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Human Vigilance

The rate of observing an instrument is controlled by the schedule of signal detections.

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Current interest in the classical problem of sustained efficiency in monotonous perceptual tasks has centered around situations in which human beings are required to monitor some display in search of critical, but infrequent, signals. Such tasks are numerous and of considerable practical importance. In air defense systems, operators must search radarscopes for extremely infrequent enemy targets. Increased automation requires human monitoring of equipment which seldom fails. In addition, cases involving assembly-line inspection of products represent another large group of monitoring tasks in which the critical signals may arise relatively infrequently.

Recent work on operators monitoring displays having infrequent signals indicates a drop in the percentage of signals detected as time on watch progresses. Mackworth (*1*) has shown a decrement in the subject's ability to detect signals as a two-hour watch progressed. The signals were double steps of a clock hand which normally stepped 0.3 inches every second but had 24 double steps per hour. Similar decrements have been demonstrated (*2–6*) when subjects were required to detect targets on simulated radar displays. Field studies also have shown the decrement as time on watch passes. This has been found true for radar operators (*6, 7*) and for a variety of industrial inspectors (*8*). In addition, Bakan (*9*), using a modified threshold measurement technique, has demonstrated a decrement in a brightness discrimination task.

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Not all investigators have found a decrement. One investigator (*10*), using the clock test, has shown an increased variance in the number of detections as the watch progresses, but no average decrement. Others (*4, 11*), using latency of detection of nontransient signals as a criterion, rather than the percentage of signals detected, have found an increase in variance but no increase in the average latency of detection.

Whether a decrement is found or not, the fact is clear that many signals well above absolute threshold are not detected either early or late in the session. Furthermore, if the frequency of signals increases, there is an increase in the percentage of signals detected (*4, 5*). For example, Deese found that with a display simulating a search-radar 'scope and using 10, 20, 30, or 40 targets per hour during a three-hour watch, 46, 64, 83, and 88 percent were detected, respectively.

In order to "account for" the decrement and the relation between signal frequency and detection probability, an abundance of theoretical constructs have been offered. The results obtained are said to reflect declines in, or waxing and waning of, attention, vigilance, or fatigue. Mackworth (*1*) tentatively postulated an excitatory state termed "vigilance" which is opposed by an inhibitory state that parallels the concept of external inhibition found in the literature on classical conditioning. More recently, Adams (*2*) has used Hull's I_R (reactive inhibition) in a similar manner. The performance decrement is supposed to be a partial extinction phenomenon reflecting the build-up of the inhibitory state. When a verbal message to the effect that the subject should "do even better for the rest of the test" was delivered, the percentage of signals detected returned to the initial level. This is explained as disinhibition and thus as evidence for the existence of an inhibitory state. When a 1-hour break was provided, again the performance returned to the initial level. This is said to reflect spontaneous recovery from the inhibitory state.

Several investigators have employed expectancy as an explanatory concept. Mackworth (*6*), Broadbent (*11*), and Deese (*12*) have used it to "explain" (i) the greater over-all percentage of detections when the number of signals per session increases (*4, 5*), and (ii) the increased probability of detection for the longer intersignal times that is observed when a signal-by-signal analysis is made (*1, 5*). [The latter finding has not always been confirmed (*3, 5*).] In addition, Broadbent has used the idea of stimulus selectivity (that is, attention or set) to explain not only the findings concerning monitoring behavior but classical conditioning as well.

In addition to these theories relative to psychic and conceptual states, a physiological theory has been advanced. Deese suggested that the waking center (*12*) of the hypothalamus may be involved and that the activity of the center depends on an influx of sensory stimulation. According to this theory, as it applies to problems of detecting infrequent signals, a varied sensory input is necessary to maintain the excitatory state in this center and thus to maintain a high level of detection.

Need for an Atheoretic Approach

The various theories have all been developed to account for a rather meager set of data. The parameters influencing

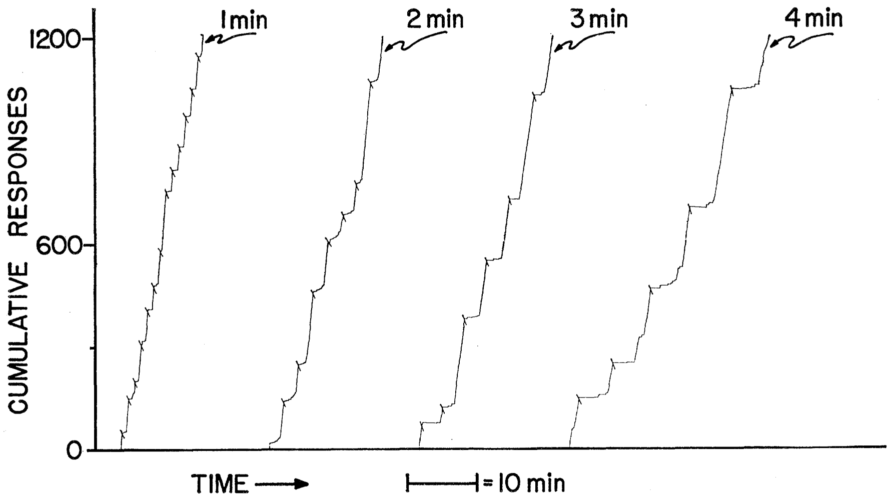

Fig. 1. Cumulative response records for 1-, 2-, 3-, and 4-minute fixed-interval schedules of pointer deflections. Detections are indicated by lines cutting across the records.

the monitoring of low-signal-frequency displays are as yet poorly explored, with the result that inconsistencies are found among the findings. In view of this state of affairs it might be well to forego the luxury of developing explanatory concepts until the empirical relations are better established.

Indeed, the necessity for theories has been sensibly challenged by Skinner (*13*) with regard to theories of learning. Theories, in Skinner's sense, are explanations of data that make use of events at another level of observation and are not to be equated with empirically defined concepts which refer to the behavioral level of observation. The latter permit generalization of empirical principles. His arguments seem at least as relevant to theories of "vigilance."

Such entities as vigilance, attention, inhibition, expectancy, and waking-center activity all fall into the category of theories, as defined above. They, like concepts in learning theories, are "at some other level of observation, described in different terms, and measured, if at all, in different dimensions" (*13*, p. 193). These concepts give the appearance of explaining the data because of the syntax of the statements. The subject is said to make a detection because he is, at that moment, vigilant or attentive or expecting a signal. But the concepts are no less mysterious than the phenomena they purport to explain. There remains the task of discovering the events which influence vigilance, attention, or expectancy. Once having done this, we may be little better off than if we had simply searched for the conditions controlling the probability of detection, since this is assumed to be directly related to the intervening explanatory concept.

The argument that theories generate research does not seem to apply to theories in this area. With one exception (*5*), the theories seem to have been offered as explanations of data already collected. But even should they generate research in the future, it is by no means obvious that this research would be of greater significance than research directed toward an empirical and behavioral systematization of the field.

However, the use of theories is by no means surprising in view of the types of measure used. In practice, only the percentage of signals detected, latency of detection, or change in threshold intensity is measured. The investigator is then faced with the problem of saying what it is that changes during the monitoring task. It is unsatisfactory to say that the percentage of signals detected *is* the vigilance rather than a *result* of vigilance, attention, or expectancy, just as the learning theorist is unsatisfied in saying that decrease in errors *is* learning. Instead of proceeding to search for a satisfactory datum on the behavioral level of observation, the investigator postulates events for other levels of observation. Signal detection is said to *reflect* states of vigilance, attention, or expectancy. The result of this is that the search for an appropriate behavioral datum is impeded, and in its place assumed causes are used which are mental, physiological, or conceptual events not describable in behavioral terms.

One approach to discovering a satisfactory datum is to consider the behavior which may be involved in monitoring and then to determine the variables which control that behavior. Success in detecting signals may depend on the emission of responses which will make the detection possible. These could be responses of orienting toward the correct portion of the display and fixating or scanning the display. Such responses can be termed observing responses in that they bring about the observation of signals (*14*). Furthermore, these observing responses might follow the same principles as instrumental responses and thus be subject to control by the same type of environmental variables. It is suggested that the observing responses which make detections possible follow the principles of operant behavior. The reinforcement for these observing responses could be the detection of the signals. That is to say, the detection itself could exert control over the rate or probability of emission of observing responses in exactly the same manner as food reinforcement controls the rate of operant responses in animals.

Signal Detection as Reinforcement

In order to evaluate this formulation of "vigilance" it was first necessary to determine whether signal detection really could serve to reinforce an observing response. To do this, subjects (Navy enlisted men), working in the dark, were required to report deflections of a pointer on a dial; but the pointer could be seen only when the subject pressed a key which provided a brief flash of light that illuminated the face of the dial. When the key was pressed, the light flashed for a period of only 0.07 second, even if the subject held the key down. Thus he had to release and redepress the key to obtain another look at the dial. When the subject observed a pointer deflection he reported it by pressing another key, which reset the pointer. The pointer remained deflected until this key was pressed. The deflections of the pointer were programmed so as to make possible various schedules of detections (or reinforcements). Each subject was advised that his only aim should be to make as many detections as he could and to reset the pointer as rapidly as possible. At the end of each session he was informed of the number of detections made and the average time per detection. He was not informed that the experimenter was in any way concerned with the frequency with which he flashed the light. Cumulative response records were made of his responses on the light-flashing key. This type of recording, commonly used in operant conditioning (see *15, 16*), consists of a pen which moves in small discrete steps across the recorder paper as responses are made, while the paper moves slowly in a direction perpendicular to the direction of pen movement. The result is a tracing in which the slope of the line reflects the rate of responding.

In order to determine whether signal detection can serve as reinforcement for observing behavior, various schedules of signal presentation were used, analogous to the scheduling of more conventional reinforcers, such as food and water, employed in operant conditioning with animals. Throughout all of the various schedules to be discussed below the subjects were *never* told anything about the nature of the schedule.

Fixed interval. The first schedules used were of the fixed-interval type. Five subjects began with a ½-minute fixed-interval schedule. That is to say, the needle was deflected for ½ minute after each detection and remained deflected until it was reset by the subject. After eight 40-minute sessions, the interval was increased to 1, 2, 3, and finally 4 minutes, with eight successive sessions on each.

Figure 1 presents data from comparable portions of records for a typical subject on several schedules, all of different fixed intervals. Each curve is a segment of record from the last session which the subject had on the indicated fixed interval. The individual curves are displaced along the horizontal axis. The lines cutting across the records indicate signal detections. Shortly after each detection there is a period in which no observing responses are emitted, as indicated by the flat portions of the curves. Then responding (observing) resumes in an accelerated fashion and reaches a high rate before the next signal. These "scallops" are analogous to those obtained with animals working for food reinforcement on a fixed-interval schedule (*15–17*). In either case the data represent a temporal discrimination. Responses immediately after reinforcement are not reinforced, so a discrimination is formed for "no responding following reinforcement." Responding resumes after time passes and the conditions become appropriate for reinforcement.

Examining the records, one could, if so inclined, speculate that they reflect "fluctuations of attention" or the course of "subjective expectancies." However, the temptation to do so should not be great since the dependency of observing rate on detection, or reinforcement, is clear. To postulate states accompanying the changes in observing rate adds nothing of use in controlling or predicting the observing rate.

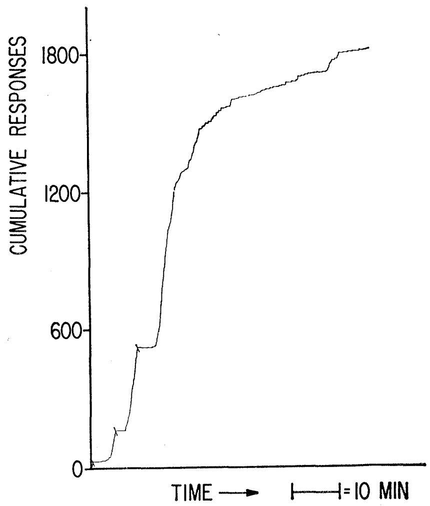

Fig. 2. Cumulative response record showing effect of withholding pointer deflections following a fixed-interval schedule. After three detections (indicated by lines cutting across the record) no further pointer deflections occurred.

Additional insight into the role of signal detection is provided when no further signals occur (that is, during extinction). Extinction data are provided in Fig. 2 for the same subject for whom data were given in Fig. 1. This is a complete record for a 1-hour session. Three signals were first provided on the 4-minute fixed-interval schedule which had maintained the observing behavior for six previous sessions; then no further signals were provided. Following each signal detection in the early portion of the record, the characteristic fixed-interval scallops are found. After the third and final detection there is again a scallop, with the high rate continuing for a time and then gradually declining to a very low value. This decline in rate of observing response is dependent upon the absence of signal detection. It cannot be interpreted as physiological fatigue, since on other schedules higher rates have been maintained, without decrement, for more than three hours.

Fixed ratio. To pursue further the analogy between signal detection and reinforcement as found in typical operant conditioning situations, fixed-ratio schedules were employed. These schedules make reinforcement contingent on the number of responses emitted rather than on the passage of time. To begin with, seven subjects were tested on a fixed-ratio schedule of 36 responses per detection. That is, a needle deflection occurred only after 36 observing responses were made following the immediately preceding detection. After six 40-minute sessions on this schedule the ratio was increased, in blocks of six sessions, to 60, 84, 108, 150, and finally 200 responses per detection. Presented in Fig. 3 is a family of curves for the various ratios for a typical subject. These curves are equivalent segments of the subject's final sessions on the indicated schedules. Tests with these schedules, unlike most monitoring tasks, permit the subject to minimize the number of signals by not re-

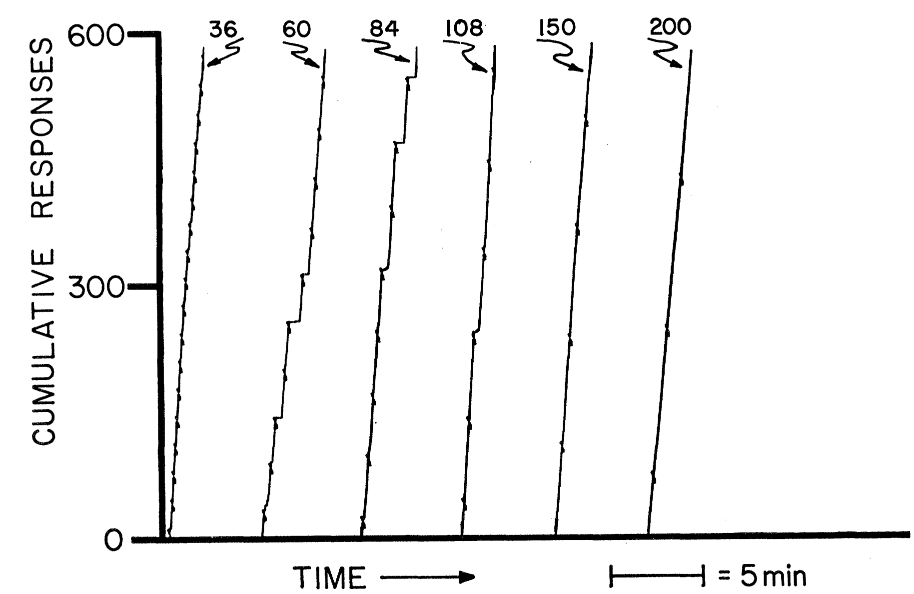

Fig. 3. Cumulative response records for 36-, 60-, 84-, 108-, 150-, and 200-response fixed-ratio schedules of pointer deflections. Detections are indicated by lines cutting across records.

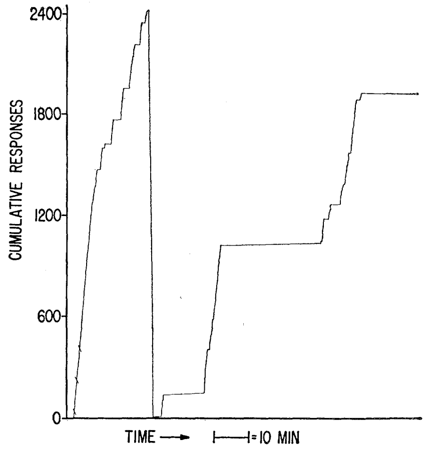

Fig. 4. Cumulative response record showing extinction following a 200-response fixed-interval schedule of pointer deflections. After three detections (indicated by lines cutting across the record) no further pointer deflections occurred.

sponding. Instead, however, he tends to maximize the number of signals by emitting responses at a high rate. Occasionally short breaks or periods of no responding occur, but only immediately following a detection. These results are also characteristic of those obtained with conventional reinforcement on fixed-ratio schedules (*15–17*).

An additional demonstration of the control exerted by the schedule of signal detection or reinforcement is seen in the extinction following fixed-ratio schedules. A 1½-hour extinction record is presented in Fig. 4 for the same subject for whom data were given in Fig. 3. Three needle deflections were provided on the 200-response ratio schedule which he had experienced for the preceding six sessions. After that, no more signals were given. The second portion of the record, following resetting of the pen at the vertical line, is continuous with the first. This record resembles extinction following fixed-ratio reinforcement with animals (*15, 17*) but is decidedly unlike typical extinction following fixed-interval reinforcement (see Fig. 2). Instead of the gradual decline seen for extinction following fixed-interval schedules, the rate, when the subject responds at all, is high. Immediately after the last reinforcement the subject continues at his normal rate for more than 800 responses. He then begins showing occasional periods of no responding, but in each case responding resumes at the original high rate. As extinction progresses the periods of no responding increase, but, throughout the session, when there is a single response there is a run of responding at the high rate that prevailed during reinforcement.

Previous analysis (*13, 17*) has indicated that the form of the extinction curves for various schedules depends on the presence or absence of conditions which were present at the moments of reinforcement in the past. In the case of fixed-ratio schedules there tends to be reinforcement for groups of closely spaced responses (see *15*). Thus, high rates are reinforced, and these high rates come to characterize ratio schedules. As a result, when a response is made during extinction, conditions are like those that prevailed at the time of reinforcement. During extinction, therefore, intermediate rates are lacking. The subject either responds rapidly or not at all.

Multiple schedule. It has also proved possible in operant conditioning to generate behavior appropriate to more than one schedule in a single organism during the same session (*17*). To do so, stimuli are provided to indicate which schedule is in effect at a given moment. The stimuli used have been alternation of schedules (called mixed schedules), different colored stimulus lights, or both. I have successfully combined a 40-response fixed-ratio and a 3-minute fixed-interval schedule, using four subjects. These tests began with six 40-minute sessions in which a small red light indicated a fixed ratio of 23 responses to be in effect and a small green light indicated a ½-minute fixed interval to be in effect. The order of appearance for these two schedules was randomly determined. Then for sessions 6 through 11, the schedules were changed to a 40-response fixed ratio and a 3-minute fixed interval. These two schedules were alternated regularly. Then for the twelfth and final 40-minute session the two schedules appeared randomly, with only the stimulus light providing the basis for discrimination. A typical record for this session is presented in Fig. 5. The 3-minute fixed-interval portions of the record are labeled *I*, and the 40-response fixed-ratio portions are labeled *R*. It can be seen that when the interval was in effect (green light on) the subject's observing rate provided the fixed-interval scallop. (There is a rougher grain to the scallop than to that found in Fig. 1. This is probably due to the experience on fixed-ratio schedules.) When the fixed-ratio schedule was in effect (red light on), the subject's observing rate was that typical for fixed-ratio reinforcement. Thus, like other operant behavior, the observing response can be brought under stimulus control. There remains no need to appeal to another level of analysis by speaking of "attention" being dependent on "context" or "meaning." Such proposed constructs are unnecessary when the control exerted by the schedule of detection under correlated stimuli can be directly demonstrated.

Differential reinforcement of low rates. One further schedule which attests to the control of observing rate by detections is one which makes detections (reinforce-

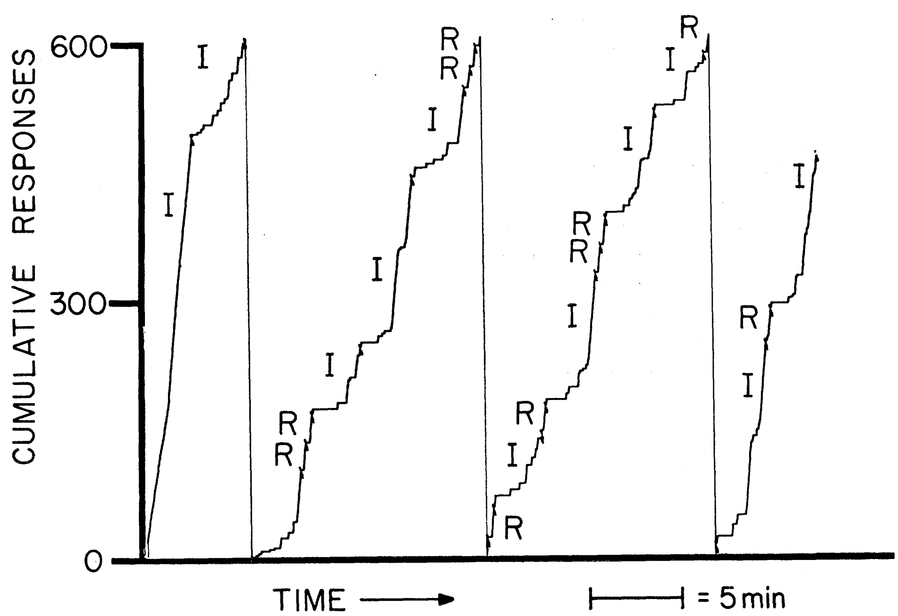

Fig. 5. Cumulative response record for a multiple schedule consisting of a 3-minute fixed interval (*I*) and a 40-response fixed ratio (*R*). Lines cutting across the record indicate detections.

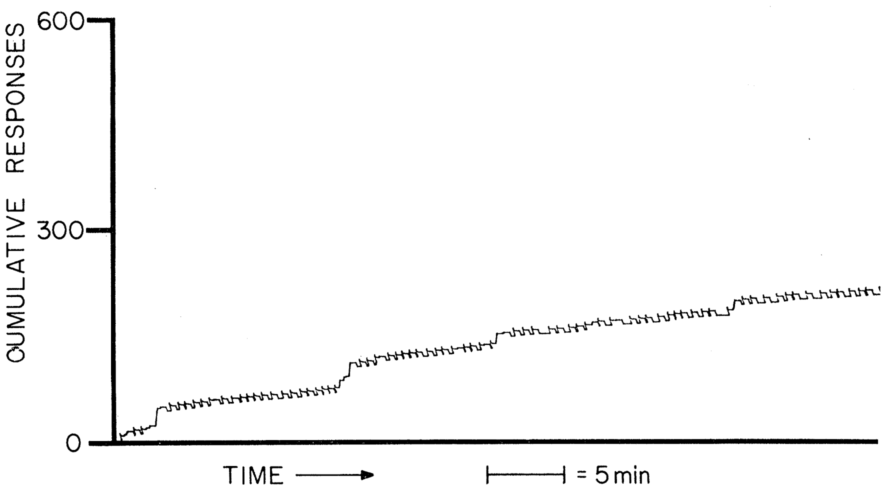

Fig. 6. Cumulative response record for differential reinforcement of a low rate. Downward deflection of the pen indicates pointer deflection, and upward deflection indicates detection. Pointer deflections occurred only after no observing response was emitted for 30 seconds.

ments) contingent on low rates of responding. Two subjects were placed on such a schedule. The needle was deflected only after they had failed to emit an observing response for 30 seconds. A record of one subject's fourth 1-hour session is presented in Fig. 6. It can be seen that this schedule provides a very low rate of responding, like that found in other operant conditioning experiments (*18, 19*) for which similar schedules were used. The few short bursts of higher rates tend to occur after the subject responded just a little sooner than the required 30 seconds. Even this detail parallels results with animals working for food on this schedule (*18*).

Conclusion. The results reported thus far demonstrate that signal detections can control the rate or probability of emission of observing responses. Furthermore, this control is of the same nature as that exerted by conventional reinforcers, thereby permitting the conclusion that signal detections serve as reinforcements for observing responses.

Observing Rates and "Vigilance"

There remains the problem of determining whether the schedules used in classical vigilance studies will generate observing rates which parallel the probability-of-detection data found in those studies. A decrement in probability of detection during the course of a session has been shown (*5*) for 20 signals per hour when the signals were arranged randomly through the session with the intersignal times drawn from a rectangular distribution. Such a schedule, in operant conditioning terms, would be a variable-interval schedule having an average interval of 3 minutes. Four subjects were placed on this schedule. Figure 7 shows the records for two of these subjects during their first session. (Vigilance studies frequently have only one session.) These records were chosen by way of illustration because these two subjects were the two extremes in terms of decrement of response rate as the session progressed. All four subjects showed periods of lower observing rates in the latter portions of the session. The drop in rate as the session progresses is brought about by the fact that reinforcement frequency is insufficient to maintain the higher initial rate, which results in part from the subject's past experience. However, some decline does continue to appear within each session for as many as 18 additional 1-hour sessions. Similarly data on pigeons (*17*) show a within-session decline in rate on a variable-interval schedule when the average interval is long. Furthermore, the drop in observing rate parallels the frequent finding, in viligance studies, of a decline in the percentage of signals detected.

It has also been demonstrated in vigilance studies that the percentage of signals detected increases as the signal frequency increases. To determine whether rate of observing responses also increases, two subjects were tested on various variable-interval schedules; first there were three 1-hour sessions in which the average interval was 15 seconds (240 per hour), then the interval was increased, in blocks of three sessions, to 30 seconds (120 per hour), 1 minute (60 per hour), and finally 2 minutes (30 per hour). In each case the distribution of intervals was rectangular, varying from 5 seconds to double the average interval. In Figure 8 there is shown a family of curves for one subject for these various average intervals. These records are for the first 3000 responses of the final session on each schedule. It can clearly be seen that the rate of observing is highest for the high signal rate and decreases as the signal rate decreases. Again this finding parallels the results of classical vigilance studies in the higher percentage of detection for higher signal rates (*5*), and at the same time it parallels other operant conditioning research with variable-interval reinforcement which also shows high response rates to be associated with schedules having a low average interval (*15, 17*).

The curvature seen in the records in Fig. 8 is also of some interest. For the average interval of 2 minutes there is a decline in observing rate as the interval progresses, while for the 15- and 30-second average intervals there is an increase in observing rate. The decrease shown in the case where the smallest number of signals is used is another illustration of a decrement in "vigilance." When larger numbers of signals are used, the "vigilance" literature reports and the present study shows that the decline during the session disappears. Actually, most studies are incapable of showing a rise in probability of detection because the signal is set so that initial detection is nearly always made.

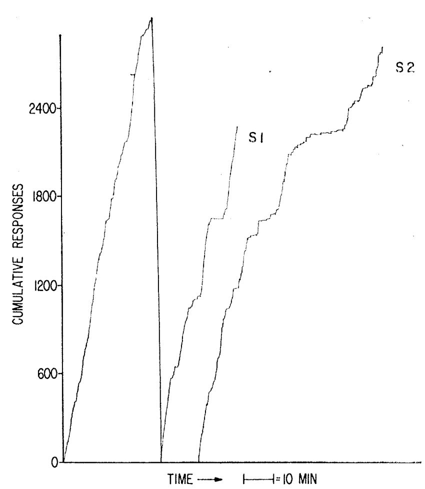

Fig. 7. Cumulative response records for the first session for two subjects (*S*1 and *S*2) on a variable-interval schedule with average interval of 3 minutes (rectangular distribution ranging from 5 seconds to 6 minutes).

Observing Behavior with the Mackworth Schedule

Additional evidence for the adequacy of the observing-behavior analysis of "vigilance" is seen when the schedule used by Macworth (*1*) is employed in the present study. The aims of this study were (i) to determine whether the schedule of signals actually used by Mackworth would confirm the data on decrement in percentage of detections found by him and at the same time provide data on decrement in observing rate, and (ii) to determine whether the data on observing rate would parallel the data on percentage of signals detected. In all of the experiments reported above, signals which remained until detected (nontransient signals) were used in order that the schedule of detections would be under the experimenter's control. The result was that signals could never be missed. But in order to determine whether the typical vigilance measure of percentage of signals detected is paralleled by the observing rate, it was necessary to make the signal automatically disappear if it was not detected within a short time (these are called transient signals). The general procedure was identical with that previously used except for the fact that when the needle was deflected it returned to its original position after 1¼ seconds unless the subject previously detected and reset in in the usual fashion by pressing the key which indicated a detection. The schedule of pointer deflections was identical with the schedule of double jumps used by Mackworth (*1*) in his clock tests, which stand as the classics in the area of vigilance. This sequence of intervals between needle deflections was ¾, ¾, 1½, 2, 2, 1, 5, 1, 1, 2, 3, and 10 minutes, in that order, and the sequence was repeated four times during the 2-hour sessions. Thus there were twelve signals each half-hour, the shortest interval between signals being ¾ minute and the longest, 10 minutes. Sixteen subjects served in two 2-hour sessions. Cumulative records were made of their observing responses. In addition, a record was kept of their successes and failures in making detections.

In Mackworth's studies, as well as in the present study, there were some important individual differences. Mackworth found that 29 percent of his subjects missed not more than one signal in the last three half-hour periods. In the present study 39 percent of the subjects missed not more than one signal in the entire two hours. The vigilance decrement is thus due to the performance of the other subjects. It turns out that the high-detection subjects show rather different observing response rates than the others. Therefore, in treating the data the subjects were divided into two groups—a high-detection group, made up of those who missed not more than one signal in a 2-hour session, and a low-detection group, made up of those who missed more than one signal per session.

The results for both the percentage of signals detected and for observing responses are summarized in Fig. 9. The data for the two 2-hour sessions are combined and show the means for each half-hour period for both measures. The curve labeled *D–H* (open circles) represents the percentage-detection data for the high-vigilance group. It shows, of course, nearly perfect detection throughout, since this was the basis for assignment to this group. The curve labeled *R–H* (open triangles) shows the mean number of observing responses for this high-vigilance group. Interestingly, these subjects actually show a rise in response rate as the session progressed. Their percentage-detection data cannot reflect this rise because these subjects are already detecting nearly all the signals. It is probable that this group has an increased detection efficiency which cannot be revealed by the detection measure. Classical vigilance studies have had no measure of observing rate and therefore have been unable to show such a phenomenon.

The low-vigilance group's detection results are shown in the curve labeled *D–L* (solid circles) and their observing response results, in the curve labeled *R–L* (solid triangles). By the second half-hour there is a drop both in the percentage of signals detected and in the rate of observing responses. In the first half-hour members of this group detected 93 percent of the signals and emitted an average of approximately 5100 observing responses, while in the second half-hour they detected 74 percent of the signals and emitted an average of about 4550 observing responses. The drop from the first to the second half-hour is significant at the 1 percent level for both measures. The slight decline from the second to the third half-hour is not significant for either measure. But the rise in the fourth half-hour is significant at the 5 percent level for both measures. This end-spurt is probably due to the fact that the subjects knew that the session was 2 hours long. Mackworth found no such end-spurt, but other studies (*5*) have shown that knowledge of the length of the session can produce such an effect.

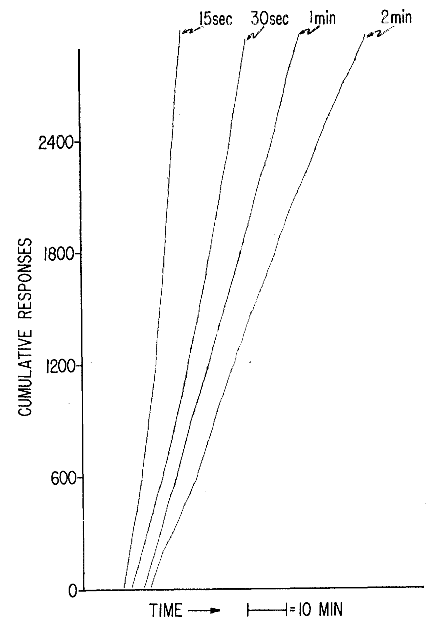

Fig. 8. Cumulative response records for variable-interval schedules with average intervals of 15 seconds, 30 seconds, 1 minute, and 2 minutes, respectively (rectangular distributions ranging from 5 seconds to double the average interval). All records are from the same subject. In each case the record was made after three previous sessions on the schedule.

In general, then, the vigilance decrement found by Mackworth was confirmed in this study, and a parallel decrement in observing rate was shown as well. It should be recalled that detections (that is, reinforcements) on variable-interval schedules show that the lower the rate of signals, the lower the rate of responding (see Fig. 8). Thus, when signals are missed, this might have the effect of lowering the rate, since the subject is then on a different variable-interval schedule with a higher average interval.

One further factor may have an influence on the response rate in this study. When transient signals are used, the situation is analogous to work with animals in which a variable-interval schedule is used, with the added contingency that when the program is set up for reinforcement, the animals have only a brief time in which to respond before reinforcement is no longer available. Such a schedule (*17*) used with animals (called "variable interval with limited hold") has shown that the use of a limited hold considerably increases the rate of response over that for the same variable-interval schedule with unlimited hold. This presumably results from the differential reinforcement of high rates, since high rates of responding are more likely to be reinforced in the case of limited hold. There may well be an analogous effect in this study. Those subjects who detect almost all signals are very probably being reinforced for high response rates, with the result that their rate increases and thus maintains maximum detection proficiency.

Additional Parallels between Response Rate and Detection Data

The similarity in the shapes of the curves in Fig. 9 for the observing rate data and the detection data for the low-detection group offers support to the position that the finding of classical vigilance studies could reflect observing behavior. Additional evidence may be adduced for this in parallels between vigilance data and work on operant behavior from animal laboratories. For example, (i) Mackworth (*6*) finds that giving subjects 10 milligrams of benzedrine raises the level of detection. Similarly Brady (*20*) has shown that doses of benzedrine administered to rats provide high response rates when the rats are on a variable-interval schedule. (ii) In addition, Mackworth (*6*) has shown that high room temperatures result in lower levels of detection; and, similarly, animals on a variable-interval schedule show lower response rates when the room temperature is high (*21*). (iii) Nicely and Miller (*22*) have investigated the effect of unequal spatial distribution of signals on a radar display. The strobe line rotated at 6 revolutions per minute. One quadrant had signals on an average of one every five rotations, while the remainder of the display had signals on an average of one every 30 rotations. Nicely and Miller found that the percentage of signals detected increased for the high signal-frequency area and declined for the low signal-frequency area. After 30 minutes the detection-data curve for the high signal-frequency area had approached a higher asymptote than had that for the low signal-frequency area. This situation is analogous to a multiple schedule having a 40-second average variable-interval schedule with one stimulus (one area) and a 5-minute average variable interval with another stimulus (the other area). Ferster and Skinner (*17*) have shown that animals on such a multiple schedule show a lower response rate in the presence of the stimulus correlated with the long variable interval than in the presence of the stimulus correlated with the short variable interval. (iv) It has been demonstrated that rest periods restore the detection efficiency to nearly what it was at the beginning of the session (*1, 2*). Similarly, Ferster and Skinner (*17*) have found that response rates on variable-interval schedules are increased by interspersing rest periods.

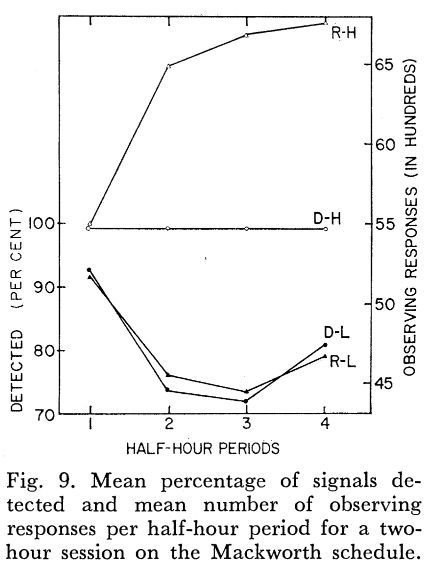

Fig. 9. Mean percentage of signals detected and mean number of observing responses per half-hour period for a two-hour session on the Mackworth schedule. Curve *R-H,* observing response data for the high-detection group; curve *D-H,* detection data for the high-vigilance group; curve *R-L,* observing response data for the low-detection group; curve *D-L,* detection data for the low-detection group.

Conclusions and Implications

This analysis (*23*) has demonstrated that detections of signals can serve as reinforcements for observing responses and, further, that the detection data of vigilance studies may reflect the observing response rates generated by the particular schedules employed. Thus a means of analysis is provided which does not appeal to a nonbehavioral level.

In other vigilance studies the observing behavior has probably been fixation and scanning with the head and eyes as well as perhaps more subtle responses. It would be of interest to extend the present technique to some of these responses, although for many problems the topography of the response may be unimportant and the present methods entirely sufficient.

So far as application is concerned, the striking fact is the rather precise control exerted by the environment over the human operator's observing behavior. Thus, in a man-machine system it should be possible for the machine to maintain control over the operator's monitoring behavior. The ideal manner for exerting such control remains to be worked out. It is hoped that this will be the goal of much additional research in this area. But one obvious way is to provide a high rate of realistic artificial signals on a schedule which would provide the desired observing rate. The most promising schedule for many situations would be a variable-interval schedule of signals having a short duration, like the limited hold in animal work. Other do's and don'ts of the engineering of monitoring tasks must be worked out. To this end it is clear that the abundant amount of systematic research on operant behavior that has been done with animals should be a fruitful source of ideas for developmental research as well as for educated guesses in designing man-machine systems requiring monitoring by human beings.

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