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EXPERIMENTAL STUDIES OF HUMAN VIGILANCE
(FINAL REPORT)

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FOREWORD

This is a final report of Contract AF 19(604)-5705 between the Operational Applications Laboratory, Deputy for Technology, Electronic Systems Division, Air Force Systems Command, and the University of Illinois. The research was performed by the staff of the Aviation Psychology Laboratory, Department of Psychology. Dr. Anne W. Story was contract monitor. The principal investigator was Dr. Jack A. Adams. Dr. Judith P. Frankmann was the principal contributor to our review of the vigilance literature. A number of graduate students contributed importantly to many phases of the program. They were: Lawrence R. Boulter, Leonard J. Goldsmith, John M. Humes, Jerome D. Maurath, Nicholas A. Sieveking, and Herbert H. Stenson.

EXPERIMENTAL STUDIES OF HUMAN VIGILANCE

ABSTRACT

A series of experiments was conducted on human vigilance or the characteristics of long-term human attentiveness for the occasional occurrences of signals which are to be detected and reported. Emphasis was given complex visual displays with multiple stimulus sources and alpha-numeric signals of the general class found in semi-automatic man-machine systems. Two major devices were developed for the laboratory study of vigilance, and periods of continuous watching were from 2.5 to 3 hours. Some experiments tested the arousal hypothesis which holds that alertness depends on the level of environmental or internal, response-produced stimulation associated with the task. Other experiments studied the effects of temporal and spatial uncertainty of signal occurrence, the effects of repeated daily sessions, and a method for training vigilance behavior to effect a relatively stable improvement in visual monitoring. A review of the literature was also made.

The results were that (1) vigilance decrement usually occurs in small but reliable amounts within a session but does not increase as a function of number of daily sessions, (2) only response-produced stimuli from simple decision behavior were a source of stimulation that deterred vigilance decrement in accord with the arousal hypothesis, (3) temporal uncertainty was not associated with differential vigilance decrement although spatial uncertainty appeared to be under some circumstances, and (4) feedback about the operator's proficiency after each response was a training method that improved monitoring behavior in a stable manner.

Recommendations for designers and users of man-machine systems were that vigilance decrement was small or absent in the type of complex task that was used and it is probably of little practical consequence for most systems, training for vigilance was a distinct possibility for the training programs of systems, and the monitoring performance of human operators can be improved by designing displays to minimize the role of visual observing responses.

PUBLICATION REVIEW AND APPROVAL

This Technical Documentary Report has been reviewed and is approved.

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1. INTRODUCTION

Vigilance, or long-term attentive behavior, is elicited in tasks that require the prolonged monitoring of a display for the occurrence of a defined signal class. This final report is the summary of a research program that set out to study the characteristics of human attentive behavior for visual tasks of the general class found in contemporary and future semi-automatic man-machine systems The displays used were complex, in the sense of having multiple, spatially-arrayed stimulus sources that emitted persistent alphanumeric characters, in contrast to simple vigilance tasks with brief, transitory signals that are usually studied.

There were occasional observations in the 1930's about vigilance in industrial workers who spent long continuous periods inspecting the monotonous flow of products on an assembly line for defective ones, but the real impetus for vigilance research came in World War II. Surveillance radar was an exciting new weapon for air defense during World War II, and it was observed that radar scope operators sometimes failed to detect and report targets that were clearly in the system and should have been obvious. After thoroughly examining the state of the equipment and being assured that the fault did not lie with hardware elements, it was surmised that the difficulty might lie with the human operator and his waning powers of attention over long periods of continuous watching. This radar vigilance problem was subjected to systematic laboratory experimentation by Lindsley and his associates (1944), using simulated A-scopes as the laboratory task, and they experimentally verified the field observations by showing that decrement in attentiveness, as indexed by an increase in missed signals, can occur over relatively long periods of continuous observation in the task. The failure of this World War II system to achieve its goal was the fault of man, not the machine.

In recent years the rise of semi-automatic man-machine systems has created new and more widespread vigilance tasks. Engineering ingenuity has created automatic control and computing devices that relieve the human operator of many of the requirements for manual responding that existed in earlier systems, and a present-day operator frequently spends a large proportion of his time simply watching a display for an occasional critical signal to command his responses. More often than not these responses are decisions, and their timely occurrence depends upon the vigilance state of the operator.

These new computerized systems have not only changed the proportion of time that a human operator spends in vigilance activities, but also has changed the basic nature of vigilance tasks. The radar surveillance problem of World War II, and the many laboratory experiments on this theme that followed, involved relatively simple tasks with only one stimulus source that emitted faint, transitory signals. In contrast, new semi-automatic systems usually have multiple stimulus sources to be watched and signals that are persistent and remain on several seconds or indefinitely until the operator detects them. Moreover, signals are often symbolic, particularly when they are generated by a digital computer. Most vigilance research that has been conducted so far has used simple tasks that are in the tradition of World War II surveillance radar, and it is unclear that the findings of this research can be freely translated to the more complex tasks of contemporary systems. Whether or not research findings of earlier research will generalize to modern systems is a matter for empirical proof, and a primary purpose of our research program was to examine the characteristics of human vigilanc in complex tasks and ask whether these tasks that are commonplace in modern systems have new implications for monitoring behavior.

The plan of this report is to examine the themes that governed our research. The research activities fell into five categories: review of the literature, determinants of vigilance decrement, effects of spatial and temporal uncertainty, effects of repeated sessions on monitoring behavior, and training for vigilance. Each of these topics will be covered in turn.

2. REVIEW OF THEORIES OF VIGILANCE

Frankmann and Adams (1962) reviewed a relatively large number of vigilance experiments as they related to contemporary theories of vigilance Among the theoretical conceptions reviewed were inhibition views of Mackworth (1961), Broadbent's view of attention, expectancy views that deal with short-term effects and the operator's expectation of when the next signal will occur rather than long-term vigilance, methodology associated with observing responses and where the operator is looking, and arousal views that emphasize stimulation as a determinant of alertness The literature review concluded that theoretical formulations for vigilance are in a primitive state, but that the arousal hypothesis is perhaps the best single explanatory framework at present, even though it has a number of shortcomings. The arousal hypothesis has promise for explaining the many diverse findings of vigilance research, but the hypothesis is loosely structured and does not explicitly define the type and amount of stimulation that can control organismic alertness. Some of our experiments, which will be discussed next, tested certain implications of the arousal hypothesis

3. DETERMINANTS OF VIGILANCE DECREMENT

3 1. The Arousal Hypothesis

The arousal hypothesis is derived primarily from physiological research on the reticular formation of the brain stem (Lindsley, 1957; Malmo, 1959; Rossi and Zanchetti, 1957; Samuels, 1959). An intriguing aspect of this research for vigilance is that the reticular formation appears intimately linked with behavioral alertness. The classical view of sensory brain pathways held that an incoming stimulus travels a sensory pathway to a localized area in the sensory cortex which, in turn, activates an effector system. Research on the reticular formation has established that the classical view is oversimplified by showing that a stimulus concurrently travels a second pathway through the reticular formation and releases a massive, diffuse bombardment over the cortex, in addition to the discharge in a specific sensory area. The firing of the reticular formation is associated with desynchronization of EEG alpha waves and behavioral changes that we customarily associate with attentiveness.

Most of the physiological work on the reticular formation has been done on animals, and signs of behavioral alertness when the reticular formation is stimulated are pricked ears, orienting responses, etc. Without arousal of the reticular and EEG desynchronization, the animal is somnolent and indifferent. A general conclusion is that the arrival of a stimulus at the sensory cortex is not sufficient for responding--there also must be a concurrent firing of the reticular formation and broad, diffuse electrical discharge at the cortex. Thus, the occurrence of an overt response is dependent both on the cue function of a stimulus through its primary sensory pathways and arousal properties through secondary pathways and the reticular formation.

Physiological research has also shown that arousal is not limited to environmental stimuli. In additon, the reticular formation can be fired by cortically-centered stimulation fed back to the reticular, so presumably central mediational and memory activity can be sources of alerting stimuli. Lastly, as an important property of the reticular formation, habituation or adaptation occurs as a function of repeated applications of a stimulus. Sharpless and Jasper (1956), using cat subjects, demonstrated that repeated stimulation reduces firing of the reticular formation and behavioral responsiveness, whereas a change in type or the patterning of stimuli overcomes habituation and restores alertness. Scott (1957) has extended this line of reasoning to cover response decrement in a number of monotonous tasks where stimuli are relatively unchanging

These recent findings on the reticular formation have important implications for vigilance. At the behavioral level, this physiological research can be translated to mean that attentiveness is a function of the amount and type of stimulation in a vigilance task. Attentiveness is high when stimulation is high or varied, and is low when stimulation is inadequate or habituation has set in through prolonged exposure to situational stimuli. Vigilance decrement is explained by habituation as time in the monotonous, unchanging task progress The well-known results that good monitoring performance level is associated with high signal rate (Deese, 1955; Deese and Ormond, 1953; Jenkins, 1958) is consistent with the hypothesis, as is vigilance performance being a positive function of signal intensity (Adams, 1956). An intriguing aspect of the arousal hypothesis, which we put to experimental tests, was that stimuli of a more central, cognitive kind, can also stimulate the reticular formation and induce behavioral alertness. For molar vigilance behavior it implies that memory and decision responses might function to keep attentiveness at a high and stable level. Similarly, proprioceptive stimuli associated with responding can fire the reticular formation and presumably promote alertness. The reticular formation is a rich center of many classes of neural afferents, and a relatively large number of internal and external stimulus classes should be manipulable to keep performance level high. Whether or not these deductions for behavior from physiological findings can be empirically sustained was a question towards which a part of our research program was directed.

3 2. Experimental Tests of the Arousal Hypothesis

Our first major experiment (Adams and Boulter, 1960) was a departure from the traditional vigilance task that was rooted in the characteristics of PPI scopes of World War II. A new vigilance task, called the Vigilance Film Apparatus, was developed that used multiple stimulus sources, symbolic stimuli, and signals that persisted for 20 seconds before being withdrawn. The task was a simulated air defense situation, where each symbol represented a moving aircraft, and the subject's task was to detect and report a random change in an alphanumeric value for an aircraft symbol. The simulation used a strip film animated with moving aircraft symbols. The film was rear-projected on a phosphor-coated, glass screen 22 inches in diameter, which a seated subject viewed from the other side as a transluscent window in a sound-treated experimental room. The animated aircraft symbols moved linearly across the screen, although at any moment the display appeared relatively static because a 1000-mile surveillance area was simulated and the amount of moment-to-moment movement was small. However, over the course of the 3-hour session (which was standard for this task), the symbols changed their position and configuration, with new symbols entering the system at randomly assigned positions when old ones reached the limits of the display and disappeared. When the subject detected a signal change, he pressed one or more buttons located on a panel at his right hand, and a measure of his response latency was obtained. Latency was measured from the onset of the signal to the pressing of the first button. Traditional vigilance tasks which use near threshold level, transitory signals, have always used per cent correct as the measure, but the Vigilance Film Apparatus with its persistent signals yielded virtually 100 per cent detections under all experimental conditions that we evaluated. Consequently, response latency was used as the measure of performance. Two units of the Vigilance Film Apparatus were built so that two subjects could be run at a time.

The first experiment had signal rate and response complexity as its variables. Duration of a session was always three hours. Mean signal rates of one per minute and one per five minutes were used, and response complexity was defined in terms of either a simple detection response or a comparatively complex evaluation response where the subject had to make a four-choice decision about the symbol that changed. Six symbols were on the display at all times, which was a moderate visual load Figure 1 shows the display. Normally a symbol had the letter G showing, and the critical signal

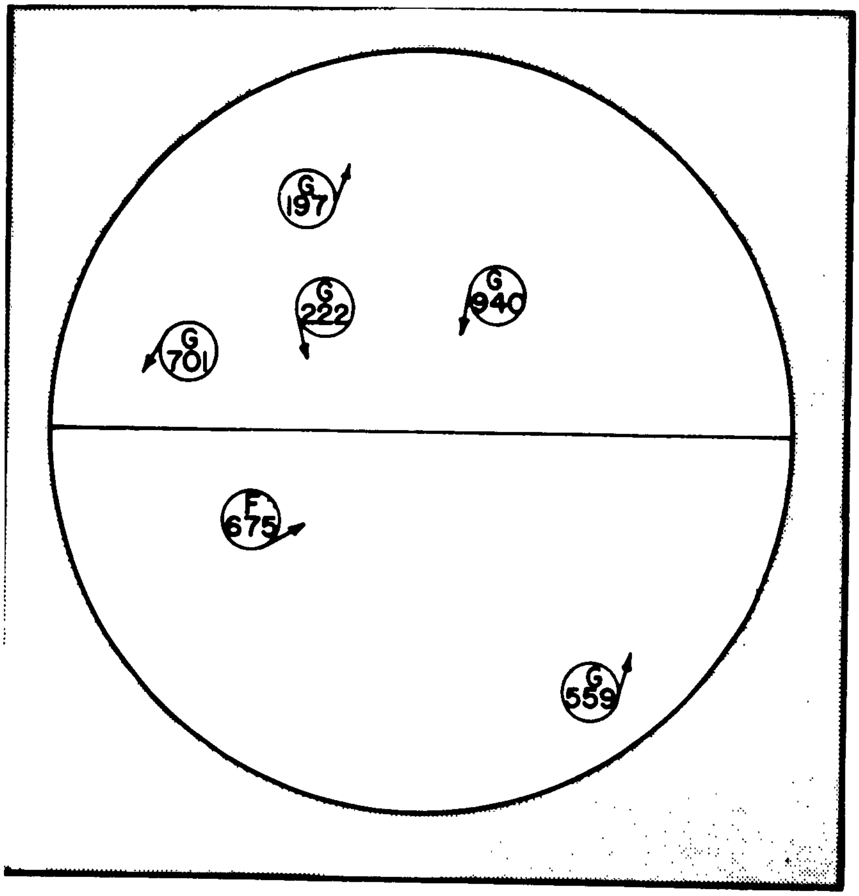

Fig. 1. The display of the Vigilance Film Apparatus, shown with a moderate visual load of six stimulus sources. Not drawn to scale.

to be detected and reported was the change of G to F. For the condition of simple detection responding the subject, as rapidly as possible, pressed four buttons on the panel--one marked F and three others designating the three-digit number of the symbol that had changed. For the evaluational response the subject had to decide whether the symbol was above or below the horizontal center line and whether the number of the symbol that had changed was odd or even. He indicated one of these four choices by pressing one of four decision buttons and, in addition, pressed the same four buttons as the subjects of the simple response condition. There were 12 subjects in the Detection Group and 12 subjects in the Evaluation Group, as these two response conditions were called. Each subject performed under both conditions of signal rate in two criterion sessions, but only one response condition. A practice session preceded the two criterion sessions, and a separate practice film was used for it. Knowledge of errors was given over an intercom system during the practice session, but no feedback was given during the criterion sessions in order to minimize stimuli impinging on the operator.

Our predictions about the outcome of this experiment were unsure--partly because of the paucity of data from vigilance research on complex tasks, and partly because of uncertainties in predicting about molar behavior from the physiologically-based arousal hypothesis The few, earlier vigilanc studies that used complex tasks with multiple sources (Broadbent, 1950; Hoffman and Mead, 1943; Howland, 1958; Jerison and Wallis, 1957; Jerison and Wing, 1957; Loeb and Jeantheau, 1958) all found no decrement, so we were not sure that any decrement at all would be found for our experimental conditions. Conceivably, the increased stimulation in a complex task may be sufficient to deter all decrement, at least according to the arousal hypothesis, and no decrement should be expected whenever a task is sufficiently com plex. However, our experiment used signal rate and response complexity as two classes of variables that the arousal hypothesis suggests might influence vigilance decrement if it occurred at all. A faster signal rate, by virtue of more stimulation per unit of time, should lessen decrement. Similarly, response complexity viewed as additional central, response-produced stimulation, should result in less decrement for the Evaluation Group than the Detection Group that used simple, non-decision responding.

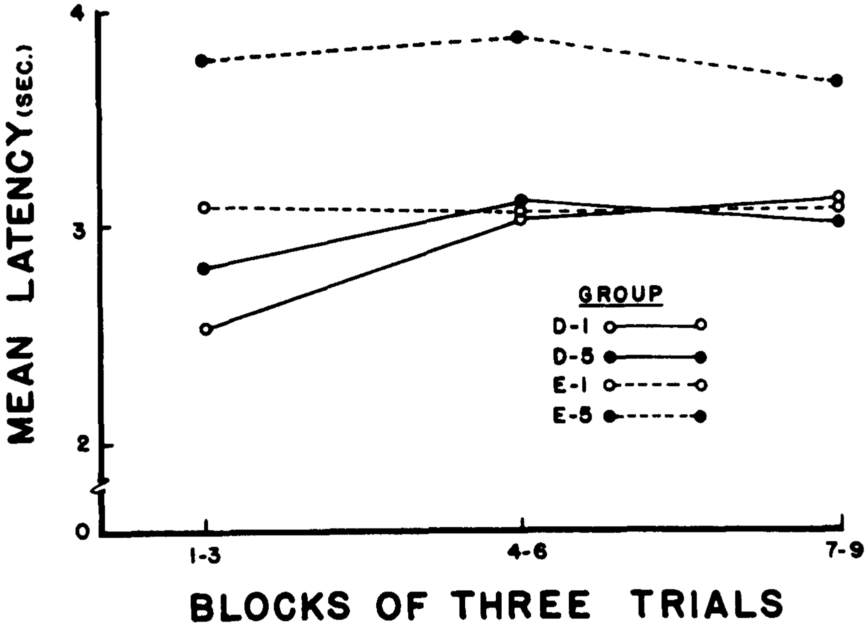

Fig. 2. Mean response latency as a function of trials for each experimental condition (Adams and Boulter, 1960).

Figure 2 shows the main results, with response latency plotted as a function of trials. The three hours were divided into nine 20-minute trials for scoring purposes The experimental conditions in Fig. 2 are designated by type of responding and the signal rate, with D being detection response, E being evaluation response, and 1 and 5 referring to mean signal rates of one per minute and one per five minutes. Mean intersignal interval and degree of response complexity produced no statistically significant effects ($\underline{p} > .05$), although Group E-5 had a distinct tendency for longer latencies. The overall trend of trials showed a statistically significant increase in response latency, which is the well-known vigilance decrement. Importantly, there was a significant Trials x Response Complexity interaction, which is revealed in Fig. 2 as decrement for D-1 and D-5 and no decrement for E-1 and E-5.

The percentage of signals detected was very high, as might be expected with superthreshold signals that persisted on the screen for 20 seconds. Detection level never fell below 96 per cent for any condition, and per cent detection had no apparent trend with trials.

The stimulus sources represented aircraft and they gradually changed their positions throughout the session. On occasion a source left the edge of the display and was replaced by a new one. This shifting pattern of sources made it possible to analyze response latency as a function of where a source emitting the signal was located with respect to the others. It was found that a signal occurring at a source that was spatially separated from the others had a longer response latency--as if a subject was selectively attending to the clustering of the other five sources. Moreover, this effect increased with observation time. This was an interesting, secondary finding because it suggested that vigilance decrement is partly associated with changes in visual observing and selective perceptual attending as observation time progresses. Not all decrement is ascribable to this phenomenon, but it does appear to be a source of decrement in complex tasks like the Vigilance Film Apparatus.

The findings had some correspondence with predictions from the arousal hypothesis. Of particular significance was the finding that response complexity is a factor in vigilance decrement. As the hypothesis says, central decision responding is a special center of stimulation that can affect the reticular formation and deter vigilance decrement. Manipulation of an external source of stimulation in terms of signal rate was not successful, and the reason for this is unclear because of positive findings for this variable in earlier studies with simpler tasks (Deese, 1955; Deese and Ormond, 1953; Jenkins, 1958). One possibility is that the level of external stimulation is already high in complex tasks, and an increase in signal rate did not appreciabl alter the base level of stimulation inherent in the task. Another possibility is that vigilance decrement is primarily a function of response-produced stimulation, and is not particularly related to external, task-derived stimulation.

A second experiment (Adams, Stenson, and Humes, 1961) was conducted to further explore implications of the arousal hypothesis. The Vigilance Film Apparatus was again used, and the principal variables were visual load (number of stimulus sources on the display), and response complexity. The levels of visual load were 6 and 36 sources, with the 36 sources creating a display that was visually crowded. The conditions of response complexity were the same as in the previous experiment (Adams and Boulter, 1960).

where detection and evaluation responding was used. Response complexity was included to validate the provocative finding of the earlier study, and to test the interaction between load and response complexity. Stimulus load was a means of varying the stimulation level in the task, and an increase in load should promote higher vigilance performance according to the arousal hypothe Thus the experimental design had two conditions of response complexity (detec ion and evaluation) and two levels of stimulus load (36 and 6). The monitoring session was three hours long. A practice session was administered on a preceding day to provide familiarization with task requirements The conditions of visual load and response complexity were the same in both the practice and criterion session, but the mean signal rate was one per minute in the practice session and one per five minutes in the criterion session. There were four independent groups of 15 subjects each--a group for each combination of the two conditions of load and the two conditions of response complexity. Knowled of omissions and errors of procedures were given only in the practice session.

Figure 3 presents the results. Detection and evaluation responding

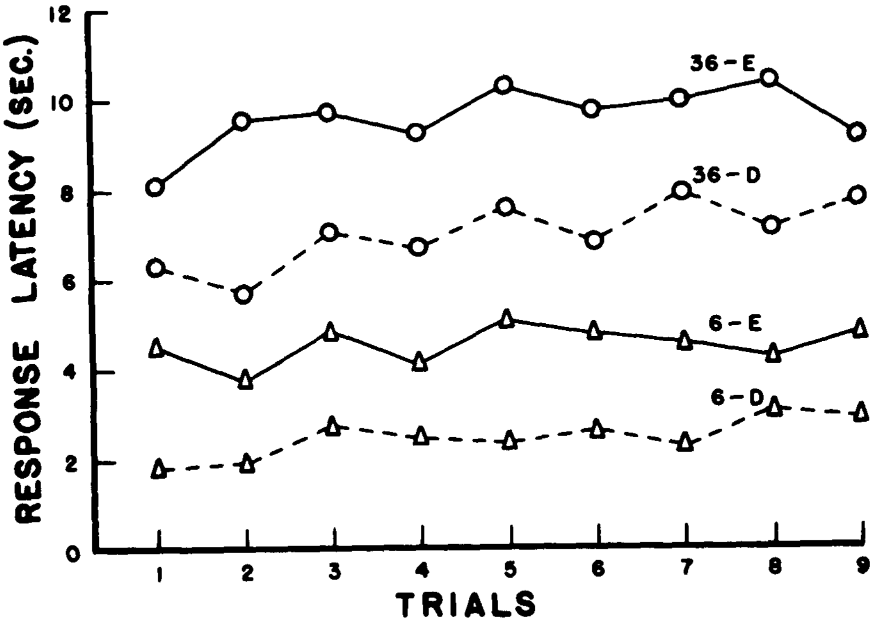

Fig. 3. Mean response latency as a function of trials for each group (Adams, Stenson, and Humes, 1961).

are symbolized by D and E, just as in the previous experiment, and 6 and 36 are the visual loads. Figure 3 shows that the heavy load resulted in longer response latencies, which is a straightforward expectation. An overall statistical analysis for the four groups indicated that main effects of response complexity, load, and trials, were significant at less than the .01 level. Because the trials variable had a significant overall decremental trend, an analysis of variance was performed on the trend of trials for each of the four groups separately. Only Groups 6-D and 36-D, which had simple detection responding, had a decremental trend over trials that was statistically significa ($p < .01$). Corresponding tests for Groups 6-E and 36-E were not statistically significant ($p > .05$), demonstrating once again that response complexity eliminates decrement in this task.

The significant finding for this experiment is a confirmation of the earlier finding (Adams and Boulter, 1960) on response complexity. Again response-produced stimulation, of a choice or decision kind, had a positive influence on alertness. Stimulus load, however, was not relevant for vigilanc decrement. There are three possibilities for explaining why decrement was not differentially associated with the two amounts of visual load: (1) the moder visual load of six sources was sufficient stimulation for high alertness, and increasing it to 36 made no further difference. This is the same line of reasoning used by Adams and Boulter (1960) in explaining why no statistically significant difference was found between a mean signal rate of one per minute and one per five minutes. (2) External environmental stimulation is far less important for vigilance than response-produced stimulation. (3) The amount of stimulation is of less significance for alertness than the variety of stimulati Increasing the visual load from 6 to 36 may increase the amount, but not the variety of stimuli, and variety may be critical as the work of Sharpless and Jasper (1956) suggests.

Two additional studies were conducted on implications of the arousal hypothesis, and were reported in a paper by Adams and Boulter (1962). Our tests of the arousal hypothesis up to this point were moderately successful, and we thought it important to assess other stimulus manipulations and test their influence on vigilance decrement. The arousal hypothesis is derived from physiological investigations, not behavioral ones, and the stimuli and their properties that influence behavioral alertness are not defined. Our work so far was somewhat encouraging for the arousal hypothesis, and we considere it worthwhile to evaluate other facets of the hypothesis even though there were uncertainties about the optimum research direction.

Adams and Boulter (1962) gave emphasis to internal stimulation that was a promising stimulus class for alertness in the two earlier studies (Adams and Boulter, 1960; Adams, Stenson, and Humes, 1961). Their laboratory task was the Multiple Source Vigilance Apparatus, of which there were two copies for running two subjects at a time. Figure 4 is a picture of this device. The subject sat at a desk and faced a semi-circular track fixed at eye level to the back of the desk. On the track were four small digital display boxes that presented two-digit numbers on signal from a digital tape reader at the Experimenter's station in another building. The subject was required to keep his forearms in the two arm rests to control the distance of arm-hand movement that is a known variable for reaction time. Signal duration for this experiment was 5 seconds. The display boxes could be arrayed anywhere over the 180-degree semi-circular track, thus allowing control over the spatial separation of stimulus sources. When a critical signal came on, the subject was to report the event as fast as

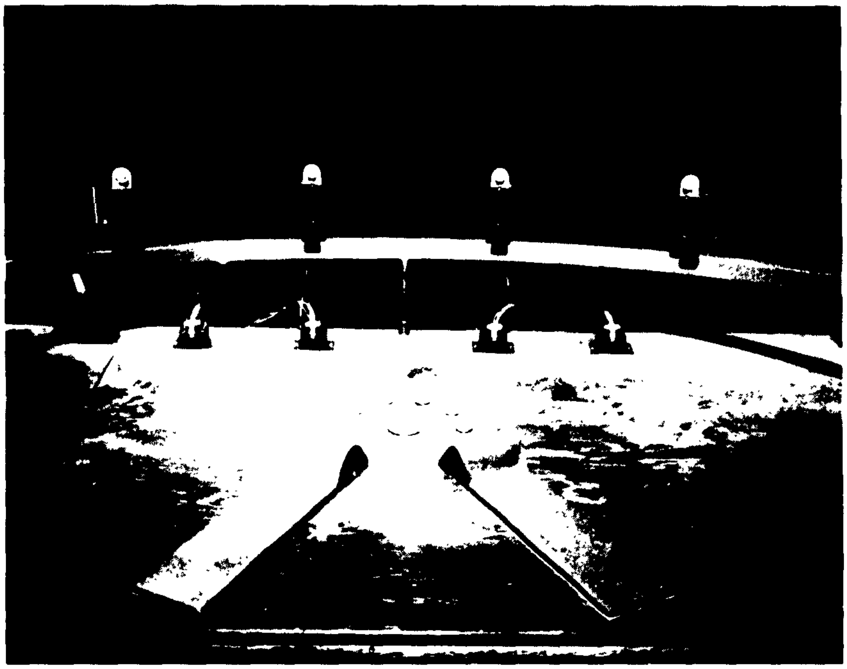

Fig. 4. The Multiple Source Vigilance Apparatus.

possible by pressing a relatively large detection button located four inches from his finger tips. A timer started at the onset of the signal and stopped when the detection button was touched--giving a response latency score. This simple mode of responding was called detection responding. Under another experimental condition called memory responding, which will be described in more detail below, the subject had a set of six small memory buttons in addition to the large detection button. These buttons were each labeled with one of the six numbers that was used, and they were arrayed in a semi-circle around the detection button and four inches from it

One of the hypotheses tested in Experiment I reported by Adams and Boulter (1962) was a derivation from physiological findings, and it was concerned with proprioceptive collaterals in the reticular formation. A special source of stimulation in complex tasks with multiple sources is proprioception from head and eye movements, and it should be a source of response-produced stimulation to deter vigilance decrement and keep monitoring performance high. When stimulus sources have wide spatial separation, head and eye movements would be a prominent source of proprioceptive stimulation, but even with stimulus sources close together there still would be proprioceptive stimulation from eye movements alone. The changing retinal stimulation as the eyes scan the visual scene is another source of stimulation associated with separation of stimulus sources. In this experiment the spatial separation of the sources was the means by which changes in proprioceptive and retinal stimulation were operationally defined.

The other variable of this experiment concerned stimulation to the reticular formation that is presumed to be cortically-centered and similar to the response-produced stimulation associated with decision behavior that eliminated decrement in the two earlier experiments (Adams and Boulter, 1960; Adams, Stenson, and Humes, 1961). For this experiment, however, immediate running memory was used as the source of internal stimulation. The subject was required to keep track of the four numbers that had last occurred at the four sources and, when the next number occurred at a source, he was to respond with the number that had occurred at that source the last time. This procedure required that the subject always had to keep the last four numbers in mind. Thus, for the memory condition, the subject first pressed the detection button when he detected a signal, and he then followed it with a choice of one of the six memory buttons to indicate the number that had last occurred at that particular source. Our interest here was not in immediate memory per se, but rather in immediate memory as a source of internal stimulation.

The experimental design had four amounts of spatial separation, specified in terms of the angular difference between the two outermost of the four sources: 18 degrees, 36 degrees, 72 degrees, and 144 degrees. The other two sources were spaced between the outer ones to give equal separation between all four sources. Separations of 18 and 36 degrees placed the four sources in a direct field of visual view, and essentially they could be scanned with eye movements alone. The 72-degree separation required some added head movements for comfortable scanning, and scanning the 144-degree separation was not possible without head movements. Two levels of response complexity defined the second principal experimental manipulation. (1) detection responding, where the subject simply pressed the detection button when a signal was detected, and (2) memory responding which was just described. Two groups of 15 subjects were used, with each subject participating for five sessions of 2.5 hours each. Each subject was used in one response complexity condition and all four conditions of spatial separation An initial practice session was given to familiarize the subject with the task. All five sessions were on separate days.

The principal results are shown in Fig. 5. The 2.5-hour session was divided into five 30-minute trials for scoring purposes. The data are plotted in terms of mean response latency as a function of trials. The latency values used for Fig. 5 are response times for the detection button. All three main effects of response complexity, spatial separation, and trials were significant at less than the .01 level. Of primary interest was the influence of spatial separation and response complexity on decremental trends over trials. If our hypotheses about the effects of spatial separation and response complexity on decrement were sound, a significant interaction effect should be expected. Less decrement over trials should be found for large spatial separations and for memory responding. None of the interaction effect were significant, however, and our hypotheses are not confirmed. Overall per cent detection was 98, which is to be expected with a signal that persists for five seconds.

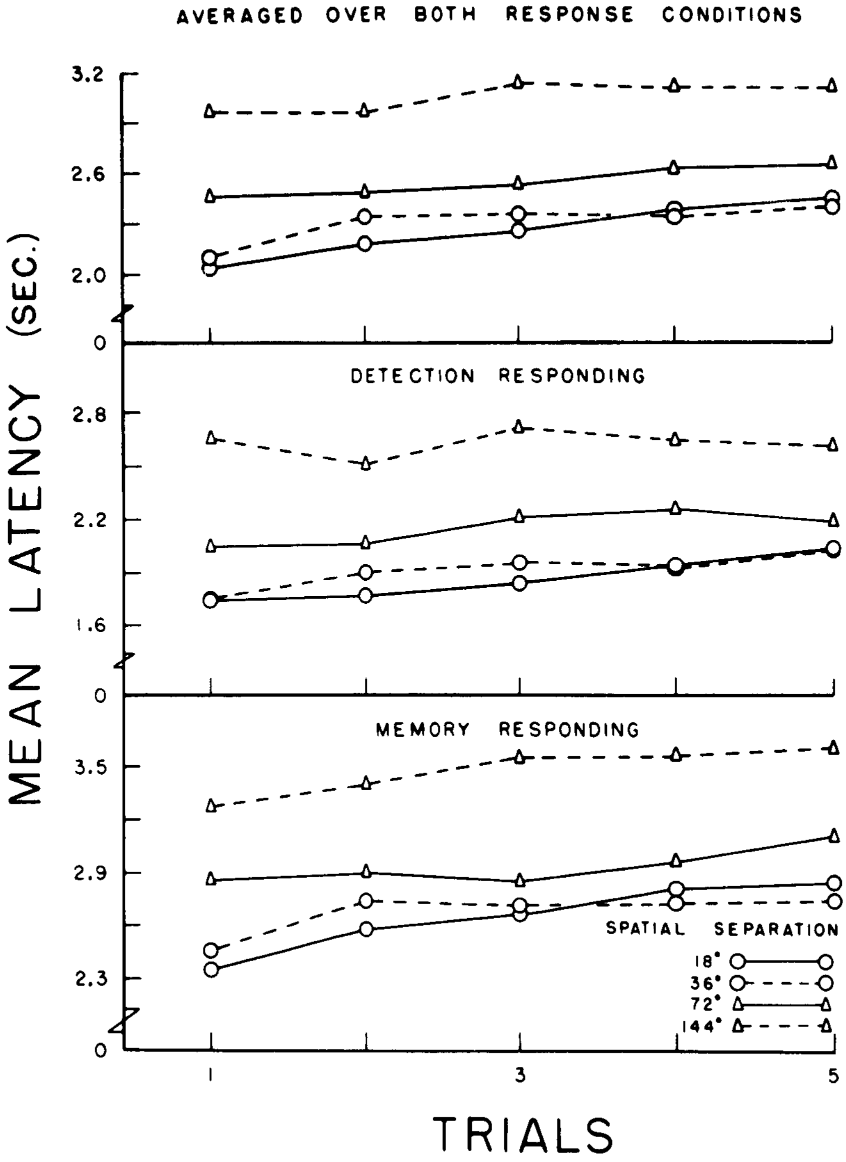

Fig. 5. Mean response latency as a function of trials for each experimental condition (Adams and Boulter, 1962, Experiment I).

A second experiment using the Multiple Source Vigilance Apparatus was conducted to see if *change* in the pattern of head and eye movements could influence vigilance decrement (Experiment II, Adams and Boulter, 1962). The negative results of the previous experiment may have resulted from the manipulation of *amount* rather than *variety* of stimulation, and Experiment II was intended to induce variety. The configuration of the apparatus was as in Experiment I with the exception that a small cue light was mounted on the top of each of the four stimulus sources and programmed from source to source by the digital tape reader A signal always occurred in coincidence with the cue light so a subject could optimize his detection by allowing the cue light to guide his visual observing response of head and eye movements. A 144-degree spatial separation was used for all groups to insure an ample observing response. The duration of the cue light at each source, and the duration of the critical signal were both two seconds, which kept the observing response moving regularly. The length of the session was again 2.5 hours. The basic idea was to establish a standard mode of scanning on the first two trials, change it on Trial 3, and then revert to the standard mode on Trials 4 and 5. If variety in head and eye movements was a significant factor, we should expect less decrement on Trial 3 where change was made, and perhaps less on Trials 4 and 5 because of persisting effects of the change. One group had repetitive back-and-forth scanning for the first two trials, and then shift to a random patterning of cue lights for Trial 3 before reverting to repetitive scanning. Another group had random cue lights for the first two trials, repetitive scanning on Trial 3, and a return to random scanning on Trials 4 and 5. One control group had repetitive scanning throughout, and a second control group had random scanning throughout. The gist of the findings was that shift in the patterning of head and eye movements had no influence on vigilance decrement.

Status of the arousal hypothesis. Our findings on the arousal hypothesis and vigilance are mixed, and we must regard the hypothesis with considerable caution as an explanatory device for vigilance behavior at this time. The only evidence that we have for it was that response complexity, defined as choice or decision in the responding, functioned to deter decrement in two experiments. This finding is repeatable because it was confirmed by Monty (1962) in a subsequent experiment. On the other hand, we were unable to establish that immediate running memory was another source of internal, response produced stimulation that negated decrement. Nor did we influence decrement with signal rate, stimulus load, or proprioceptive and retinal stimulation from head and eye movements. Despite this combination of successes and failures, we feel that grounds for rejecting the arousal hypothesis do not exist at this time. These grounds eventually may mature, but the principal problem at present for a sufficient test of the arousal hypothesis appears to be one of operational definition of stimuli. What classes of stimuli are relevant for alertness? Is it amount or variety of stimulation that is important for alertness? In its present format the arousal hypothesis is not amenable to careful testing because it says little or nothing about properties of stimuli and their relationships to behavioral measures. In the absence of careful operational definitions, investigators must try the different stimulus definitions and, by empirical trial and error, attempt to estimate their relevance for alertness. This is a laborious procedure, but we have had enough success with the hypothesis to warrant such investigations. It will take numerous experimental tests to determine relevant stimulus manipulations, but our work on response complexity (Adams and Boulter, 1960; Adams, Stenson, and Humes, 1961), as well as the substantiating work by Monty (1962), are encouraging lines of development. McGrath (1960) has also found experimental evidence for the arousal hypothesis in a vigilance situation.

4. EFFECTS OF TEMPORAL AND SPATIAL UNCERTAINTY

Temporal uncertainty and vigilance decrement. With the arousal hypothesis being less than fully verified in our experiments, we thought it desirable to explore other leads on determinants of vigilance decrement. A lead that looked particularly inviting was the findings in two studies by Baker (1959a, 1959b) that variability of intersignal intervals, i. e., the degree of temporal uncertainty of signals, is related to vigilance decrement. Baker found that an interval set with high variability was associated with vigilance decrement, while an interval distribution with lesser variability was not. It is obscure why this result should be obtained, but it occurred in two experiments and we felt it deserved clarification and, hopefully, explanation.

Because temporal uncertainty and vigilance decrement are not related by any hypothesis in which we had confidence, we considered it prudent to challenge Baker's findings on experimental details and be assured that it was sound before launching on studies of broader explanation. In a detailed examination of Baker's findings we found three difficulties. First, his findings were not fully confirmed in related studies (Dardano, 1962; McCormack and Prysiazniuk, 1961). Second, Baker did not allow for practice, and it is difficult to ascribe a role to temporal uncertainty if subjects have not had a chance to practice the intervals and know what they are. Third, Baker's subjects occasionally missed the brief, transitory signals that were used, and this could alter the subject's perception of the true signal structure and result in either biased or poor learning because a different set of perceived intervals would occur on each trial. Our experiment (Boulter and Adams, 1963) was designed to remedy these three shortcomings in a single study. A practice session was given prior to the criterion session to allow an opportunity for learning the temporal patterning of intervals. Furthermore, a persistent signal of 5-seconds duration was used to maximize detection so that perceived intersignal intervals were firmly anchored to actual intervals.

The Multiple Source Vigilance Apparatus was used but in this application the display was a single digital display box centered in front of the subject. The display was normally blank, and when the number 20 occurred the subject was to report its appearance as quickly as possible by pressing the detection button located 4 inches from his finger tips (the memory buttons used in the earlier study were removed for this experiment). Latency between onset of the signal and the subject's response to it was the performance measure. The signals and the intervals between them were programmed on punched tape and automatically read by a digital tape reader.

The duration of each vigilance session was three hours, and the three hours were divided into four 45-minute trials for purposes of analysis. All subjects had a practice and a criterion session, which were administered on separate days. Twelve signals occurred on each trial, and the variability of time intervals between them was the experimental variable. Three groups of 20 subjects each were distinguished by the degree of temporal uncertainty in their signal series. Group HU (high uncertainty) had a wide range of time intervals between signals. The twelve intervals used for Group HU on each 45-minute trial were: 15, 15, 30, 30, 30, 60, 120, 120, 300, 420, 600, and 900 seconds. For Group MU (medium uncertainty), the twelve intervals on a trial were two of 120 seconds, six of 220 seconds, and four of 270 seconds. The intervals for Groups HU and MU were separately randomized on each trial. For Group NU (no uncertainty) all intervals were of the same length of 220 seconds, which was the mean intersignal interval for Groups HU and MU. Because variability of the distribution of intersignal intervals was being studied, the mean interval was kept the same for all groups.

The principal results are given in Fig. 6. Mean response latency for each group is plotted with respect to trials. Overall, a significant amount of vigilance decrement was obtained, with the trend being essentially the same for all groups. There were no between-groups differences, however, and we were unable to confirm the expectation from Baker's findings that vigilance decrement should be greater as temporal uncertainty of intervals increases.

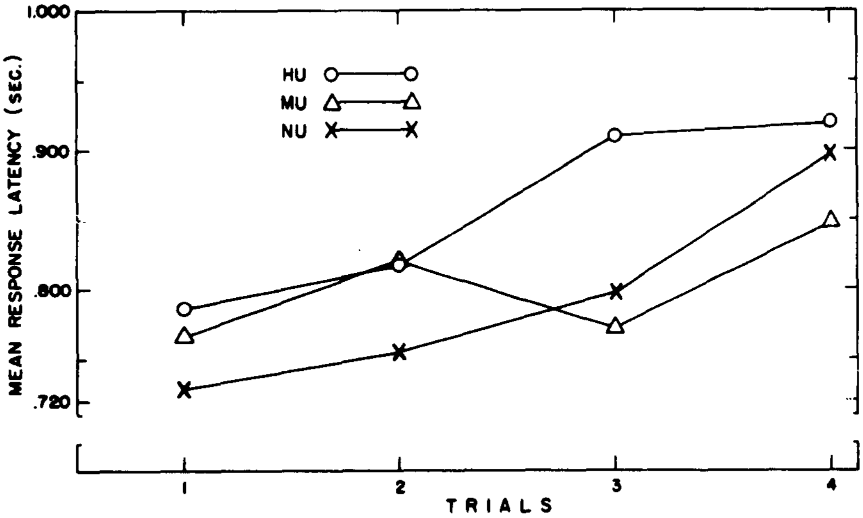

Fig. 6. Mean response latency as a function of trials for each condition of temporal uncertainty (Boulter and Adams, 1963).

Other findings of this study concerned the nature of the temporal expectancy function, or the subject's learned state of readiness (anticipation) of when the next signal will occur. The principal hypotheses in this area have been by Deese (1955) and Baker (1959c). Deese and Baker both hypothesized a single, although different, function for expectancy but our findings demonstrated that no single function will describe the data. The nature of the function seems at least related to the variability of the intersignal intervals. In a larger sense, research should be directed toward expectancy as related to the form of the distribution function for intersignal intervals, and mean and variance.

Combined effects of spatial and temporal uncertainty. Most vigilance tasks are simple, with a single source to be monitored (Frankmann and Adams, 1962), but the special problems and issues for complex tasks with multiple, spatially-arrayed sources have been the emphasis of our research program. Complex visual tasks of this sort have two primary determinants of vigilance. The first is *temporal uncertainty*, defined by the temporal regularity of signals, and it is assumed to determine temporal expectancies that the subject learns about when the next signal will occur. The second is *spatial uncertainty*, defined by the regularity with which signals occur at the spatially-arrayed stimulus sources. When a subject must scan several stimulus sources, the functioning of his visual observing responses of head and eye movements (Wycoff, 1952) that intervene between the display and the subject's instrumental motor response of, say, pressing a button to report a signal detection can be fundamental for his efficiency in the task because they are a primary mechanism for signal reception The subject can learn spatial expectancies about where the next signal will occur through experience in the task, and these expectancies are inferred from performance as a function of the spatial patterning of signals. Our method for controlling the observing response was to manipulate the amount of spatial uncertainty and thus the predictability that the subject could acquire about where the next signal would occur With spatial certainty the subject could easily learn where the next signal would occur, and he needed to exert only a minor observing response to be properly oriented for the next signal. But with spatial uncertainty, where the spatial patterning of signals was random, the subject had to maintain an active scanning of stimulus sources to insure speedy signal detection because he could never really be sure where the next signal occurrence would take place. Thus, through predictability, a measure of control was gained over the observing response. Similarly, by using repetitive or random intersignal intervals, we gained some control over temporal uncertainties.

The Multiple Source Vigilance Apparatus was again used. On the semi-circular track were mounted three digital display boxes that presented the number 20, which was the signal to be detected. The three boxes were arrayed over 144 degrees, with one box placed in the center position directly in front of the subject and the other two boxes placed at 72 degrees to the left and right of center. The 144 degrees required head and eye movements to scan the boxes, and this wide separation was used intentionally to elicit an ample, distinctive observing response. The performance measure was latency between the onset of the signal and the subject's reponse to it. A signal remained on for 5 seconds, and the signals and the intervals between them were programmed on punched tape and automatically read by a digital tape reader.

Each session was 2.5 hours long, divided into five trials of 30 minutes each for scoring purposes. A trial had nine signals. All subjects had a practice and a criterion session, which were administered on separate days. The practice session was administered to insure that the subject was thoroughly familiar with the task and procedures, and to provide an opportunity for learning about the conditions of spatial and temporal uncertainty.

The experiment had an independent group of subjects in each cell of a 2 x 2 factorial design, with temporal certainty and uncertainty as one dimension and spatial certainty and uncertainty as the other dimension. For temporal uncertainty, the following intersignal intervals were separately randomized for each of the five trials: 15, 33, 81, 129, 180, 234, 291, 354, and 438 seconds. For temporal certainty the intersignal interval was constant at 195 seconds, which was the mean value of the intervals for the temporal uncertainty condition. Spatial uncertainty had the nine signals separately randomized among the three sources on each trial, with the restriction that each of the three sources be assigned three signals on a trial. Spatial certainty was a repetitive movement of signals from left to right, right to left, etc., and again with three signals at each source on a trial. Each of the four groups had 20 subjects. Group TU (temporal uncertainty) had temporal uncertainty and spatial certainty. Group SU (spatial uncertainty) had spatial uncertainty and temporal certainty. Group C (certainty) had both temporal and spatial certainty, and Group U (uncertainty) had both spatial and temporal uncertainty. Thus, Group C had signals that were perfectly predictable in time and place, Group TU had signals predictable only in spatial position, Group SU had signals predictable only in time, and Group U had signals that were uncertain in both time and place.

The score for a subject on a trial was the mean of his response latencies on the trial, and Fig. 7 shows a plot of mean latency for each group as a function of the five trials of the criterion session. Mean performance is shown for each of three stimulus sources, as well as for overall performance where all three sources were combined. Group C had the best performance, and performance level decreased for Group TU with the addition of temporal uncertainty. Groups SU and U had performances distinctly poorer than the other two groups, showing that the requirement for extensive visual scanning when signals had high spatial uncertainty is impairing for vigilance performance. The overall differences between groups were statistically significant ($p < .01$). When a three-way analysis of variance (5 trials, 3 sources, 20 subjects) was performed for each group, only Group TU had a significant trials decrement and only Groups SU and U had significant F ratios for sources. No group had a Trials x Sources interaction effect that was significant.

Both temporal and spatial uncertainty emerged in this study as clear-cut variables for vigilance behavior in a complex task with multiple stimulus sources, with spatial uncertainty of signals being the most potent contributor to performance. Being directional, the observing response stands a good chance of being temporarily oriented towards a wrong source when a signal occurs, and the result can be a response latency that is increased by the time it takes the observing response to shift to the source displaying the signal. Some of our other research (Adams and Boulter, 1960; Adams and Humes, 1963; Adams, Humes, and Stenson, 1962) has found data suggesting that the observing response

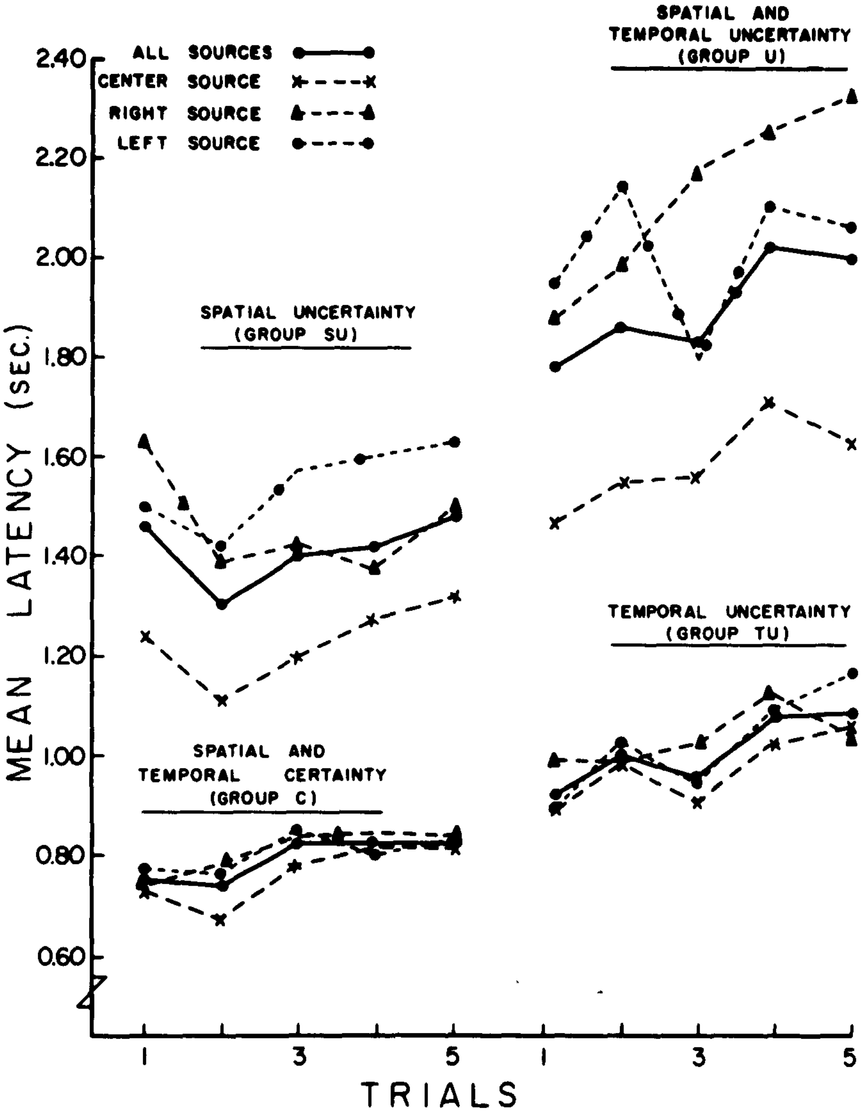

Fig. 7. Mean response latency as a function of trials for each group (Adams and Boulter, 1963). Response latency is shown for each source separately, as well as for all sources combined.

can be a determiner of decrement when a signal occurs at a source that is separated from a clustering of five others. In the present experiment, however, there was no evidence of selective observing revealed as better performance for one or two of the stimulus sources at the expense of the others as time in the session went on. If this effect had occurred for a group there would have been a significant Trials x Sources interaction, but this was not found. Tentatively, we conclude that the selective observing inferred in other research is a function of a clustering of signals that command a subject's observing response much of the time, and subjects respond to the cluster as if they were probabilistically orienting their observing response to that part of the display which had the greatest likelihood of signal occurrence. The three stimulus sources in this study were equally spaced on the display, and there was no clustering of sources to pre-empt the observing response. The organization of stimulus sources, and their relationship to the observing response in vigilance decrement, is a topic in need of research.

5 EFFECTS OF REPEATED SESSIONS

The usual vigilance experiment will use one or two sessions, but the conditions of work in industrial and operational military environments often have work sessions that are repeated a large number of times. The purpose of our laboratory research on repeated sessions was to generate laboratory data that would improve our understanding of conditions of the real world.

The Vigilance Film Apparatus was used in our first experiment on repeated sessions (Adams, Humes, and Stenson, 1962), and a single group of 12 subjects was given ten daily sessions. The display had six stimulus sources. Each subject had a three-hour session for nine consecutive days. Seven-days rest followed Session 9, and Session 10 was then given. The seven-day rest was included in the design to see if a longer rest would dissipate any cumulative effects that conceivably might occur over the first nine sessions. The mean intersignal rate was one per minute. The method for scoring response latency was changed from previous uses of the Vigilance Film Apparatus. Two timers were activated when a signal first appeared on the screen. The subject normally kept his hand on a large rest button and, when a signal was detected and the subject moved his hand from the rest button, one of the timers stopped and gave a measure of basic importance which we called the Detection Latency. When he pressed the F button on the panel 16 inches from his hand, the second timer stopped, giving Total Latency for the response. Total latency was not used per se. Instead, Detection Latency was subtracted from Total Latency to yield Motor Movement Latency, which was a new measure. This latter measure was to check the possibility that some of the vigilance decrement can be ascribed to a progressive slowing of the motor response over the course of the session, and we considered it worthwhile to assess the relative contributions of visual-perceptual and motor processes.

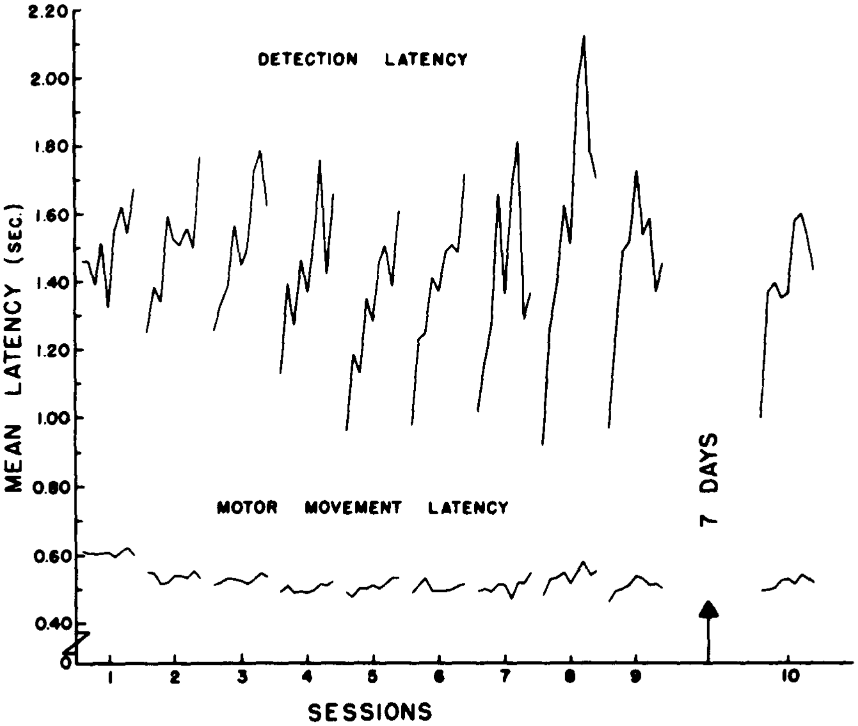

Fig. 8. Mean response latency as a function of trials for ten sessions. Sessions 1 - 9 were on consecutive days, and a 7-day rest separated Sessions 9 and 10. Visual load was 6 stimulus sources. (Adams, Humes, and Stenson, 1962).

The results of this first experiment on repeated sessions are shown in Fig. 8 Figure 8 has a plot of group mean Detection Latencies and Motor Movement Latencies as a function of trials and sessions There was a significant decrement within sessions, but statistical analysis failed to confirm decrement as a function of sessions. Nor was there a significant effect attributable to the seven-day rest. The Motor Movement Latency had both a significant within-session and between-sessions change, although the between-sessions change appears to be a learning effect of the sort commonly reported for reaction time. The seven-day rest had no influence on Motor Movement Latency

A second experiment (Adams, Humes, and Sieveking, 1963) was performed on repeated sessions, and it was the same as the previous one except that visual load was increased from six to 36 stimulus sources The first study had only six stimulus sources, which is a relatively easy visual scanning task, and we surmised that it might be relatively insensitive to the effects of repeated sessions With a more demanding task of 36 stimulus sources, however, subjects may become decreasingly interested in scanning the difficult display and an effect of sessions would emerge. The mean signal rate was again one per minute, and again there were 12 subjects in the single group.

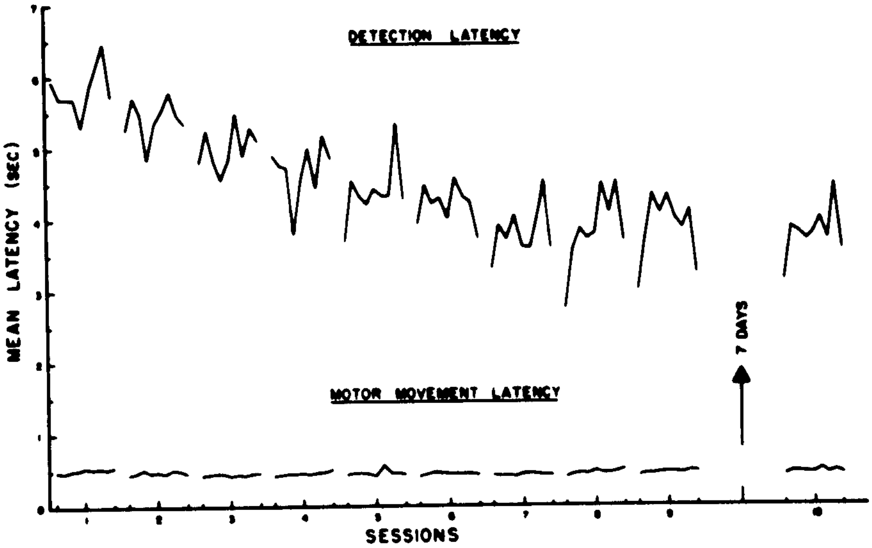

Fig 9 Mean response latency as a function of trials for ten sessions Sessions 1 - 9 were on consecutive days, and a 7-day rest separated Sessions 9 and 10. Visual load was 36 stimulus sources. (Adams, Humes, and Sieveking, 1963).

Figure 9 shows the results for both Detection Latency and Motor Movement Latency. When compared with Fig. 8, we see that heavy visual load increases average Detection Latency roughly by a factor of three. Once a detection is made, however, a mean Motor Movement Latency of about one-half second prevails in both studies. Rather than a decremental trend for Detection Latency as a function of number of sessions, we found a gradual improvement up to about the seventh session, at which time a leveling off occurred. A decremental trend within sessions, however, is evident for most days, despite the variability that occurred within sessions. Both sessions and trials were significant sources of variation. No significant change over the seven-day rest interval was found for either measure. Fig. 9 does not clearly show a decremental trend within sessions for Motor Movement Latency, but the trend was nevertheless sustained statistically

6. TRAINING FOR VIGILANCE

Is it possible to train an individual and better his monitoring of a display? Studies of vigilance have taken a passive attitude toward the operator and have been interested mostly in examining the effects of task variables and time But, if training techniques for vigilance were developed we could use them along with our knowledge of task variables to produce a high, stable level of monitoring performance. This experiment (Adams and Humes, 1963) tested the hypothesis that knowledge of results (KR) is a training method that can be effective for producing a heightened and relatively stable level of vigilance performance in a visual monitoring task

It is well-known that KR is effective in the session in which it is administered, but this is not the big issue for training programs where training operations, such as KR, must transfer positively to the post-training operational situation where KR is absent. The Vigilance Film Apparatus was used, with three hours of observation for each of four daily sessions. The mean signal rate was one per minute, and six stimulus sources were on the display. A primary experimental group (Group KR) had KR administered after each response of two training sessions, and two transfer sessions followed where a conventional, non-KR vigilance task was used. A second experimental group (Group S) had two initial sessions of neutral stimulation after each response, followed by two transfer sessions where conditions were the same as for Group KR. The neutral stimulation was to check the possibility that KR, defined as feedback that contains information relative for response proficiency, and stimulation qua stimulation, are essentially the same. A control group (Group C) had four conventional vigilance sessions with no feedback at any time. Superior performance was expected in the first two sessions for Group KR, where feedback about response proficiency was administered after each signal, but the key issues are whether these positive effects will carry over to subsequent non-KR sessions, and whether KR is basically different in its effects from the neutral stimulation administered to Group S.

The response feedback for Group KR was to report after a signal the discrepancy between a subject's present Detection Latency score and his best trial mean score so far. Thus, the intent of the KR procedure was to push a subject towards better and better performance (smaller latency values) by reporting to him the deviation from his own best prior performance. In the case of Group S, the Experimenter merely acknowledged the subject's response by telling him the identification number of the stimulus source that just had a critical change. There were 15 subjects in each group.

The results are shown in Fig. 10. Group mean Detection Latencies are plotted as a function of blocks of three trials and sessions. The statistical analysis established a decrement over trials within each session, and there was a reliable between-groups difference for all sessions, with Group KR being the principal contributor to these differences. It is not surprising that KR made a difference in Sessions 1 and 2 where KR was administered after each signal, but most significant for the hypothesis is that the positive effects of KR persist in the non-KR transfer sessions. Our operations induced a permanent (for two sessions, at least) and enhancing effect for monitoring behavior. Nor was neutral stimulation delivered to Group S sufficient to change performance. The feedback had to be response-relevant.

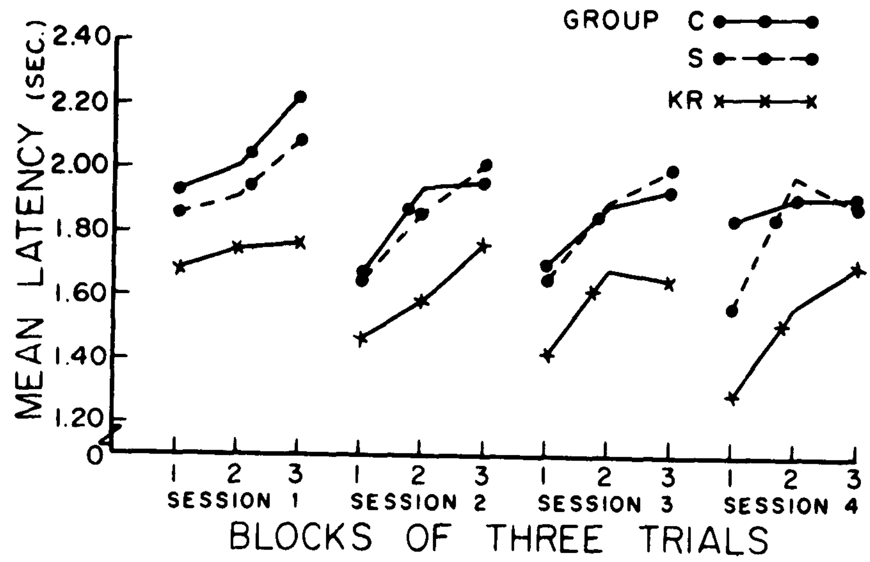

Fig 10 Mean response latency as a function of blocks of three trials and sessions for each of the three groups (Adams and Humes, 1963)

7 IMPLICATIONS FOR THE OPERATION AND DESIGN OF MAN-MACHINE SYSTEMS

Vigilance in day-to-day system operations Our research program was designed to examine certain basic dimensions of vigilance behavior in complex visual tasks with multiple stimulus sources, and in carrying out this program we generated a number of findings that have direct implication for the managers who design and operate systems. The most significant finding of our experiments was that vigilance decrement is small and no serious threat to most man-machine systems. This generalization must be qualified to apply to complex tasks with alphanumeric characters and signals that persist for several seconds but, given this class of task, we found virtually all signals detected and no decrement in response latency that exceeded 2 seconds over a three-hour monitoring period. In fact, mean decrement in response latency was almost always less than one second An examination of Figs 2, 3, 5, 6, 7, 8, 9, and 10 more often than not had a trivial amount of vigilance decrement for most system operations Gloomy observations are commonly heard about poor characteristics of the human operator as a monitor, and these views were justified in earlier research that used simple tasks with brief, transitory signals like those found for PPI scopes and sonar Damaging decrements do indeed occur for these simple tasks, but these tasks are of an earlier technological era and generalizations from research on simple tasks do not seem to apply to the complex monitoring tasks of our present and future man machine systems Rather than gloominess about human attentiveness, we conclude from our nine experiments that the human operator is a surprisingly good monitor for periods up to three hours (which was the maximum amount of time that we studied) Furthermore, repeated daily sessions with either light or heavy visual load do not generate a cumulative deterioration of monitoring behavior, as one might intuitively surmise for tasks that are introspectively so boring

A further note of encouragement is that vigilance decrement occurs only when the response is very simple (and only then in small, almost trivial amounts) but, when the response is more complex, decrement is absent We established in two studies (Adams and Boulter, 1960; Adams, Stenson, and Humes, 1961) that vigilance decrement is eliminated when a decision response is required, and this finding has since been confirmed by Monty (1962) Because monitoring tasks in military and industrial situations often have decision elements in them, it is unlikely that their operators will show any decrement at all

<u>Training for vigilance</u> It is encouraging to know that the amount of vigilance decrement in complex tasks is small when it is found at all, but it is even more enheartening to know that something can be done about the decrements that are found It is conceivable that these small decrements might, for some systems, have significance When this happens, it is good to know that the use of knowledge of results (KR) is a distinct possibility for positive training action to enhance monitoring proficiency We found that KR operations transferred from a training situation where KR was administered to a non-KR session, and this implies that KR used

in a training program for monitoring can be expected to benefit field operations where KR is absent Our results established this finding for only two post-KR sessions, however, and additional research must further investigate the stability of transfer effects

The design of displays Our research program was not a series of human engineering experiments where vigilance was studied as a function of physical configurations of displays, but our findings on the observing response have implications for display design Although not always explicitly discussed in this report, we found in three studies (Adams and Boulter, 1960; Adams and Humes, 1963; Adams, Stenson, and Humes, 1961) that a signal occurring in a source that was separated from a clustering of the others resulted in a longer response latency It was evident that subjects were unduly focussing on clusters of sources and were temporarily ignoring those sources that were spatially separated from others Adams and Boulter (1962, 1963) found related findings on the spatial separation of sources Adams and Boulter (1962) had the spatial separation of four stimulus sources as an experimental variable, and they found that mean performance worsened as spatial separation increased The greater the demand on the visual observing response, the poorer the performance. Similarly, Adams and Boulter (1963) found that spatial uncertainty, which placed heavy demands on the visual observing response for continually searching the display, had a damaging effect on monitoring proficiency In one way or another, these findings all document the significance of the observing response for proficiency in tasks where visual monitoring is required Any design feature of a task which reduces the amount of visual observing should be a significant contributor to vigilance performance, according to our findings One way of accomplishing this is to have close spacing of multiple stimulus sources on the display, and another is display integration where a single display substitutes for two or more separate ones While the advantages of closely spaced sources and integrated displays are known in engineering psychology, our research demonstrates that a reason for these advantages is the lowered demands for an active observing response.

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HQ ESD, L.G. HANSCOM FIELD, BEDFORD, MASS.
ESD TDR 63-320 EXPERIMENTAL STUDIES OF HUMAN VIGILANCE. FEBRUARY 1963, P 35 INCL FIGS
UNCLASSIFIED REPORT

A series of experiments was conducted on human vigilance or the characteristics of long-term human attentiveness for the occasional occurrences of signals which are to be detected and reported. Emphasis was given complex visual displays with multiple stimulus sources and alpha-numeric signals of the general class found in semi-automatic man-machine systems. Two major devices were developed for the laboratory study of vigilance, and periods of continuous watching were from 2.5 to 3 hours. Some experiments tested the arousal hypothesis which holds that alertness depends on the level of environmental or internal, response-produced stimulation associated with the task. Other experiments studied the effects of temporal and spatial uncertainty of signal occurrence, the effects of repeated daily sessions, and a method for training vigilance behavior to effect a relatively stable improvement in visual monitoring.

1. HUMAN ENGINEERING
2. ATTENTION
3. REACTION (PSYCHOLOGY)
4. BEHAVIOR

I PROJECT 9678, TASK 967803

II AF19(604)5705

III AVIATION PSYCHOLOGY LAB,
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ESD TDR 63-320 EXPERIMENTAL STUDIES OF HUMAN VIGILANCE. FEBRUARY 1963, P 35 INCL FIGS
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A series of experiments was conducted on human vigilance or the characteristics of long-term human attentiveness for the occasional occurrences of signals which are to be detected and reported. Emphasis was given complex visual displays with multiple stimulus sources and alpha-numeric signals of the general class found in semi-automatic man-machine systems. Two major devices were developed for the laboratory study of vigilance, and periods of continuous watching were from 2.5 to 3 hours. Some experiments tested the arousal hypothesis which holds that alertness depends on the level of environmental or internal, response-produced stimulation associated with the task. Other experiments studied the effects of temporal and spatial uncertainty of signal occurrence, the effects of repeated daily sessions, and a method for training vigilance behavior to effect a relatively stable improvement in visual monitoring.

1. HUMAN ENGINEERING
2. ATTENTION
3. REACTION (PSYCHOLOGY)
4. BEHAVIOR

I PROJECT 9678, TASK 967803

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