SOME RECENT STUDIES IN VIGILANCE

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In this article an attempt has been made to review the vigilance literature. Experimental studies and their theoretical analysis have been discussed and the inadequacy of the existing theories has been brought out. The need for a field approach to solve problems involving vigilance tasks has been emphasised.

Henry Head[1] employed the word 'vigilance' to denote the state of 'high grade physiological efficiency'. He pointed out that this high grade of physiological efficiency differs from a pure condition of raised excitability, for, although the threshold value of the stimulus is not of necessity lowered, it is associated not only with increased reaction but also with high adapted responses. The main factor is not the decrease or increase in the strength of the stimulus required to evoke a reaction, but the fundamentally divergent nature of response, according as the subject is in a high or low state of vitality. The subject may be more prepared to receive and react to an external impression at one time than at another; also an identical stimulus may produce a different result and, during a high state of vitality, tend to evoke more or less high grade adapted movements.

The more highly differentiated the act, the greater the degree of vigilance required and the more easily it is abolished by toxic influences, such as chloroform, or other conditions unfavourable to physiological activity. Many acquired actions tend to be carried out at the physiological level during the life of the individual. A child has to be taught not to wet the bed at night, and this control of a spinal reflex becomes so completely automatic, that it is maintained even in the deepest sleep. But anything which lowers the vigilance of the central nervous system, such as dyspnoea or a debilitating illness, is liable to disturb this control and the bed is again wetted at night.

The same effect is illustrated in many aptitudes, such as flying, shooting and out-door games, which are acquired and maintained by conscious effort. But all these aptitudes are profoundly influenced by conditions of general health and conditions which affect physiological vitality. Vigilance may be lowered and specific mental aptitudes die out. Consciousness stands in the same relation to vigilance of higher centres as adapted and purposive reflexes do to lower centres in the neural hierarchy. When vigilance is high, mind and body are poised in readiness to respond to any event, external or internal.

Several experimental studies have been undertaken in order to understand the phenomenon of vigilance. The chief feature of the experiments is to plan them in such a way that the subject is required to respond to infrequent signals, but may have to watch for them over a long period. A study of this type was first made by Mackworth[2] during the war in detecting submarines from the air by radar. Advances have been made in the use of radar for fire control, interception and navigation, as well as for early warning. New and critical roles for radar operators are being created and it is apparent that a direct attack is needed upon specific operating problems and this will be possible if vigilance problems are tackled in field situations rather than in the laboratory.

Some basic experiments on vigilance

It is known that after prolonged observation of one source of information, a man shows brief intervals during which he can take in information from other sources. His attention will wander. It is in vigilance tasks that we may find evidence for it.

Mackworth's original experiment[3] related to a synthetic task embodying the work of a radar operator. The subject watched not the radar screen, but a pointer moving round a clock face in regular jumps, one every second. At rare intervals the pointer gave a jump of double length, which the subject had to report by pressing a key. In the first place, the subject was asked to work at this task for 2 hr. When $\frac{1}{2}$ hr. periods within the session were compared, it was found that the first $\frac{1}{2}$ hr. was considerably better than any other. This finding was confirmed using a simulated radar screen. In another experiment, the subject was given an auditory task, in which regular bursts of tone were heard; the subject was required to report rare bursts which were of extra length. When the results were communicated to R.A.F., records of submarine detections at various times since the start of the operator's watch were examined and it appeared that a similar rapid drop in efficiency was occuring.

Mackworth[2] was able, by manipulating the conditions, to produce instances in which no decline in performance appeared after the first half hour. Thus we are confronted with a situation in which some experiments show rapid deterioration in human performance in a task in which the work output is slight, yet other experiments show no such decline.

Although vigilance decrement or deterioration of long term attentive behaviour, has been found for a wide variety of visual and auditory monitory tasks[4], the isolation of variables that can reliably be shown to influence its development, has been slow. Nor have the theories suggested to explain vigilance decrement been too successful in specifying the variables and their effects. Perhaps it is better to exploit empirical leads on determinants of decrement in an attempt to build an orderly body of findings that will eventually lead to a sound theoretical structure, rather than to codify a theory on the basis of our present scanty findings.

Mackworth[2], using clock test type tasks, employed a number of techniques to prevent decline in performance. The first technique for maintaning continued efficiency is to carry out the task with two men, each taking alternate $\frac{1}{2}$ hour. This gave a roughly constant level of performance. Whatever the reason for the decline, it disappeared with rest.

A second technique was to keep the man at the task for the full two-hour spell, but to call him up over a telephone system after one hour and ask him to do even better for the rest of the test. This produced a temporary return to full efficiency, which died away after another half hour.

If a loudspeaker message informed the subject whether he was "right" or "missed", efficiency was continuously maintained throughout the two-hour period. The result was the same with the auditory test as well as the clock test. But interestingly, if they were told that they must be especially vigilant when a pointer travelling over a map reached a certain region, there was deterioration. It is clear that the "motivational" nature of the knowledge of results and the telephone message were effective while other methods of exhorting the subjects were ineffective. The administration of dummy inert tablets did not affect the performance; while benzedrine caused performance to remain at the same level throughout the work period. The role of knowledge of results in monitoring tasks is largely of theoretical interest, since in the practical setting, the giving of knowledge of results implies information, the availability of which would eliminate the need for a monitor. Nevertheless the possibility that training under conditions of knowledge of results could facilitate subsequent performance when no knowledge of results is available has both practical and theoretical implications. In addition, the vigilance situation is ideal for studying the relation between knowledge of results and performance efficiency, uncontaminated by the influence of acquisition processes.

That knowledge of results which affects monitoring performance, has been demonstrated by Mackworth[2,3] and by others (Baker[5], Loeb & Schmidt[6] and Weidenfeller, Baker & Ware[7]).

Interpretations of these effects are generally in terms of either increased information input or increased stimulation leading to higher arousal level[8]. Other possible interpretations may be in terms of a combination of information and arousal effects or in terms of motivating affect of performance evaluation, especially, if the knowledge of results is presented by another person. Thus Baker[5] refers to added information which knowledge of results provides on the true temporal nature of signals, which is seen to increase the probability of confirmation of the monitor's expectancies. However, recent findings suggest that either true or false knowledge of results may improve performance[8]. These latter results fail to support the stimulus arousal interpretation, since added input alone does not affect performance unless interpreted by the subject(s) as task-relevant information.

These findings suggest that knowledge of results may be perceived by *S* as an evaluation of his performance, thereby inducing in him a greater desire to achieve. This is supported by studies on the effect of introducing another person in the monitoring situation. While the presence of another monitor in the same room does not affect the subject's performance[9], the introduction of an authority figure, "monitoring the monitor", facilitates performance[10]. Vigilance performance has been tested by Hardesty[11] and his collaborators with six independent groups using a modified aversion of the Mackworth clock test[3]. The groups consituted a 3×2 factorial design with (*i*) no knowledge of results, observer-presented knowledge of results as one dimension, and (*ii*) physical presence or absence of an observer in the test cubicle as the other variable. All groups were retested without knowledge of results, one and seven days after the initial test. On the initial test day, groups with no knowledge of results and machine-presented knowledge of results showed the typical decrement function throughout the session. In contrast, subjects receiving verbal knowledge of results from the experimenter showed less decrement and a significantly higher over-all performance. The superiority of groups receiving the verbal report persisted on two subsequent test days despite the fact that all extrinsic knowledge of results was withdrawn in these tests. It was thus found that observer-presented knowledge facilitated performance regardless of the physical presence or absence of the observer in the test cubicle.

In another experiment, employing a transfer of training approach, Weiner[12] investigated the transfer effects of training with three signal rates and three levels of knowledge of results (KR) in a visual monitoring task. It was found that training a monitor with KR and high signal rates may improve performance when the monitor is required to operate with low signal rates and no feedback.

Fraser[13], using the clock test in his experiments, reported that the usual decline in efficiency could not be obtained after ½ hr. Suspecting that the presence or absence of the experimenter in the room during the experiment may be a motivational variable, Fraser[14] framed another vigilance task in which the subject was asked to watch a series of circles projected on a screen and report the occasional one which was of unusual size. The presence of the experimenter along with the subject improved the performance.

In another experiment, Bergum and Lehr[15] studied the effect of authoritarian monitoring conditions upon vigilance performance. The results indicated that the detection performance by subjects was far better when officers, rather the other ranks, were introduced into the test cubicle as observers. Such conditions can be considered to represent an extreme point of perceived threat to the monitor.

Using the same circle detection task, Fraser[14] varied the time during which each circle was visible before the next circle appeared. When it was visible for only 1 sec. the usual decline appeared with prolonged watch-keeping. When it was visible for more than 2 sec. no decline occurred. It must be noted here that in the original clock test situation, jumps of the pointer took place every second, so that the signal took less than 1 sec.

Broadbent [16] offers the following objections to Fraser's finding[14]. First, in Mackworth's radar test[2], the signal was visible for 4 sec. but a decline was observed. The radar test differed from the clock and from Fraser's task,[14] in that signals appear in a number of spatial positions; and unlike synthetic radar tasks used by Baker[17] and Deese[8], the appearance of signals was unrelated to the position of the rotating sweep line. If, therefore, the watcher had to spread his observations over a large area he would only be able to look at any one point for a part of the time: the signal might, therefore, have to be present for a longer time than it would in a situation not involving the search factor (as in the circle detection task of Fraser).

Secondly, Adams [18] found that the effect of signal variables on vigilance decline was not statistically significant, although there was a slight declination in the direction predicted by Fraser [14]. The effect of signal brightness on decline has been found in other experiments, and is implied in the results by Bakan[19]. With these exceptions [14], experiments with long lasting signals have not established any decline in performance as the duration of the task increases.

It is clear from clock tests that decline in performance can be prevented by (*i*) knowledge of results, (*ii*) increasing the visibility of the signal, (*iii*) outside stimuli such as telephone message, (*iv*) the presence of the experimenter, (*v*) brief rest, or (*vi*) lengthening the time of appearance of the signal.

Many investigators have used vigilance tasks which are more sensitive than the clock test. For example, Bakan[19] delivered to the subject a regular series of light flashes. Occasionally one of these flashes would be slightly brighter than others and the subject had to report this. If he failed to do so, another flash which was even more bright was inserted, and so on until the subject did report a flash. The intensity of the flash reported can be used as a measure of the state of the subject. Bakan[19] found a rise in threshold as the task proceeded in any one session. This method gives a numerical measure from each signal rather than a detected-missed dichotomy.

In an auditory task, the subject had to listen to a stream of digits spoken at the rate of one per second; he was required to report digits occuring in a particular sequence. If the subject is set a simple task, say, the occurrence of three successive identical digits, there was little decrement in vigilance over a given period of time. However, if the subject is required to respond to a more complex sequence, such as one in which an odd digit is followed by an even one and then by another odd one, decrement appeared[20,21]. This is comparable with the results of Fraser [13] and Mackworth [2] experiments on signals.

There are other vigilance tasks which do not show any change in performance when continued over a prolonged period. Broadbent[22,23] used the 'twenty dials' test, in which twenty dials had to be watched and action taken if any of them showed an unusual reading. In this case the signal remained visible until a response occurred. The time taken was measured and the dichotomy of detention or failure to report a signal was avoided.

Elliott[24] using the same technique as Bakan[19] but with auditory signals also got negative results. The subject had to detect the presence or absence of a sound, rather than an increase in intensity in one member of a regular series of stimuli. Elliott[24] allowed the subjects to read or write as they chose during the course of the experiment; but this had no effect on their performance. Elliott's results do not mean that the subjects were achieving good performance throughout. On the contrary, their thresholds were far above those obtained in a normal situation when the subject was expecting a signal. This is an instance where average performance can be moved up and down independently of the deterioration of performance from beginning to the end of a session.

Bowen[25] used a method similar to that of Bakan[19] and Elliott[24] but with visual signals. A spot of light was to be reported on a screen covered with twinkling "noise" spots. The signal was repeated again and again at the same intensity until the subject reported it. The length of the series of repetitions necessary to secure response did not increase during the run, except with a very low signal rate of one signal per hour. Bowen[25], however, found that the rate at which the signal was repeated influenced the performance.

Deese[8] used a simulated radar task in which subjects had to watch a screen for targets. He failed to find a uniform decline in performance as time passed. In some of his experiments he used a technique very similar to Bakan's[19] increasing stimulus intensity until detection occurred. Like Elliott[24], he was concerrned with absolute detection rather than detection of an increase in intensity.

Baker[17] carried out experiments with a simulated radar screen bearing a sweeping line of light comparable to that used on real radar screens. Signals might appear anywhere along the line of the sweep. Records were made not only of the number detected but also of the reaction time to each signal and the restlessness of the subject. The latter was recorded by electrical contacts under the chair. The results showed that if the signals came fairly evenly every 2 min. there was no increase in the number of missed signals, but there was an increase in restlessness. If the timing of signals was changed, so that some intervals were longer than others, the results were similar to those of the clock test. This experiment also showed that the subjects could be biased towards various parts of the display by altering the arrangement of the sweep, with a normal sweep they tend to see signals in the middle of the sweep line rather than at the ends.

These experiments point to the existence of a change in subjects required to perform watching tasks over prolonged periods. Under certain conditions, their performance deteriorates with time. Under other conditions, either the deterioration does not take place or the measuring technique does not reveal it.

In a vigilance task, the index of performance is usually the percentage of signals correctly reported. Many studies, however, demonstrate, as pointed out by Swets, Tanner, and Birdsall[26] that this index is not a reliable measure of the efficiency of the observer. An observer may alter the proportion of correct detections merely by changing his criterion or his willingness to give a false alarm. Alteration in correct detection cannot be compensated by the usual correction for guessing. Accordingly a measure, *d* or index of detectability of a signal, independent of the observer's criterion was suggested. The results of three experiments[27] in which changes in *d* (a short pause in the motion of the second hand of a clock) were measured as a function of time on the watch, suggest that the "vigilance decrement" is not associated only with infrequent and randomly timed signals, but it is also a general effect occuring with prolonged observation.

THEORETICAL ANALYSIS

At present, five different approaches have been tried to explain the experimental findings:

Inhibitory theory—The first of these is to postulate an inhibitory state, similar to the one supposed by behaviour theorists to explain the extinction of conditioned responses. Many of the phenomena of extinction resemble those of declining vigilance. For example, a man can be asked to press the response key when a flash appears on a radar screen. He watches the screen for a prolonged period, receiving occasional signals but he is not given any reward for detecting them. Mackworth[2] reported that the results of the tests were similar to those of the clock test. However, the situations in the two tests are not parallel. For example, we cannot regard the decline of vigilance simply as an extinction of conditioned response to a signal stimulus. If it were, the decline would be more rapid when signals are more frequent, whereas some results show that the reverse is the case. Moreover, in vigilance tasks, the vigilance does not merely decline, but as proved by Deese[8] and Brodbent[16], it improves or oscillates. In the clock test there is evidence of a warming up effect at the beginning of the task, and Deese found signs of an end-spurt. The inhibitory construct postulates a rather complicated form.

Expectancy theory—Deese[8] proposed an expectancy hypothesis which states that "the probability of detection......is determined by a large and rather indeterminant number of signals preceding the signal in question........ The observer....continuously performing a kind of averaging of previous inputs in order to extrapolate the results to future behaviour of the search field". He goes on to predict that "expectancy should be low immediately after a signal, should increase as the mean inter-signal interval is approached, and finally should become quite high as the inter-signal interval grows beyond the mean." This prediction has been expanded to read, "as the interval grows still longer, expectancy again falls to a low level."

Three experiments were undertaken by Baker [28] to test inferences from the expectancy theory. In the first the reaction time was measured to demonstrate the expectancy concept; the second was undertaken to examine the hypothesis that vigilance decrement is a function of inter-signal regularity and the third was intended to show that knowledge of results in a vigilance setting operates by informing the observer of the true nature of the temporal structure of a series of signals.

In the reaction time experiment, the subjects responded to a light which flashed once every 10 seconds, but they were not informed that the flashes were to appear regularly. The light flashed 20 times. If an expectancy was established for the twenty-first flash (signal) arriving 10 seconds after the twentieth, then a twenty-first signal arriving before 10 seconds and a twenty-first signal arriving 10 seconds after, should each result in reaction times which are longer than the mean reaction time of preceding signals in the series. Therefore, on five separate trials a twenty-first signal was inserted at 2, 5, 20, 25, and 30 seconds after the twentieth.

In the case of signals at 202 and 205 seconds, the mean response time was longer (43 and 37 per cent respectively) than the mean of the preceding series. This difference was significant at the 1 per cent level. The apparent downward trend of the three "late" signals was not statistically significant.

The data may be interpreted to mean that response to a signal is a function of the probability of that signal, the probability being derived from the past incidence. The decline in efficiency during a session may be ascribed to a gradual drop in expectancy from the normal fairly high level to a low level appropriate to a vigilance situation with few signals.

The results of Fraser's experiment[13] on the effect of signal duration may possibly be explained on the assumption that any reduction in signal length when the probability of detection is not 100 per cent, will reduce the number of signals seen and so the estimated probability of seeing more. But this explanation ignores the fact that decrement is not observed in long-signal tasks with very infrequent signals (the twenty dials test and Bowen test) and yet is present in short signal tasks with more frequent signals, such as the clock test and the tests of Bakan[19], Adams[18], Fraser[10] and others.

We have seen that the proportion of signals detected during a vigilance task has been shown to increase as the rate of signal presentation increases. From this it follows, and this has been demonstrated [29,30] that if "artificial" signals indistinguishable from "real" ones are injected into the task, the performance on "real" signals will improve. Garvey[29] showed that when the artificial signals were indistinguishable from real ones, they still helped performance on real signals. In an effort to determine the effect of extra signals on the detection of infrequent signals, Mackworth[31] projected signals on a clock with alternate black and white segments. When subjects were told that signals would occur only on black segments they detected more signals than when they were told that signals may occur anywhere on the clock face. However, the rate of decrement in performance was not affected by the locations of signals, nor did the addition of extra signals reduce the rate of decrement. The more accurately a subject is able to predict when and where a signal is likely to occur, the more likely he is to detect the signal. The more information a signal carried in terms of temporal or spatial position, the more difficult it is to detect. This is the expectancy theory, as outlined by Deese[8] and Baker [17]. In the 'black' condition, the subject knows that there will not be a signal as the hand is passing a white segment, so that for half the time he can relax while in the 'double' (black and white) and whole condition he must remain alert continuously.

Again the expectancy theory predicts that the "probability of detection should be lowest immediately following a signal and should increase as the mean inter-signal interval is approached,........and as the interval grows still longer should fall again to a low level"[17,28]. The data of Mackworth[31] do not appear to support this theory.

Activation theory—The activation theory assumes a constant background of stimulation as a necessity for general efficiency. It is in consonance with Kleitman's[32] theory of sleep and wakefulness. Kleitman held that wakefulness was maintained by a neural center at the base of the train, near hypothalamus. This centre is kept active partly by sensory impulses; it maintains the efficiency of the brain, probably by transmitting facilitating impulses to the cortex. In monotonous surroundings, the level of nervous activity is low and response to clock test signals is also low. The theory, however, fails to explain cases of lack of decline in performance.

The temporal course of vigilance performance demonstrates a decline in efficiency as time on-duty increases[2]. The 'activation hypothesis' provides a possible explanation of this decline[16,33]. It is based on the idea that a temporally correlated loss in performance efficiency will occur in the presence of a uniform sensory environment, and a typical vigilance task places the subject in such an environment. Conversely, the presence of extraneous stimuli will keep to maintain or restore vigilance behaviour to the extent that they provide a varied sensory environment[34].

In order to test the hypothesis, five AFROTC (Air Force Reserve Officers Training Corps) students were subjected to an auditory vigilance task 4 hours a day on each of 4 days while concurrently performing two other passive tasks and various combinations of three active tasks. In spite of the multiple-task activity, auditory-vigilance performance declined in the typical way during each 4-hour duty period. This is interpreted as a demonstration of the inapplicability of the activation hypothesis of vigilance behaviour[35].

Filter theory—Broadbent[16] propounded a filter theory to explain the performance of vigilance tasks. According to this theory, the information reaching the senses is filtered and only part of it passes to the perceptual system. This part is determined by the instructions given to the subject, but the filter possesses a permanent bias in favour of channels which have not recently been active. This bias is likely to undergo a change when the source of information controlling the response changes after some time. In ordinary terms, attention wanders.

In explaining noise effects, Broadbent[16] argued that the filter was more likely to select auditory information when an intense noise was present. Faint sounds or preperceptive stimuli may provide competing information; and stored material may even pass through the same filter. In ordinary language, the man notices odd features of his surroundings and his sensations may be interpreted as discomfort or day dreams. Such breaks in the intake of task information will be brief, but will increase in frequency as the task is continued. Thus vigilance decrement may be explained by supposing that signals arriving later in the task are more likely to be missed.

Decision theory—In order to apply laboratory vigilance data to manned space missions, there is need to develop a comprehensive theory which will clearly bring out the difference between field and laboratory situations.

The statistical decision theory, [36, 37, 26] provides an analysis of the process which generates the dichotomy between stimuli, the subject reporting that he does or does not perceive. The theory recognized that *a priori* probabilities, values and costs of correct and incorrect decisions, as well as the physical parameters of the signal, play a decisive role in establishing this dichotomy[36].

We can imagine the process of signal detection to be a choice between two Gaussian variables. One having a mean equal to zero, is associated with noise alone; the other, having a mean equal to d', is associated with signal plus noise. In the most common detection problem, the observer decides, on the basis of an observation that in a sample of one of these populations, which of the two alternatives existed during the observation interval. The particular decision that is made depends upon whether or not the observation exceeds a criterion value; the criterion, in turn, depends upon the observer's detection goal and upon the information he possesses about relevant parameters of the detection situation[26].

In a recent review[38], the problem of signal detection vis-a-vis decision theory approach, with its bearing upon manned space missions, has been analysed. The decision theory model seems to supplement rather than compete with other theories.

EXPERIMENTAL EVIDENCE

There are few investigations relevant to the inhibitory approach except those of Wilkinson[39]. Wilkinson observed vigilance when watching a flash of light on a plain screen. In one condition the subjects heard an even noise background at low intensity. In another, a regular buzz was inserted above the background noise every 4 sec. The flash occurred just after one of these buzzes, so that the subject could relax briefly between buzzes; moreover, this condition provided sensory stimulation. The average number of signals seen in the two cases was the same, but in the buzzer condition, the average was achieved by higher efficiency at the beginning and lower efficiency at the end; the decrement was greater. This argues against the activation theory of decrement. Its relevance to the inhibitory theory is that the stimulus of the buzz as a source of extra response is extinguished and the total inhibition is increased.

A repeated neutral stimulus is characteristic of the clock test, Mackworth's listening test[2], Fraser's variance test [10], and Bakan's threshold test[19], all of which show a decline with prolonged performance. There was no repeated stimulus in the twenty dials test or in the radar tasks of Bowen[25] and Deese[8]; and these tasks showed no decline. However, Mackworth's radar test[2] and Baker's simulated radar task[17] both show decrements, but have no obvious repeated stimulus between signals; both include the simulated sweep line of a radar set rotating around the screen regularly. In one of Baker's conditions[17], there was no sweep; Deese's task[8] included the sweep. Another and more doubtful case is the work of Elliott[24]; in his listening task, there was sometimes a repeated neutral stimulus but no decrement.

Many experiments have been designed to uphold the expectancy theory. One can readily change the probability of a signal occuring and observe the resulting change in the performance of the subject. If, for example, signals arrive $\frac{1}{2}$ min. on the average, the probability of a signal at any given time is higher than if the average interval between signals is 3 min.

It is established that a high average rate of signalling produces a high average performance. There may be an upper limit where the absence of a signal becomes less usual than its presence; in such a case, the subject may be regarded as watching for a no-signal and one may expect that the lower the incidence of no-signal the lower his efficiency. The activations theory also predicts that a high rate of stimulation produces efficiency, but this relation will hold, presumably, up to an indefinitely high level. The expectancy theory predicts an optimum performance when signal and non-signal are equally probable.

Working within the frame work of the expectancy theory Baker[5], has shown in two experiments that variability of inter-signal intervals, that is, the degree of temporal uncertainty of signals appears to be related to vigilance decrement. The constant attentiveness required in a vigilance task is fundamentally due to the uncertainty about when a critical signal will occur, and Baker's studies indicate that vigilance decrement is a function of this basic requirement in vigilance tasks. Baker found that the set of inter-signal intervals originally used by Mackworth[2] in his classic experiments, which vary from 3/4 to 10 min., produced vigilance decrement while interval sets with less variability did not. If Baker's findings are confirmed, they will be of basic significance to the understanding of attentive behaviour; a new determinant to vigilance decrement will have been identified.

Baker's findings[5] can be challenged for three reasons. First, his results have not received full confirmation; Dardano[40] found that the rate of vigilance decrement was independent of the three degrees of variability for inter-signal interval that were studied. Secondly, Baker[5] and Dardano [40] gave no practice session prior to the criterion session to allow subjects sufficient opportunity to learn the statistical structure of temporal intervals. It is difficult to assign the temporal uncertainty of intervals a role in vigilance decrement if subjects have had little opportunity to learn what the intervals were. Baker reports on practice opportunities prior to the criterion session. Dardano[40] allowed 3—5 practice responses for task familiarization and McCormack and Prysiazniuk[41] used the same subjects in all the three interval conditions which confounded the task of learning any particular set of intervals. Baker [5] also used the same subjects in differert interval conditions. Thirdly, investigators in this area often failed to control perceived intervals. For stable learning of interval occurance, the design of the vigilance task must guarantee with near certainty that each stimulus will be sensed each time and a response made to it. By creating an awareness of each event, the subject has a distinct basis for defining the end of the interval that has just passed and the beginning of the next one. Baker[5] reported that subjects occasionally missed brief transitory signals and Dardano[40] reported occassional false reports of critical signals. Both response events alter the subjects perception of the true signal structure and lead to biased learning or poor learning.

Frankman & Adams[33] investigated the influence of temporal uncertainty of signals on vigilance decrement. Subjects were required to detect a two-digit number that occurred 48 times in three hours on a display box. Each signal lasted 5 sec. and response latency was the performance measure. Each of the three groups had a different degree of temporal uncertainty in the signal series. There were 20 subjects in a group. All subjects were given a practice and a criterion session on different days.

The three groups developed significant performance decrement during the 3-hour criterion session, but the three degrees of temporal uncertainty did not differentially influence the decrement. Analysis of performance as a function of inter-signal intervals suggested that the functions hypothesized for temporal expectancy states in vigilance tasks are oversimplified.

To summarize: the inhibition view is better able to deal with declines within each run than with low average for the whole run. The expectancy view is satisfactory for explaining average preformance, but less convincing when applied to trends within a run.

The activation theory has certain advantages over the other two. It can clearly cope with decline in performance during vigilance tasks and also with low average performance. No matter how familiar the task, monotonous circumstances and deprivation of stimuli produce decreasing efficiency. The difficulty is to explain why some vigilance tasks show so little decrement during a run. If decrement on the clock test is due to the absence of activating stimulation why is there no decrement in the dials test? Further, certain tasks which have been tried under various levels of stimulation show no change in the decline of performance with time. Several experiments confirm that noise produces higher activation. But why should performance under high level of auditory stimulation be worse than in a low one? In his investigation on the effects of lack of sleep on vigilance task, Wilkinson [39] designed tests in which the subject pressed a key to neutral stimuli and refrained from action when a signal occurred, the exact reverse of the normal situation. There was no difference in the amount of decrement.

Two explanations suggest themselves. First, as pointed out by Hebb[34] too high a level of activation is as bad for efficiency as too low a level. Consequently, raising the stimulation level was ineffective because the level was already too high. This explanation is inadequate. The decrement observed in an ordinary vigilance task is explained by the stimulation level being too low: if the level after raising the stimulation is too high, the rise must have covered the whole range, from too low to too high. This is not borne out by the results of Wilkinson, Whittenburg, Ross and Andrews.

A second possible explanation is that from the activation point of view the important variable is the amount of information presented rather than the physical energy in stimulation. This explanation too is not adequate, because in some of the experiments in support of activation theory, irrelevant rather then relevant stimuli have been used, and supporting stimuli contributed no information. Why do some tasks, especially those with long signals, show no decrement as time goes on?

Most of the experiments mentioned under the filter theory do not relate to vigilance tasks. Bills[42] work on prolonged performance of task on colour naming, is an instance in point. A series of colours is presented to a subject and a fresh stimulus follows every response. After some time the subject shows an occasional or slow response due to "mental block". Bills used the mean response latency as criterion for detecting the blocks. After a certain lapse of time, mental blocks increase in frequency, but the mean response time need not increase. The subject's response becomes variable. In general, the whole picture is one of intermittent failure in efficiency interspersed with normal performance.

Shapin and Bills[43] examined the effect of presenting stimuli at a fixed rate which is somewhat faster than the normal capacity of subjects to adopt themselves to such stimuli. They found that such pacing delayed the onset of decline in performance. This agrees with the requirements of the activation theory. The larger the number of stimuli presented in a given time, the greater the efficiency of the subject. Conrad[44] found the same results by altering the signals per minute even within the same number of trials.

The interpretation of blocking, favoured by Broadbent, is that it represents an interruption in the intake of information from one source, owing to the intake of information from another. In other words, if we think of a filter selecting one type of information, then it ceases for a second or so, and information relating to another task is selected. As novel stimuli have a higher probability of passing the filter, shifts in selection do not occur until the task has been continued for some time. From the point of view of vigilance tasks, there is little to choose between the filter theory and the block theory. The filter view harmonizes well with the results of the dials test. The central dial is the best observed immediately after a signal, but after some time, it is not so well monitored as peripheral dials. This indicates a tendency to shift the source of information which controls response. The 'shift of selection' view is also supported by the fact that blocks in the five choice task last for about 1½ sec. and this is the time taken to shift selection twice.

The average level of performance during a run may be explained by activation and expectancy. Blocking explains the decline during a run. The filter theory requires supplementing with the principles of expectancy and activation theories. The conception that the intake of information from a task is occasionally interrupted seems to be well-founded, and this may be attributed to the passage of some irrelevant information through the filter.

VIGILANCE AND INDUSTRY

The extent to which the different experimental findings are relevant to the practical problems of inspection and checking in the factory has been studied by Colquhoun.[45]

The response required of the examiner in a factory is rather more elaborate than that in a laboratory. He must either pick up the defective article and place it aside or, if the article is large, he must mark the defective part with chalk or similar material. He may also be required to enter his observations on a work sheet. If the object is of large size or complexity, he may have to manipulate it so that all parts are inspected.

Noise, atmospheric conditions and lighting may be expected to vary widely between workplaces, as do the actual layouts of particular jobs. Though there are cases where inspection is completely machine paced, more often the examiner has a degree of control over his speed of work which allows him time to take rest (unauthorised rest pauses) in addition to the time officially sanctioned. If a quality bonus system is in operation, it becomes important not only to detect faults, but also to avoid rejecting good items. Information about the efficiency of his work only reaches the examiner after a considerable time delay, either from subsequent check inspection from later processing faults or from customer's complaints.

It is quite common for one examiner to check thousands of items in a day's work, and the number of rejects may vary from one to hundred. Although the temporal occurrence of faults is unpredictable, the mean interval between them may be only seconds, as compared to minutes in laboratory tasks. The accuracy of discrimination may be extremely fine, but such discrimination may be necessary at relatively infrequent intervals, particularly if the defect sought varies in magnitude over a wide range. These factors affect the nature of the response. It may not be sufficient for the examiner to divide the items into "passes" and "rejects"; he may be required to grade them into several categories and also to sort them according to the kind of defect. This requires the exercise of judgement.

In inspection work, only signals which fall outside the given tolerance limits are responded to. Tolerance limits are normally laid down in the specification of the article, but in many cases they may be varied to match fluctuations in general trade or to suit the requirements of particular customer. There is clearly room for a considerable degree of subjective estimation. The examiner's work is considerably more complex than that of the subject in the laboratory vigilance studies. Relatively little attention has been devoted to the inspection problem so far.

CONCLUSION

The chief feature of vigilance task is that a subject responds only to infrequent signals but he may have to watch for the signal for a long period. There is a dearth of theoretical models which can explain all the basic problems of vigilance. A comprehensive theory of vigilance is urgently needed if practical applications are to be possible.

The problem of vigilance has applications in defence and also in inspection task in industry. Relatively little attention has been devoted to the study of vigilance work in industry and its implications for production in field situations.

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