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**CONTROLLED AND AUTOMATIC PROCESSING
DURING TASKS REQUIRING SUSTAINED ATTENTION:
A NEW APPROACH TO VIGILANCE**

Arthur D. Fisk and Walter Schneider

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HUMAN ATTENTION RESEARCH LABORATORY

Psychology Department
University of Illinois
Champaign, Illinois 61820

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20. automatic processing and significant decrements in control processing. A second experiment replicated the first and showed the control processing performance vigilance decrement reduced when memory load was increased and number of channels was decreased. A third experiment showed that when subjects were required to continually and consistently allocate controlled processing resources to display locations the vigilance decrement was maximal. The results disconfirm the habituation of neural responding vigilance hypothesis. The results indicate vigilance decrements are largest when subjects must consistently apply control processing resources. Suggestions are made for structuring tasks in order to obtain maximal sustained performance when observers are faced with tasks requiring vigilance over extended periods of time. Methods for developing automatic processing to minimize vigilance decrements are proposed.

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Controlled and Automatic Processing
During Tasks Requiring Sustained Attention:
A new approach to vigilance

Arthur D. Fisk and Walter Schneider

Report 8006

Human Attention Research Laboratory

University of Illinois

February 9, 1980

Abstract

Vigilance has been investigated in a variety of settings using a multitude of independent and dependent measures (see Mackworth (1970) for a review). Vigilance experiments typically show a decrease in detection performance as the period of target monitoring increases; but, many experimental conditions do not show a vigilance decrement. This investigation attempts to predict when a vigilance decrement will occur by analyzing performance within the automatic and controlled processing perspective (Schneider and Shiffrin, 1977). The normal observed vigilance curve is assumed to be composed of a controlled process vigilance decrement, a simple task practice effect, and in some instances automatic process learning. This analysis explains some conflicts in the vigilance literature. An experiment which examined vigilance decrements found no significant decrement in automatic processing and significant decrements in control processing. A second experiment replicated the first and showed the control processing performance vigilance decrement reduced when memory load was increased and number of channels was decreased. A third experiment showed that when subjects were required to continually and consistently allocate controlled processing resources to display locations the vigilance decrement was maximal. The neural habituation hypothesis of vigilance decrements was disconfirmed. The results suggest vigilance decrements are largest when subjects must consistently apply control processing resources. Suggestions are made for training operators and structuring tasks in order to obtain maximal sustained performance when observers are faced with tasks requiring vigilance over extended periods of time.

Schneider & Shiffrin (1977) and Shiffrin & Schneider (1977) have proposed two distinct types of information processing. One, called automatic processing, is thought to be a parallel search, not limited by short term memory, and requires minimal effort. The other, called controlled processing, is high in its attentional demands, requires a limited comparison rate serial search, and is highly dependent on load. Since automatic processes require minimal effort, no vigilance decrement is expected in experiments measuring automatic process performance. However, tasks requiring effortful controlled processing would be expected to show a vigilance decrement. The automatic/controlled processing framework predicts when either process is expected and therefore predicts when a vigilance decrement is expected.

In light of the data presented by Schneider and Shiffrin (1977) the present research investigated performance differences between the two above mentioned types of human information processing, controlled processing and automatic search (detection), in a setting where the observers were required to remain vigilant for a 50 minute time period. By utilizing an experimental design where both automatic and controlled processing could be employed (at different time periods) a priori predictions were made concerning performance. In brief, the normal decrement in performance as time passes should not be detected when the observer can rely on automatic processing. But, one would expect to see a vigilance decrement when the observer is forced to control process the stimuli throughout the watch.

A necessary condition for the development and subsequent efficient utilization of automatic processing is that subjects must have extensive practice (e.g., 200 target detections per member of the target set) and must be able to deal with the target stimuli in a consistent manner. In consistently mapped (CM) conditions, target stimuli occur only as targets and never as distractors. Controlled processing must be utilized when the stimuli cannot be dealt with in a consistent manner. This occurs when the stimuli are varied in their mapping (VM), sometimes occurring as targets and sometimes functioning as distractors. In this situation controlled processing is expected (see Schneider and Shiffrin, 1977).

One of the confoundings often introduced in vigilance research is the potential for practice effects occurring during the session for poorly trained subjects. Figure 1 shows what components might be operating to generate a vigilance curve. Figure 1a presents a theoretical controlled processing vigilance decrement. Figure 1b shows a predicted improvement of performance (controlled processing) due to simple practice effects. Figure 1c represents a hypothesized controlled processing vigilance curve given the combination of "actual" vigilance decrement (1a) and effects of practice (1b). Note, there is still a "vigilance decrement" portrayed in Figure 1c but it is much attenuated from the vigilance drop shown in Figure 1a. Figures 1d and 1e represent the effect of using a task which may become automatized. Figure 1d shows automatic processing development for three tasks. Task 1 is more readily automatized than task 2 or 3 within a vigilance session (e.g., memory set size one versus memory set size four). Figure 1e shows that depending on the amount of automatic processing learning performance may improve, remain stable, or decline as a function of time on the task. The point of this example is that researchers must concern themselves with both the effects of practice and the type of

vigilance task. In the typical experiments carried out in our laboratory we routinely observe the effects portrayed in Figures 1b and 1d. The size and time course of the effects depends on specific experimental manipulations.

 Insert Figure 1 about here

A brief review of the vigilance literature reveals that often in experiments where the stimuli may be dealt with in a consistent manner no decrement is observed. In addition to the consistency of the stimulus mapping, the experimental design must be such that automatic processing can be developed within the time constraints of the experiment. For example, Childs (1976), using auditory presentation, presented subjects with either a "simple" signal condition (the target would always be a 7) or a "complex" condition where the signal was either a 2, 4, 7, 8, 11, 14, or 18. These conditions were factorially combined with instructions that either specified the target(s) or left them unspecified. For the unspecified condition subjects were told to respond to any number below 19. The background events, or distractors, were the numbers 19 or above.

The subjects in the Childs experiment participated in only one 50 minute session. All conditions mapped the target(s) consistently; but, one would expect the simple conditions to allow the development of an automatic process more quickly than others. Childs' data indicate no drop in performance over time for the simple-specified condition, a slight decrement for the simple-unspecified, and about a 10 percent drop in performance (from beginning time period to the last time period) for the complex conditions.

A study by Smith, Lucaccini, Groth, & Lyman (1966) and one by Lucaccini, Freedy, & Lyman (1968) used a task that required subjects to respond to a blackened square which contained a certain appendage. Distractors consisted of blackened squares with no appendages, an appendage in the wrong place, or more than one appendage. Each subject participated in a one hour session. Both of these studies reported no vigilance decrement. Again, an argument can be made that the target stimuli were consistently mapped as targets, resulting in an interaction between the effects of time and the development of a different mode of information processing; thus, the flat function over time.

The performance stability in the above mentioned studies could be due to simple practice effects and not due to the rudimentary development of an automatic process. This problem is eliminated with the present experiments because extended amounts of practice were given to subjects in all experimental conditions. Subjects were practiced sufficiently such that the control process practice effect (Figure 1b) and automatic process learning effects (Figure 1d) will have asymptoted allowing examination of the actual vigilance decrement (Figure 1a).

In sum then, the purpose of the present research was to test the notion that once a subject had developed an automatic process, subsequent search in a vigilance task, for the consistently mapped stimuli, would show little or no decrement as time passed during the watch. Since subjects also participated in conditions that required controlled search of the stimuli (the varied mapping

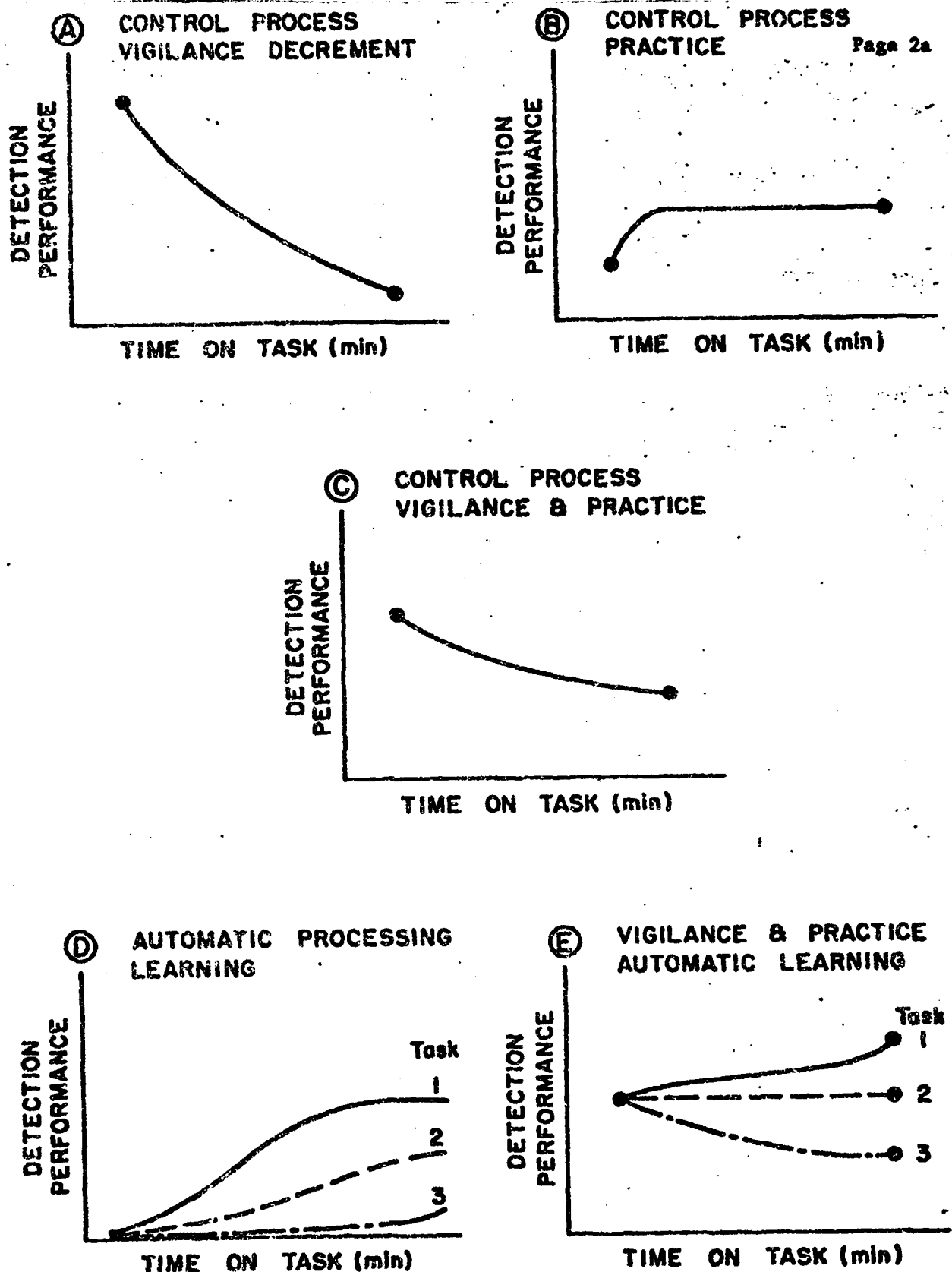


Figure 1. Hypothesized components of vigilance curves. A - assumed "Actual" control processing vigilance decrement. B - control processing practice improvement. C - potential observed vigilance decrement which is a convolution of curves A and B. D - assumed automatic processing learning improvement for three different tasks where automatic processing develops at different rates. E - the combination of the vigilance decrement due to control processing, the practice effect, and automatic process learning (figures A, B, and D).

condition), the relationship between simple practice effects and type of processing mode could be controlled and evaluated.

Experiment 1

Method

Subjects. Five University of Illinois students (one male) were paid for their participation in this experiment. All subjects had normal or corrected to normal 20/20 vision and reported English as their first language.

Equipment. The experiment was controlled by a Digital Equipment Corporation PDP 11/34 computer. The computer was programmed to present the appropriate stimuli, collect responses, and control timing of the display presentation. The stimuli were presented on Tektronics Model 604 cathode ray scopes which contained P-31 phosphor. Each subject wore a headset through which white noise (80 db) was carried. An error tone, used during training, was delivered through the headset.

Stimuli. The characters used in the present experiment were digits and upper case letters of the English alphabet. The characters were constructed from dots on a rectangular grid 32 dots wide by 48 dots high. The character size was .52 degrees in width and .58 degrees in height. The refresh rate of the dots making up the stimuli was 10 msec. The display of the characters was divided into frames where each frame consisted of four characters positioned to form a square around a center fixation dot. The subjects sat 46 centimeters from the CRT display. The distance from the focus dot to the center of each character was one degree visual angle. Three of the subjects were assigned the digits 2, 3, 5, 6, 8, and 9 as their CM character set and the letters A, C, E, M, R, and S as their VM character set. This was reversed for the other two subjects.

Design. The primary independent variables manipulated were the following: 1) The mapping of the stimuli, being either varied or consistent. This was a between session variable. 2) The number of target stimuli per 30 sec interval. Either zero, one, two, or three target stimuli occurred between memory set displays (i.e., every 30 sec). Fifty percent of the 30 sec intervals contained no targets, 20 percent contained one and 20 percent two targets, and 10 percent of the intervals contained 3 targets. 3) Frame time, the time from the onset of one frame to the onset of the next frame, was 240 msec for the VM condition and 100 msec for the CM condition. (The faster frame time for the CM condition was needed to eliminate ceiling effects as CM performance is generally far superior to VM performance (see Schneider and Shiffrin, 1977)).

Although the task appeared continuous to the subjects, for scoring purposes the data were grouped into 10 minute intervals. There were 18 target stimuli presented per ten minute interval in both the VM and CM conditions. Since there were differential frame times, a ten minute interval consisted of 2500 frames in the VM condition and 6000 frames in the CM condition. If each frame is defined as an event, the probability of a target was .007 and .003 per event in the VM and CM conditions, respectively.

Training Procedure. Prior to the actual vigilance experiments, the subjects participated in nine 50 minute training sessions (approximately 4000 trials). The purpose of the training was to develop an automatic process to the consistently mapped character set. All training sessions contained discrete trials of 12 frames per trial. The memory set size was one for the first seven and the ninth sessions. The eighth training session used a memory set size of two. For the first six sessions of practice a target occurred on every trial. The trial type, either CM or VM, was manipulated between trials. Performance feedback of two types was given to the subjects: 1) Error feedback consisted of a tone burst given through the subject's headset and the illumination of a red light (LED) on the subject's response box. The error feedback was given when the subject incorrectly indicated the target's display position. 2) Accuracy feedback was of three types. First, when the subject correctly indicated the target's location a random dot pattern would appear to spin off the screen from the target's location. Second, the subject's current accuracy for the block, indicated by a two digit number, was presented along with the memory set display. The accuracy level was initialized to zero at the beginning of each block of trials. Third, a "skill" rating which corresponded to a given accuracy level was given to the subject. The ratings and the accuracy level needed were: 100-90, Ace; 89-80, Expert; 79-60, Average; 59 & below, Novice. The "skill" rating was initialized to zero at the beginning of each trial block. The feedback procedure was utilized to maximize the development rate of automatic detection.

The remaining training sessions (7-9) were different from the first six in the following ways. CM and VM trials changed between blocks. The targets were presented in only 50 percent of the trials. Subjects received accuracy feedback as before, but the spin off and skill rating were eliminated. The error tone feedback was the same as before. Finally, in addition to the practice sessions, the subjects participated in one 50 minute vigilance task which corresponded to the actual upcoming vigilance sessions. This was included to help eliminate contrast effects due to a drastic reduction in signal frequency (see Colquhoun and Baddeley, 1967).

For all training sessions, the subjects initiated each trial by pushing a button with their left index finger. Upon detection of the target, the subjects were required to press a button on their response box that corresponded to the target's location in the target frame. The buttons were positioned to form a square on the response box with the display positions and the buttons representing a one-to-one mapping. The subjects were given up to 2.5 seconds from the onset of a target frame to respond. If no target was detected the subjects were instructed to guess at the end of the display sequence.

Testing Procedure. Following the initial training to develop an automatic process to a given set of characters, the subjects participated in the vigilance task. In the vigilance task subjects were presented with a memory set item for approximately one second. The memory set was followed by the presentation of a fixation dot for 100 msec which was followed by the presentation of the "trial" frames. This frame sequence continued for 30 seconds. For any given 30 sec presentation a target could not occur during the first four or last 2.4 seconds. (Subjects were not told about this fact.) The targets were also required to lag the presentation of a previous target by at least three seconds. When three

targets occurred during a given 30 sec period the last target was forced to occur in the final one-sixth of the legitimate frames. This restriction was meant to guard against the subjects "giving up" as a trial progressed simply because they by chance never received a target in the latter part of the 30 sec interval. The subjects were not informed concerning the number of targets that could occur. They were simply told that multiple targets might occur between memory set presentations.

Subjects were required to press a button on the response box that corresponded to the target's location in the target frame. The subjects were given up to 2.5 sec from the onset of a target frame to respond in order to have the response recorded as a hit. No performance feedback was given to the subjects.

Order of CM and VM conditions was counterbalanced such that two of the subjects began with the VM condition. The subjects participated in one session of each processing mode condition per day, and participated for two days. Subjects were tested in groups of two.

Evaluation of the data. The theory of signal detection (TSD) has often been used to evaluate observers' sensitivity (ability) to distinguish between signals and noise. Recently, the TSD measure of sensitivity, d' , has been criticized because of problems of validity and reliability when derived from vigilance data (see Craig, 1979a). Swets and Kristofferson (1970) have recommended the use of nonparametric sensitivity measures rather than d' . A' was chosen as the measure of sensitivity for the current experiments because it is more robust than d' to violations of distribution assumptions and is, therefore, a more appropriate index of sensitivity when a small number of signals are presented and a low rate of false alarms are observed (see Craig, 1979a; Norman, 1964, for a review). The use of A' necessitates the knowledge of hits and false alarms. Since the vigilance task is continuous, or nearly continuous, a problem arises in specifying the false alarm rate (because we must assume the number of false alarm intervals). Kessel and Wickens (1978) summarized techniques available which deal with this problem. They suggest employing a modification of the method of free response called the method of undefined intervals. This technique allows the breakdown of the continuous flow of events into discrete intervals.

In the present experiment the hit interval was defined to be up to 2.5 sec from the onset of the target frame. False alarm intervals were similarly defined as intervals of 2.5 seconds which did not contain a target. A subject could have only one hit per hit interval but each button push not defined as a hit was recorded as a false alarm. The probability of a hit was calculated by dividing the number of hits by the number of targets occurring during a 10 minute interval. The probability of a false alarm was calculated by dividing the number of false alarms per 10 minute interval by the number of false alarm intervals during that period.

Results. Figure 2 shows the percentage of targets detected for both the CM and VM conditions at each time interval. An analysis of variance was conducted on the corresponding frequency data (a processing mode X time X subject repeated measures analysis). The relevant analysis for the conceptual purpose of the

research is the interaction between processing mode and time. This interaction was significant [$F(4,16)=3.463$, $p<.05$]. An analysis of the simple main effects revealed that time had a slight effect on performance in the automatic processing condition [$F(4,16)=3.11$, $p<.05$]; but the effect of time was much greater for the controlled processing condition [$F(4,16)=26.57$, $p<.001$]. As can be seen from Figure 1, the significant time X processing mode interaction is due primarily to the accelerated drop in controlled processing performance.

 Insert Figure 2 about here

The averaged sensitivity data, A' , are presented in Figure 3. An A' of 1.0 represents perfect detection sensitivity and .5 chance performance. These data were evaluated in a manner similar to the performance measure presented above. An arcsin transform was performed on the individual subjects' A' scores and then entered into the analysis. The processing mode X time interaction was significant [$F(4,16)=3.91$, $p<.025$]. An analysis of the simple main effects revealed that time had an effect on the subjects' sensitivity when performing in the controlled processing condition [$F(4,16)=28.15$, $p<.001$]. The effect of time in the automatic processing condition did not reach statistical significance [$F(4,16)=2.25$, $p>.05$].

 Insert Figure 3 about here

Discussion. The hit rate data (the "raw" performance measure) clearly indicate that a vigilance decrement was observed when subjects were required to utilize controlled processing. It is apparent, from Figure 2 and the analysis of the simple main effects of time, that the subjects were much more resistant to a vigilance decrement when they were able to utilize automatic processing to perform the detection task. The drop in performance in the controlled processing condition is 2.25 times greater than the vigilance decrement in the automatic processing condition. Also of interest is the effect of time on the task sensitivity decrement in the two conditions. This measure indicates that the decrement in performance is due to a drop in sensitivity when the subjects participated in the controlled processing condition. This is not the case for the automatic processing condition. Since a reliable non-parametric response criterion measure is not available (Richardson, 1972), it can only be inferred (and not shown) that the slight drop in performance in the automatic processing condition is due to a shift in the subjects' response criterion. This seems a reasonable assumption given the stability of the sensitivity measure over time for this condition. Another possibility is that the slight drop in performance, as measured by the number of targets detected, in the automatic processing condition was due to the subjects employing a controlled processing check after attention was drawn to the target.

The results of experiment 1 are consistent with our predictions; that is, the normal decrement observed in tasks requiring sustained attention is due to the inability to maintain controlled processing of the stimuli. When automatic processing may be utilized to perform the detection task, little performance decrement is observed. Sensitivity remained stable in the automatic processing condition indicating that it could be possible to eliminate even the slight

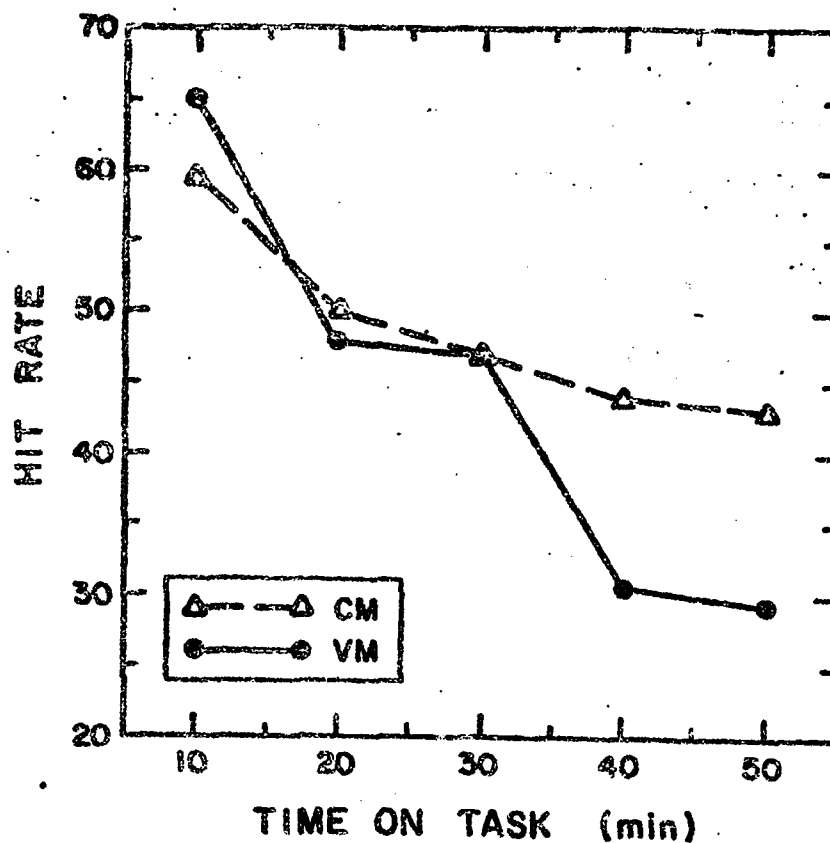


Figure 2. Experiment 1 hit rate for consistently mapped (CM) and variably mapped (VM) conditions. Memory set size was 1, frame size 4, frame time 100 msec CM and 240 msec VM.

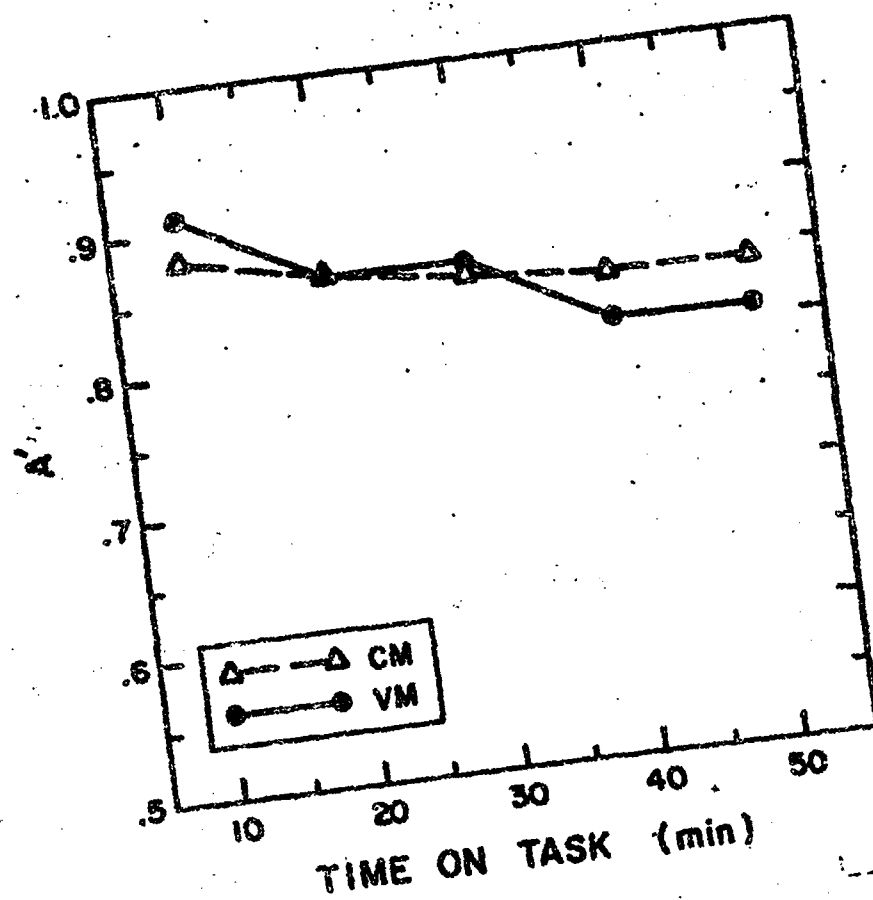


Figure 3. Experiment 1 A' detection sensitivity results.

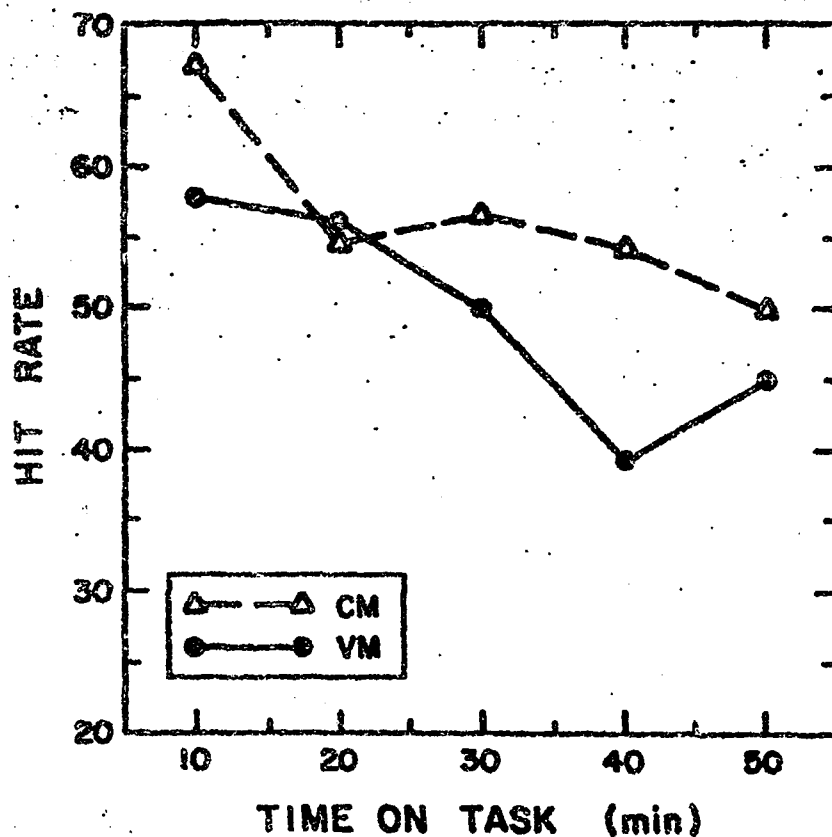


Figure 4. Experiment 2 hit rate for consistently mapped (CM) and variably mapped (VM) conditions. Memory set size was 2, frame size 2, frame time 100 msec CM and 300 msec VM.

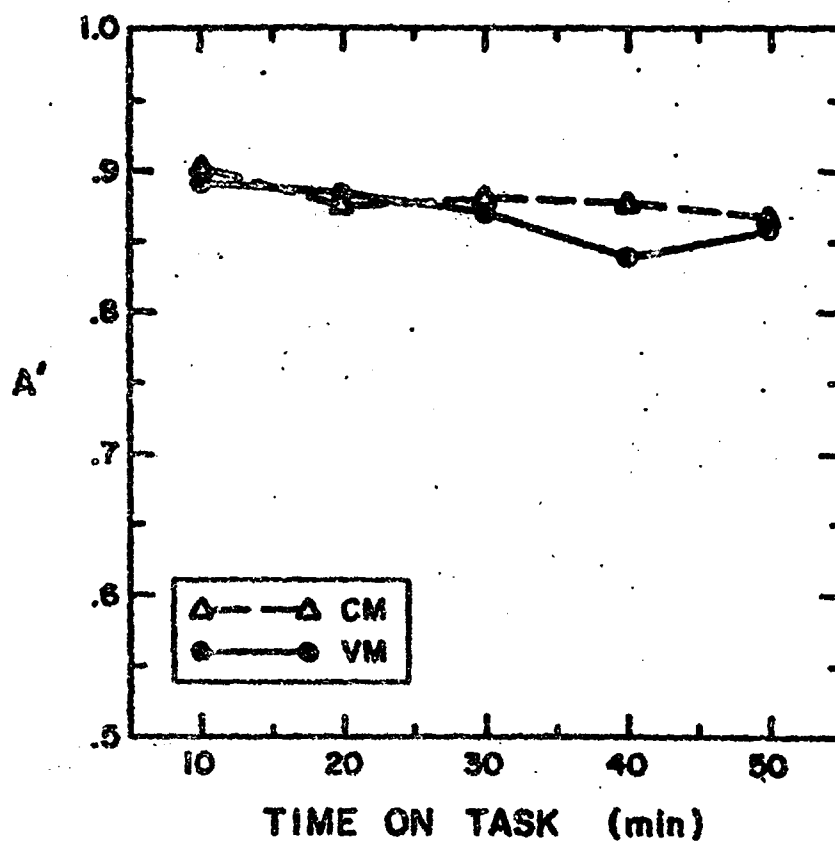


Figure 5. Experiment 2 A' detection sensitivity results.

performance decrement through proper training.

Parasuraman (1979) has proposed that a primary determinant of vigilance decrement occurs when the task requires utilization of short term memory. The next experiment was designed to examine the effect of memory load in both the controlled and automatic processing conditions. In order to maintain a reasonable frame time (event rate) in the controlled processing condition, it was necessary to reduce the frame size to two (see description below). Therefore, the subjects were presented with a different "visual environment". In addition to the effect of memory load, the following experiment looked at the stability of the previous results (and predictions) across different display characteristics.

Experiment 2

The primary difference between the first experiment and the second experiment is that the memory set size and frame size were two. Random dot patterns occurred as "place holders" in the display positions not containing characters. The actual display positions of the characters were randomly assigned for each frame. The procedure and evaluation of the data were the same as the previous experiment. As in Experiment 1, each subject participated in each condition (controlled/automatic processing) once per day for a total of two days. All subjects, stimuli, and equipment were the same as described in Experiment 1. The frame time for the VM condition was increased to 300 msec. Therefore, each 10 min interval contained 2000 frames. If each frame is considered an event, the probability of a target was .009 per event. The CM frame time remained at 100 msec as in Experiment 1.

Results. Performance, represented by percentage of hits, is shown in Figure 4. The analysis was conducted as in Experiment 1 and revealed a significant main effect of time [$F(4,16)=4.249$, $p<.025$]. Neither the main effect of processing mode nor the interaction reached significance at the .05 level.

Insert Figure 4 about here

The data presented in Figure 5 show the level of sensitivity (A') for each processing mode at each time period. The analysis of variance performed on the transformed A' scores (arcsin transform) indicates the same pattern of results as shown above for the performance measure. That is, there was a significant main effect of time [$F(4,16)=3.99$, $p<.025$] with the main effect of processing mode and the interaction not reaching significance at the .05 level. A post hoc analysis (Newman-Kuels) revealed no difference in sensitivity at any time period for the automatic processing condition. There was a reliable difference ($p<.05$) between the first time period and the 40 minute period for the controlled processing condition.

Insert Figure 5 about here

Discussion. The present experiment offers an interesting comparison to Experiment 1. In this second experiment, absolute performance decrements did not differ between the two conditions (VM-.18, CM-.17) and did not differ from the automatic processing condition in Experiment 1 (.16 drop).

Relative to Experiment 1, the present vigilance task positively affected the controlled processing performance (.36 decrement Experiment 1 compared to .18 Experiment 2) but left performance in the automatic processing condition unchanged (in terms of absolute vigilance decrement). This demonstrates the performance stability of the automatic processing mode and the susceptibility of controlled processing to task manipulations. The underlying reason for the slight vigilance decrement obtained in the present experiment is a decrease of sensitivity for the task requiring controlled processing; but, as in the previous experiment, the automatic processing condition did not show a sensitivity decrement. This indicates the use of different processing modes. The controlled processing vigilance decrement, although slight in the present experiment, seems due to the inability of the observer to allocate processing resources to the task at hand. This notion is examined further in the General Discussion. The automatic processing vigilance decrement, which was small in both experiments, is not due to a decrease in sensitivity. Other factors, such as a shift in the observer's response criterion or perhaps extraneous factors like eye blinks, may have caused the performance decrement observed in the automatic processing condition.

In terms of Parasuraman's analysis of vigilance and memory load, a larger vigilance decrement should have been observed for the controlled processing condition in the present experiment than seen in Experiment 1. The present results are not in line with the analysis by Parasuraman (1979). However, the data cannot be used to dispute his claim since the "visual environment" was not consistent across the two experiments.¹

The results of Experiments 1 and 2 suggest that the source of vigilance decrement is the requirement that observers continually and consistently allocate controlled processing resources to the task at hand. The next experiment directly tests this assumption by requiring observers to search for targets when events (distractors) are presented randomly in one of four display locations or two fixed display locations. The habituation theory (see Mackworth, 1968) is tested by alternating the presentation diagonal on a frame by frame basis.

Experiment 3

Method

Subjects. Eleven students (three males) from the University of Illinois were paid for their participation in this experiment. All subjects had normal or corrected to normal 20/20 vision and reported English as their native language.

Design. All experimental conditions varied the mapping of targets and distractors thus requiring controlled processing. Memory set size was two and

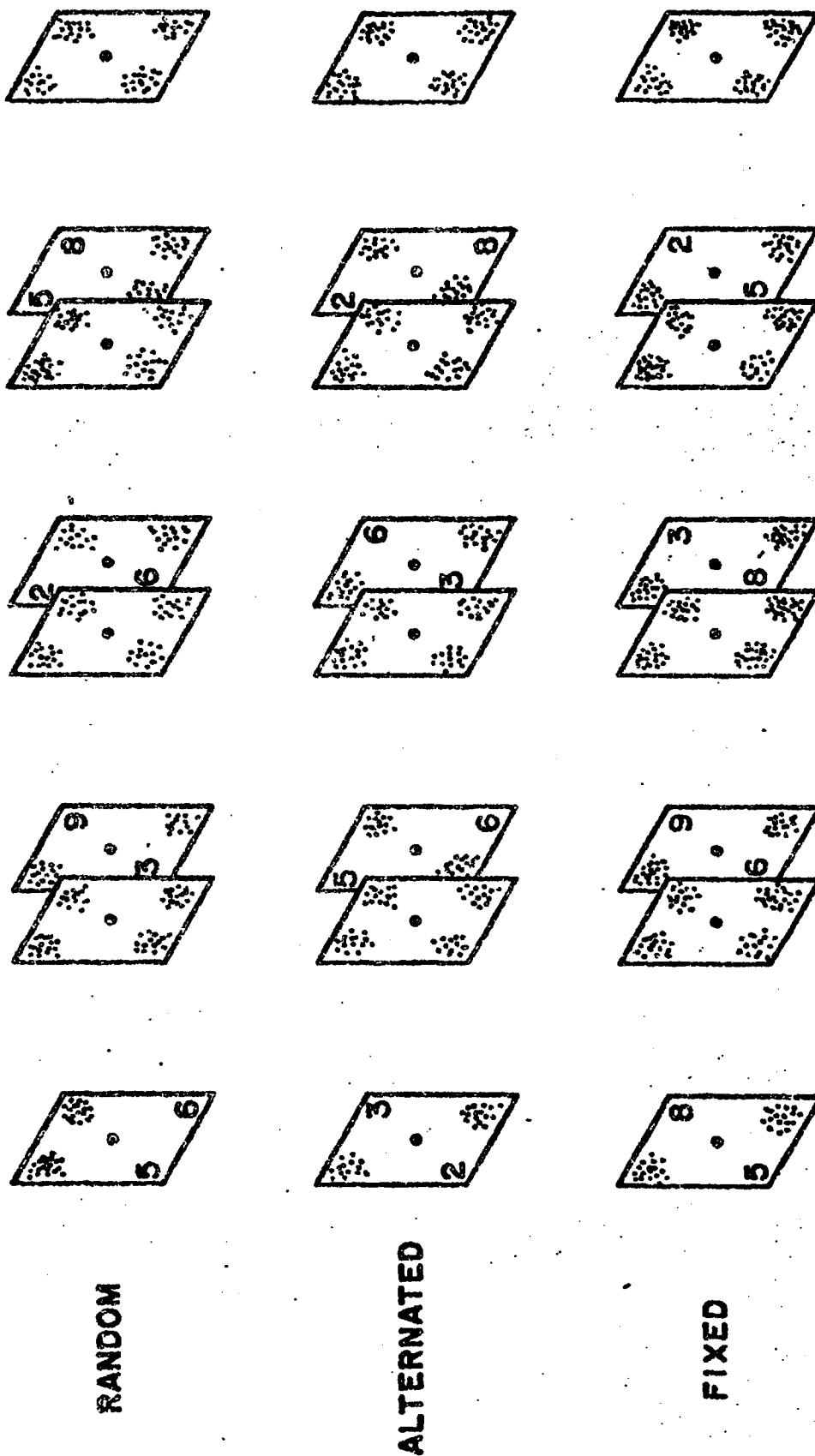


Figure 6. Examples of the display characteristics for the search condition used in Experiment 3. Spacing of the frames represents time being 270 msec for presentations of the character displays and 30 msec for the intervening mask frames.

frame size was two. Frame time was 300 msec for all experimental conditions. The frames were constructed as in Experiment 2. The primary independent variable manipulated was the search condition being either random, alternated diagonal, or a fixed diagonal (see Figure 6). The Random search condition (RS) was a replication of the VM search condition used in Experiment 2. That is, character display positions were randomly determined with the restriction that the same character was not presented in the same display position on two successive frames. Dot patterns occurred as place holders in the display positions not containing characters. During the Alternated diagonal search condition (AS) characters were presented on first one diagonal and then the other, the alternation being on a frame by frame basis. The diagonal not containing characters contained random dot patterns. This condition was included as a test of the habituation hypothesis since perceptual channels were cleared every other frame. The Fixed diagonal search condition (FS) presented characters on one diagonal of the display for the entire vigil with dot patterns used as place holders on the other diagonal. Which diagonal was to be searched was counterbalanced across the subjects. The manipulation of the search conditions was within subjects with order of participation in the conditions controlled by a Latin square. In addition, whether the subject's character set was letters or numbers was counterbalanced across subjects. (Note, due to loss of one subject the letter character set and the search condition participation order AS, FS, RS was not completely represented.)

 Insert Figure 6 about here

Training Procedure. All subjects participated in two hours of training where all search conditions were equally represented. The training was divided into two 50 minute sessions. The first 30 minutes of the first session utilized a target probability (per trial) of 50 percent. This was followed by a target probability of .009 which was the same as the target probability used during the actual vigilance experiment. During the training sessions there were only 12 frames presented between each memory set presentation. There was only one target presented during a trial if it was a target trial. The memory set was displayed for one second after which the trial frame sequence began. The subjects did not initiate the trials themselves and no performance feedback was given during training.

Testing Procedure. The procedure for the vigilance task was the same as Experiment 2 with the following exceptions. The fixation dot was presented for 500 msec subsequent to the memory set display and prior to the frame sequence. Each subject participated in two 50 minute vigilance sessions per day separated by at least one hour. All subjects participated during the same time periods each day. Each subject was assigned to a search condition presentation order and went through this order twice.

The equipment, stimuli and evaluation of the data were the same as the previous experiments.

Results. The subjects' performance during the vigil, represented as percentage of targets detected, is presented in Figure 7. (One subject's data from the second session of the AS condition and one subject's data from the

second session of the FS condition were deleted because they fell asleep during these vigilance sessions.) The analysis of the performance data revealed a significant main effect of search conditions [$F(2,20)=8.8724$, $p<.002$] and a significant main effect of time [$F(4,40)=47.6922$, $p<.00001$]. The interaction between experimental conditions and time was significant [$F(8,80)=2.589$, $p<.015$]. Simple main effect analysis indicated that there was a significant difference in ability to detect targets across the search conditions at the 30 minute point [$F(2,20)=21.55$, $p<.0001$] and at the 50 minute point [$F(2,20)=6.33$, $p<.0075$]. Ability to detect targets decreased with time in all search conditions with $p<.001$ in all cases.

Insert Figure 7 about here

The averaged sensitivity data (A') are presented in Figure 8. All conditions show a decrease in sensitivity as time passed during the vigil with the AS condition showing the fastest and most severe sensitivity decrement. The analysis of variance on the transformed A' scores (Arcsin transform) revealed a main effect of both search conditions and time [$F(2,20)=5.9403$, $p<.01$ and $F(4,40)=38.8052$, $p<.00001$], respectively. The interaction between search conditions and time was marginally significant, $F(8,80)=1.9624$, $p=.061$. The analysis of the simple main effects indicated a pattern similar to the hit rate analysis. There was a significant difference in sensitivity across the search conditions at the 30 minute point [$F(2,20)=16.53$, $p<.0001$] and at the 50 minute point [$F(2,20)=4.95$, $p<.02$]. Sensitivity decreased with time in all search conditions with $p<.01$ in all cases.

Insert Figure 8 about here

Discussion. The purpose of Experiment 3 was to test the hypothesis that tasks requiring continual and consistent allocation of controlled processing resources lead to maximal vigilance decrement. This hypothesis was confirmed by both the performance measure (hit rate) and the measure of perceptual sensitivity (A') of the AS and FS conditions when compared to the RS condition. The habituation hypothesis which argues that vigilance decrement is due to the habituation of neural responding (Mackworth, 1968) was not supported by the present data. The AS condition, which showed the largest decrement in sensitivity and a performance decrement equivalent to the FS condition, cleared the perceptual channels on alternating frames. If neural habituation in the visual channel were the cause of the vigilance decrement the AS condition would have been superior to the FS and RS conditions, but it was clearly not.

Subjective reports and subject concentration problems confirm the empirical data showing consistent control processing is difficult. Many subjects stated that performance in the AS and FS conditions was easier than the RS early in the vigil, but that it was harder to maintain concentration in these conditions as time passed. Subjects indicated Experiment 2 (RS search) was less boring than Experiment 1 (FS search). Perhaps the strongest evidence illustrating the difficulty of maintaining concentration in AS and FS search is that one subject in each condition fell asleep (Experiment 3). These "sleeper" subjects were generally good subjects and were embarrassed about their performance. These two

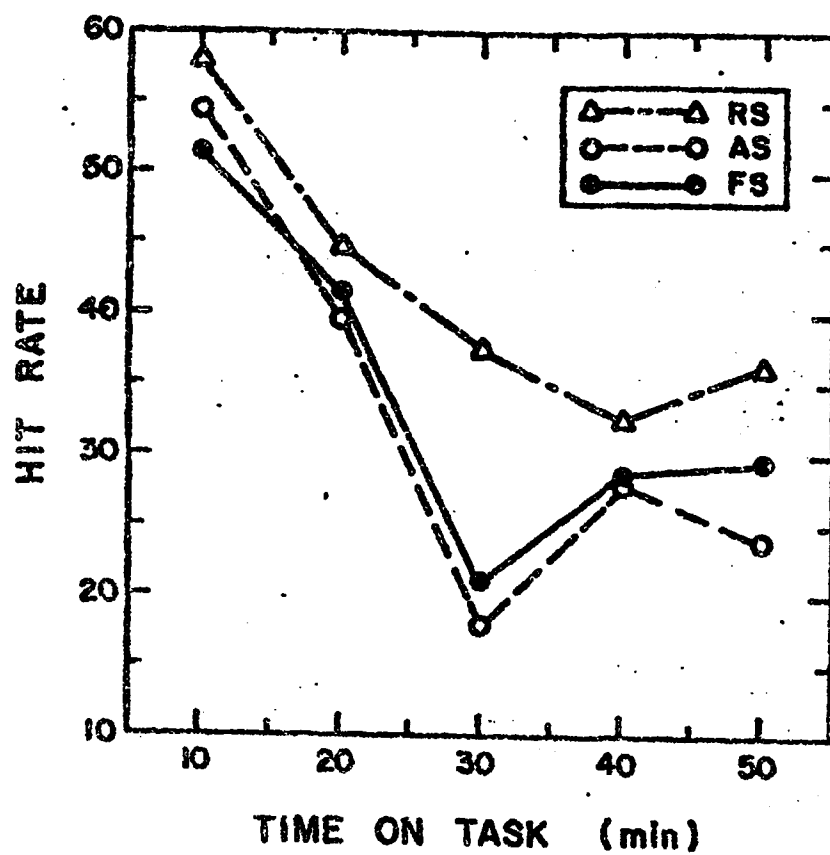


Figure 7. Experiment 3 hit rate for random search (RS), alternated diagonal search (AS), and fixed diagonal search (FS) conditions.

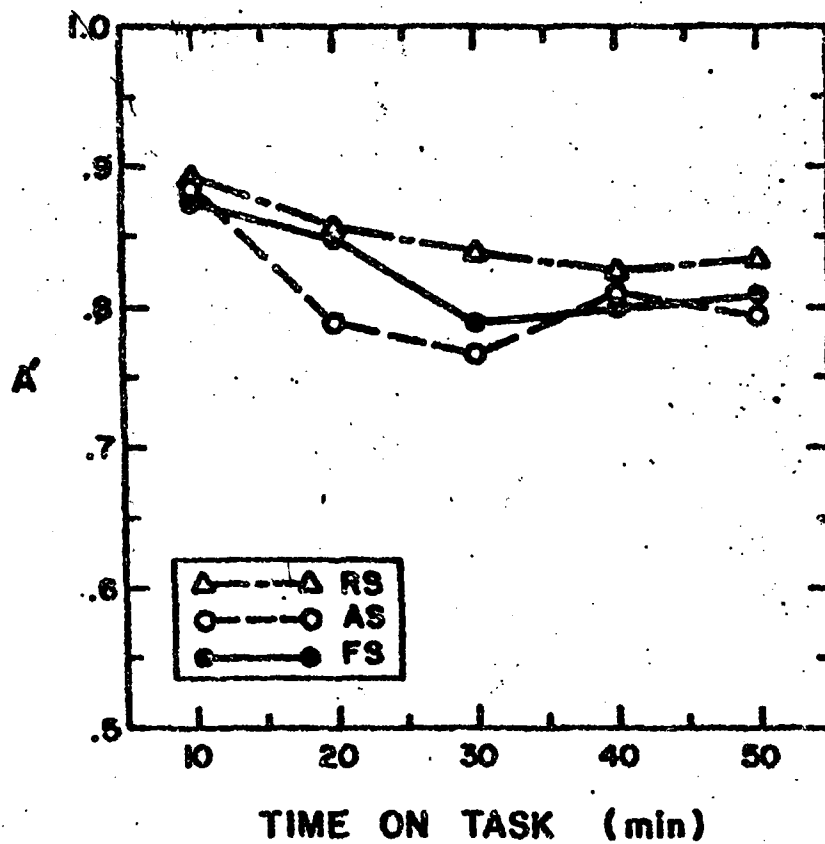


Figure 8. Experiment 3 detection sensitivity (A') data for the random search (RS), alternated diagonal search (AS), and fixed diagonal search (FS) conditions.

cases of an inability to remain awake while consistently control processing suggest the difficulty of such processing.

It is interesting to note that the AS condition showed a performance and a sensitivity decrement (maximum decrement) exactly the same as the VM condition in Experiment 1. This would indicate that a fixed display with all channels conveying information is equivalent to a display that alternates information across the channels in a consistent pattern (at least up to a frame size four).

The present data may help explain why monitoring performance ret to a level at or above that observed during the beginning of a session when the vigil is interrupted and observers are given a message (Mackworth, 1948). When the observers receive a message they presumably reallocate their controlled processing resources to encode and interpret the message. The shifting or reallocation of controlled processing resources seems to be sufficient to break the vigilance decrement for at least a brief period. Support for this argument is given by the differences between the RS and both the AS and FS conditions. The reason for the drop in the RS condition is that controlled processing must be allocated to the task at hand whereas in the Mackworth "interruption" resources are shifted to an entirely different task.

General Discussion

Apparent conflicts in detection, search and attention literature have recently been resolved by proposing a two-process theory of human information processing. (See Schneider and Shiffrin, 1977; Shiffrin and Schneider, 1977.) It was shown by Schneider and Shiffrin that subjects could process information utilizing one of two quantitatively and qualitatively distinct processing modes. Which mode was used was dependent on the target to distractor mapping. If the subjects could deal with the target stimuli in a consistent manner, then automatic processing would be employed. Otherwise, controlled processing had to be utilized.

Given the present data, a similar statement seems appropriate in regards to the vigilance literature. That is, if the experimental design is such that the mapping of the target stimuli is consistent then an automatic process may develop. If this occurs then little or no decrement is expected during the vigil. When the vigilance task is designed such that controlled processing must be used throughout the watch then a vigilance decrement, due to a decrease in perceptual sensitivity, is expected. In other words, this variable, the mode of information processing, must be carefully considered when examining data across experiments.

Craig and Colquhoun (1977) and Craig (1979b) claim that the monitoring requirement does not substantially influence vigilance performance. This conclusion was based on studies designed to show that laboratory vigilance experiments have relevance for "real-world" tasks. We believe that many vigilance experiments have ecological validity; but, the statement that the monitoring requirements of a task do not influence performance seems too simplistic. The data presented in the current report indicate that the type of information processing, either controlled or automatic, will lead to different

vigilance functions. The monitoring requirements for tasks demanding controlled processing are clearly different from those of tasks that may utilize automatic detection.

The present data indicate that the ability to structure a task such that there is a consistent relationship between signals and noise will allow the human monitor to be resistant to vigilance decrement. Also, given that this consistency can be maintained, the monitor's performance will be more stable across various task situations.

An examination of the "current" theories of vigilance decrement (see Loeb and Alluisi, 1977) leads to the conclusion that none are sufficiently supported by the present data. For example, habituation of the neural response cannot account for the controlled and automatic processing differences in Experiment 1. The habituation argument actually would predict the automatic processing condition to show more of a vigilance decrement than the controlled processing condition. Data from Experiment 3 also do not support the habituation theory. Specifically, the alternating diagonal search condition cleared the perceptual channels every other frame and showed a performance decrement equivalent to the fixed diagonal search condition. The habituation theory would predict that the fixed diagonal condition would show a larger decrement since perceptual channels were not "cleared" for the entire vigil.

An alternative explanation could be a "levels of activation" hypothesis. This explanation could account for the sensitivity data from Experiment 1 due to a lower level of activation required to perform well in the automatic processing than controlled processing condition. As time passed the activation level dropped an equal amount in both conditions, but it did not drop below the level needed for sustained performance (performance equivalent to initial level) in the automatic processing condition.

The data from Experiment 2 are inconsistent with the above levels of activation hypothesis. There was little difference between the controlled and automatic processing conditions in regards to the amount of decrement observed in the performance measure.

A more plausible explanation is that as time passed during the vigil, the observer became less able to allocate controlled processing resources to the display positions. Since automatic processing requires little or no processing resources (Schneider and Fisk, 1980a) this is consistent with Experiment 1. The second experiment does not support this "simple" allocation of resources hypothesis but suggests that the allocation of controlled processing resources interacts with some other factor. This other factor appears to be the inability of the observer to continually and consistently allocate controlled processing resources to the same display locations. Experiment 3 supports this interpretation. When the subjects in Experiment 3 were required to continually and consistently allocate controlled processing resources to display locations the vigilance decrement was maximum (i.e., the AS and FS conditions). In the situation where the continual and consistent search requirement was reduced (the RS condition) the vigilance decrement was also reduced.

We conclude that vigilance decrements are the result of continuous and consistent allocation of control processing. As a task requires less control processing resources vigilance problems should reduce. As a control process task is made more variable, even though total processing demands are fixed, vigilance decrements should also reduce.

These present data lead to several suggestions for future design of tasks which require the observer to remain vigilant for extended periods of time. First, when possible the critical signals (targets) and target features should be consistently mapped as targets or have a high probability of being a critical signal. Second, training should be carried out to maximize the development of automatic processing (e.g., carry out training when targets are very frequent; see Schneider and Fisk, 1980b) prior to placing the observer in the task requiring vigilance.² Third, information which cannot be consistently mapped should not be presented in a continual and invariant pattern to the observer. For example, instrument design in situations requiring primarily control processing should induce the operator to sample the instruments in a varying pattern. This may seem counter-intuitive but follows from the results of Experiment 3. Fourth, the general task should be structured such that the observer must reallocate controlled processing resources to other tasks from time to time. This is not meant to imply that the operator should be given an overload, but enough diversity (of mental processes) to allow reallocation of resources.

In sum, we believe that the nature of the cognitive processes involved in target discrimination determines, to a large degree, the ability to sustain attention. Also, as indicated by the data of Schneider and Shiffrin (1977), the stimulus processing rate must surely have an effect. The rate of information processing should affect the ability to sustain attention for those tasks requiring controlled processing to a greater extent than when the observers may rely on automatic processing. In addition, we believe that the ability to sustain attention during a watch requiring controlled processing of the stimuli is related to the amount of continual and consistent allocation of controlled processing required of the monitor. It is not just the demands of allocation of controlled processing resources but the requirement to continually and consistently allocate those resources that leads to substantial vigilance decrement.

Footnotes

¹ Parasuraman (1979) presents data which indicate that memory load and event rate are the determining factors of sensitivity changes in vigilance tasks. Both a high event rate and a target discrimination task which loads memory are required before a sensitivity decrement will be observed in a vigilance task. Parasuraman suggests that the sensitivity decrement is due to the data-limiting nature of this type of task. He states the limitation may be due to signal-data or memory-data limits on processing (Norman and Bobrow, 1975).

Our data do not support the interpretation that the decrement is due to data-limits. Norman and Bobrow (1975) point out that a pure data-limited function is a straight line and that performance is completely independent of resources. Schneider and Fisk (1980, Experiments 9 and 10) have shown that controlled processing is affected by the resources (emphasis) given to a task. Although it may be reasonable to assume that the quality of the memory trace changes over the course of the vigil, it seems unreasonable to assume, for controlled processing, that performance is independent of the amount of resources applied to the task. If changes to the stimuli do not occur during the vigil, then the observed controlled processing decrement will be related to the reduction of the resources allocated to the display positions.

² In order to develop an automatic process the target stimuli must consistently appear as target stimuli and not as distractors (Schneider and Fisk, 1980c), the elemental features of target stimuli should be kept as consistent as possible (Schneider and Eberts, 1980), and operators should train with high target probabilities (Schneider and Fisk, 1980b) and few non-target searches. Our experience has shown that even tens of hours of training where the above rules are not observed does not lead to automatic processing. This suggests that putting an operator into a normal vigilance paradigm may be one of the worst ways to train operators to maintain detection performance over the vigil. This work also suggests that short refresher detection tests (e.g., ten minutes per day) might be helpful to maintain automatic detection.

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