeps. In addition, because the cerebral cortex to a large extent controls waking and sleeping patterns of the organism, wakefulness can be dichotomized in terms of the wakefulness of choice as opposed to the wakefulness of necessity which is exemplified by the sleep patterns of many animals and human infants. Thus, it seems reasonable to assume that wakefulness of choice, besides being

dependent upon the cerebral cortex for control, is also dependent upon the level of sensory input. Other supporting evidence comes from research on sensory deprivation (Wheaton, 1959) and studies demonstrating lower performance on homogeneous as opposed to heterogeneous tasks (Bills, 1943; Barmack, 1937).

If systematic changes in sensory thresholds are the behavioral manifestations of the process postulated by activation theory, then to demonstrate the validity of such changes in relation to vigilance performance it is necessary to demonstrate them independently of the vigilance measures per se but in a vigilance-type situation. This presents a difficult experimental design problem in that interpolated threshold tests, even employing independent groups for each test point, might destroy the vigilance effect and lead to negative results.

A different approach might be to demonstrate a relationship (or the lack of one) between sensory thresholds and conditions known to significantly affect vigilance performance. This is essentially the approach taken by McFarland et al. (1942) who found a systematic decline in DL's over time. Other examples of such studies might include the systematic testing of thresholds over extended periods during which drugs such as benzedrine are employed, and systematic testing of the thresholds of individuals who have demonstrated significantly different performance under vigilance conditions. In the first example the prediction would be no threshold changes; in the second, it would be significant changes for individuals known to show performance decrement under vigil and no change for individuals known to be unaffected by vigil.

Finally, a general implication of the activation hypothesis is that the provision of a high level of variegated background stimulation should maintain a relatively high level of vigilance performance. A variety of testable hypotheses can be derived from this notion. For example, it could be predicted that the use of artificial signals and increases in extraneous stimulation in the situation should lead to improved vigilance performance.

The variety of vigilance data which appears to conform with the predictions of activation theory suggests that from it, in combination with general conditioning theory, a number of fruitful hypotheses might be derived which would be of value in research on vigilance performance. These possibilities are considered in the following chapter.

Chapter 4

IMPLICATIONS FOR ACTION

The question raised in the introductory chapter of this report was: What can be done to maintain vigilance performance at a level that will not reduce total system performance? The purpose of this chapter is to consider three alternative approaches toward answering this question.

HUMAN ENGINEERING

An examination of the history of vigilance phenomena strongly suggests that the vigilance problem must be considered in terms of the state of machine technology. A decade ago, when serious concern for the problem of vigilance was first generated, man was the best and only practical sensor-detector "device" available. At that time, electro-mechanical sensors were in a relatively primitive state of development and little attention was given to designing systems to maximize human performance. The development of long-range sensors shifted reliance upon direct visual surveillance to indirect surveillance through surveil-lance of the products of the artificial sensors.

The resulting change in the nature of the monitoring task introduced new problems, but at the same time carried with it clues to the practical solutions to the vigilance problem. Unfortunately, these solutions were not recognized at the time that the new-style detection systems were designed, and vigilance continues to be a problem for many presently operational systems. This suggests that, in future systems employing man as a detector, recognition and implementation of known human engineering principles could in many cases reduce the decrements characteristic of vigilance.

Manned Monitoring

Several well-established human engineering principles could be implemented for more effective design of man-monitored systems:

(1) Signals should be as large in magnitude as is reasonably possible. This includes size, intensity, and duration.

(2) Signals should persist until they are seen, or as long as is reasonably possible.

(3) The area in which a signal can appear should be as restricted as possible.

(4) Although "real" signal frequency often cannot be con-trolled, it is desirable to maintain signal frequency at a minimum of 20 signal/hr. If necessary, this should be accomplished by introducing artificial (noncritical) signals to which the operator must respond.

(5) Where possible, the operator should be provided with anticipatory information. For example, a sound of a buzzer might indicate the subsequent appearance of a critical signal.

(6) Whenever and however possible, the operator should be given knowledge of results.

(7) Noise, temperature, humidity, illumination, and similar factors should be automatically maintained at optimal levels.

(8) The system should be so designed that operators do not work in isolation from other individuals.

(9) Whenever possible, the system should be so designed that individual watches do not exceed 30 minutes.

Implementation of these principles in current and proposed man-monitored systems would do much to reduce vigilance effects on the operator.

Automatic Monitoring

In the interval following the design of currently operational systems, the sensor-detector machine technology has developed to a point where many of the functions presently performed by man can be performed equally as well by the machine, and often with greater reliability and at less cost. This is particularly true in fixed, "low-density" ground-based systems where space and weight considerations are of secondary importance. In "high-density" systems such as mobile ground-based systems, space vehicles, and the more traditional airborne systems, however, where weight and space factors are critical, man still represents the best compromise in many instances. The applicability of human vigilance performance research thus appears to be limited largely to currently operational, inadequately human-engineered systems and high-density systems of the present and future.

The most significant advances in machine technology in recent years have been in the development of high-speed, compact, and reliable computers. New developments are appearing so rapidly that it would be impossible to specify the exact current status, but in view of what is already generally known about current capabilities, the design of automatic and semiautomatic sensor-detector systems that can effectively replace the monitoring functions of man is clearly feasible.

For example, where distinctive and describable stimuli are involved, as in the case of panel light, ammeter, and digital-type indicators, relatively simple circuitry can be built into the system to yield stimulation in any desired human sensory mode at sufficient intensities to alert even the least vigilant monitor.

Where more ambiguous stimuli of the kind involved in radar scope monitoring are involved, the electromechanical implementations are more complex but quite feasible. Examples of successful implementations of this kind are found in U.S. Air Force ground-based system and a U.S. Navy airborne system. In the airborne system, for example, radar returns are processed in terms of several criteria and presented in the form of distinctive symbology on the radar scope at intensities precluding the development of vigilance effects.

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Work is advancing rapidly on the development of high-resolution machine discriminators, and it can reasonably be anticipated that within the next decade the discrimination capabilities of such devices will at least equal, and possibly surpass, those of man.

All of these developments have important implications for the course of research in this area. The most significant implication is the probable obsolescence of vigilance as a major human factors problem in future air defense systems if proper consideration is given to the problem in the initial design stages of the system. If such consideration can be assumed, there is the further implication that an extended research program on the effects on vigilance performance of learning and motivational variables might yield results that would no longer be of any practical interest.

It is clear that adequate human engineering and/or the automation of monitoring functions present feasible solutions to the vigilance problems associated with many future systems. It is equally clear that activities in this area are outside the capability and responsibility of HumRRO.

SELECTION RESEARCH

It seems quite reasonable to expect, for the reasons cited in the previous section, that vigilance will not constitute a serious problem in future low-density systems. However, there is still the problem of vigilance in present and near-operational low-density systems and in present and future high-density systems.

On the basis of the current evidence, research in the area of selection appears to hold the greatest promise for solution of the immediate problem. Among the variables that appear to have some potential for predicting individual vigilance performance are initial difference limens, age, sex, intelligence, and susceptibility to boredom; in addition, observing response rates and initial detection thresholds have been found to significantly differentiate individual vigilance performances. Probably only three or four of these variables would have implications for solution of the immediate operational problem; these would include difference limens, intelligence, initial detection thresholds, and possibly observing response rates. It should be noted that the work accomplished to date in this area by no means exhausts the full range of possibilities, and emphasis would be placed in this program upon the development of other parameters of individual differences.

The selection approach has a number of advantages: (1) The apparatus requirements are simple and inexpensive and the support requirements are relatively small. A fair amount of information could probably be gained for a minimal investment. (2) The evidence suggests a high "pay-off" potential in this area. (3) The simplicity and ease of administration of the pretests would make early implementation of the research possible if significant relationships are demonstrated.

A possible shortcoming to this approach is that the population available for application of selection procedures might yield too few

highly proficient operators to satisfy current needs. This question is an empirical one, however, and requires the data from at least an initial experiment to be properly evaluated.

JOB ENGINEERING

Another approach to reducing vigilance decrements in present and near-operational systems is through research on job engineering. A number of hypotheses concerning job engineering have been developed from the discussions of theoretical alternatives presented earlier. Experimental tests of all of these hypotheses are feasible; however, not all have equally significant practical implications.

For example, research on hypotheses relating to the effects of "disinhibiting" stimuli presumably would have little utility because of probable adaptation effects. The same can be said of the effects of threatening stimuli, such as shock or the presence of a person of authority. Research on hypotheses relating to the effects of knowledge of length of watch or impending termination of the watch would be of theoretical interest but would have little practical value because such information is typically readily available to the operator in the operational situation. Similarly, hypotheses relating to the effects of signal rate have few implications for present systems because of the cost of providing reliable devices for generating synthetic signals at each fire unit. Lack of practical utility also compromises the value of hypotheses concerning the effects of drugs.

The ultimate utility of research along the lines suggested by the above hypotheses is not denied, nor is their intrinsic psychological interest. In terms of the immediate objectives of applied research, however, other hypotheses with more practical implications are available.

For example, hypotheses concerned with the effects of different schedules of reinforcement for observing responses (presentation of a signal when the observing response is performed) and hypotheses relating to the transfer of established observing responses might have considerable utilitarian value. Examples of such hypotheses are: (1) The partial reinforcement of observing responses will maintain a high level of performance longer than will total reinforcement. (2) Operators trained with one signal rate will perform less efficiently when they are presented with a slightly different rate.

In addition to the hypotheses derived from the theoretical discussions, examination of the results of the empirical studies cited in this report indicates that four variables have consistently significant effects on vigilance performance—variations in signal rate, the use of benzedrine, group vs. individual monitoring, and interpolated rest periods.

Two of these factors are somewhat impractical in terms of the operational situation. Except for the possible employment of artificial signals, signal rate cannot be controlled in the present operational environment. The use of drugs presents practical administrative problems in addition to the unknown and possibly deleterious effects of continued use of drugs.

The remaining two variables, interpolated rest and group vs. individual monitoring, appear to have important practical implications. A number of questions can be raised concerning the optimum arrangements for group monitoring activities and interpolated rest periods. In a sense, the two variables are interrelated. Both imply the employment of additional operator personnel, and both are forms of altering or increasing the general stimulation level for the operator. Comprehensive considerations of either variable would require some consideration of the effects of the other, and the interactive effects of the two variables combined.

Among the questions which appear to be of interest in terms of these variables are the following:

(1) In connection with the demonstrated superiority of pairs in monitoring (see Chapter 2), does the performance of individuals improve, or deteriorate, as a result of working in pairs? If individual performances do not show a gain, is the pair superiority some function of overlapping individual detections?

(2) Are the effects of pairing greater with both individuals watching the same display and in close communication with each other, or are they greater with individual displays and limited communication?

(3) Are the effects of pairing lasting, or do they result from the novelty of the situation?

(4) Are better and poorer operators differentially affected by the conditions of pairing?

(5) Do pairs of individuals matched on "personality" factors perform better than randomly paired individuals?

(6) Are pairs affected by interpolated rest periods?

(7) Is it better for paired individuals to alternate work periods or is it better for both to work continuously?

(8) What minimum length and what frequencies of rest periods yield optimum performance?

(9) What types of rest interval activities yield optimum performance?

(10) What individual characteristics are related to the effects of interpolated rest periods?

(11) Are the characteristics described in the preceding question related to those affected by pairing?

(12) Is performance in multiple and single display tasks differentially affected by paired monitoring and rest intervals?

This discussion of job engineering, although brief, is enough to indicate that there are a variety of problems that can be studied in an extended program of vigilance research. It is probable that such a program would yield positive products that could lead to increased operator proficiency.

Chapter 5

SUMMARY

The purpose of this report has been to present the results of a comprehensive survey and analysis of vigilance research. Vigilance phenomena constitute a military problem insofar as they contribute to a reduction in over-all system effectiveness. It can be demonstrated that in some cases this reduction can be large. The psychological problem as it relates to the military needs is one of isolating the relevant behavioral variables leading to optimal human performance under vigilance conditions.

A wide variety of parameters have been investigated in relation to vigilance performance and several have been found to be significantly related to such performance as described in Chapter 2. The effects of the many variables studied to date were summarized on pp. 23-24.

Three general classes of theory were discussed. Of these, expectancy theory appears to be the least comprehensive and least satisfactory; the most significant criticism of this position is the inherent implication that, except for a very restricted range of stimulus conditions, perfect or near-perfect performance would logically be impossible. Conditioning theory seems to account satisfactorily for a broad range of the data; its greatest weakness is the failure to consider motivation. Activation theories of motivation appear to correspond well with a variety of facts, and it was suggested that an attempt to integrate conditioning and motivation theories might prove profitable.

On the basis of the evidence obtained in the survey, three alternative approaches—human engineering, selection research, and job engineering—to the solution of the vigilance problem were outlined. In evaluating these approaches an important consideration was the current and projected "state of the art" of machine technology and the important effects this could have on the time factors involved in research.

It was pointed out that sufficient human engineering information is presently available to eliminate many vigilance problems if this information were properly incorporated into new equipment designs. In addition, a good possibility exists that the human monitor can eventually be replaced in low-density ground-based systems.

Thus, there appears to be a limited period of time during which human monitoring activities will constitute a significant military problem for low-density systems. It was therefore suggested that a second approach to solution of the vigilance problems, directed toward problems existing in currently operational systems, would be a program of selection research. Such research would have a reasonably high probability of success and could be accomplished in a relatively short period of time.

The third approach, job engineering, would involve a more extensive research effort but also appears to have a reasonably high probability of success.

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A SURVEY AND ANALYSIS OF VIGILANCE RESEARCH—Bruce O. Bergum and I. Charles Klein (U.S. Army Air Defense Human Research Unit, Fort Bliss, Texas)

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Empirical data drawn from a survey of the research literature on vigilance behavior are presented in terms of the effects on vigilance of variables discussed under the groupings of task, environmental, and motivational factors. The adequacy of current interpretations of vigilance data is considered for three classes of theories: conditioning, expectancy, and motivation. Approaches to the solution of the vigilance program are discussed in terms of anticipated technological developments, and areas of research on monitoring problems associated with air defense systems are suggested.