SIGNAL COMPLEXITY, RESPONSE COMPLEXITY,
AND SIGNAL SPECIFICATION IN VIGILANCE

by

JERRY MICHAEL CHILDS, B.A.

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CHAPTER I

INTRODUCTION

Although there has been a recent discontent with mechanistic or component interpretations of psychological processes, adherence to scientific methodology by those in experimental psychology often necessitates a reductionistic orientation, i.e. explaining and evaluating complex phenomena in terms of corresponding simpler processes. To a large extent, such has been the case with regard to the study of human attention. In spite of increased awareness of the complexity of this attentional construct and the interactive components by which it is characterized, there remains a preoccupation with methodological reductionism. The present goal, then, seems to be one of attempting to obtain enough data from rather diverse subareas of human attention to permit at least partial explanatory closure while maintaining a general recognition that the human organism is realistically greater than the sum of its parts, as Gestaltists have maintained.

The value of contributions put forth by psychologists with cognitive orientations should not be overlooked in assessing the progress made to date in the study of human attention. The idea that reality is mediated not only by the sense organs but by complex cognitive systems which

interpret and transform sensory information has influenced even the most rigid behaviorist's conception of human attention (Neisser, 1967).

Although many contemporary systems have succeeded in eliminating the human component with respect to operating characteristics, there has remained continuing need for specification of factors which relate to and function in the maintenance of long-term human arousal and its perceptual correlates. Hence, the vigilance task has taken on significance with regard to the provision of these factors. Previous research has focused upon factors relating to the individual (e.g. personality, intelligence, motivation, sex, age), the task (simple vs. complex, time-shared, cross-modal monitoring, signal and event variations, task duration), and the environment (ambient temperature, noise, experimental coercion, sleep deprivation).

The importance of human vigilance may be shown by examining applied environments which require sustained, efficient monitoring. These situations entail detection of critical stimuli (signals) which, by definition of the task, occur within a distribution of perceptually monotonous, irrelevant stimuli (events). Individual monitors generally begin to miss (i.e. fail to respond to) important signals after a period of ten to twenty minutes (Baker, Ware, and Sipowicz, 1962). Following this interval, there is generally -- depending upon the complexity of the task and environmental variables -- a somewhat gradual

decline in signal detections until an asymptotic performance level is reached. Although signals are suprathreshold -- and hence, readily detectable -- both errors of omission (misses) and errors of commission (false alarms) are common occurrences in the vigilance task.

Misses are characterized by the monitor failing to respond to a signal (presumably because it is not perceived), while false alarms are defined by a response to a "signal" which has not occurred (i.e. responding to a non-signal event). These two performance indices together with response latencies -- i.e. the amount of time needed to respond to signals -- have been the primary dependent variables examined in the vigilance context. The extent to which the operating characteristics of a system are contingent upon the efficiency of individual monitoring determines the extent to which these characteristics will be disrupted or negated by excessive misses or false alarms and by longer response latencies.

Examples of applied vigilance tasks may be found in industry where quality control of production elements depends upon sustained attention by assembly line monitors, and in the military where complex visual and auditory displays must be monitored for efficient operation of the systems which these displays comprise (e.g. navigational problems of pilots and other crew members often relate to attentional deficits). A more common variation of vigilance application relates to arousal deficits which plague

the driver of a car on long-distance trips. Although the task involves simple execution of conditioned responses, a failure to detect or heed critical environmental stimuli (signals) such as the velocity and direction of other vehicles can prove hazardous or disastrous. Stimuli used as signals in vigilance tasks can take virtually any form. For example, the signal may consist of a discrete stimulus either added to or subtracted from the environment, or it may consist of a change in a stimulus which is continuously or intermittently presented. Thus some vigilance tasks involve the detection of the presence or absence of a stimulus, while others require the observer to detect differences between different stimuli which are either signals or non-signals.

Vigilance tasks can also be divided into sensory and cognitive kinds on the basis of the stimulus characteristics of the task situation (Davies and Tune, 1969). In sensory vigilance tasks, the signal is a change in purely sensory stimulation: for example, a change in the brightness of a light or in the pitch, loudness or duration of a tone. In cognitive vigilance tasks, a series of letters or numbers is presented and the observer is required to detect a specified stimulus sequence, for example, an X followed by an A, or three successive odd numbers that are all different.

The intensity of signals used in sensory vigilance tasks has generally been near the observer's threshold and the duration of the signal has usually been brief, although

some investigators, employing response latency as the dependent variable, have used tasks in which the signal has remained present until detected. Signals occur at irregular time intervals, although in order to examine changes in performance over time the task is usually divided into sub-periods of equal length in each of which the same frequency and temporal arrangement of signals is preserved.

Although there appear to be no formal rules governing the periodicity of signal occurrence in vigilance, the general criteria used to differentiate the vigilance task from other attentional tasks are that signals tend to occur infrequently and unpredictably, and that the task tends to be prolonged. However, Williges (1973) has employed one-to-one signal-to-event ratios and Thompson, Opton, and Cohen (1963) have used tasks lasting only five minutes.

The function and rate of vigilance errors have unfortunately not lent themselves to specific behavioral categories. In view of the complexity of human behavior, this is unlikely to occur within the near future, if ever (Colquhoun, 1966). However, there are a number of general factors which seem to relate to optimal vigilance performance. The following discussion will direct itself to the presentation of some of these factors.

Motivational Factors

Characteristics associated with the individual monitor are varied and complex although capable of general classification. Most recent approaches have focused upon intricate

individual differences related to subject-paced monitoring (Tyler, Waag, and Halcomb, 1972), variable confidence models based upon subjective uncertainty of signals (Miehle and Siegel, 1970), applications of signal detection theory (Tanner and Swets, 1954), and upon subject motivational characteristics (Sipowicz, Ware, and Baker, 1962; Bevan and Turner, 1965; Halcomb and Blackwell, 1969).

Hebb (1955) indicated that sensory events have two functions -- a cue function and an arousal or vigilance function which is mediated by the reticular activating system in the brain. Hebb suggested that the vigilance function might be optimal at intermediate levels of arousal as did Schlosberg (1954) and Malmö (1959). According to Hebb's interpretation, low levels and high levels of arousal would not be conducive to efficient performance, but intermediate levels would be. Hebb further postulated that cognitive feedback might function to arouse the vigilance mechanism. The role which this cognitive feedback assumes has been the primary focus of studies concerned with the motivational characteristics of subjects within the vigilance paradigm. Smith (1966) asserted that vigilance performance should be considered totally a function of motivation. Unfortunately, motivational characteristics which influence monitoring performance are numerous and complex and have been found to interact with other factors related to the task and environment. Some motivational correlates will now be reviewed.

It has been found by many investigators that the effects of knowledge of results in the form of augmented feedback are to enhance monitoring performance (McCormack, 1959; Mackworth, 1961; Loeb and Schmidt, 1963; Weiner, 1963; Mackworth, 1964; McCormack, 1967). However, some studies which have incorporated knowledge of results have failed to support its facilitating effects (Weidenfeller, Baker and Ware, 1962; Johnson and Payne, 1966; Anotelli and Karas, 1967).

There has been recent support for the notion that instructions relayed to subjects may facilitate or impair performance depending upon instructional mode and content. Lucaccini, Freedy and Lyman (1968) successfully produced a positive set by instructing subjects a priori that vigilance tasks are perceptually and intellectually challenging. Results showed that subjects receiving positive set instructions performed significantly better than subjects receiving negative set instructions.

Williges has suggested that accuracy of instructions (Williges, 1969) and knowledge of results on response ratios (Williges and North, 1972) can powerfully affect subjects' criterion for response (β) and hence influence detection percentages. More recent support was obtained for variables related to signal-to-event ratios and signal detectability (d'). Williges (1973) found that when signals become more detectable and occur more frequently relative to events, subjects' response criterion

(beta) remains less conservative, i.e. response rate increases. However, Williges' (1973) signal-to-event ratios (one-to-one and one-to-nine) were sufficiently unrepresentative of applied monitoring to question their validity in relation to classic notions of the vigilance paradigm which define signals as aperiodic and infrequent.

Recent data concerned with instructional parameters (Childs, Locke, and Byrd, in preparation) has indicated that the degree of structure associated with instructions given to high-level mental retardates in a vigilance task may have pronounced effects upon detection percentages. It would appear that instructional considerations are more critical for this subject population than for normals.

Another motivational component in the vigilance literature relates to the use of incentives or rewards to coerce subjects to perform at optimal levels. The primary objection to the use of incentives has been that individual differences preclude the use of a "universal" incentive. That is, the reinforcing value of a given incentive may be higher for one person than for another person. Furthermore, incentive values tend to fluctuate even for one subject. One of the most effective uses of incentives was by Sipowicz, Ware, and Baker (1962). It was found that experimental groups receiving both monetary rewards and knowledge of results performed better than groups receiving only monetary rewards or only knowledge of results. All experimental groups exhibited significantly higher detection

percentages than the control group. Similar findings were reported by Montague and Webber (1965) and by Smith, Luaccini, and Epstein (1967).

Bevan and Turner (1965) found that subjects who received a penny for each correct detection performed significantly better than an unreinforced group. Furthermore, a group which received a mild electric shock for each error also performed significantly better than the control group. The best performance was obtained by a group which experienced a qualitative shift in reinforcement midway through the task -- specifically from reward to punishment. Bergum and Lehr (1964) found that monetary incentives exerted differential effects upon performance relative to no-incentive conditions. These effects were interpreted as resulting from experimentally induced changes in the motivational level of the reward group.

One relevant incentive associated with the college subject population (contingent course credit) was examined by Halcomb and Blackwell (1969). Two groups of subjects were employed. One group received credit contingent upon optimal performance and the other received credit for participation with no restrictions upon performance level. Higher overall detection percentages were obtained for the contingent group. This supported the hypothesis that extra class credit provides a relevant incentive for college students who participate in psychological experiments.

Pollack and Knaff (1958) reported minimal effects of monetary incentives in elevating detection percentages while positive results were reported by Sipowicz, Ware, and Baker (1962) and by Smith and Lyman (1968). The latter study found that incentive significantly elevated performance relative to knowledge of results and coercion (subject awareness of experimenter's presence in the monitoring environment).

The most general findings with the use of incentives for vigilance have been positive. Levine (1966) varied payoffs for correct detections on an auditory task and found that performance was differentially affected by payoff amount.

Task and Environmental Factors

The majority of research concerned with human vigilance performance has been directed toward manipulation of the variables concerned with the task itself. The basic task has been investigated both alone and in conjunction with other types of tasks. Recent trends have been to concentrate upon its relation to other perceptual and attentional tasks -- i.e. to assess performance differences as a function of task complexity and task-specific parameters.

Montague, Webber, and Adams (1965) employed two response conditions (simple and complex) on a complex vigilance task lasting 18 hours. No significant differences in performance occurred as a function of response complexity.

Monty (1962) reported significant improvement in detection percentages in two of three complex response conditions relative to a simple-response control group. Subsequent findings have supported this study and have been interpreted as a function of intraorganismic arousal (Childs and Halcomb, 1972).

It has been shown that when evaluative decisions were made about display changes, no performance decrement occurred, while conditions in which subjects simply reported presence or absence of display changes showed significant decrements (Adams and Boulter, 1960; Adams, Stenson, and Humes, 1961). However, it has also been demonstrated that when subjects were required to remember and report past signals in relation to existing signals, no improvement in correct detections occurred (Adams and Boulter, 1962; Luce, 1964). Thus active information processing does not necessarily lead to optimal vigilance performance.

Signal characteristics have played a prominent role in consideration of task factors. Investigation of signal rate has shown that it is generally positively related to correct detections (Deese and Ormand, 1953; Jenkins, 1953; 1958; Bowen and Woodhead, 1956; Hickey and Blair, 1958; Garvey, Taylor and Newlin, 1959; Weiner, 1963; Bergum and Lehr, 1963; Bowen, 1964; Stern, 1966).

Signal intensity exerts an important effect on vigilance performance in the visual, auditory, and cutaneous

modalities (Adams, 1956; Smith and Boyes, 1957; Teichner, 1962; Hawkes and Loeb, 1962; Baker and Harabedian, 1962; Loeb and Schmidt, 1963; Wiener, 1964). The general conclusions point to more intense signals as elevating detection probabilities. However, recent formulations stress the importance of the interactive nature of signal rate and intensity with other task factors (event rate, display complexity, etc.) in the determination of vigilance performance.

Event rate may also be manipulated and general findings are that it is inversely related to detection percentage (Bowen, 1964; Jerison, Pickett, and Stenson, 1965; Mackworth, 1965). Goldstein, Johnston, and Howell (1969) varied both signal rate and event rate and found that as the latter increases relative to the former, performance decreases.

With regard to signal duration, it has been observed that although overall detection percentages increase as a function of longer signals, the basic decrement pattern (positive deceleration) remains much the same. Davenport (1968), for example, found that both duration and intensity of signals contributed to the efficiency of signal detection over time although the typical vigilance decrement obtained. Adams (1956) examined signal duration and found significant improvement in performance of monitors exposed to 2-second (as opposed to 1-second) signals.

Recent evidence for the importance of signal and event color was offered by Reynolds, White, and Hilgendorf (1972). They found that response latencies were fastest for red (with background color held constant), and that detection percentages were highest for green. Four stimulus-light colors and four background colors were employed.

The intersignal interval -- i.e. the temporal duration elapsing between signals -- must be of sufficient variability to prevent the subject from correctly estimating the temporal pattern. It has been shown that as signal predictability decreases, so do detection percentages (Buckner and McGrath, 1963). Wherry and Webb (1959) showed that detection performance is most generally affected by the interaction between signal rate and inter-signal interval variability. However, Wilkinson (1960) provided data which seems to indicate that this is not necessarily the case. Employing a signal rate of thirty-two per hour, it was found that subjects performing in a paced condition did not perform significantly better than those monitoring in an unpaced treatment group. These results seem to indicate that intra-organismic arousal is more critical than the pattern of environmental stimulation in maintaining optimal performance.

The inter-signal interval has been made the primary focal point for theoretical speculations concerning the subject's probability of correctly detecting signals as time-on-task progresses. Baker (1958) hypothesized that

subjects' attention drops immediately after a detection of a signal, gradually increases according to the subjective expectancy of the mean inter-signal interval, then gradually decreases. Subsequent research has supported this "expectancy hypothesis" in some cases (Baker, 1962; Hardesty and Bevan, 1965; McFarland and Halcomb, 1970) and refuted it in others (McCormack, 1960; Boulter and Adams, 1963). Baker (1962), for example, found that detection probabilities increased as a function of the signal occurring around a temporal interval which was equivalent to the mean of the preceding inter-signal intervals. The results support the expectancy hypothesis and are contrasted by the findings of Boulter and Adams (1963) who reported no reliable differences in response latencies as a function of increased temporal uncertainty of signal occurrence.

Correlates of monitoring performance have been shown to vary as a function of several variables related to the task. Longer monitoring sessions usually produce lower overall detection percentages than shorter tasks (Buckner and McGrath, 1963) though the shape of the decrement function remains much the same. Again, there appears to be other factors which affect the extent to which the duration of the task influences monitoring performance. One of these factors concerns a priori expectancies of subjects regarding the duration and complexity of the task. These expectancies have been attributed major impetus in increasing correct detections toward the end of the monitoring

session. This "end-spurt" effect is a common occurrence when subjects are aware of the length of the task and have access to temporal feedback throughout the vigil (Bergum and Lehr, 1963) although the effect has been shown to obtain when subjects were not provided with this feedback (Childs and Halcomb, 1972).

With the exception of one study by Buckner et al (1960), there has been no evidence to indicate that subjects performance increases across monitoring sessions. Baker, Sipowicz, and Ware (1961) concluded that subjects monitoring a visual display over a 5-day period which included 15 monitoring sessions exhibited no significant improvement in detection percentages.

Imposition of rest periods of short duration (Bergum and Lehr, 1963; Bevan, Avant, and Lankford, 1967), of environmental stimulation associated with ambient temperature fluctuations (Mackworth, 1950; Teichner, 1966), and of variations in noise types, intensities, and frequencies (Broadbent, 1953; 1954; Jerison, 1957; McGrath, 1962; Kirk and Hecht, 1963; Broadbent and Gregory, 1965; Mirabella and Goldstein, 1967; McCann, 1969; Harris, 1972; Warner and Heimstra, 1972) have all shown to be significantly related to monitoring performance. Rest periods have generally enhanced performance while departures from normal room temperature have typically been disruptive to optimal signal detection performance. Colquhoun and Goldman (1972) recently reported that increasing subjects' body

temperatures via physical exertion increased their confidence levels with regard to accuracy of signal detections although paradoxically, detection percentages did not change and false alarms increased. This represents a change in the tendency for subjects to report signals -- an increase which corresponds to an increment in beta in signal detection theory.

Organismic Factors

Because the success of any monitoring system ultimately depends upon long-term attentional characteristics of individuals within that system, there has been a continuing interest in attempting to ascertain and isolate specific factors related to the subject population (Solandt and Partridge, 1946; Mackworth, 1950; Holland, 1958; Buckner et al, 1960; Waag, 1971). This "individual difference" approach has produced some fairly consistent results although the bulk of investigatory findings has failed to provide highly reliable predictors of what constitutes a "good monitor". Mackworth (1950) found that consistently efficient monitors (or detectors, as he called them) could be differentiated from consistently inefficient monitors (non-detectors) on the basis of performance across time. Again, the basic vigilance decrement was similar for both groups although the former group detected significantly more signals overall than did the latter group.

The age variable has shown to be related to vigilance performance in only a few instances. For example, Tune

(1966) found that older subjects made significantly more false alarms than younger subjects, though no more omissions. In contrast, Craik (1965; 1966; 1967) found positive correlations between age and beta, which points to response conservatism for older subjects. Davies and Griew (1965) concluded that age is not a significant factor in the consideration of optimal vigilance performance. This conclusion was advanced on the basis of a literature review of previous studies which had all produced null effects (York, 1962; Griew and Davies, 1962; Davies and Griew, 1963; Thompson, Opton, and Cohen, 1963; Neal and Pearson, 1966). However, Surwillo and Quilter (1964) found that mean detection percentages for subjects under sixty years of age were significantly higher than those sixty years or over. Age differences, when found, have been attributed to memory deficits in older subjects (Davies and Tune, 1969).

Deese (1955), in a discussion of problems associated with the formulation of a theory of vigilance, was one of the first to suggest that personality factors might be associated with optimal performance. The most general findings have related to performance of subjects classified as introverts (self-reinforcing) or extraverts (externally reinforced). Introverts have been shown to perform better than extraverts in most cases (Eysenck, 1955; Bakan, 1959; Broadbent, 1963; Hogan, 1966). Eysenck (1955) believes this is because extraverts generate reactive inhibition faster and dissipate it slower than introverts. Tune

(1966) found that correct detection percentages were not significantly different for the two personality classifications, but that introverts committed significantly less false alarms than extraverts. This observation is consistent with predictions of response styles as they relate to both groups. Findings with regard to neuroticism scores have been negative (Bakan, 1959; Colquhoun, 1959; 1962; Wilkinson, 1961).

High self-control scores on the California Personality Inventory (Halcomb and Kirk, 1965) and low Factor A scores (indicating internal orientation) on the 16PF (Waag, 1971) have both related positively to correct detections. Eysenck (1967) has indicated that some personality correlates are curvilinearly (and not linearly) related to attentional deficits. Because linear correlational techniques have traditionally been used in conjunction with vigilance-personality relationships, it is possible that these correlations may have been inaccurately low. Sanders (1973) combined measures of need achievement, field dependence-independence, and locus of control in an attempt to predict vigilance performance. Although need achievement related positively to several performance measures, the latter two measures did not approximate effective predictors.

Drug effects associated with monitoring performance have been well-documented. Mackworth (1950) reported a reduced across-time decrement when subjects were

administered 10 mg. of benzedrine one hour prior to task onset. Response latencies were also shorter than for controls. Employment of amphetamines (a class of stimulants to which benzedrine belongs) has been generally consistent with this finding (Solandt and Partridge, 1946; Loeb, Hawkes, Evans, and Alluisi, 1965; Talland and Quarton, 1966). However, Jane Mackworth (1965) used a similar doseage and reported no effects either on correct detections or d' . Smaller doses of 5 mg. (Neal and Pearson, 1966) and placebo administrations (Mackworth, 1950) have produced no effects. Tarriere, Hartemann, and Niarfiex (1966) found that when smokers were allowed to smoke during the task, their performance was significantly better than when smoking was not permitted (the decrement was less pronounced across time).

In general, depressant drugs impair performance (Neal and Pearson, 1966). Colquhoun (1962) found that alcohol ingestion significantly decreased performance and Bakan (1960) reported significant reductions in detection rates with pre-task doses of meprobamate. Chlorpromazine impaired performance on a paced vigilance task (Kornetsky and Orzack, 1964) and produced lower overall detection percentages in two subsequent studies (Rappaport, 1966; Kopell and Wittner, 1968). Rappaport and Hopkins (1971) more recently reported contrasting results (i.e. no appreciable decrement with the drug) presumably because a cuing light was presented prior to each signal.

Theories of Attention and Vigilance

From among the deluge of potential stimuli the human organism can attend only to a very few at any given moment. Limited as to the amount of information he can process, the observer is forced to perceive or to respond to less than the total array. Work on attention centers on describing the manner in which the organism responds to and maintains that particular response.

One of the most influential descriptions of attention was developed by Broadbent (1958). In his model he assumed that when several stimuli impinge on the senses, each evokes an initial response. Experimental observations indicate that the observer's capacity for processing stimuli from the environment is limited. At some point in the perceptual process, then, some of the stimuli must be selected for further processing and some disregarded. Broadbent solved this problem by assuming the existence of a selective filter that eliminates the irrelevant stimuli. Such a filter allows only as much information from the environment to pass on for processing as can be handled by the observer.

Treisman (1960) has argued that one cannot speak of a rejection of the irrelevant information, but rather of a weakening or an attenuation. The original processing of relevant and irrelevant input must be the same; however, the relevant message is processed further on the basis of some characteristic of the stimulus.

Deutsch and Deutsch (1963) suggest that all stimuli are processed perceptually (i.e., enter short-term storage) but that selection occurs only as the observer responds to the stimuli. Selective attention, then, depends on generated response rather than on a filtering of incoming stimuli.

Attentional theories of vigilance emphasize the process of entry into the nervous system and account for omission errors and for the vigilance decrement in terms of failures of an attentional mechanism.

Broadbent's filter theory was devised to explain data not only from vigilance experiments but from several other situations, including, for example, dichotic listening, extinction procedures and the effects of noise on performance. Because the central nervous system is limited in its capacity to handle stimulus information and hence the stimuli present in the environment cannot all be analysed simultaneously, it follows that competing stimuli must be selected for analysis sequentially. Broadbent (1958) suggested that the major factors determining the selection of a particular stimulus for analysis were intensity, biological importance and novelty.

Filter theory has been applied to vigilance performance in the following way. The repeated presentation of an unchanging stimulus series encourages the filter to select fresh information from another sensory channel, although at the same time instructions will tend to keep

the filter linked to sensory channels which are receiving input from the task.

Deese (1955) assumed that an observer's general expectancy about a vigilance task is determined by the course of stimulus events during his previous experience with the task. The level of expectancy established in this way determines in turn the observer's level of vigilance and hence his level of signal detection. So long as the average frequency of signal occurrence remains low, the expectancy of observing a signal is low and if the signal frequency is raised, the expectancy of observing a signal also increases. Deese's expectancy hypothesis also takes account of inter-signal intervals, and regards the observer as performing a continuous averaging process on previous inter-signal intervals in order to extrapolate the results and thus predict the occurrence of the next signal in the series.

Mackworth's (1950) inhibition theory of vigilance was much more concerned with explaining vigilance decrement than the overall level of performance. Mackworth considered the vigilance decrement as analogous to extinction, which is most generally described as a procedure involving the repeated evocation of a non-reinforced response. Since such a procedure leads to the weakening and eventual cessation of the response, an inhibitory construct has been proposed which is roughly analogous to fatigue. Inhibition is considered to accumulate with

each non-reinforced occurrence of a response, and when this accumulation becomes sufficiently great the response no longer occurs.

Mackworth (1950) considered that the reinforcing agent in his vigilance situation was the knowledge-of-results given during the practice period preceding the test session. Since knowledge-of-results was not given during test sessions, except in Clock Test 7 where, in consequence, performance was markedly improved, the partial extinction observed in Mackworth's studies can be considered as originating during the practice period.

Theories of arousal have stressed the importance of environmental or organismic stimulation in detection maintenance across time. For example, some studies (Adams and Boulter, 1960; Adams, Stenson, and Humes, 1961) have provided evidence suggesting that the vigilance decrement could be reduced if post-detection responses were made more complex, while others (Luce, 1964) have failed to report such an effect.

Impetus for the Present Investigation

The present focus within vigilance research is upon factors which relate to the complexity of the monitoring environment. While most contemporary researchers recognize the need for and value of vigilance performance as it relates to attentional problems, they are not willing to accept the traditional simplicity of the isolated

laboratory vigilance task as representative of more complex phenomena in the applied environment. This, of course, was recognized during the last decade (Elliott, 1960; Jerison and Pickett, 1963; Smith and Lucaccini, 1969; Harris, 1969; Chapanis, 1967) and even before (Colquhoun, 1957).

Many of the past criticisms of traditional vigilance research have focused upon two important variables which seem to distinguish monitoring environments in the "real-world" from those in the laboratory. The more obvious distinction relates to the complexity of the task -- i.e. the perceptual and informational load with which the subject is confronted in making a decision regarding signal presence or absence. However, a more recent distinction relates to the response required of the subject after the decision is made regarding signal presence. It is with regard to the variables of signal complexity and response complexity that the proposed study was formulated. The purpose of the present study was to dichotomize signal demands and response demands in hopes of providing some information about elements of "task complexity".

Task Complexity

Kibler (1965) stressed the fact that aerospace monitoring tasks typically include multiple signals or information classes. Smith and Lucaccini (1969), discussing industrial monitoring tasks, point out that the most

demanding task requirements of the industrial inspector are perceptual, i.e. difficult judgments are made regarding the quality of complex mechanical or electronic components. Harris (1969) agrees that "most inspection tasks are typically more complex and more intellectually demanding than the tasks studied in vigilance research".

Conrad (1955), in one of the earliest treatments of task complexity, varied perceptual load by increasing the number of display pointers from four through twelve on a serial search task. Results indicated that attention was apparently distributed strictly according to display demands as errors increased linearly in relation to task complexity.

Adams and Boulter (1964) varied temporal and spatial uncertainty of stimulus source and found that as temporal and spatial uncertainty increased, response latencies also rose. This experiment employed three stimulus sources (displays).

An earlier investigation of task complexity utilizing multiple sources (Jerison and Wallis, 1957) found that subjects who monitored one Mackworth clock exhibited the fundamental decrement in performance across time. However, an experimental group which was required to monitor three clocks (and hence, to time-share) exhibited detection percentages which remained low but stable throughout the two-hour session. These results were supported by Wiener (1964) in his multiple channel research and by Harris

(1966). The latter study produced inverse correlations between inspection efficiency and equipment complexity.

Donald Brown of Sylvania Electronic Systems performed two studies (Brown, 1963; Brown and Fox, 1965) concerned with task complexity and observer redundancy in monitoring performance. Response latencies were significantly greater for subjects who monitored complex displays than for those in simple conditions. The latter study also demonstrated that the number of positive errors (false alarms) was inversely related to task complexity.

Alluisi and Hall (1963) found typical auditory monitoring decrements each day on a four hour per day, four-day task. This occurred in spite of a high level of multiple task activity (both passive and active) and prompted the authors to denounce the activation hypothesis which assumes an increase in arousal with corresponding activity increments.

Gould and Schaffer (1966) employed multi-channel displays for signal based upon simultaneous values of all alphanumeric channels. The number of monitored channels (8, 12, 16, or 24), the range of values per channel (2, 4, or 8), and the number of signals attended (8, 16, or 24) were varied. Performance decreased with an increase in the display change rate. Additionally, detection performance decreased with an increase in number of signals attended although this variable exerted the least effect upon performance.

In an extension of this study (Gould and Schaffer, 1967), an additional factor was examined. Contradictory results relating to essentially the same variables (with the addition of tasks to divide attention) were:

1. divided attention did not lead to a decrease in monitoring, compared to controls.
2. rate of display change had the greatest effect upon performance.
3. untrained Ss detected 80% of the signals even when monitoring up to 12 channels.

Goldstein, Johnston, and Howell (1969) more recently } varied the ratio of relevant to irrelevant stimuli on the display (20:10, 15:15, 10:20) and ratio of relevant to irrelevant signals (40:20, 20:40). Decrement rates were largest in conditions where the proportion of relevant to irrelevant signal changes was smallest. This is consistent with data related to signal confusability and signal-event ambiguity (Buckner and McGrath, 1963).

Hawkes, Meighan, and Alluisi (1964) examined performance efficiency on three watchkeeping tasks as a function of task demand characteristics and several different kinds of secondary tasks. These additional tasks involved mental arithmetic, group coordination and cooperation, and form perception systematically presented during selected portions of the task sequence. Results indicated statistically different watchkeeping performances as a function of task demand level. Efficiency was highest when task demand was low, next most efficient with medium level demand, and least efficient with high level demand.

Complexity (defined as the number of categories of critical signals) had a pronounced negative effect upon auditory detection percentages in a study by Kidd and Micocci (1964). Komaki (1967) more recently demonstrated favorable performance with complex multiple signal-switching than with groups in control conditions. A probable explanatory factor for this data relates to stimulus novelty. The findings were discussed in relation to both filter and arousal theories and seemed to relate to McGrath's (1965) report of increased detectability of easily seen signals when simultaneously requiring the observer to monitor another display of less detectable signals via a different sensory modality. However, these results do not agree with several other investigations which have examined task complexity (Gould and Schaffer, 1966; 1967; Adams and Boulter, 1964; Brown, 1963; Brown and Fox, 1965). Wiener, Pooch, and Steele (1964) found no significant differences between time-shared monitoring and control conditions. However, Tyler and Halcomb (1974) recently produced contrasting results in that detection percentages were significantly better by groups which performed a time-shared auditory-visual monitoring task than by single-modality groups. Bell, Symington, and Bevan (1974) found that although detection latencies were as long for a four-element display as for a twelve-element display, commissive and omissive errors increased significantly with the latter task. Kennedy (1971) varied complexity (one-channel vs.

three-channel) on auditory and visual monitoring tasks. Results indicated that the decrement was less pronounced with the complex (three-channel) auditory and visual groups than with the one-channel auditory group. However, overall detection percentages were substantially higher in the latter condition.

Response Complexity

In most monitoring tasks, determining the appropriate response to a signal entails a decision process much more complex than those required in laboratory vigilance studies. Situations which at one time may have required a simple well-defined response to an unambiguous signal can be and often are, accomplished entirely by machines (Kibler, 1965).

The response required of the examiner is rather more elaborate than it is in the laboratory. Thus, he must either pick up the defective article and place it aside, sort the object in some way, or mark the defective part of the large article with chalk or other similar material. He may also be required to enter his observations on a worksheet. If the object is of any size or complexity he may have to manipulate it so that all parts of it are examined (Colquhoun, 1964).

Although many investigators have recognized the importance of task complexity and its influence upon sustained performance, this is not true of the variable of response complexity. As was mentioned earlier, response complexity differs from task complexity in that it is concerned with the manipulative characteristics of the subject following signal detection, while the latter variable applies more to the perceptual processing capability during task execution.

Monty (1962) investigated the effects of response complexity and signal rate upon a simple one hour visual vigilance task. A deflection of a db. meter pointer from the 9 o'clock position to the 12 o'clock position constituted events. Aperiodic deflections exceeding the 12 o'clock position constituted signals. Four conditions and two signal rates were employed. Condition S (simple) consisted of a response button mounted beneath the db. meter. The subject's response merely consisted of pressing this button when a signal was detected. Condition A consisted of the above-mentioned response button plus a patchboard mounted on the response panel. This board consisted of six segments, each segment containing a number of sockets. Subjects' task, in addition to pressing the response button when a signal was detected, was to unplug a cord from one segment and plug it into the following segment. Condition B was similar to Condition A except that each segment contained an indicator lamp. When subject pressed the response button, a stepper was activated which caused one of the lamps to light showing subject into which segment to plug the cord. Condition C was the same as Condition B except buttons on the response panel were substituted for the cords and sockets. Subjects' task was to press the response button under the meter and then to press a button in whichever segment the lamp was lighted.

Condition S was compared separately with each of the other conditions. Performance under Conditions A and C

were significantly better than Condition S in terms of detection percentage over the one hour task. Condition B, although non-significant, showed trends toward better performance than Condition S.

Montague, Webber, and Adams (1965) employed two response conditions (simple and complex) on a complex task lasting 18 hours with a 10-minute break every three hours to eat and/or go to the restroom. Subjects were 60 male undergraduate students who were paid for their participation.

The display unit for each subject consisted of three rows of four small digital display boxes arrayed one row above the other. Each row contained a standard reference number -- 40, 50, and 60 from top to bottom respectively. A change in the reference number of one box in any row was a signal. Only one change occurred at a time.

Subjects sat in chairs equipped with control switches on the arms intended to fix the position of their hands and to control the extent of arm-hand movement which is a known variable for reaction time. When subject detected a signal, he used his preferred hand, and pressed the detection button centered in front of him 18 inches from the hand position on the arm rest.

Performance was measured in terms of errors of omission, detection latencies, and motor movement latencies (MML). Detection latency provides a measure of visual-perceptual detection time; MML provides a measure

of motor transit speed analogous to simple reaction time.

In the simple (detection) condition, subject merely had to press the detection button as quickly as possible upon observing a signal. In the complex (evaluation) condition, subject indicated the detection in the same way and, in addition, performed an arithmetic computation with respect to numbers on the display. The complex condition more specifically required subject upon pressing the detection button to add the normal value of the box to the changed value, divide the sum by four, and indicate the answer if it was a whole number by pressing one of the buttons in the row above the detection button. The buttons were labeled with possible answers for this purpose and one button was provided as a response when the answer was not a whole number.

Results showed that no significant effects on performance were obtained by employing the complex response condition (except in MML).

These studies (Monty, 1962; Montague, Webber, and Adams, 1965) employed different types of response complexities and produced contrasting results.

However, it would appear that in the latter study, null effects resulted from the extreme duration of the vigil (18 hours) and from increased perceptual and processing demands which influenced the complexity of the task rather than the complexity of the response. A

subsequent study by Childs and Halcomb (1972) confirmed Monty's (1962) results. However, Luce (1964) incorporated different conditions of response complexity and found no appreciable difference in detection performance as a function of more complex response requirements.

A more extensive review indicates some methodological contradictions. Studies which have purported to examine response parameters have concluded that when evaluative decisions were made concerning display changes, no decrement occurred (Adams and Boulter, 1960; Adams, Stenson, and Humes, 1961). These evaluative decisions were produced by increased task demands, not response demands.

An excellent example of recent task-response confusion is taken from a study concerned with properties of the monitoring situation:

Increasing the number of response alternatives represents a complication of the subject's task (Bell, Symington, and Bevan, 1974).

Some vigilance investigators have employed response and signal variables as if these were the same behavioral designations of task complexity. Because the human monitor's actual responses are often dictated by perceptual demands which are inherent in the task, this descriptive error is somewhat logically consistent. However, empirical orientation suggests that the two variables be experimentally dichotomized so that monitoring complexity can be delineated regarding signal vs. response considerations.

As with signal variables, response complexity has produced contradictory evidence. However, much of the confusion appears to stem from the failure to properly define and manipulate signal considerations relative to response considerations. A major purpose of this study was to delineate signal vs. response variables within the task so that main effects and interactions could be examined.

Signal Specification

Colquhoun (1964) emphasized that the detection of a fault in an industrial product is largely dependent upon the definition of fault (i.e. signal). The complexity of faultiness, in many products, according to Colquhoun, is such as to defy analysis. The well-taken point here seems to relate to the fact that in many (if not most) applied monitoring tasks, signals are not well-defined stimuli. In fact, many environments include detection of signals which represent vague or ambiguous subsets of larger non-signal populations. Subjects are often not aware of exactly what "signal" they are attempting to detect. They are merely aware that some discrepancy has arisen between the past and present state of affairs.

Although signal parameters have been extensively studied (Deese, 1955; Adams, 1956; Bowen and Woodhead, 1956; Baker, 1958; Jenkins, 1958; Garvey, Taylor, and Newlin, 1959; Kappauf and Powe, 1959; Wherry and Webb, 1959; Colquhoun, 1961; Baker, Ware, and Sipowicz, 1962; McDonald

and Burns, 1964; Wiener, 1964; Davenport, 1968), there appears to be no study to date of the effects of signal specification upon complex monitoring performance. Previous studies have specified signal characteristics to subjects even when heterogeneous signals were employed. Thus, for example, subjects were instructed to respond to three successive odd digits (Bakan, 1959; Davies and Griew, 1963; Halcomb, McFarland, and Denny, 1971), interruptions of a continuous light source (Baker, Ware, and Sipowicz, 1962), additions and deletions of alphanumeric stimuli (Johnston, Howell, and Goldstein, 1966), double movements of the Mackworth clock pointer (Mackworth, 1964; Surwillo and Quilter, 1964), or changes in tone frequencies or intensities (Davenport, 1968; Baker, Ware, and Sipowicz, 1962).

Belt (1971) utilized an inspection task which included heterogeneous signal characteristics (ball bearings containing the letters A, D, H, or N) and heterogeneous non-signal events. However, Belt's (1971) investigation included specific information concerning signal parameters (A, D, H, or N).

A more recent treatment of signal conditions focused upon complex monitoring of multiple television screens containing various videotaped recordings of prison scenes (Tickner, Poulton, Copeman, and Simmonds, 1972). The screens exhibited occasional movements lasting two to forty seconds. Subjects responded whenever "suspicious

incidents" occurred. More of these incidents were missed when they were brief and when they were scattered over 24 screens rather than 16 screens. This study apparently represents the sole investigation of unspecified signals. A problem associated with the ambiguity in definition of "suspicious incidents" is immediately obvious. An attempt to overcome this problem was made in the proposed study.

Statement of the Problem

Although a few studies have provided discrepant results (Alluisi and Hall, 1963; Gould and Schaffer, 1967; Wiener, Pooch, and Steele, 1964; Komaki, 1967), the most general finding with regard to task complexity in monitoring performance is that either pronounced decrements occur relative to simpler tasks (Conrad, 1955; Adams and Boulter, 1964; Brown, 1963; Brown and Fox, 1965; Gould and Schaffer, 1966; Goldstein, Johnston, and Howell, 1969; Hawkes, Meighan, and Alluisi, 1964; Kidd and Micocci, 1964; Bell, Symington, and Bevan, 1974) or decrements are minimal or absent but overall performance is substantially reduced, (Jerison and Wallis, 1957; Wiener, 1964; Harris, 1966; Kennedy, 1971).

Response complexity as an independent variable has received minimal treatment in the vigilance literature. Where this variable has been utilized, there has often been a tendency to contaminate complex response conditions with increased perceptual encoding tasks thus preventing straightforward interpretation of results. Two studies

(Monty, 1962; Childs and Halcomb, 1972) have taken particular care to isolate response complexity as a primary variable and both have reported superior detection performance with more complex responses. No research has been directed toward variation of signal vs. response requirements which have been factorially combined.

Signal specification has been traditionally employed in tasks of monitoring efficiency. Only one study employed signals which remained undefined throughout the task (Tickner, Poulton, Copeman, and Simmonds, 1972) and was not primarily concerned with manipulation of this variable as no control conditions were provided. More extensive treatment needs to be devoted to this very critical variable because many applied monitoring environments include tasks which employ undefined signal conditions. Quality control inspection and flight navigation are excellent examples. Here, the inspector or operator must be aware of significant differences (signals) between past and present events. Very often these differences remain elements in a subset of possible discrepancies and hence, are defined only in relation to non-signal conditions.

A primary purpose of this study related to signal specification and its interactive properties with signal and response complexity. It was hypothesized that conditions in which signals remained unspecified would exhibit lower overall detection performance across time; that complex signals would deteriorate performance relative to

simple signals, and that inverse effects would occur with complex responses in relation to simple responses.

CHAPTER II

METHOD

Subjects and Experimental Design

Sixty-four college students (32 men) drawn from undergraduate psychology classes served as volunteer subjects. The mean age of subjects was 20.27 years. Subjects were randomly assigned to one of eight treatment groups comprising a split-plot factorial (SPF 2, 2, 2.5) analysis of variance design (Kirk, 1968) with the restriction that each cell of the design contained an equal number of males and females. Three primary variables -- signal complexity (A), response complexity (B), and signal specification (C) -- were examined. These between-measures were combined with five successive 10-minute intervals for time (within-measures) as shown in Table 1.

Subjects were required to remove watches in order to minimize end-spurt effect (Bergum and Lehr, 1963; Childs and Halcomb, 1972). Although no formal tests of auditory sensitivity were employed, a 5-minute practice session served as a screening procedure for subjects with possible auditory impairments. No such subjects were found.

Task, Apparatus, and Procedure

The auditory task consisted of a 50-minute taped series of randomly presented 2-digit numbers ranging from 19 to 36

TABLE 1
DESCRIPTION OF VARIABLES

Between Measures	
A - Signal Complexity	
a ₁ - simple signal	
a ₂ - complex signal	
B - Response Complexity	
b ₁ - simple response	
b ₂ - complex response	
C - Signal Specification	
c ₁ - signal specified	
c ₂ - signal unspecified	
Within Measures	
D - Time	
d ₁ - 1st 10 minutes	
d ₂ - 2nd 10 minutes	
d ₃ - 3rd 10 minutes	
d ₄ - 4th 10 minutes	
d ₅ - 5th 10 minutes	

inclusive. These numbers comprised non-signal events as shown in Table 2. Event schedule remained constant across conditions. Signals were randomly selected from the signal subset in Table 2 and are underlined. Specifically, signals were the number '7' (simple signal condition), or any of the numbers '2', '4', '7', '8', '11', '14', or '18' (complex signal condition). Thus, signal complexity was defined by the number of possible signals monitored (one signal vs. any of the seven signals).

TABLE 2
SIGNALS AND NON-SIGNAL EVENTS

Signal Subset (signals underlined)					
1	<u>2</u>	3	<u>4</u>	5	6
<u>7</u>	<u>8</u>	9	10	<u>11</u>	12
13	<u>14</u>	15	16	17	<u>18</u>
Non-Signal Events (randomly presented)					
19	20	21	22	23	24
25	26	27	28	29	30
31	32	33	34	35	36

These signals were either specified in the instructions ("respond when you hear the number 7", for the simple signal condition; "respond when you hear 2, 4, 7, 8, 11, 14, or 18", for the complex signal condition) or they were left unspecified ("respond when you hear anything other than 19 through 36 inclusive").

In order that signal complexity could be factorially combined with signal specification, signals and non-signals remained constant across conditions except with regard to number of signals monitored.

Subjects were instructed either to simply press a button activating a buzzer upon signal detection (simple response condition) or to perform the following response sequence upon signal detection (complex response

condition):

1. press response button activating buzzer.
2. monitor electric counter for number currently registered.
3. write this number on sheet provided.
4. continue listening for signal.

Subjects received auditory events via a Craig Model 2603 cassette tape recorder and were comfortably seated at a table located in a room approximately 10' x 12' in size. The table included a 110 volt buzzer mounted in a 8" x 6" x 4" gray metal box, a response button mounted in a 4" x 2" x 1.5" gray metal box (wired to the buzzer), the tape recorder, information printed on 3" x 5" index cards concerning signals and response requirements, an electric counter (Lafayette Instruments), and paper and pencil (for use by complex response groups). The experimenter was seated approximately 8 feet behind subjects and recorded responses as they occurred. Standardized taped instruction, were presented to each subject prior to the 5-minute pre-task practice session. Subjects performed the task individually.

Events were presented at the rate of one every two seconds yielding a total of 1500 events for the 50-minute task. Fifty signals were randomly dispersed throughout the task and occurred at the mean rate of one per minute with the restriction that no inter-signal interval was greater than 2 minutes. Each 10-minute time block included a total of ten randomly dispersed signals. Specifically, signals replaced event numbers 30, 75, 86, 103,

122, 144, 204, 238, 263, 279, 315, 366, 373, 418, 476, 501, 537, 551, 571, 603, 615, 621, 675, 723, 739, 758, 800, 816, 876, 893, 915, 938, 975, 992, 1014, 1051, 1062, 1119, 1138, 1173, 1215, 1219, 1264, 1280, 1301, 1333, 1368, 1386, 1445, 1468, and 1491. This yields a signal-to-event ratio of 1/30. Signals for complex signal conditions were randomly assigned to the above event numbers. Subjects were instructed to respond to signals within 2 seconds following detection. All responses which occurred outside this interval were recorded as false alarms.

Dependent Variables

Dependent variables were correct detection percentage (converted from number of signals detected during each of the five 10-minute monitoring sessions), false alarm commission, and number of total errors (omissions + false alarms).

CHAPTER III.

RESULTS

The data were analyzed with respect to three measures -- correct detections, false alarms, and total errors (omissions + false alarms). No transformations were performed on the data due to a non-significant $F_{\max}$ test (Kirk, 1968) for homogeneity of variance. This test was applied to all main effects and interactions for all three measures and resulted in assumption of homogeneity of variance. Power was computed for all groups (Cohen, 1970) and ranged from .76 to .99.

Detections

Correct detection percentages were derived by dividing the number of signals presented during each of the 10-minute time blocks into the number of signals detected by subjects. Treatment means and standard deviations for this measure are presented in Table 3. Figure 1 presents detection percentages for combined groups as a function of time-on-task. A moderate decrement over time was obtained. The split plot factorial analysis of variance for detections is presented in Table 4. Significant differences ($p < .01$) were obtained for the variables of signal complexity and signal specification with reliably

TABLE 3
TREATMENT MEANS AND STANDARD DEVIATIONS
(CORRECT DETECTION PERCENTAGE)

C O N D I T I O N S			Mean %	Standard Deviation
Signal Complexity	Response Complexity	Signal Specification		
simple	simple	specified	92.50	0.70
simple	complex	specified	95.75	0.59
complex	simple	specified	85.75	0.90
complex	complex	specified	86.75	0.92
simple	simple	unspecified	89.50	0.90
simple	complex	unspecified	92.00	0.82
complex	simple	unspecified	82.50	1.28
complex	complex	unspecified	78.75	0.97

Figure 1. Mean Correct Detections as a Function of Time-on-Task (Combined Groups)

TABLE 4
ANALYSIS OF VARIANCE: PER
CENT CORRECT DETECTIONS

Source	SS	df	MS	F
A - Signal Complexity	64.799	1	64.799	33.231**
B - Response Complexity	0.450	1	0.450	0.231
AB	3.613	1	3.613	1.853
C - Signal Specification	16.210	1	16.210	8.308**
AC	1.013	1	1.013	0.519
BC	1.513	1	1.513	0.776
ABC	0.800	1	0.800	0.410
Ss within groups	109.200	56	1.950	
D - Time	22.606	4	5.652	11.582**
AD	7.981	4	1.995	4.089**
BD	1.019	4	0.255	0.522
ABD	1.169	4	0.292	0.599
CD	0.706	4	0.177	0.362
ACD	1.456	4	0.364	0.746
BCD	1.144	4	0.286	0.586
ABCD	1.419	4	0.355	0.727
D X Ss within groups	109.299	224	0.488	
TOTAL	344.387	319	1.080	

*p < .05

**p < .01

greater percentages obtained by groups monitoring simple and specified signals. A significant effect ($p < .01$) also occurred with respect to time-on-task. Tukey's HSD procedure (Kirk, 1968) was employed to localize differences within the five levels of time. This procedure revealed that significant differences ($p < .01$) in detection percentages were obtained between the first and fourth, the first and fifth, the second and fourth, and the second and fifth 10-minute time blocks.

A significant ($p < .01$) Signal Complexity X Time-on-Task interaction resulted in a simple main effects analysis (Kirk, 1968) to determine effect sites within variables. Results of this test are shown in Table 5 and it can be observed that the effect was due to rather pronounced differences between simple and complex signals at each level of time, and to the relatively greater decrement by complex signal groups as compared to simple signal groups across time. These effects are apparent in Figure 2 which exhibits detection percentages for signal complexity.

Figure 3 presents detection curves for specified vs. unspecified signal conditions. Although the rate of decrement is somewhat consistent across both conditions, groups monitoring with specified signals produced reliably ($p < .01$) greater performance (mean percentage detected = 90.19) than did groups monitoring unspecified signals (mean percentage detected = 85.69).

TABLE 5

SIMPLE MAIN EFFECTS ANALYSIS OF VARIANCE FOR PER
CENT CORRECT DETECTIONS - SIGNAL COMPLEXITY(A) X TIME(D)

Source	SS	df	MS	F
Between Subjects				
Between A at d ₁	5.66	1	5.66	8.08**
Between A at d ₂	6.20	1	6.20	8.86**
Between A at d ₃	9.80	1	9.80	14.00**
Between A at d ₄	18.10	1	18.10	25.86**
Between A at d ₅	33.00	1	33.00	47.14**
Within Cell	218.50	310	0.70	
Within Subjects				
Between D at a ₁	2.50	4	0.63	1.29
Between D at a ₂	28.10	4	7.03	14.35**
AD	7.98	4	1.99	4.06*
D X Ss within groups	109.30	224	0.49	
TOTAL	344.39	319	1.08	

*p < .05

**p < .01

Figure 2. Mean Correct Detections for Signal Complexity as a Function of Time-on-Task

Figure 3. Mean Correct Detections for Signal Specification as a Function of Time-on-Task

It should be pointed out that the two groups monitoring complex, unspecified signals showed substantial increments in performance during the second 10-minute block. An inspection of Figure 4 (response complexity variable excluded) reveals that this increment is primarily the result of signal specification rather than complexity.

False Alarms

The analysis of variance summary for false alarms is shown in Table 6. As with correct detections, significant main effects occurred with respect to signal complexity and signal specification ($p < .05$) and to time-on-task ($p < .01$). Figure 5 reveals the decrease in false alarm commission (all groups) across time. This result is very typical of tasks of monitoring ability (Davies and Tune, 1969) and, coupled with a decrease in correct detections, represents a general decline in response motivation in subjects. Table 7 presents means and standard deviations for number of false alarms committed by the three conditions. As with correct detection measures, groups monitoring complex, unspecified signals committed a significantly greater number of errors ($p < .05$) than did groups monitoring simple and specified signals. Figure 6 shows mean false alarm rates over time for simple vs. complex signal groups. The more stable rate of the simple signal condition is readily apparent. A virtually identical non-significant function occurred with respect to specified and unspecified signals

Figure 4. Mean Correct Detections for Signal Complexity and Signal Specification as a Function of Time-on-Task

TABLE 6

ANALYSIS OF VARIANCE: FALSE ALARMS

Source	SS	df	MS	F
A - Signal Complexity	2.113	1	2.113	4.240*
B - Response Complexity	0.200	1	0.200	0.401
AB	0.001	1	0.001	0.002
C - Signal Specification	3.200	1	3.200	6.423*
AC	0.450	1	4.500	0.903
BC	0.013	1	0.013	0.025
ABC	0.313	1	0.313	0.627
Ss within groups	27.899	56	0.499	
D - Time	11.763	4	2.941	9.780**
AD	3.138	4	0.784	2.609*
BD	0.175	4	0.044	0.146
ABD	0.875	4	0.219	0.728
CD	4.050	4	1.013	3.367*
ACD	0.800	4	0.200	0.665
BCD	0.238	4	0.059	0.197
ABCD	0.813	4	0.203	0.676
D X Ss within groups	67.350	224	0.301	
TOTAL	123.388	319	0.387	

*p < .05

**p < .01

Figure 5. Mean False Alarms as a Function of Time-on-Task (Combined Groups)

TABLE 7
TREATMENT FALSE ALARMS AND STANDARD DEVIATIONS

C O N D I T I O N S			Absolute Number of False Alarms	Standard Deviation
Signal Complexity	Response Complexity	Signal Specification		
simple	simple	specified	15	0.54
simple	complex	specified	10	0.44
complex	simple	specified	16	0.55
complex	complex	specified	16	0.59
simple	simple	unspecified	17	0.64
simple	complex	unspecified	18	0.64
complex	simple	unspecified	29	0.78
complex	complex	unspecified	25	0.67

Figure 6. Mean False Alarms for Signal Complexity as a Function of Time-on-Task

with the former treatment level exhibiting greater stability (less decrement across time) than the latter level.

Tests of simple main effects (Kirk, 1968) were performed for significant ($p < .05$) Signal Complexity X Time and Signal Specification X Time interactions. Summary data for these tests are presented in Table 8 and Table 9 respectively.

For Signal Complexity X Time (Table 8), significant differences occurred between simple and complex signal conditions during the first 10 minutes ($p < .05$) on task. Additionally, there was a statistically reliable decline in false alarm commission for both groups over time (simple signal, $p < .05$; complex signal, $p < .01$).

With the Signal Specification X Time interaction (Table 9), no significant decline in false alarms occurred within specified signal groups across time. Otherwise, these effects were similar to Signal Complexity X Time. The most prominent difference between specified and unspecified conditions occurred during the first 10 minutes of the task ($p < .01$). A significant ($p < .01$) decline in false alarm rate occurred as a function of time with unspecified signal groups.

Tukey's HSD procedure (Kirk, 1968) was applied due to the significant ($p < .01$) decrease in false alarm rate for combined groups across time. This resulted in significant differences beyond the .01 level between the first and third, first and fourth, first and fifth, and

TABLE 8

SIMPLE MAIN EFFECTS ANALYSIS OF VARIANCE FOR
FALSE ALARMS - SIGNAL COMPLEXITY(A) X TIME(D)

Source	SS	df	MS	F
Between Subjects				
Between A at d ₁	2.20	1	2.20	7.09**
Between A at d ₂	0.39	1	0.39	1.26
Between A at d ₃	1.27	1	1.27	4.10*
Between A at d ₄	0.14	1	0.14	0.45
Between A at d ₅	0.40	1	0.40	1.29
Within Cell	95.25	310	0.31	
Within Subjects				
Between D at a ₁	3.17	4	0.79	2.63*
Between D at a ₂	12.58	4	3.15	10.50**
AD	3.14	4	0.78	2.61*
D X Ss within groups	67.35	224	0.30	
TOTAL	123.39	319	0.39	

*p < .05

**p < .01

TABLE 9
SIMPLE MAIN EFFECTS ANALYSIS OF VARIANCE FOR
FALSE ALARMS - SIGNAL SPECIFICATION(C) X TIME(D)

Source	SS	df	MS	F
Between Subjects				
Between C at d ₁	5.13	1	5.13	16.55**
Between C at d ₂	0.77	1	0.77	2.48
Between C at d ₃	1.26	1	1.26	4.06*
Between C at d ₄	0.02	1	0.02	0.06
Between C at d ₅	0.14	1	0.14	0.45
Within Cell	95.25	310	0.31	
Within Subjects				
Between D at c ₁	1.26	4	0.32	1.07
Between D at c ₂	14.35	4	3.59	11.97**
CD	4.05	4	1.01	3.37*
D X Ss within groups	67.35	224	0.30	
TOTAL	123.39	319	0.39	

*p < .05
**p < .01

second and fifth 10-minute time blocks. An inspection of Figure 6 shows that false alarms somewhat stabilized after the initial 30 minutes of monitoring.

Total Errors

Treatment means and standard deviations for total errors are presented in Table 10. Because this measure represents a composite of the other two measures (misses + false alarms), there is a noticeable relationship between those measures and total errors with respect to analysis of variance results (Table 11).

Significant main effects occurred due to signal complexity and signal specification ($p < .01$). No other main effects or interactions attained statistical significance.

Complex response groups responded correctly to 95% of the post-signal numbers which were registered on the counter at the time of detection. No significant overall time effect occurred and no statistically reliable difference was found among the four complex response groups with respect to correct post-signal responses.

TABLE 10
TREATMENT TOTAL ERRORS (MISSES + FALSE ALARMS)
AND STANDARD DEVIATIONS

C O N D I T I O N S			Absolute Number of Total Errors	Standard Deviation
Signal Complexity	Response Complexity	Signal Specification		
simple	simple	specified	45	0.99
simple	complex	specified	27	0.80
complex	simple	specified	73	1.06
complex	complex	specified	69	0.96
simple	simple	unspecified	59	1.18
simple	complex	unspecified	50	1.10
complex	simple	unspecified	99	1.45
complex	complex	unspecified	110	1.24

TABLE 11
ANALYSIS OF VARIANCE: TOTAL ERRORS

Source	SS	df	MS	F
A - Signal Complexity	90.313	1	90.313	28.892**
B - Response Complexity	1.250	1	1.250	0.400
AB	3.613	1	3.613	1.156
C - Signal Specification	33.800	1	33.800	10.813**
AC	2.813	1	2.813	0.900
BC	1.800	1	1.800	0.576
ABC	0.113	1	0.113	0.036
Ss within groups	175.050	56	3.126	
D - Time	5.988	4	1.497	1.813
AD	2.188	4	0.547	0.662
BD	1.625	4	0.406	0.492
ABD	1.450	4	0.363	0.439
CD	7.700	4	1.925	2.331
ACD	3.126	4	0.781	0.946
BCD	1.013	4	0.253	0.307
ABCD	2.763	4	0.691	0.836
D X Ss within groups	184.950	224	0.826	
TOTAL	519.550	319	1.629	

*p < .05
**p < .01

CHAPTER IV

DISCUSSION

The present investigation provided data which was rather consistent with past studies of monitoring performance. Regarding correct detection percentage, Figure 1 shows the classical decrement in performance over time. There are, however, two important distinctions to be made between the present curve and the more traditional curves of decrement as reviewed by Davies and Tune (1969) and by Buckner and McGrath (1963).

First, the correct detection percentages presented in Figure 1 were higher overall than would normally be expected of tasks which include monitoring "complexity" (i.e., complex and unspecified signals). This might be explained by the fact that the experimenter was present in the room at all times during the task and was, in fact, situated only a short distance behind subjects. Fraser (1953) has shown that presence of experimenter during task execution can enhance performance. An arousal factor provided by a rather noisy response buzzer should also be considered as a possible explanation for overall detection elevations. Another interpretation of the elevated overall detection percentages relates to the auditory

nature of this task. Ware (1961) demonstrated higher within-subject detection probabilities for auditory than for visual tasks. The present study supported these findings and those of Ware, Sipowicz, and Baker (1961) which showed that auditory signal detection started high and remained rather stable across time.

Secondly, there is a slight (non-significant) improvement in performance during the second 10-minute time period relative to the first 10 minutes. Two unspecified signal groups exhibited increments during this period of time. These increments were probably caused by increased task familiarity by subjects in these groups relative to specified signal groups. This familiarity could feasibly have resulted from increased awareness of signal demands relative to the first 10 minutes of monitoring by unspecified signal groups.

A priori hypotheses about treatment groups were largely supported with respect to correct detections. Performance was superior (larger mean percentage detections and less variable) in groups monitoring only one signal (simple signal) as opposed to any of seven different signals (complex signal). Additionally, decrement was steeper across time for the latter conditions. A significant Signal Complexity X Time interaction showed that differences between simple and complex signal groups increased statistically ($p < .01$) as time-on-task progressed. This result is somewhat consistent with expectations derived from past research

(Adams and Boulter, 1964; Brown and Fox, 1965; Gould and Schaffer, 1967; Goldstein, Johnston, and Howell, 1969; Bell, Symington, and Bevan, 1974). It is also consistent with some past theoretical formulations related to information processing capability (Treisman, 1964; Deutsch and Deutsch, 1963). Apparently complex signal groups' monitoring capability decreased in relation to the amount of interference generated by both signals and non-signals over time. A combination of Treisman's (1964) information processing hypothesis and the expectancy theory seem appropriate in explanation of the greater vigilance decrement by complex signal conditions in the present study. According to Treisman (1964), features of incoming messages are analyzed successively by the nervous system, starting with sensory features and proceeding to identification of meaning. Treisman postulated an analytical mechanism that performs a series of tests on incoming messages. Analysis is much simplified for items that are expected to occur. If channels have physical distinctions, then it will be possible to separate one from the others. This is done by attenuating the irrelevant channel. It seems reasonable to suggest that in the present study, an increase in the number of physical distinctions (i.e. signals) to which monitors were attending created problems in the attenuation process. This may have been caused by a breakdown in the expectancy of subjects for upcoming signals. If, for example, subjects in complex signal

groups were not certain that their responses were being made only to signals, this could have disrupted the expectancy process, thus resulting in lower overall detection rates relative to simple conditions.

A further explanation of these results relates to a hypothesis concerned with the pertinence in sensory analysis (Deutsch and Deutsch, 1963). According to this interpretation, all sensory signals excite their stored representation in memory while analysis of previous signals is occurring. This establishes information which is pertinent to the ongoing analysis. The set of most pertinent items excite their representation in memory and are thus available for subsequent processing. Therefore, if subjects assigned some pertinence magnitude to signals, performance in complex signal conditions would be hampered more than in simple treatments. This indeed was the case in this study.

The absence of a significant Signal Complexity X Signal Specification interaction for correct detections proved to be one of the more surprising results. Performance indices were quite consistent for Simple-Specified, Simple-Unspecified, Complex-Specified, and Complex-Unspecified treatment groups. The signal specification variable presumably added a separate dimension of complexity so that the four conditions mentioned above represented four divergent points on a complexity continuum. Again, this finding is somewhat unexpected in view

of the fact that one would hypothesize signal complexity decrements to be dependent upon whether signals were specified or unspecified.

Simple-Specified and Simple-Unspecified conditions remained incongruent across time even after an elevation by the latter group during the second 10-minute time block. This may be explained by the fact that a general search strategy rule was provided for the latter group ("respond when you hear anything other than 19-36 inclusive"). Because it requires a finite amount of time to process this instruction, it could conceivably disrupt performance relative to the simple-specified group, which was fully aware of what to monitor (the number 7).

Additional treatment levels of signal complexity (e.g. 1, 7, 12, or 20 possible signals) would have provided an interesting extension to the present study. This study represented the sole attempt to isolate signal and response variance factorially. Results would support the notion that true variance was contingent upon manipulation of signal (rather than response) parameters.

Because many monitoring environments include conditions which involve undefined signals, a major purpose of the present study was to ascertain the importance of this variable in relation to signal and response complexity in the determination of sustained monitoring efficiency. Results indicated that signal specification is indeed critical for monitoring effectiveness over time. Although

detection decrement occurred in a predictable fashion for both groups across time, unspecified signal groups detected reliably fewer ($p < .01$) signals overall than specified signal groups. Thus these results point to the importance of subject awareness of what specifically is being watched or listened for in the monitoring task.

Significant differences in false alarm commissions occurred between simple and complex signal groups and also between specified and unspecified conditions. Complex signal groups committed a total of 86 false alarms (mean = 2.69 per subject) while simple signal conditions yielded a total of 60 false alarms (mean = 1.88 per subject). Unspecified signal conditions produced a total of 89 false alarms (mean = 2.78 per subject) while specified signal groups accounted for 57 false alarms (mean = 1.78 per subject). This finding is more consistent with past results than the correct detection data. Subjects in unspecified signal conditions responded in a manner which would be expected when undefined stimuli are being monitored. Because signals were defined only in relation to non-signal events, subjects had to "learn" what to monitor and because most false alarms occurred during the first 30 minutes of the task, the interpretation seems extremely plausible.

Rates of false alarm commission decreased markedly over time and within-subject variability remained stable. This decrement is consistent with previous results (Davies

and Tune, 1969). It is interesting to note that of the 64 subjects who participated in this study, 61 (or 95%) committed one or more false alarms during the 50 minute task. This finding is somewhat unusual in view of the fact that many vigilance studies have found that a minority of the total subject population commit a majority of the total number of false alarms. However, Davies and Tune (1969) have pointed out that cognitive tasks often do not exhibit this extreme variability in false alarms as with purely sensory tasks. The present task represents such an example.

Curves for mean false alarm rates across time as a function of simple and complex signal conditions showed pronounced differences. The substantial false alarm decrement in complex groups across time blocks is apparent. This decrement coupled with the relatively stable rates exhibited by simple signal conditions as a function of time resulted in a statistically significant ($p < .05$) Signal Complexity X Time interaction. The greater relative decrement by complex signal conditions may be attributed to within-subject adaptation to task demands. Post-experiment verbal reports by some subjects in complex signal groups may be worthy of note at this point. These reports reflected strong feelings of apprehension and pessimism during practice and initial phases of the task. That is, some subjects felt that seven signals were excessive and that they could not possibly detect them due to the perceived rapidity of event rates (1 event every

2 seconds). However, as the task progressed, subjects apparently discovered that no specific orienting response was required and that given an ability to filter non-signal stimuli (Broadbent, 1958), signals could be readily detected. This interpretation seems to apply more to false alarm rates than to correct detection percentages.

The most pronounced differences in false alarm errors for specified and unspecified signal conditions occurred during the first 10 minutes of monitoring, although, as with the signal complexity variable, differences between specified and unspecified signal conditions also occurred during the third 10-minute time block. No significant change in false alarm rate occurred within specified signal conditions. However, pronounced decrements occurred in unspecified conditions. Again this finding is in line with expectations arising from the anticipated ability to subjects in unspecified conditions to differentiate signals from non-signals as a function of time-on-task. Mackworth's (1950) reinforcement views seem to apply not only to this result but also to differences between complex and simple signal conditions with respect to correct detections. It would seem reasonable to assume that in the latter case, reinforcement would obtain in simple conditions more than in complex conditions because of less response inhibition. That is, if subjects are uncertain about signal characteristics, it is understandably

more difficult to obtain intrinsic reinforcement from responses to "hypothesized signals".

The implications of the present results for the applied monitor is pragmatic and wide-ranging. Information processing demands placed upon the military, industrial, or civilian monitor must be considered in the maintenance and design of displays and in the ultimate appraisal of that monitor's performance. In other words, according to the present results, a quality control inspector should not be expected to perform as efficiently over time when watching for any of seven distinct flaws as when watching for only one flaw in an industrial product or component. These results are consistent with much previous research on task complexity where perceptual load increments have disrupted performance (Conrad, 1955; Adams and Boulter, 1964; Brown, 1963; Brown and Fox, 1965; Gould and Schaffer, 1966; Goldstein, Johnston, and Howell, 1969; Hawkes, Meighan, and Alluisi, 1964; Kidd and Micocci, 1964; Bell, Symington, and Bevan, 1974).

The present results unfortunately lent no new evidence to hypotheses supporting the notion that increasing post-detection response requirements leads to organismic arousal, thus leading to more efficient overall monitoring. Differences between simple response and complex response groups were minimal with regard to all three dependent measures. Two previous studies (Monty, 1962; Childs and Halcomb, 1972) had reported superior detection

performance with more complex responses. These results could have occurred because of environmental influences not present in this study. As mentioned earlier, presence of the experimenter might have negated these influences. However, a more tenable explanation of these results relates to the response buzzer used by both simple and complex response groups. It is not unreasonable to believe that the degree of autonomic arousal produced in both groups was equal due to the intensity of the buzzer. Because the primary purpose of response complexity is to increase organismic arousal via motor movement subsequent to signal detection, this variable may have been negated by unwanted sensory stimulation, i.e. the loud buzzer.

Future research concerned with this variable should deal with the possibilities of increasing the complexity of subjects' response as time-on-task progresses.

Because many applied monitoring environments -- e.g. quality control inspection, flight navigation, and driving an automobile -- include perceptual tasks which employ undefined signal conditions, the applicability of the present results with respect to signal specification is quite apparent. Unspecified signal conditions exhibited consistently lower detection percentages ($p < .01$), higher false alarm rates, ($p < .05$) and a greater number of total errors ($p < .01$) than specified signal conditions.

To apply results to the example of the quality control inspector, once more, one should not expect this individual to perform as efficiently when watching or listening for something which merely represents a discrepancy between past and present states of affairs as when this discrepancy is clearly defined. Consider the plight of the automotive quality control inspector whose task includes many unspecified signal conditions which must be corrected or removed. If these conditions could be transformed so that a subset of the most common problems, flaws, or errors could be specified, the consumer would probably receive a more reliable, less noisy car. Furthermore, these results are consistent with expectations derived from learning theory. The same quality control inspector mentioned above probably learns this subset of most common problems encountered on the assembly line and becomes more proficient in their detection. Thus, evaluations of quality control skills need to take into consideration the fact that an adaptation period may be in order (especially for unspecified, complex condition). The most effective search strategies will probably come about only subsequent to such an adaptation. This process was reflected in the present study. Considerations of signal specification must be stressed in applied monitoring environments in the future.

Implications of the present results for future research relate to:

1. partitioning real-world and laboratory analogs so that the parameters investigated in the laboratory approximate the applied task with respect to signal considerations (complexity, specification etc.).
2. extending signal and response considerations to the study of both short-term and long-term attentional tasks.
3. focusing upon intricate interactions dealing with subjects' response strategies.
4. the inclusion of response complexity as a within-measure for time.

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