A BEHAVIORAL ANALYSIS OF AN ASSEMBLY-LINE
INSPECTION TASK

by

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CHAPTER I

INTRODUCTION

Man has long attempted to control the behavior of his fellows. In the past these attempts have been little more than haphazard. It is only recently that the study of behavior, and attempts to predict and control it, have been conducted under the systematic and rigorous rules of science.

In the now classic study of behavior, Pavlov, in 1906, demonstrated that through experimental manipulation, regular, predictable relationships could be established between changes in the behavior of the living organism and the environments to which it was exposed. In 1920, Watson and Rayner extended Pavlov's findings to the human organism by conditioning an emotional fear response in an eleven-month-old child. Both Pavlov's study, and that by Watson and Rayner, are examples of conditioning "respondent" behavior. This is behavior in which a specific kind of response is elicited by a specific kind of stimulus, and the stimulus always precedes the response.

In 1938, B. F. Skinner defined another type of behavior, which he termed "operant" behavior. This is behavior which "operates" upon the environment producing

certain consequences. Depending on their nature, these consequences can serve either to diminish the probability of the given behavior occurring again, or to increase it. Consequences which strengthen behavior are called "reinforcers."

The principle of reinforcement has great generality and plays a very important part in the molding of human behavior. This principle may be simply stated as follows: "When certain stimuli closely follow a certain behavior, they increase the probability of that behavior occurring again in the future. Stimuli that serve this function are called positive reinforcers. Other stimuli increase the probability of behavior occurring again when their removal closely follows that behavior. These stimuli are called negative reinforcers" [Staats and Staats, 1964].

An important characteristic of much behavior is that a particular response may be repeated in anticipation of reinforcement, once some "schedule" of intermittent reinforcement has been experienced. This schedule of reinforcement may occur by accident and be arranged in a completely random fashion, or it may be designed for a particular purpose and its arrangement may be carefully planned and controlled. A schedule of reinforcement is a statement of the contingencies on which reinforcement depends. These contingencies are specified in terms of the number of responses emitted, or the passage of time, or both. Schedules based primarily on the number of responses

emitted are called "ratio" schedules while those based primarily on the passage of time are called "interval" schedules. Both ratio and interval schedules may be fixed or variable. For example, if the schedule is Fixed Ratio 20, then each twentieth response is reinforced: reinforcement is contingent upon the emission of 20 responses. Under a variable ratio schedule, the number of responses required for successive reinforcements varies about some mean. For example, in a Variable Ratio 20 the following number of responses might be required for successive reinforcements: 5, 10, 30, 25, 35, 15, 20. There are certain characteristics of responding on each basic schedule that have been obtained for many species of animals, including man.

In a ratio schedule, the more rapidly the subject responds, the sooner he is reinforced. Ratio schedules are therefore characterized by a high rate of response. In a variable ratio schedule, the reinforcement can ostensibly come at any time and therefore the high rate of responding is sustained. On the other hand, one reinforcement will never follow another on a fixed ratio schedule, until the specified number of responses has been emitted. Fixed ratio schedules are therefore characterized by a high rate of responding with a pause following reinforcement. The postreinforcement pause is generally very brief (and not easily detectable) for low ratios such as FR-20, but increases with the size of the ratio.

Compared to ratio schedules, the over-all rate of response on interval schedules is low. This follows from the fact that interval schedules do not differentially reinforce rapid responding. Reinforcement depends on the passage of time and is delivered at specified intervals regardless of the rate of responding. Fixed interval schedules are characterized by a pause after reinforcement and then a gradual increase to a very high rate at the end of the interval. This results in a "scallop" effect and reflects the fact that the probability of one reinforcement immediately following another is zero and increases with the passage of time. Variable interval schedules produce sustained responding at a low rate since, again, reinforcement can come at any time.

The principles of operant behavior have been useful in analyzing the many and varied aspects of man's everyday activities. Hart, et al., [1964] used behavioral methods to demonstrate that certain crying in pre-school children was operant rather than respondent, and therefore under the control of operant conditioning and extinction procedures. The way normal children learn to talk has been studied from the standpoint of operant behavior [Rheingold et al., 1959]. Operant methods have been used to study hallucinatory behavior in psychotics and to control psychotic verbal behavior in chronic schizophrenics [Lindsley, 1956, 1960 and Ayllon and Haughton, 1964]. Behavioral

science is playing an increasingly important part in the technology of education, where one of the most widely publicized contributions is that of programmed instruction [see Holland, 1960 and Homme and Glaser, 1959]. There are many other areas today in which the science of behavior is coming to be used more and more frequently. One of these areas is the study of human vigilance, and it is with this area that the following research is concerned.

The human organism is constantly bombarded by sensory inputs: light, sound, pressure, temperature, etc., all of which combine to form its environment. The organism's survival, both individual and species, is dependent upon an orderly extraction of information from this environment. To be orderly, the organism must be selective. This process of stimulus selection constitutes attention.

William James [1890] defines attention as, "the taking possession by the mind, in clear and vivid form, of one out of what seem several simultaneously possible objects or trains of thought. Focalization, concentration of consciousness are of its essence. It implies withdrawal from some things in order to deal effectively with others . . ." James goes on to say that, "fatigue and monotonous mechanical occupations that end by being carried on automatically tend to produce distraction in men." Sustained efficiency in monotonous perceptual tasks is a problem which has been investigated by many men since James.

The situation is one 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. Cases involving assembly-line inspection of products represent a large group of monitoring tasks in which the critical signals may arise relatively infrequently. This research will attempt to analyze the assembly-line inspection task, and the problem of sustained efficiency, by utilizing the principles of operant behavior.

Purpose and Scope

This research will attempt a behavioral analysis of an assembly-line inspection task. That is, an attempt will be made to show that the behavior exhibited by a subject acting as an inspector can be predicted and controlled using the principles of operant behavior. The inspection task falls into the category of a "monotonous perceptual task," i.e., a situation in which a human being (the inspector) is required to monitor a display (the assembly line) in search of critical, but infrequent, signals (defectives). It is postulated that the discovery of a defective serves as a reinforcement in maintaining a "vigilant" monitoring behavior and further, that the "schedule of defectives" corresponds to a schedule of intermittent reinforcement and therefore, can serve to

control the inspector's monitoring behavior. In order to test this hypothesis, the experimenter has devised an "observing response" required of the inspector during his monitoring of the assembly line. This response will be recorded over time and the results will be compared with stylized records of responding under basic schedules of reinforcement. The study will involve four schedules of defectives, each at two levels. Each subject will perform the task under each schedule for both levels, one time only. The subject's response rate will be measured under each schedule at each level. In addition, for each schedule and level, a record will be kept of the number of "good product" rejected, the number of "bad product" rejected, and the number of "bad product" accepted. This information will be used in an effort to correlate the subject's "inspector accuracy" with the schedule of defectives and the subject's response rate. Note will also be taken of whether or not a decrement occurs in the subject's ability to detect defectives as time on watch progresses. In the final analysis then, it is hoped that this study will demonstrate that in an assembly-line inspection task, the detection of defectives can serve as reinforcements for observing responses and, further, that inspector accuracy may be correlated to the particular "schedule of defectives" employed.

Background Information

Interest in the problem of sustained efficiency in monotonous perceptual tasks probably became most pronounced during and immediately following the Second World War when research was being carried out to determine the optimum length of watch for radar operators on antisubmarine patrol. These operators were required to monitor a display in search of critical, but infrequent, signals. Research in this area indicated a drop in the percentage of signals detected as time progressed. A report by Mackworth [1948] on signal detection (auditory and visual) under conditions requiring prolonged vigilance indicated a decrement in the subject's ability to detect signals as time on watch progressed. Similar decrements have been demonstrated when subjects were required to detect targets on simulated radar displays [Anderson, 1944]. Perhaps the classic study on human watch-keeping was the "clock test" designed by Mackworth [1950]. A pointer rotated in successive small jumps, one every second, around a clock-like dial, and at irregular and comparatively infrequent intervals it made a double jump. Observers had to notice and signal each of these double jumps by depressing a key. After about only thirty minutes, they began to miss the double jumps, and the number missed increased throughout a two-hour period. Broadbent [1953] has shown a similar decrement

using a dial-watching task. A study of continued "alertness" and its implications for inspection work in industry was made by Colquhoun [1957]. Colquhoun states that: "the ability to detect small changes in a display declines considerably within thirty minutes of beginning a watch," and he goes on to say: "mental fatigue, a state that arises with continued performance of the same task, is characterized by a fall in work output, a widening of subjective tolerance and an increased variability in both accuracy and in the timing of responses." Colquhoun states that certain "inherent task-conditions" may affect sustained efficiency in inspection tasks and mentions, among others, "the frequency of faults" and "the temporal structure of the sequence of faults." In 1953, Deese demonstrated that as the frequency of signals increases, there is an increase in the percentage of signals detected. He found that with a display simulating a 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 [Deese and Ormond, 1953]. Mackworth's findings were repeated for men and women in a study by Whittenburg, et al. [1956], in which it was also shown that variability among subjects, which was high initially, increased with continued time on task and that females were superior to males in the monitoring task. Adams [1956] demonstrated that the decrement obtained in a monotonous perceptual task despite variations

in the stimulus intensity, although it was less for higher intensity stimuli.

An abundance of theoretical constructs have been offered to account for the decrement and the relation between signal frequency and detection probability. Mackworth postulated the term "vigilance" and used it to mean "a high state of readiness to perform adaptive and purposive acts." He further postulated that the "excitatory" state of "vigilance" was opposed by an inhibitory state which paralleled the concept of external inhibition of classical conditioning [Mackworth, 1948]. More recently, Deese [1955] postulated the "expectancy" hypothesis in which he states that "the feedback from the search task determines what the observer expects from further participation in the task in a simple proportional relationship and his vigilance will vary accordingly." Broadbent [1958] attempts to explain the findings concerning monitoring behavior in terms of stimulus selectivity, expanding on Mackworth's conception of external inhibition and Pavlovian (classical) conditioning.

It is difficult, if not impossible, to explain the data of the so-called "vigilance" studies by employing any of the constructs so far developed. These concepts give the appearance of explaining the data because of the syntax of the statements, when, in fact, they are no less mysterious than the phenomena they purport to explain. For

example, a subject is said to make a detection because he is, at that moment, vigilant, or attentive, or "expecting" a signal. But how do we measure this vigilance, attention, or expectancy? We cannot compare the number of defectives detected by the subject versus the actual number of defectives and say this is a measure of the subject's vigilance, because it is simply a measure of his efficiency as a result of his vigilance, or to quote J. G. Holland [1958]: "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." Terms such as "vigilance" or "expectancy" develop descriptive value only after the behavior itself, and its controlling variables, have been explicitly described.

In 1958, J. G. Holland suggested that the "observing responses" which make detections possible follow the principles of operant behavior. In order to test his hypothesis, Holland experimented with Navy enlisted men as subjects and a task of reporting pointer deflections on a dial. The subjects were completely in the dark and in order to see the dial they had to press a key which illuminated the dial for .07 seconds. Holland's analysis showed that detections of the dial deflections served as reinforcements for observing responses. In arriving at this conclusion, Holland employed various "schedules" of dial deflections.

The rate of responding (pressing the key for light) was found to vary directly with the schedule employed.

Additional evidence for the adequacy of the observing-behavior analysis of "vigilance" was supplied by Holland in an extension of his aforementioned study. Holland employed the schedule used by Mackworth [1950] in his clock test to demonstrate that the "vigilance" decrement found by Mackworth was accompanied by a parallel decrement in observing rate. Holland concluded 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."

It would be of interest to extend Holland's technique to a situation in which the observing behavior is slightly more involved. Such a situation is encountered in the assembly-line inspection of products. Here, the observing behavior involves a scanning with the head and eyes, as well as perhaps more subtle responses.

The striking fact is that rather precise control can be 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 approximate control over the operator's monitoring behavior. If this

is in fact the case, then the application of the concept to the assembly-line inspection of products would be a fruitful pursuit.

CHAPTER II

TASK DESIGN AND EQUIPMENT

This study is designed to test the hypothesis that the monitoring behavior exhibited by a subject acting as an inspector in an assembly-line inspection task follows the principles of operant behavior. In order to carry out this objective it was necessary to simulate an assembly-line inspection task, complete with assembly-line and product to be inspected. In addition, an "observing response" had to be specified and devised, such as the key-pressing response used by Holland [1958], in order to compare the observing response rate against the various "schedules of defectives" employed. This chapter will describe the basic task design and procedure together with the specific equipment utilized in fulfilling the experimental requirements of this study.

Task Design and Procedure

The "assembly line" in this study was simulated by a rotating disk, or wheel, which was provided with ten equispaced slots within which the item to be inspected was carried. The "products" employed were simulated printed circuits (Figure 1). These circuits were printed on a

Fig. 1--The simulated printed circuit. Note that none of the lines are completely cut by a white dot; therefore the circuit is good.

Fig. 2--A defective circuit. Note that the white dot in the lowest portion of the circuit completely cuts a line.

2 3/4 x 3 1/4 inch white card, and were spotted with from four to five white dots (applied with white poster paint). A defective circuit was defined as any circuit in which one or more of the lines in the circuit was completely cut or covered by a white dot (Figure 2).

The "observing response" decided upon was the pressing of a button to stop the rotating disk. The button was limited-hold and stopped the disk for a period of one second only, even if the subject held the button down. After one second, the disk immediately began rotating again and the subject was required to release and redepess the button in order to restop the disk.

Before beginning the experiment, each subject was presented with a standard written briefing which gave as the purpose of the study the testing of the subject's "inspector accuracy." No mention was made that the subject's response rate (pressing the button to stop the disk) was to be measured. The briefing was designed to encourage button-pressing with the object of accomplishing as high a detection rate as possible (see Appendix A). In addition, each subject was carefully briefed on what constituted a defective circuit and then given a 7 to 10 minute trial-run prior to taking part in the actual experiment.

Subjects were seated at the disk between two hanging screens extending from the center of the disk

outwards to approximately six inches beyond the edge. This limited the subject's visual inspection field to a wedge-shaped area subtending an angle of 68° (Figure 3). The stop-button was placed on a stand at the subject's left and a container for defective circuits was situated to the right of the subject. The experimenter, situated to the left of the subject behind the screen, manipulated the defective items presented to the subject during the trial so as to maintain the predetermined "schedule of defectives." The subject was instructed to stop the disk (by pressing the button) if he wished to inspect a particular circuit "more carefully." When the subject discovered what he thought was a defective, he was told to call "reject" and remove the defective from the disk placing it in the container. If a defective was presented to the subject and the subject failed to detect it, the experimenter immediately placed an "unmissable" defective on the disk for the subject to detect. In this way, the schedule of defectives was maintained relatively close to the planned schedule, even though the subject missed some defectives. An "unmissable" defective was one so obvious that the probability of its being missed was practically zero (Figure 4).

Each time the subject pressed the button to stop the disk his action was recorded by an "event-recorder," which then provided a history of the subject's responses

Fig. 3--Schematic illustrating basic equipment set-up

Fig. 4--An "unmissable" defective. This defective circuit was presented to a subject who failed to detect the immediately preceding defective.

over time, or response rate. In addition, a simple electrical counter was used to facilitate the employment of ratio schedules.

The task required from 60 to 63 minutes (FI-7 schedules were run for 63 minutes in order to have nine intervals to evaluate; all other schedules were run for 60 minutes) and was accomplished without extended rest breaks. The experimenter did allow the subjects to stretch their necks or rub their eyes, etc., by allowing three or four empty slots to go by on the assembly line. These breaks were short, lasting only 10 to 20 seconds, and were given only when requested by the subject. Such requests were infrequent, never occurring more than once in a trial and, in the great majority of trials, not

occurring at all. There were, however, other unplanned-for breaks which occurred due to equipment failures. These breaks lasted from 1 1/2 to 2 minutes; they had no significant effect on the results.

At the conclusion of each trial the experimenter inventoried the box containing the rejected circuits and recorded total number of defective circuits presented, number of defective circuits rejected, number of defective circuits accepted, and the number of good circuits rejected.

The rotating disk simulating the assembly line, the limited-hold stop-button, the event-recorder, and the other items of equipment utilized in carrying out the above procedure will be described in the following section of this chapter.

Equipment

The essential equipment requirements of this study were (1) equipment associated with the simulation of an assembly-line inspection task, and (2) equipment required to measure certain behavioral variables involved in the inspector's monitoring of the assembly line. The equipment used to fill the first requirement consisted of a rotating disk, or wheel, a small motor to power the disk, a limited-hold button to arrest the rotation of the disk for a short time, two screens limiting the inspection

area and reducing distraction to the inspector and, of course, the product to be inspected--the printed circuits (Figure 1). An event-recorder and a simple electrical counter served the second requirement. The equipment was arranged as shown in Figure 3.

The rotating disk was fabricated of 3/4 inch-plywood cut to a 4 foot diameter and painted light gray. The disk was provided with ten equispaced slots to carry the printed circuits. A 115 v, 36 amp speed reducer motor rated at 1/50 HP was used to power the disk.

The limited-hold button was provided the subject in order to facilitate his inspection task. The pressing of this button was defined as the "observing response" corresponding to the key-pressing response used by Holland [1958]. The button was designed with an adjustable time delay which was set at one second for the purposes of this study (Figure 5). Pressing the button would stop the disk for a period of one second. After one second, the disk immediately began rotating again, even if the subject was holding the button down. In order to restop the disk the subject was required to release and redepress the button. Pressing the button required little effort and it was depressed up to 1388 times in one hour without any noticeable effect on the part of the subject.

Subjects were seated at the disk between two

Fig. 5--Limited-hold button

hanging screens extending from the center of the disk outwards to approximately six inches beyond the edge. This limited the subject's visual inspection field to a wedge-shaped area subtending an angle of 68° (Figure 3). The screens were fabricated from black photographer's cloth.

Simulated printed-circuits served as the "product" in this study. The circuits were printed in heavy black on a $2\frac{3}{4}$ by $3\frac{1}{4}$ inch white card, slightly thinner than a standard playing card. All the circuits were spotted with from four to five white dots applied with white poster paint. A defective circuit was defined as any circuit in which one or more of the lines in the circuit was completely cut or covered by a white dot. An "unmissable" defective was one so obvious that the probability of its being missed was practically zero (see Figures 1, 2, and 4). With the exception of the "unmissable," the defectives were approximately equal in the discrimination: good circuit--bad circuit. On the other hand, the good circuits varied within a narrow (subjective) range as to their difficulty of inspection. It was felt that this variation was needed in order to keep the task fairly realistic.

Each time a subject pressed the button to stop the disk his response was recorded over time on a 115 v, AC event-recorder (brand name: Oscillograph), and an electric counter, also 115 v, which provided the

cumulative number of responses at any given time. The counter was used to facilitate the employment of ratio schedules, while the event-recorder was used to give an accurate history of the subject's responding pattern. These items are pictured in Figure 6.

Figures 7, 8, and 9 show the equipment arrangement and the inspection task in progress.

Fig. 6--Event-Recorder and
Response Counter

Fig. 7--Overhead view of inspection area showing limited-hold button on left

Fig. 8--Overhead view of subject seated at work place

Fig. 9--Left-side view of subject,
left screen removed

CHAPTER III

DESIGN OF THE EXPERIMENT

The evidence, derived from a prior pilot study, that subject differences would be large, dictated treating the subjects as blocks in a randomized block design approach to this experiment. Thus, each subject performed the task on each schedule, but the order in which the schedules were employed was random. It will be noted that this design does not permit the separating of possible learning effects and this aspect will be discussed at a later point in this thesis. Subjects and Schedules of Defectives were treated as independent variables, while the subject's Response Rate and Inspector Accuracy were treated as dependent variables. The analysis of results is almost exclusively graphical, rather than statistical.

Selection of Factors

Schedules

Eight schedules of defectives were evaluated as independent variables in this experiment. The number of schedules employed was arrived at by utilizing two levels of each basic schedule, i.e., VR-20 and VR-75, FR-20 and

FR-75, VI-2 and VI-7, and FI-2 and FI-7. Each schedule must be considered as a separate factor, since, for example, a temporal pattern in which there are exactly seven minutes between each defective is quite different from one in which there are two minutes between each defective, even though they are the same basic kind of schedule, i.e., fixed interval.

The criteria used in selecting the levels for each basic schedule were as follows: (1) the high and low levels for the variable and fixed ratio schedules should be the same, and the high and low levels for the variable and fixed interval schedules should be the same; (2) the high and low levels for the ratio and interval schedules should be as nearly equivalent as possible in terms of the probable number of signals that might be presented, i.e., thirty signals are presented in an hour long task using a VI-2 schedule. What VR schedule should be used in which the "average" subject would emit the required number of responses, on the average, every two minutes?; (3) the high and low levels should be sufficiently separated so that the effect is pronounced; however, the low level should produce a signal rate which is well within the subject's ability to "keep-up" and the high level should produce a signal rate which maintains the subject's responding behavior, i.e., does not induce extinction phenomena.

A pilot study was accomplished in order to be better

able to select schedule levels which satisfied the 2nd and 3rd criteria. The results of this study led to the selection of the following levels for each basic schedule: variable and fixed ratio--20 and 75, variable and fixed interval--2 and 7. In other words, in a ratio schedule the subject was required to emit either 20 or 75 responses (depending on the level of schedule being used) before a defective circuit was presented, while in an interval schedule, a period of 2 or 7 minutes elapsed before a defective was presented.

Subjects

Four male college students were randomly selected to serve as subjects in this experiment. They ranged in age between 21 and 25 years. Each subject had 20/20 vision. One subject (#2) wore glasses. Pertinent subject data is given in Table 1.

TABLE 1
SUBJECT DATA

Number	Initials	Age	Height	Weight	Vision
1	E.G.	25	5' 9"	165	20/20
2	D.B.	23	5'10"	160	20/20*
3	L.M.	25	5'10"	167	20/20
4	J.K.	21	5' 8"	190	20/20

* corrected

Dependent Variables

The dependent variables being evaluated in this experiment are the subject's observing response, i.e., his button pressing, and the subject's inspector accuracy. The subject's observing response was recorded continuously throughout each schedule and level by the event-recorder. This not only provided the cumulative number of responses from which the overall response rate could be calculated, but also provided a continuous record of the subject's responding which, in turn, could be examined for any patterns of responding that might exist. In addition, for each schedule and level, a record was maintained of the total number of defective circuits presented, the total number of defective circuits rejected, total defective circuits accepted, and the number of good circuits rejected.

In the study by Holland [1958], the observing response emitted by the subjects was a key-pressing which illuminated a dial which they were required to monitor. Without pressing the key the subjects could not see the dial, since they were completely in the dark. The subjects key-pressing behavior was verbally shaped by Holland before the experiment began. After that, a subject's key-pressing behavior was maintained by detections of dial deflections (the critical signals). In other words, detections of the dial deflections served as reinforcements for observing responses.

The observing response devised for this study was similar in concept to that used by Holland. The subject's button-pressing behavior was shaped both verbally and by a written briefing, prior to his taking part in the actual experiment. The subject's button-pressing was not required by any necessity other than the need (developed by the experimenter) for the subject to detect as many defective circuits as possible. Unlike the subjects in Holland's experiment, the subjects in this study could monitor the display without pressing the button at all. However, at the rate the disk was rotating (2.5 RPM), their ability to completely scan each circuit before it passed through the designated inspection area was seriously impaired unless they did stop the disk. This was shown to be the case when a subject attempted to perform the inspection during the pilot study without pressing the button more than one time per minute. His inspector accuracy fell from 89% on the previous run, where his button-pressing was approximately 6 per minute, to 36%, the lowest mark obtained for any subject. Therefore, it is probably safe to say that a certain amount of button-pressing was mandatory for the subject in order that he be able to make a good inspection. This initial level of responding (corresponding to the so-called operant level in operant conditioning) varies widely among subjects. For example, during the pilot study, subjects attaining the same degree of accuracy in their inspection

had response rates which differed by almost 14 responses per minute. The observing response then was evaluated both in terms of averages derived from all subjects, as well as individual characteristics of responding. Again, the hypothesis is that the subject's button-pressing behavior will be maintained by detections of defective circuits, or that the detections of defective circuits serve as reinforcements for observing responses.

Two measures of inspector accuracy are used in evaluating the subject's efficiency in the inspection task. The first is the Percent of Defective Product Rejected, and the second is Juran's Special Measure, designated $A_3\%$ and $A_4\%$ respectively [after Sosnowy, 1967]. These measures are calculated as follows:

1. Percent of Defective Product Rejected (A_3),

$$A_3\% = \frac{\text{number of defective product rejected}}{\text{number of defective product}} \times 100$$

2. Juran's Special Measure (A_4),

$$A_4\% = \frac{\begin{array}{c} \# \text{ defective} \\ \text{product rejected} \end{array} - \begin{array}{c} \# \text{ good} \\ \text{product rejected} \end{array}}{\begin{array}{c} \text{number of defective} \\ \text{product} \end{array} - \begin{array}{c} \# \text{ good product} \\ \text{rejected} \end{array}} \times 100$$

The first measure used, A_3 , is a standard measure used in the evaluation of vigilance tasks. The second, A_4 , is a measure developed by Juran [1951] and used by Sosnowy in evaluating the results of a study he conducted on inspector accuracy under varying conditions of incoming quality

[Sosnowy, 1967]. As can be readily seen, this measure penalizes the subject for making the wrong decision in terms of "good product rejected" as well as "bad product accepted," whereas, the first measure, A_3 , penalizes the subject only in terms of "missed signals," that is, "bad product accepted."

CHAPTER IV

ANALYSIS OF EXPERIMENTAL RESULTS

The results are presented in five sections: (1) The first of these deals with the effect of the schedule employed on the subject's pattern of responding and overall response rate. (2) The subject's are then divided into pairs, one reflecting a high rate of response and the other a low rate of response. They are then compared with regard to their percentage of signals detected and number of false alarms (good product rejected), versus time on watch. (3) The schedules are then divided into two groups: those providing a high signal rate (high frequency of defectives) and those providing a low signal rate. These groups are compared with regard to percentage of signals detected and number of false alarms over time. (4) The schedules are then grouped in four different ways: (a) all schedules are combined; (b) fixed and variable ratio schedules are combined and fixed and variable interval schedules are combined; (c) variable ratio schedules are combined and fixed ratio schedules are combined; and (d) variable interval schedules are combined and fixed interval schedules are combined. Comparisons are then made with respect to the percentage of signals detected and response rate versus

time on watch. Finally, (5) the average response rate and percentage of signals detected for all subjects, regardless of schedule, is presented in order for sessions one through eight.

Effect of Schedule on Response Pattern and Rate

A subject's responding pattern for any given schedule was obtained from the record of responding maintained by the event-recorder during each trial. Figures 10 through 17 illustrate representative patterns from the last portions of the trials obtained for subjects on each of the eight schedules employed. These curves were obtained by plotting the cumulative responses on the ordinate against the time on watch as the abscissa, then stylizing the graph by tracing over it to smooth out the stair-step effect. The detection of a defective is designated by a short vertical line on the curve. Where more than one curve appears on a graph (Figures 11, 13, 14, 15, 16 and 17), the upper curves are continuations.

It can be seen that, in general, these records conform closely to the characteristic records of responding that have been found to obtain for many species of animal, including man, during operant conditioning.

The fixed ratio schedules are characterized by a pause after detections, which is small for the FR-20 and larger for the FR-75 (Figures 10 and 11). On the other

Fig. 10--Cumulative response record, FR-20 schedule

Fig. 11--Cumulative response record, FR-75 schedule

Fig. 12--Cumulative response record, VR-20 Schedule

Fig. 13--Cumulative response record, VR-75 schedule

Fig. 14--Cumulative response record, FI-2 schedule

Fig. 15---Cumulative response record, FI-7 schedule

Fig. 16--Cumulative response record, VI-2 schedule

Fig. 17--Cumulative response record, VI-7 schedule

hand, the rate of responding is sustained on the variable ratio schedules and the curves obtained are very nearly straight lines (Figures 12 and 13).

The fixed interval schedules are characterized by a pause in responding after a detection and then an increase in response to a high rate just prior to the next detection (Figures 14 and 15). Again, the variable interval schedules are characterized by a sustained rate of response, i.e., no pause after a detection (Figures 16 and 17).

Figures 18 and 19 illustrate the overall response rates for the low and high levels, respectively, of the four basic schedules. In Figure 18, it can be seen that the VR-20 and VI-2 schedules resulted in higher overall response rates than the FR-20 and FI-2 schedules, respectively. This is not the case for the higher level schedules (Figure 19). Here, both fixed schedules result in higher overall response rates than the variable schedules. However, it should be noted that none of the high level schedules are significantly different from one another at the 5% level and only the VI-2 schedule is significantly different from the FI-2 and FR-20 for the low level schedules (determined by the Duncan Multiple Range Test). Figure 20 shows the relative response rates for all ratio schedules combined and all interval schedules combined. The difference between them is not significant.

Fig. 18--Relative slope of low-level schedules

Fig. 19--Relative slope of high-level schedules.

Fig. 20--Relative slope of ratio vs. interval schedules

Detection Data for High-Response-Rate
Group vs. Low-Response-Rate Group

Upon reviewing the data it was discovered that subjects two and four were responding at a considerably higher rate than subjects one and three. In order to determine what effect, if any, this difference in response rates had, the subjects were grouped in pairs, two with four and one with three. The data for each group was then compared with regard to percentage of signals detected and number of false alarms over time. Figures 21 and 22 show the results of these comparisons. In Figure 21, the cumulative percent of signals detected is plotted as the lower portion of the ordinate, while cumulative response rate is plotted on the upper portion. The abscissa represents time on watch divided into six, 10-minute periods. It can be seen that the low-response-rate group (open circles) shows a marked decline in the cumulative percentage of signals detected as time on watch progresses. On the other hand, the high-response-rate group, even though they start out lower, shows an increase in cumulative percent detected and, in fact, end by discovering a greater overall percentage of signals. Both groups show a slight decline in response rate as time on watch progresses, but at the end of the watch the high group is still responding by more than 10 responses per minute over the low group.

In Figure 22, the cumulative number of false alarms

Fig. 21--Cumulative response rate and cumulative percent detected vs. time on watch

Fig. 22--Cumulative good rejected vs. time on watch

is plotted on the ordinate against the time on watch as the abscissa for both groups. It can be readily seen that the high-response-rate group is rejecting considerably more good product over time than the low-response-rate group.

Effect of Signal-Rate

Certain of the schedules employed provided a higher frequency of signals (defectives) during the watch than others. These schedules were as follows: VR-20, FR-20, VI-2 and FI-2, i.e., the lower levels of the four basic schedules. These schedules provided, on the average, 72% more signals during the watch than the higher level schedules, i.e., VR-75, FR-75, VI-7, and FI-7. In order to determine the effect of signal-rate on the subject's performance, the schedules were grouped according to the frequency of signals presented. In Figure 23, the cumulative percentage of signals detected (designated $\text{cum. } A_3\%$) is plotted on the ordinate against time on watch as the abscissa, for both groups. It can be seen that there is a marked decline in signals detected for the low frequency schedules (open circles) as time on watch progresses. There is no such decline for the schedules providing a high frequency of signals. In Figure 24, the ordinate is cumulative $A_4\%$ (see Chapter III, page 33), while the abscissa is again time on watch. As before, the low-frequency group shows a considerable decline when compared with the high-

Fig. 24--Juran's Special Measure (cum. $A_4\%$) vs. time on watch

High Freq. Sched's. ---△---

Low Freq. Sched's. ---○---

Fig. 23--Percent of total signals detected (cum. $A_3\%$) vs. time on watch

frequency group, and the difference between the two groups has been increased by introducing the factor of good product rejected. That is, the curve representing the low-frequency group (open circles) shows an overall decrease throughout the watch when the good product rejected is taken into account, while the curve representing the high-frequency group is little affected by the introduction of this factor. In Figure 25, the cumulative number of good product rejected has been plotted against time on watch for both groups. It can be seen that the high-frequency group results in less good product rejected than the low-frequency group.

Effect of Schedules on Cumulative Response Rate
and Cumulative Percent Signals Detected

Figure 26 represents the cumulative percentage of signals detected and cumulative response rate on the lower and upper scales of the ordinate, respectively, plotted against the time on watch for all the schedules combined. It can be seen that there is a general decline in response rate as time on watch progresses up to about forty minutes. After this, response rate remains fairly stable throughout the final twenty minutes of the watch. There is a corresponding decline in the percentage of signals detected for the first thirty minutes of the watch, a rise in percentage of signals detected in the next ten minutes, and then a fairly stable percentage of signals detected throughout the

Fig. 25--Cumulative good rejected
vs. time on watch

Ratio Sched's.
Interval Sched's.

Fig. 27--Cum. % of signals detected and cum. response rate vs. time on watch: ratio and interval schedules 56

Fig. 26--Cum. % of signals detected and cum. response rate vs. time on watch: all schedules

remaining twenty minutes of the watch.

In Figure 27, the schedules have been subdivided into ratio schedules and interval schedules, and the data plotted exactly as in the previous case. Here we notice that the ratio schedules (triangles) have both a higher overall response rate and a higher overall percentage of signals detected than the interval schedules (circles).

In Figures 28 and 29, ratio and interval schedules have been further subdivided into variable ratio and fixed ratio schedules (Figure 28) and variable interval and fixed interval schedules (Figure 29). In both figures we notice that the variable schedules have both a higher overall response rate and a higher overall percentage of signals detected than the fixed schedules.

Order of Sessions

This experiment was run as a randomized block design with subjects as blocks. The order in which the schedules were employed for any given subject was random. Figure 30 shows the average percentage of signals detected and the average response rate for each session, for all subjects. Points on this graph were obtained by averaging the data for all subjects on sessions one through eight, respectively, regardless of the schedules being employed. It should be noted that the experimental design does not permit us to separate the possible effects of learning from one session

Fig. 28--Performance curves; variable ratio and fixed ratio schedules

Fig. 29--Performance curves; variable interval and fixed interval schedules

Fig. 30--Average percent signals detected and average response rate vs. sessions, all subjects

to the next. However, it appears from Figure 30 that if such an effect exists, it is not predominant.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

This research has attempted a behavioral analysis of an assembly-line inspection task. Essentially, the aim has been to demonstrate that in a relatively complex inspection task, the observing responses which make detections possible follow the principles of operant behavior. The study by Holland [1958] was the impetus for this research. In pursuing the objective of this research an observing response was devised which consisted of pressing a limited-hold button to stop a rotating disk (simulating the assembly line). A simulated printed circuit was used as the product to be inspected. Eight schedules of defective circuits were employed. These schedules consisted of two levels each of the four basic schedules of reinforcement, i.e., variable ratio, fixed ratio, variable interval and fixed interval. The observing responses emitted by the subjects were evaluated with respect to the schedules employed. In addition, the subject's inspector accuracy was evaluated for each schedule. The results of the experiment, as presented in Chapter IV, were broken down into five sections: Effect of Schedule on Response Pattern and Rate, Detection Data for High-Response-Rate Group versus Low-Response-Rate Group,

Effect of Signal Rate, Effect of Schedules on Cumulative Response Rate and Cumulative Percent Signals Detected, and Order of Sessions. These same five sections are the organizational basis for this chapter, in which the results are discussed and appropriate conclusions are drawn from them. It must be remembered that these conclusions are limited in their application by the restrictions of the experiment itself. Recommendations for further study in the area are presented at the end of this chapter.

Conclusions

1. Effect of Schedule on Response Pattern and Rate

The results of this facet of the experiment demonstrated that the detections of defective circuits served to control the rate or probability of emitting observing responses, and furthermore, this control was of the same nature as that exerted by conventional reinforcers in operant conditioning. For example, Figures 10 and 11 (pages 37 and 38) are stylized records of responding during the employment of FR-20 and FR-75 schedules, respectively. Notice that these records are characterized by a pause after detections which is small for the FR-20 and larger for the FR-75. Recall that on a fixed ratio schedule one reinforcement will never follow another until the specified number of responses has been emitted (page 3, Chapter I). Responses immediately following reinforcement are

never reinforced; therefore the stimuli connected with reinforcement become discriminative stimuli for nonreinforcement. Fixed ratio performances are therefore characterized by a pause after reinforcement followed by an abrupt change to a high stable rate. On the other hand, variable ratio schedules tend to sustain responding since reinforcement can come at any time (Figures 12 and 13, pages 39 and 40).

The records obtained with interval schedules in this experiment are also characteristic. Notice that the fixed interval schedules (Figures 14 and 15, pages 41 and 42) are characterized by a pause in responding after a detection and then an increase in responding to a high rate just prior to the next detection. This reflects the fact that the probability of one reinforcement immediately following another is zero and increases with the passage of the fixed interval of time. Again, the variable interval schedules (Figures 16 and 17, pages 43 and 44) produce sustained responding since reinforcement can come at any time.

These results permit us to conclude that, within the limitations of this experiment, the detections of defectives can serve as reinforcements for observing responses.

2. Detection Data for High-Response-Rate Group versus Low-Response-Rate Group

In the studies by Holland [1958] and Mackworth

[1950], as well as in this study, there were some important individual differences. Both Mackworth and Holland found that they could divide their subjects into two groups, a high-detection group and a low-detection group. In both cases, the vigilance decrement was due to the low-detection group. In addition, Holland showed that the high-detection group demonstrated a high response rate, while the low-detection group had a low response rate. The subjects of the present study were found to fall into two groups, one emitting a distinctly higher response rate than the other. Upon comparing these groups with respect to the percentage of signals detected (Figure 21, page 50), it was found that the vigilance decrement was due to the low-response-rate group. This finding agrees with that of Holland. Holland concludes that "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." Recalling that the schedules which differentially reinforce high responding are ratio schedules, the performance of each group has been plotted separately for ratio and interval schedules (Figure 31). It can easily be seen that the vigilance decrement occurs during the performance of the low-response group (open circles) on ratio schedules (solid line). In addition, we see that the high-response group performs markedly better on ratio schedules. We can

Fig. 31--Cumulative % detected vs. time on watch for high and low response rate groups on ratio and interval schedules

conclude therefore, that the vigilance decrement may be a function of the differential reinforcement of observing responses. In other words, the group that responds at a low rate will be reinforced at a low rate thereby incurring a vigilance decrement, while the group that responds at a high rate will be reinforced at a high rate thereby preventing the vigilance decrement. This finding can be related to studies on the effect of signal rate on performance and this aspect will be discussed in the next section.

In addition to comparing the high and low response groups with respect to their percentage of signals detected, they were also compared in terms of number of good product rejected, i.e., false alarms (Figure 22, page 51). It was found that the high-response group rejected considerably more good product than the low-response group. Again breaking down the performance of each group into ratio and interval schedules (Figure 32), we find little or no difference in the performance of the low-response group on either schedule; however, the high-response group again shows a better performance (less good rejected) on ratio schedules as opposed to interval schedules. It appears then that the differential reinforcement of a high response rate with a high frequency of signal presentation (frequent occurrence of defectives) serves not only to prevent the vigilance decrement in terms of missed signals, but also

High res. group { ratio sched's. —△— HRR
 int. sched's. - -△- - HRI

Low res. group { ratio sched's. —○— LRR
 int. sched's. - -○- - LRI

Fig. 32--Cumulative good rejected vs. time on watch, high and low response groups on ratio and interval schedules

reduces the number of false alarms.

In general then, the vigilance decrement reported by Mackworth, Holland, and others was confirmed in this study, and further, this decrement was found to be associated with the differential reinforcement of observing responses.

3. Effect of Signal Rate

It has been demonstrated in vigilance studies that the percentage of signals detected increases as the signal frequency increases. In the study by Deese and Ormond [1953], the probability of detection was found to vary directly with the rate of signal presentation. Jenkins [1957], using signal rates of 480, 60, 30 and 7.5 per hour, found that the decline in signals detected depended upon the signal rate, with lower rates producing greater declines. In addition, Jenkins found that the percentage of false alarms increased sharply as rate decreased. The present study also demonstrates a decline in signals detected and a greater number of false alarms for the low-frequency signal rate (Figures 23, 24 and 25, pages 53 and 55). The interesting thing here is that the curves for cumulative percent signals detected versus time for high and low signal rates (Figure 23) are very similar to the same curves plotted for high and low response groups (Figure 21, page 50). It appears then, that the presenta-

tion of a high rate of signals is akin to differentially reinforcing a high response rate, both in terms of preventing missed signals and lessening the probability of false alarms.

The fact that a high rate of emitting observing responses, which are differentially reinforced, and the presentation of a high signal rate, both serve to prevent the vigilance decrement, would seem to indicate that both phenomena are acting to maintain attentive behavior throughout the monitoring task. Thus, the subject's ability to discriminate a signal (defective) from a non-signal (good product) is sustained.

This finding may help clarify a dichotomy of opinion in the literature on inspector performance reaction to good and poor quality lots. One school of thought believes that a decrease in the incoming quality of a lot causes a decrease in inspector accuracy because of the increased number of chances for error by the inspector. The other school of thought contends that a decrease in the incoming quality of a lot causes an increase in inspector accuracy because the work of the inspector is less monotonous. The results of this study, as well as some other vigilance studies [Deese and Ormond, 1953 and Jenkins, 1957], would seem to support the second school of thought. However, one must be careful not to make too general a statement covering this area since the typical industrial inspection task is far more complex [see, for example, Colquhoun, 1957] than

the usual tasks required of subjects in most vigilance studies. Still, it is illuminating to look at the problem of sustained efficiency in industrial inspection tasks from the standpoint of reinforcement and operant conditioning. For example, a recent study on inspector accuracy by Sosnowy [1967] produced results which, at first glance, did not seem altogether consistent. In his study, Sosnowy required subjects to inspect small plastic balls simulating ball bearings. These balls were displayed on a rotating disk at three inspection rates: 160, 200 and 240 balls per minute. The balls were all marked with letters of the alphabet. Certain of these letters were designated as representing defective balls. The incoming quality at each inspection rate was varied between 5 and 25% defective in steps of 5%. Upon discovering a defective, the subjects were required to remove the ball from the disk and place it in a nearby container. Sosnowy found that inspector accuracy decreased as the inspection rate increased and, at 240 balls per minute, as the incoming quality decreased. However, at the lower inspection rates the results were somewhat different. To quote Sosnowy, "for the lowest inspection rate in this experiment, 160 balls per minute, inspector accuracy does not seem to decline significantly for any of the five levels of incoming quality." This observation also holds for the first four levels of incoming quality at the inspection rate of

200 balls per minute. Beyond this point--20% defective and 200 balls per minute--inspector accuracy declines markedly at each decreasing level of incoming quality (see Appendix B). It appears that there are at least two factors working here. At the lower inspection rates, the effect of decreasing the incoming quality is exactly that of increasing the signal rate in vigilance studies, i.e., efficiency is enhanced through the maintaining of the subject's attentive behavior. However, the difficulty of the inspection task reaches a point--20% defective and 200 balls per minute--beyond which vigilance alone is not sufficient to maintain inspection proficiency. The task becomes so demanding, in terms of the response repertoire required of the subject (at 200 balls per minute and 25% defective the subject is looking at a defective on the average every 1.2 seconds), that each decreasing level of incoming quality causes a corresponding decrease in the subject's inspection accuracy. It is important to realize then that in most industrial inspection tasks, it is probably unrealistic to assign the effect of incoming quality to either school of thought exclusively. Just as in the above example, an increasing percent defective may have beneficial effects only up to a certain point, after which the corresponding difficulty of inspection overrides the increased vigilance, to decrease inspector proficiency.

To summarize this section and the last, we can

conclude that, within the limits of this experiment, the presentation of a high rate of signals is akin to differentially reinforcing a high response rate in maintaining attentive behavior throughout the monitoring task, thus preventing a vigilance decrement, both in terms of missed signals and false alarms. The application of these findings to actual industrial inspection tasks is possible, but must be accomplished with care.

4. Effect of Schedule on Cumulative Response Rate and Cumulative Percent Signals Detected

We have already discovered that, within the limitations of this experiment, the detection of defectives can serve as reinforcement for observing responses and furthermore, the differential reinforcement of a high response rate, or a high frequency of signal presentation can serve to prevent a vigilance decrement. This section will discuss the characteristics of the various schedules employed in this experiment which best preserved efficiency in the inspection task.

In Figure 27, page 56, the curves of Figure 26, page 56, representing all the schedules combined, have been broken down into ratio schedules (triangles) and interval schedules (circles). As we noted in Chapter IV, the ratio schedules seem to maintain both a higher response rate and a higher percentage of signals detected over the duration

of the watch. If now, we break down ratio and interval schedules into variable ratio and fixed ratio schedules, and variable interval and fixed interval schedules (Figures 28 and 29, pages 58 and 59), we can see immediately that the variable schedules in both the ratio and interval categories are superior to the fixed schedules, in terms of maintaining both a higher response rate and a higher percentage of signals detected throughout the watch.

We can conclude then, that within the limitations of this experiment, the differential reinforcement of responding through a variable ratio schedule is superior to other schedules in maintaining inspector efficiency throughout the watch.

5. Order of Sessions

As has been noted in Chapter IV, the design of this experiment does not permit us to separate the possible effects of learning from one session to the next. The average percentage of signals detected and the average response rate over all the subjects has been plotted for each session in Figure 30, page 60. If we had used exactly the same schedule on all subjects throughout this experiment, we could expect this graph to have an upward trend due to learning. The fact that this is not the case leads us to conclude that the effects of learning do not predominate over the effects due to schedules.

The problem of learning confounding other results can be overcome in essentially two ways: (1) by redesigning the experiment, notably, into a latin square, and (2) by holding extensive pre-trial training sessions until the learning associated with the task is essentially complete.

It should be obvious that the conclusions reached through this experiment are limited in their application to actual inspection tasks, such as those found in industry. For example, it has been pointed out that variable ratio schedules are best in maintaining inspector proficiency throughout the watch. The ratio referred to here is the number of "observing responses" emitted to the reinforcement provided, i.e., the detection of a defective. In an actual industrial inspection task it would be extremely difficult to either find or devise an appropriate observing response and then impossible to reinforce it on a set ratio basis, since the occurrence of a defective cannot be predicted. We did, however, discover that a variable interval schedule providing a high signal rate (in other words, a variable interval schedule with a small, or short interval) can also serve to maintain inspector proficiency. It might be feasible, in a particular industrial inspection situation to program a certain temporal pattern of known or artificial [Baker, 1960] defectives onto the inspection line in order to form a (somewhat variable) variable interval schedule in combination with naturally occurring defectives. However,

this type of control should not be attempted hastily. A great deal more study is required which more closely approximates actual industrial situations before the techniques discussed in this thesis can be applied with confidence. Possible areas of research are discussed in the following section.

Recommendations for Further Study

As stated above, an attempt should be made to more closely approximate field conditions in vigilance studies; and more particularly, those dealing with industrial inspection tasks. An attempt should also be made to develop techniques for applying behavioral methods to these tasks. There are a number of areas which could be profitably explored.

In general, laboratory experiments in vigilance have been limited to relatively short periods of time on watch. Mackworth [1950] required a two-hour watch of his subjects; Deese and Ormond [1953] had their subjects on watch for three hours; Jenkins [1957] tested his subjects on two, 90-minute sessions, one in the morning and one in the afternoon; Holland [1958] ran his subjects on sessions of from 40 to 90 minutes; Jerison and Pickett [1964] ran their subjects for one hour; and so on. The usual work day for an inspector is eight hours. It may be that only about five hours are actually spent in the inspection

process; still, this is far longer than the average laboratory vigilance study has even approached. Those contemplating research in the vigilance area might consider utilizing subjects for one day only, for a full eight hours. The subjects might be required, for example, to accomplish four, 40-minute monitoring sessions in both the morning and afternoon, with 15-minute breaks between sessions and a 60-minute lunch break. Thus, the subjects would be involved in the actual monitoring for only about five hours. The subjects would not necessarily be idle during the 15-minute breaks, but could be required to perform some ancillary task, not involving monitoring. It has already been demonstrated that in a 90-minute vigilance task, subjects allowed a 5-minute break each 30 minutes in which they carried out various activities, performed significantly better than a control group who performed the task continuously. In fact, the experimental groups performed the task with no decrement throughout [Bevan, et al, 1967]. It would be interesting to extend this study beyond 90 minutes to determine how long the decrement could be prevented. In addition, longer "on the job" vigilance tasks may demonstrate that there is a "trade-off" on the advantages of high signal frequency and lower signal frequency in terms of physical fatigue versus monotony.

The techniques of behavioral analysis, employed by both Holland and the present author, should be extended to

longer and more complex vigilance tasks, and evaluated in conjunction with the effects of breaks, noise, knowledge of results, and physical fatigue (as determined by various physiological measures). A good deal of research has been accomplished on each of these areas separately [Jerison, 1957; Jerison and Wing, 1957; Kirk and Hecht, 1963; Mirabella and Goldstein, 1967; Baker, 1960], but little or no research has attempted to evaluate their effect in combination with behavioral methods.

Finally, it has been pointed out in this study and others, that there are large individual differences among subjects. Although there has been some research in the area of psychological correlates of vigilance [Bakan, et al, 1963; Halcomb and Kirk, 1965] it would be of interest to combine this approach with that of behavioral analysis. In addition, it may be feasible, and certainly profitable, to combine research concerning both physiological and psychological correlates of attention, with a behavioral analysis of vigilance. Work with the so-called "orienting reflex" [Maltzman and Raskin, 1965] is especially interesting and of vital importance to vigilance studies.

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APPENDIX

- A. Subject Briefing
- B. Inspector Accuracy As A Function of Inspection Rate
and Incoming Quality (Adapted from Sosnowy, 1967)

APPENDIX A: SUBJECT BRIEFING

SUBJECT BRIEFING

The purpose of this experiment is to test your inspector accuracy on a simulated assembly-line inspection task. You will be inspecting simulated printed circuits with the object of removing any bad circuits you find from the line. You are to assume that these circuits play a vital part in some system and that it is essential to detect all defects. However, the circuits are also very expensive to manufacture and you must avoid rejecting good circuits.

The assembly line is simulated by a rotating disk upon which the circuits are placed. You are seated at the disk between two screens which limit your visual field to a wedge-shaped area. The disk rotates counter-clockwise at 2.5 RPM thus allowing you approximately 2 seconds of inspection time per circuit. As this is an inordinately short period of time to carefully inspect a rather complex item, a stop-button will be provided for use at your discretion. By depressing this button you may stop the disk for approximately 1 second. It is a limited-hold button and in order to stop the disk for a longer period you must release and redepress the button. You may press the button as often as you like, remembering that your object is as high a detection rate as possible.

Since the disk is rotating counterclockwise, you will be pressing the stop-button with your left hand and removing any defectives you may discover with your right hand. There will be a container placed at your right where you will deposit the rejected circuits. When you discover a defective circuit call "reject" to the experimenter, remove the defective circuit and place it in the container. The experimenter will inventory this container at the conclusion of each trial.

Before your first run you will be carefully briefed on what constitutes a defective circuit and given a short trial run at the disk to help you adjust to the experimental conditions.

APPENDIX B: INSPECTOR ACCURACY AS A FUNCTION OF
INSPECTION RATE AND INCOMING QUALITY
(ADAPTED FROM SOSNOWY, 1967)

Fig. 33--First order interaction, incoming quality x inspection rate, on A_3 (Adapted from Sosnowy, 1967)