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# THE EFFECTS OF SIGNAL RATE, SCHEDULE VARIABILITY, AND OBSERVING RESPONSE IN VISUAL MONITORING

By
David W. Bessemer

A Thesis

Submitted in Partial Fulfillment of the

Requirements for the Degree of

Master of Science in Psychology

The University of New Mexico

1962

This thesis, directed and approved by the candidate's committee, has been accepted by the Graduate Committee of the University of New Mexico in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

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June 8, 1962
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THE EFFECTS OF SIGNAL RATE, SCHEDULE VARIABILITY, AND OBSERVING RESPONSE IN VISUAL MONITORING

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# CHAPTER I

## INTRODUCTION

In recent years, considerable effort has been expended in the experimental investigation of human performance in tasks involving monitoring or inspection behavior. Due to rapid technological progress during this period, the manipulative operations formerly required of the human component in man-machine systems have been increasingly replaced by observational responsibilities. Along with this trend, there has been a growing awareness of the limitations of the human observer in maintaining alertness or "vigilance" for extended periods of time, and of his shortcomings as a detection instrument. An industrial study by Jacobson (1952) is of particular interest in this respect because it investigated a supposedly nonroutine task using quality control inspectors rather than line inspectors. Jacobson constructed a small wire unit consisting of 1,500 wires and 30 "built-in" defects. Inspector accuracy, as measured by the percentage of defects detected ranged from 32% to 80%. Opinion had previously held that the inspectors were 95% to 98% effective. Apparently inspection performance falls far short of expectation even in the less monotonous tasks.

A monitoring or inspection task may be distinguished from other human functions in military or industrial systems by certain essential characteristics: (1) The task involves passive detection rather than active manipulation of environmental stimuli. An observer is required to perceive and report the presence or absence of some specified supra-threshold change in the environment. (2) The task is prolonged, continuous and monotonous. More than a single momentary discrimination is required, and the observer is permitted little behavioral variability in the performance of his duties. (3) The frequency of occurrence of the discriminative stimulus, or "signal," is very low in relation to total task duration or to the occurrence of "non-signal" stimuli.

The present experiment was designed to study the independent effects of signal rate and intersignal interval variability upon detection performance in a visual monitoring task. Several studies (Deese and Ormond, 1953; Ellis and Ahr, 1960; Jenkins, 1958; and Kappauf and Powe, 1959) have indicated that, within limits, performance is superior with high rates of signal presentation. However, in these studies the variability of intersignal intervals has been confounded with signal rate, high rates being associated with low degrees of variability. The results of other studies (Baker, 1958, 1959; Dardano and Mower, 1959; Wherry and Webb, 1959) appear to indicate that the interval variability alone may be a more important factor in monitoring performance than is signal rate. To date, no single study has provided a direct and independent comparison of the importance of these factors, or of their interaction effects.

A second purpose was to examine the influence of an overt observing response on detection behavior in the same task. Recent experiments by Holland (1957, 1958) on the operant control of monitoring behavior indicates that the rate of emission of overt observing responses (key-depressions which permit the observation of the vigilance display) may serve as a sensitive continuous measure of the course of vigilance between signal presentations. The availability of such a measure is a basic prerequisite to an analysis of monitoring tasks, both in laboratory and field situations. However, the possibility exists that Holland's measurement procedure may itself affect the course of vigilance, thus restricting the generality of results obtained by the procedure. Since the making of a key-depression response tends to alter the element of passivity characteristic of monitoring tasks, the use of observing response rate as a dependent variable involves the simultaneous introduction of an independent variable. Holland's observing response procedure has not been employed as an independent variable in any previous experiments.

Thus, the aims of the present research may be summarized in five major experimental questions: (1) What is the influence of the rate of signal presentation on detection performance, independent of the variability of the intersignal intervals? (2) What effect does variability of the intersignal intervals have on detection performance, independent of the effect of signal rate? (3) Do signal

rate and intersignal interval variability interact in their influence on detection performance? (4) Does the measurement of an overt observing response alter the functional relationships observed for (1), (2), and (3) above? (5) What relationship exists between observing response rate and detection performance?

## CHAPTER II

## HISTORY

Over fifty studies of the effects of more than thirty variables upon monitoring performance have been reported, and are summarized in comprehensive reviews by McGrath, Harabedian, and Buckner (1959), and Bergum and Klein (1961). The most consistently verified finding of monitoring studies has been that detection performance declined considerably as time on watch progressed. In general, this deterioration in performance has occurred in the first ten to thirty minutes of the task after which performance has stabilized at a reduced level of signal detection. Results of this kind were first reported by Mackworth (1948, 1950) and have been repeatedly demonstrated by numerous other investigators, for both percent of signals detected and latency of detection response as dependent variables.

The majority of studies of the temporal course of vigilance have reported average detection percentages over blocks of signals, which has resulted in monotonic, negatively accelerated decrement functions. More recent findings by Jerison (1958) and Jerison and Wallis (1957), employing a more molecular, signal-by-signal analysis, have indicated that all or most of this decrement may occur within the first three to five minutes, particularly in more complex monitoring tasks. In addition, there appears to be a great deal of variation in the level of vigilance from signal to signal, even when these are separated by short intervals of time.

Since detection has been found to be nearly perfect in pre- and post-task tests under momentarily alerted conditions (Garvey, Gulledge, and Henson, 1958; Jenkins, 1958), the bulk of monitoring research has been directed toward the discovery of methods by which the vigilance decrement may be modified or abolished. Perhaps the most significant findings of such studies concern the effects of signal rate. The experiments of Jenkins (1958), Deese and Ormond (1953), and Kappauf and Powe (1959), indicate that increases in the rate of signal presentation are accompanied by concomitant increases in detection performance.

These findings are somewhat modified by the results of Ellis and Ahr (1960), who found performance to increase to a maximum and then decline as signal rate was further increased. Within limits, however, the studies agree in showing superior performance with high rates of signal presentation.

Since signal rate is a fundamental parameter of all vigilance tasks, control of monitoring behavior through manipulation of signal rate would appear to provide a general solution to the vigilance problem. While it may not be possible to control the rate of occurrence of "real" signals in practical situations, it is possible to introduce "artificial" signals at a high rate. Garvey, Taylor and Newlin (1959), found the introduction of many artificial signals to be effective in abolishing the vigilance decrement, even when the observer has been able to clearly distinguish between artificial and real signals.

Unfortunately, previous studies of the effects of signal rate have not been definitive for two major reasons. First, and perhaps most important, there has been a general confounding of the effects of signal rate with other schedule characteristics, such as intersignal interval variability, and the frequency distribution of intersignal intervals. Clearly, these factors are not usually independent since intersignal intervals necessarily become more restricted in range and less variable as signal rate is increased. It should be pointed out that it has been the degree of <u>absolute</u> variability (as measured by standard deviation of the intersignal intervals) which tends to be confounded in this way, rather than the degree of <u>relative</u> variability (as measured by the coefficient of variability). Furthermore, as intervals greater than twice the mean interval are employed, the interval distribution of the signal schedule necessarily begins to assume a J-shape. This is because several very short intervals are required to compensate for one long interval, if the mean rate is to be maintained.

Studies by Baker (1958, 1959), Dardano and Mower (1959), and Wherry and Webb (1959) raise the possibility that intersignal interval variability may be more important in determining monitoring performance than signal rate. Baker used equal signal rates for all groups and found that performance deteriorated with a highly variable schedule, but not with more regular ones. Similar results were obtained by Dardano and Mower. On the other hand, Wherry and Webb found no

differential effects of signal rate when schedule variability was controlled. Thus, a difference is found when both absolute and relative variability are varied, but no difference when absolute variability is constant and relative variability is allowed to vary. To date, there have been no studies reported which have simultaneously evaluated the relative effects of signal rate and interval variability.

A second shortcoming of studies of signal rate has been a lack of control of the signal rates actually observed by the subjects. This factor arises partially through the use of "transient" signals whose duration is controlled by the experimenter, and which may thus be missed entirely by the subjects. The occurrence of "false detections" introduces an additional uncontrolled variable. The signal of many monitoring tasks consists of a change in the magnitude of a recurrent "non-signal" stimulus. In such tasks, many subjects will report the occurrence of a signal, when in fact a nonsignal has occurred. Such reports are termed "false detections," and may have the same behavioral effects as the occurrence of a real signal.

Precise analysis of the role of any independent variables in monitoring performance has been seriously hampered by the lack of a continuous measure of vigilance. With few exceptions, monitoring studies have employed percentage detections or latency of response as criteria of vigilance. Such criteria obviously require the presentation of signals before the measurement may be made, so that little is known of the course of vigilance within the intersignal interval. The need for continuous measurement has led to the study of various physiological concomitants of vigilance, in the hope that these could be used as indirect measures of the vigilance state. While gross relationships have been shown to hold between monitoring performance and muscle action potentials (Travis and Kennedy, 1947) as well as the galvanic skin response (Morgan, Stea and Bessemer, 1960), these relationships are not sufficiently precise to permit the use of such variables as vigilance measures.

A more direct solution of this problem has been proposed by Holland (1957). This approach is based upon the assumption that success in detecting signals is dependent upon the emission of observing responses which make detection possible.

In visual monitoring tasks such responses would include orientation of the head and eyes toward the display upon which signals may appear, focusing of the eyes at the proper distance, along with many other overt or covert responses which are necessary for observation of the signal. Obviously many of these responses are immeasurable or measurable only with difficulty. Rather than attempting to measure the whole array of "natural" observing responses which are intrinsic to the perceptual system, Holland elected to measure an overt, motor observing response, usually extrinsic to the perceptual system, but which the subject is nevertheless forced to perform in order to observe the display. This was done under the assumption that independent variables which affect intrinsic observing responses would also affect extrinsic responses in a similar fashion. Thus, it was assumed that the anatomical topography of the response is unimportant, in that any single member of the total class of observing responses which are required in a given monitoring situation may validly serve to index the effects of environmental variables upon all the members of that class.

In the technique employed by Holland, subjects worked in a dark room. In order to inspect the display for the presence of a signal, they were required to depress a key which provided momentary illumination. These key-depression responses served as the overt observing response discussed above, and the rate of emission of such responses provided a continuous measure of vigilance. In a series of experiments using this technique along with a number of standard operant conditioning schedules of signal presentation, Holland (1958) was able to demonstrate rather convincingly that signal detection serves to reinforce the emission of observing responses in much the same way that food serves to reinforce lever pressing responses of rats in Skinner apparatus. In a further experiment employing the classical Mackworth (1948) vigilance schedule, Holland showed that detection performance was highly dependent upon the rate of emission of these observing responses.

The implications of these findings are of importance, not only for the experimental and practical analysis of monitoring tasks, but for the control of monitoring behavior. First, it would appear that the schedule of signal

presentations exerts a fairly precise control over the human monitor's observing behavior. Second, the large body of animal research literature on the effects of various kinds of reinforcement schedules may be applicable to monitoring problems, particularly the optimal scheduling of artificial signals. Finally, the Holland technique may provide a general methodological tool of value in the study of vigilance, both in the experimental laboratory and in practical field situations.

Before these implications can be fully accepted, however, the Holland approach requires cross-validation. Since the making of a key-depression response tends to remove the element of passivity which generally characterizes monitoring tasks, the use of such a dependent variable involves the simultaneous introduction of an independent variable. Since all of Holland's subjects employed the observing response, no data exists which would permit the evaluation of the effects of this variable. Thus, the application of Holland's results to monitoring tasks in general must be cautious in scope until it has been demonstrated that the effects of the technique itself do not seriously alter the basic phenomena of the vigilance situation.

## CHAPTER III

## METHOD

Design: Nine schedules of signal presentation were employed, combining three levels of signal rate and three levels of intersignal interval variability. The three rates were 15, 30, and 60 signals per hour, which correspond to mean intersignal intervals of 4, 2, and 1 min., respectively. The three variabilities were S. D. s (standard deviations) of 0. 00, 0. 25, and 0. 50 min. These were the S. D. s of the distributions of intersignal intervals used in schedules at the three variability levels.

The nine signal schedules were combined in the experimental design with two observation conditions, thus making a total of 18 experimental conditions. The two observation conditions were: (1) active, in which the Ss were required to depress a key in order to illuminate the vigilance display; and (2) passive, in which key-depression responses were not required since the display was continuously illuminated. There were three male and three female Ss used with each combination of signal rate, schedule variability, and observing condition.

Subjects: A total of 135 volunteer undergraduate psychology students at the University of New Mexico served as Ss in the study. Of these, 15 Ss were involved in preliminary experimentation, 9 Ss were discarded due to extinction in the experimental situation, uncooperativeness, or failure to understand instructions, and 3 Ss were discarded after apparatus failure. The remaining 108 Ss, 54 males and 54 females, were used in the major experiment. The median age of the males and females was 19. 0 and 18. 8 years, respectively. The ages of both males and females ranged from 17 to 44 years. There were 10 female and 5 male lefthanded Ss. All Ss were randomized among the 18 experimental conditions with the restriction that an equal number of each sex were placed in each condition.

Signal Schedules: Characteristics of the frequency distribution of intersignal intervals for each signal schedule are described in Table 1. Schedules 1, 2, and 3 served as fixed interval controls. As Col. 2 and 3 reveal, all

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Subjects. A total of 126 volunteer undergraduate psychology students at the University of New Mexico served as Ss in the study. Of these, 15 Ss were involved in preliminary experimentation, 9 Ss were discarded due to [illegible] in the experimental situation, unexpected drowsiness, or failure to understand instructions, and 3 Ss were discarded after apparatus failure. The remaining 108 Ss, 54 males and 54 females, were used in the major experiment. The median age of the males and females was 19.9 and 19.2 years, respectively. The ages of both males and females ranged from 17 to 44 years. There were 10 female and 8 male left-handed Ss. All Ss were randomized among the 18 experimental conditions with the restriction that an equal number of each sex were used in each condition.

Signal Schedules. Characteristics of the frequency distribution of intersignal intervals for each signal schedule are described in Table 1. Schedules 1, 2, and 3 served as fixed interval controls. As Col. 2 and 3 reveal, all

TABLE I

CHARACTERISTICS OF THE FREQUENCY DISTRIBUTIONS
OF INTERSIGNAL INTERVALS USED
IN THE NINE SIGNAL SCHEDULES

| Signal Schedule (1) | Intersignal Intervals (Minutes) (2) | Frequency of each Interval (3) | Mean Interval (Minutes) (4) | Standard Deviation (Minutes) (5) | Coefficient of Variability (100 S.D./M) (6) |
|---|---|---|---|---|---|
| 1 | 4.000 | 7 | 4 | 0.00 | 0.0 |
| 2 | 2.000 | 14 | 2 | 0.00 | 0.0 |
| 3 | 1.000 | 28 | 1 | 0.00 | 0.0 |
| 4 | 3.625, 3.750, 3.875, 4.000, 4.125, 4.250, 4.375 | 1 | 4 | 0.25 | 6.2 |
| 5 | 1.625, 1.750, 1.875, 2.000, 2.125, 2.250, 2.375 | 2 | 2 | 0.25 | 12.5 |
| 6 | 0.625, 0.750, 0.875, 1.000, 1.125, 1.250, 1.375 | 4 | 1 | 0.25 | 25.0 |
| 7 | 3.250, 3.500, 3.750, 4.000, 4.250, 4.500, 4.750 | 1 | 4 | 0.50 | 12.5 |
| 8 | 1.250, 1.500, 1.750, 2.000, 2.250, 2.500, 2.750 | 2 | 2 | 0.50 | 25.0 |
| 9 | 0.250, 0.500, 0.750, 1.000, 1.250, 1.500, 1.750 | 4 | 1 | 0.50 | 50.0 |

intervals in these first three schedules had a constant duration equal to the mean intersignal interval given in Col. 4. Thus, the S.D.s of the distributions were equal to zero in each case, as shown in Col. 5. The C.V.s (coefficients of variability) which appear in Col. 6 were also equal to zero for schedules 1, 2, and 3.

The remaining six schedules involved intersignal intervals of variable duration. Schedules 4, 5, and 6 employed variations with a total range of 0.75 min. about their respective mean intervals of 4, 2, and 1 min. For each of these schedules, therefore, the longest interval was 0.375 min. longer than the mean, and the shortest interval was 0.375 min. shorter than the mean. Within these limits, intervals at 0.125 min. steps were used in all three schedule distributions. As Col. 3 shows, each interval was used with equal frequency in a given schedule. The intersignal interval distributions for schedules 4, 5, and 6 were thus identical except for differences in the mean interval, or equivalently, differences in signal rate. The use of such identical, symmetrical, and step-wise rectangular distributions permitted variations of signal rate without concomitant and confounding variations in S.D. or skewness of the frequency distribution. The S.D.s for schedules 4, 5, and 6 were each equal to 0.25 min., as shown in Col. 5. The C.V.s in Col. 6 were 6.2, 12.5 and 25.0, respectively.

Schedules 7, 8, and 9 also involved mean intervals of 4, 2, and 1 min., respectively, but with a greater degree of variability. The distributions for these three schedules employed intervals at 0.250 min. steps about their mean intervals, with 1.50 min. being the total range of variation. Thus, these distributions were also identical, symmetrical, and step-wise rectangular, permitting unconfounded variation of signal rate. The S.D.s for schedules 7, 8, and 9 were each 0.50 min., while the C.V.s were 12.5, 25.0, and 50.0, respectively.

The intervals in the frequency distributions described in Table 1 were ordered to produce the signal schedules shown in Table 2. Of course, no ordering of intervals was required for schedules 1, 2, and 3, so that the following explanation does not apply to these schedules.

TABLE 2

TIMES OF SIGNAL OCCURRENCE IN MINUTES FROM THE BEGINNING OF THE TEST PERIOD FOR THE NINE SIGNAL SCHEDULES

| Standard Deviation (Minutes) | 0.00 | | | 0.25 | | | 0.50 | | |
|---|---|---|---|---|---|---|---|---|---|
| Mean Interval (Minutes) | 4 | 2 | 1 | 4.000 | 2.000 | 1.000 | 4.000 | 2.000 | 1.000 |
| Signal Schedule | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Signal No. | | | | | | | | | |
| 1 | | | 1 | | | 0.875 | | | 0.750 |
| 2 | | 2 | 2 | | 2.250 | 2.250 | | 2.500 | 2.500 |
| 3 | | | 3 | | | 2.875 | | | 2.750 |
| 4* | 4 | 4 | 4 | 4.000 | 4.000 | 4.000 | 4.000 | 4.000 | 4.000 |
| 5 | | | 5 | | | 5.375 | | | 5.750 |
| 6 | | 6 | 6 | | 6.125 | 6.125 | | 6.250 | 6.250 |
| 7 | | | 7 | | | 6.750 | | | 6.500 |
| 8* | 8 | 8 | 8 | 0.750 | 7.750 | 7.750 | 7.500 | 7.500 | 7.500 |
| 9 | | | 9 | | | 8.875 | | | 8.750 |
| 10 | | 10 | 10 | | 9.750 | 9.750 | | 9.500 | 9.500 |
| 11 | | | 11 | | | 11.000 | | | 11.000 |
| 12* | 12 | 12 | 12 | 12.125 | 12.125 | 12.125 | 12.250 | 12.250 | 12.250 |
| 13 | | | 13 | | | 12.750 | | | 12.500 |
| 14 | | 14 | 14 | | 14.000 | 14.000 | | 14.000 | 14.000 |
| 15 | | | 15 | | | 15.000 | | | 15.000 |
| 16* | 16 | 16 | 16 | 16.375 | 16.375 | 16.375 | 16.750 | 16.750 | 16.750 |
| 17 | | | 17 | | | 17.125 | | | 17.250 |
| 18 | | 18 | 18 | | 18.000 | 18.000 | | 18.000 | 18.000 |
| 19 | | | 19 | | | 19.250 | | | 19.500 |
| 20* | 20 | 20 | 20 | 20.000 | 20.000 | 20.000 | 20.000 | 20.000 | 20.000 |
| 21 | | | 21 | | | 21.000 | | | 21.000 |
| 22 | | 22 | 22 | | 22.125 | 22.125 | | 22.250 | 22.250 |
| 23 | | | 23 | | | 22.875 | | | 22.750 |
| 24* | 24 | 24 | 24 | 23.875 | 23.875 | 23.875 | 23.750 | 23.750 | 23.750 |
| 25 | | | 25 | | | 25.125 | | | 25.250 |
| 26 | | 26 | 26 | | 25.750 | 25.750 | | 25.500 | 25.500 |
| 27 | | | 27 | | | 26.625 | | | 26.250 |
| 28* | 28 | 28 | 28 | 28.000 | 28.000 | 28.000 | 28.000 | 28.000 | 28.000 |

Critical signals, at which data was taken for analysis.

The schedules were randomly ordered, except for two restrictions. The restrictions were imposed in order to minimize, insofar as possible, differences between the schedules which were not directly involved in the independent variables. First, within each level of variability, signals occurred at the same point in time in all three schedules, except that certain signals were omitted from the schedules having lower rates. For example, signal no. 2 occurred after 2.500 min. in both schedules 8 and 9, but was omitted from schedule 7. Similarly, signal no. 12 occurred after 12.125 min. in schedules 4, 5, and 6. Thus, while the schedules were randomly ordered, the same randomization was used in ordering the three schedules at each variability level.

The second restriction on randomization was similar to the first, but applied to schedules having the same rate and different degrees of variability. As Table 1 shows, seven interval durations were used in the distributions for each of the six variable interval schedules. While the temporal duration of intervals used in distributions having the same mean and different S.D.s could not be equated, the intervals could be matched in terms of ordinal position within the distributions. For example, the intervals in the first position of schedules 6 and 9 are 0.625 and 0.250 min. respectively, and are matched in terms of their position in these distributions. In the construction of the schedule orders, such matched pairs of intervals were used at corresponding points in schedules 4 and 7, 5 and 8, and 6 and 9. Thus, the intervals immediately preceding the third signal of schedules 6 and 9 are 0.625 and 0.250 min., respectively. Similarly, the intervals appearing immediately before signal no. 16 in schedules 4 and 7 are 3.250 and 3.500 min., respectively. These latter intervals can be found in the sixth position of the distributions for schedules 4 and 7 in Table 1. In this way, the same randomization was not only applied to schedules having the same S.D. and different mean intervals, but also to schedules having the same mean and different S.D.s.

Each schedule, 28 min. in duration, was punched into 8 mm film leader for use with the Gerbrands variable interval tape programmer. A given schedule was presented twice in succession to each <u>S</u> during a 56 min. test period.

Apparatus: The vigilance task employed in this experiment was patterned after that of Holland (1957, 1958). The vigilance display, shown in Plate 1 of Appendix I, was a 4" square zero-center milliammeter mounted inside a box fronted by a one-way glass panel. The meter face was illuminated by a 6-watt fluorescent lamp shielded so that its light did not fall directly on the one-way glass. Thus, the meter face was visible only when the light was on. The signal to be detected appeared on the meter as a 45° deflection of the pointer to the left of the null position.

The display box was placed on a table in the S's cubicle as shown in Plate 2 of Appendix I. Two telegraph keys, also shown in Plate 2, were mounted at the other end of the table, and cables from the keys were plugged into the display box. A depression of the right-hand key produced a single 0.07 sec. flash of the fluorescent lamp. This key was weighted via a pulley arrangement so that a force of approximately 4.5 lbs. was required for depression. A depression of the left-hand key when a signal was present, i.e., the pointer deflected, caused the pointer to return to the null position. A cable from the display box passed through the wall to connect, via a Foringer 2212 control panel, with the programming and recording apparatus located in an adjacent room.

A small squirrel cage blower mounted on the wall behind the S's chair provided masking noise to eliminate auditory cues from the programming apparatus. Additional masking noise was provided by a large air conditioner located in the E's cubicle along with the programming apparatus. A Brownie Model B (7 watt) darkroom lamp was placed above and to the rear of S's head. This lamp permitted visual inspection of the cubicle in the absence of the fluorescent flash, which had been found to be intrinsically reinforcing in completely dark conditions. When the lamp was not used in preliminary experimentation, extremely high and constant observing response rates were observed, such rates producing continuous illumination of the cubicle.

The programming and recording apparatus is shown in Plate 3 of Appendix I. Depressions of the flash key were recorded on a Gerbrands C-2 cumulative recorder. Signal occurrences also appeared as events on the cumulative record. A Foringer 1193MI cumulative recorder control panel provided input

to the recorder. The numerical frequency of both observing and detection responses were separately cumulated on a Foringer 1704-2 counter panel. A Foringer 1161 response translation panel was used to stabilize flash-key depressions and to provide controlled input pulses to the 1193MI and 1704-2 panels.

The latency of each detection response was measured by a Standard S-1 Laboratory Timer. The timing cycle was initiated by the signal occurrence and terminated, due to circuitry interposed between the detection key and the timer, 0.12 sec. after the detection response. The reaction time was recorded by E and the timer manually reset. Later, 0.12 sec. was subtracted from each latency.

A Gerbrands V.I. tape programmer was used in conjunction with a Foringer 1182MI programmer panel and 1183 lockup switch panel to control signal occurrences and associated events. When a signal occurred the programmer locked up, i.e., did not advance, until the detection response occurred. The lockup feature provided a persistent signal terminated by the S, and permitted precise control over the time interval between each detection response and the occurrence of the next signal.

A Foringer 1171 indicator panel was used to provide visual indication of observing responses, detection responses, signal occurrences, and programmer status as an aid to E. A warning light, also on this panel, was illuminated several seconds prior to each signal.

Power for the programming and recording apparatus was provided by a Foringer 1153MI low voltage supply. All components of the apparatus were arranged on a Foringer 1151S relay rack provided with the necessary mountings and connections.

Procedure: Prior to the running of an S, the E placed the practice schedule on the programmer, and checked the operation of the apparatus. The S was then seated in front of the display and E read the instructions shown in Appendix II. The S was then given a one-min. practice period, with one signal occurring at the end of the period. The E recorded the latency of detection response and placed the test schedule on the programmer. After completing the instructions and answering S's questions, E then started the 56-min. test period. During the

test period, E recorded the latency of each detection response. If the S was in the "active" observation condition, E also recorded the cumulative number of observing responses at the detection of each signal in both the practice and test periods. Ss were not allowed to wear a watch during the course of the experiment.

## CHAPTER IV
## RESULTS OF THE PRACTICE PERIOD

Data obtained in the one-minute practice period included the number of observing responses emitted by Ss in the active observation condition, as well as the latency of detection response for all Ss. These data permitted the evaluation of group differences prior to the introduction of effects associated with the signal schedules. The only independent variables actually involved at this point in the experiment were sex and observation condition.

Table 3 shows the detection performance of males and females in both the active and passive observation conditions. While the mean reaction time for males is somewhat less than that exhibited by the females, the outstanding feature of these data appears to be the difference between the active and passive observation conditions.

Apparently, the observing response procedure interferes considerably with detection performance, as the mean for the active condition is some two and one-half times larger than the mean for the passive condition. In addition, the sex difference appears to be somewhat larger in the active condition, which may have been due to the weighting of the observing response key.

An analysis of variance, shown in Table 4, confirmed the statistical reliability of the effects of sex and observing condition; however, the interaction effect was not significant. Since the sources of variance involving signal rate and interval variability had been found to be insignificant ($F = 0.82$; $df = 32, 72$), these sources were pooled into the error term of the analysis. In view of the fact that the rate and variability conditions were not involved in the practice period, differences among groups which later experienced these conditions in the test period could only involve random sampling errors. Since the insignificance of the rate and variability effects supported randomization, pooling was justified.

The difference in detection performance between the observation conditions was not, however, confined to means. The observing response procedure was also found to markedly increase individual differences in performance. In the

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TABLE 3

MEAN LATENCY OF DETECTION RESPONSE (IN SECONDS), IN THE ONE-MINUTE PRACTICE PERIOD

| Observation Condition | Sex of Subject | | Total |
|---|---|---|---|
| | Male | Female | |
| Active | 2.02 | 3.10 | 2.56 |
| Passive | 0.84 | 1.12 | 0.98 |
| Total | 1.43 | 2.11 | 1.77 |

TABLE 4

ANALYSIS OF VARIANCE OF THE LATENCY MEASURES FROM THE PRACTICE PERIOD

| Source | df | Sum of Squares | Mean Square | F |
|---|---|---|---|---|
| Observation (O) | 1 | 67.4344 | 67.4344 | 21.09*** |
| Sex (S) | 1 | 12.6759 | 12.6759 | 3.96* |
| O x S | 1 | 4.2483 | 4.2483 | 1.33 |
| Pooled Error | 104 | 332.5936 | 3.1980 | |
| Total | 107 | 416.9522 | | |

* $P < .05$

*** $P < .001$

passive condition the Subjects (within-cells) variance was 1.1321 sec., but in the active condition this variance was 5.6440 sec. Such a difference is statistically significant at $P < .001$ ($F = 4.99$; $df = 36, 36$). A difference of this magnitude in the variances is not surprising when related to the difference in means. Reaction time data tends to be distributed log-normally, and the standard deviation of a log-normal distribution is proportional to the mean. Thus, two log-normal distributions which differ in means tend to have equal coefficients of variability. This is approximately the case in the present data; the coefficients of variability for the passive and active conditions are 108.6 and 92.8, respectively. Since the coefficient for the active condition is the smaller of the two, it might therefore be argued that the increase in variability in the active condition was actually somewhat <u>less</u> than would be expected on the basis of the increase in mean.

In the light of such heterogeneity of variance, the sex difference observed in the previous analysis should be regarded cautiously. When an analysis of variance was performed separately for each observation condition, neither analysis revealed a significant sex effect. At any rate, such a sex difference - whether reliable or not - is of little import to the purpose of the experiment since an interaction with the major experimental variables is not involved.

During the one-minute practice period, a mean of 43.9 observing responses were emitted by the male <u>S</u>s in the active observation condition, while a mean of 52.5 responses were emitted by the female <u>S</u>s. If statistically reliable, this difference would suggest a negative relationship between rate of observing response and detection performance. Despite the fact that the females responded at a higher rate than the males, and thus illuminated the vigilance display more frequently, the detection performance of the females was inferior to that of the males. However, analysis of variance of the observing response data did not support the statistical significance of the sex effect ($F = 1.05$; $df = 1, 52$). Apparently, observing response rate and detection performance may vary with at least some degree of independence. As in the analysis of the latency data, no significant effects of signal rate or interval variability were observed, and the sources of variance involving these variables were pooled into the error term of the above F-ratio.

## CHAPTER V
## RESULTS OF THE TEST PERIOD

Treatment of Data: Data obtained in the test period included (1) the latency of detection response at all signals of the schedules shown in Table 2, and (2) the number of observing responses emitted in the active observation condition between successive detection responses. Since a number of signals in the 30 and 60 sig./hr. schedules did not occur in the 15 sig./hr. schedules, latency data at such signals could not be used to compare the detection performance of all rate groups. There were 14 signals (the critical signals shown in Table 2) which occurred at approximately the same time in all schedules. Only latency data at these signals were used in the analysis of the results. Similarly, only the number of observing responses emitted between critical signals could be compared across all rate groups. Thus, only the response rate for the total interval preceding each critical signal was used in the analysis of observing behavior in the active condition. There were 14 such intervals, corresponding to the 14 critical signals.

The distribution of the latency data was disturbed by several extreme scores. These scores were 3 to 150 times the size of the typical reaction latency for the S making the score, and actually appeared to belong to a different population than that of the typical scores. Since the extreme scores would tend to obscure otherwise systematic trends in the results, and also would serve to artificially inflate the error estimates of the statistical analysis (with a consequent underestimation of the reliability of the results), such scores were dropped from the data. The mean reaction latency for the S involved was substituted for each atypical latency. One degree of freedom was removed from subsequent analyses of variance for each score so substituted.

An extreme latency in the present experiment may be regarded as somewhat analogous to the "missed signal" observed in vigilance tasks involving transient signals. In this experiment, however, the frequency of such scores was very low; only 9 and 23 atypical latencies were observed in the active and

passive observation conditions, respectively. Percentage-wise then, only 1.19% of signals were "missed" in the passive condition, and only 3.04% in the active condition. It should be remarked that a score was regarded as extreme by comparison with the typical performance of the S. Thus, the criteria for such a score differed markedly in the active and passive conditions and from S to S in each condition. Since the extreme scores were infrequent, were scattered unsystematically among the data, and were based on differing criteria, no conclusions may be drawn by use of these scores.

A problem of a different nature was involved in the evaluation of the observing response data. Six of the nine schedules involved intersignal intervals of variable duration. In these schedules, therefore, the frequencies of observing response would differ as a function of the duration of the interval in which they were emitted. Even with a constant response rate, few responses would be emitted in a short interval and many responses in a long interval. In addition, the duration of each interval between critical signals would vary as a function of the S's detection performance. While the use of a persistent signal controlled the interval between the detection response and the occurrence of the next signal, the interval between the occurrence and the detection of the signal depended on the latency of S's response. Thus, the time between detection responses to successive critical signals was the sum of the programmed interval and the latencies of all detection responses in the interval, including the response to the second critical signal itself. In order to correct this bias and to obtain measures independent of interval duration, it was necessary to convert the raw number of observing responses obtained in each interval to a direct rate measure - responses per second. First, the total number of seconds in the interval was determined by adding the scheduled number of seconds to the response latencies in the interval. Then the number of responses was divided by the number of seconds to obtain the rate measure.

Detection Performance in the Active and Passive Conditions: Fig. 1 shows the mean latency of detection response at each critical signal for the active and passive observation conditions. Interestingly, the usual vigilance decrement was not observed in either condition. While the deletion of the extreme scores contributed significantly to the lack of a decrement, such scores formed only a

passive observation conditions, respectively. [illegible] of signals were "detected" in the passive condition, [illegible] to the active condition. It should be remembered that scores were [illegible] in keeping with the typical performances of the S. Thus, [illegible] score differed markedly in the active and passive conditions and [illegible] to 8 in each condition. Since the detection scores were [illegible] were collected unsystematically during the days, and were based on differing criteria, [illegible] clusions may be drawn on any of these scores.

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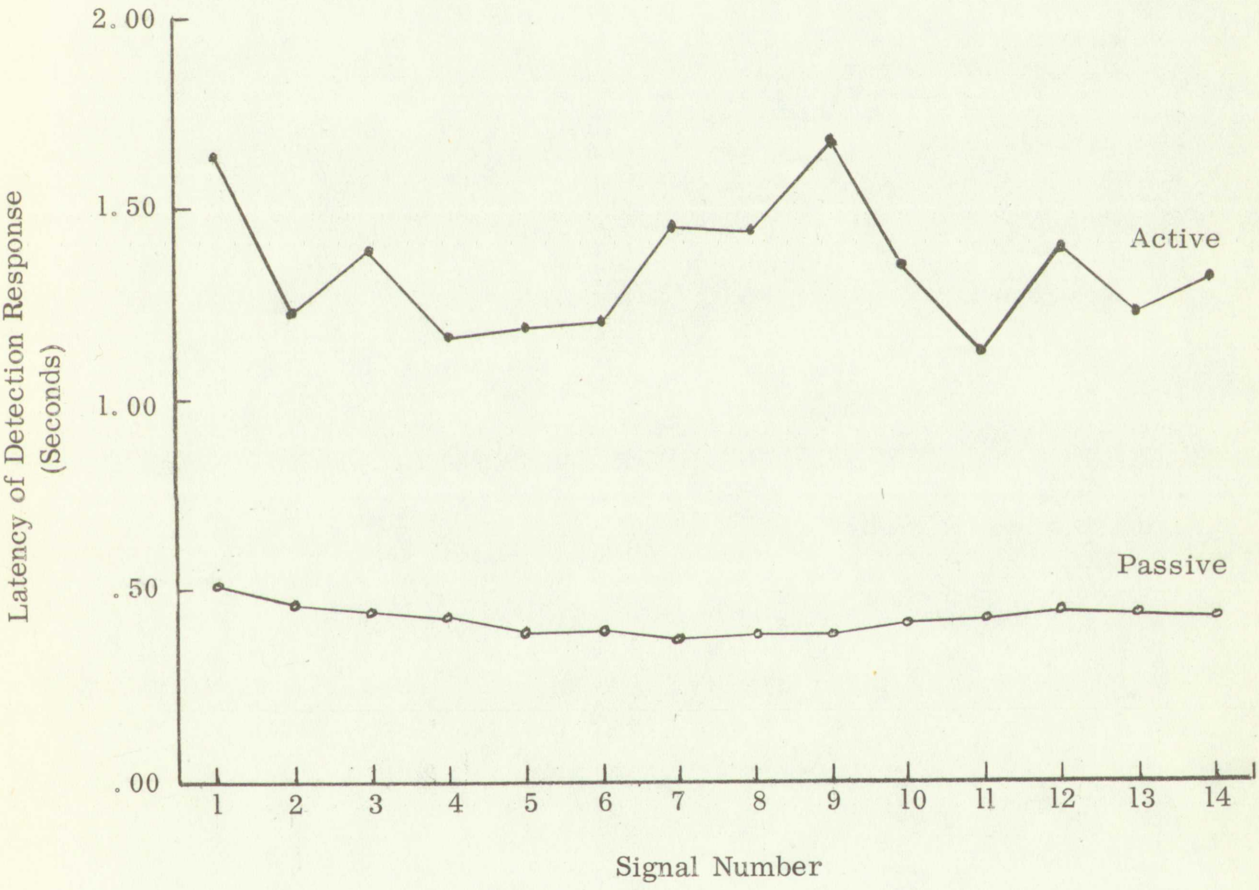


Fig. 1.--Overall detection performance in the active and passive observation conditions. Each point is the mean latency of 54 Ss.

small part of the data entering into Fig. 1. Thus, the vigilance decrement is not characteristic of detection performance in the present experiment. There are several factors which contribute to this finding over and above the discarding of data, but these will be examined at a later point.

Also apparent in Fig. 1 is the marked overall difference in detection performance between the active and passive observation conditions: not only are the mean reaction latencies inferior in the active condition, but detection performance is much more variable in this condition as well. Such findings are entirely consonant with those discussed previously for the practice period.

The mean latency of detection response for all Ss and signals in the passive observation condition was 0.44 sec.; this latency in the active condition was 1.41 sec. When these means are compared with the practice session means in Table 3, it is apparent that detection performance was considerably superior in the test period. The nonparametric sign test yielded a $z$ of 4.75 for the difference between the passive condition means in practice and test. For the active condition the $z$ was 3.13. Both $z$s are significant with $P < .001$.

The improvement between practice and test may be attributed partially to warm-up, as a slight decrease in response latency in both conditions was observed between signals 1 and 2, as shown in Fig. 1. However, an additional factor would appear to be increased motivation; i.e., before the practice period the Ss were told that a practice period would follow, and before the test period they were told that the test period would follow. In view of this difference, it appears doubtful in retrospect that the practice data provided a reliable test of S randomization. On the other hand, the general similarity of the active-passive results in the two situations suggests that the practice data had at least some validity.

Along with the decrease in means, a concomitant decrease in variance would be expected in the test period. This was the case for the passive observation condition: the Subjects (within-cells) variance was 0.2100 sec. as compared with 1.1321 sec. in the practice period ($F = 5.39$; $df = 36, 36$; $P < .01$). Thus, the coefficient of variability was 105.1, which is almost identical to the 108.6 observed in the practice period.

On the other hand, the Subjects variance in the active condition was actually found to increase to 10.5438 sec. in the test period, from 5.6440 sec. in the

practice period ($F = 1.87$; $df = 36, 36$; $P < .10$). Thus, the coefficient of variability was 231.1 as opposed to 92.8 in the practice period. Such results suggest that the performance of only a portion of the Ss in the active condition improved between the practice and test periods, thus producing a decrease in mean along with an increase in variance. While the difference in variances is of doubtful reliability, there was at least no tendency for the variance to decrease between practice and test as expected. In any case, the assumption of a log-normal distribution does not appear tenable for the latency data of the active condition in the test period.

The difference in Subjects variance between the active and passive conditions was statistically significant ($F = 50.21$; $df = 36, 36$; $P < .001$), which confirms the similar finding of the practice period. However, the apparent difference in variabilities which is shown in Fig. 1 actually stems from a different source - the Subject x Signal interaction. This source represents random variability of the Ss' performance from signal to signal, and measures the degree of intra- rather than inter-individual differences. In the passive condition this variance was 0.007053 sec.; in the active condition it was 1.096620 sec. A difference of this magnitude is significant well beyond $P = .001$ ($F = 155.48$; $df = 445, 459$). Apparently the active observation condition increases intra-individual differences even more strongly than inter-individual differences.

In order to prevent the variability of the active data from masking results in the passive data, these data were treated separately in most subsequent statistical analyses. However, comparison of the overall detection performance for the two observation conditions was attempted using the median response latency for each S. The median was used to reduce the degree of variability of the data from the active condition. The analysis of variance of medians is shown in Table 5. Despite reduction of the error variance (the Subjects variance would have been 5.3769 sec. if means were used) only the difference between the active and passive conditions was found to reach significance.

Schedule Effects in the Passive Condition: Of the two independent variables involved in the signal schedules, signal rate was found to have the greater effect on detection performance in the passive observation condition. This effect is shown in Fig. 2, where the latencies of detection response for successive pairs

TABLE 5

ANALYSIS OF VARIANCE OF MEDIAN RESPONSE LATENCIES FOR BOTH THE ACTIVE AND PASSIVE OBSERVATION CONDITIONS IN THE TEST PERIOD

| Source | df | Sum of Squares | Mean Square | F |
|---|---|---|---|---|
| Rate (R) | 2 | 4.5206 | 2.2603 | <1 |
| Variability (V) | 2 | 6.2722 | 3.1361 | 1.11 |
| Observation (0) | 1 | 30.9711 | 30.9711 | 11.01** |
| Sex (S) | 1 | 3.8251 | 3.8251 | 1.36 |
| R x V | 4 | 8.0787 | 2.0197 | <1 |
| R x O | 2 | 3.0691 | 1.5346 | <1 |
| R x S | 2 | 12.0655 | 6.0328 | 2.14 |
| V x O | 2 | 7.2644 | 3.6322 | 1.29 |
| V x S | 2 | 3.1259 | 1.5629 | <1 |
| O x S | 1 | 2.4586 | 2.4586 | <1 |
| R x V x O | 4 | 7.8506 | 1.9627 | <1 |
| R x O x S | 2 | 13.2232 | 3.3058 | 1.18 |
| V x O x S | 2 | 3.2586 | 1.6293 | <1 |
| R x V x O x S | 4 | 24.0642 | 6.0161 | 2.14 |
| Subjects | 72 | 202.5596 | 2.8133 | -- |
| Total | 107 | 332.8733 | | |

**P<.01

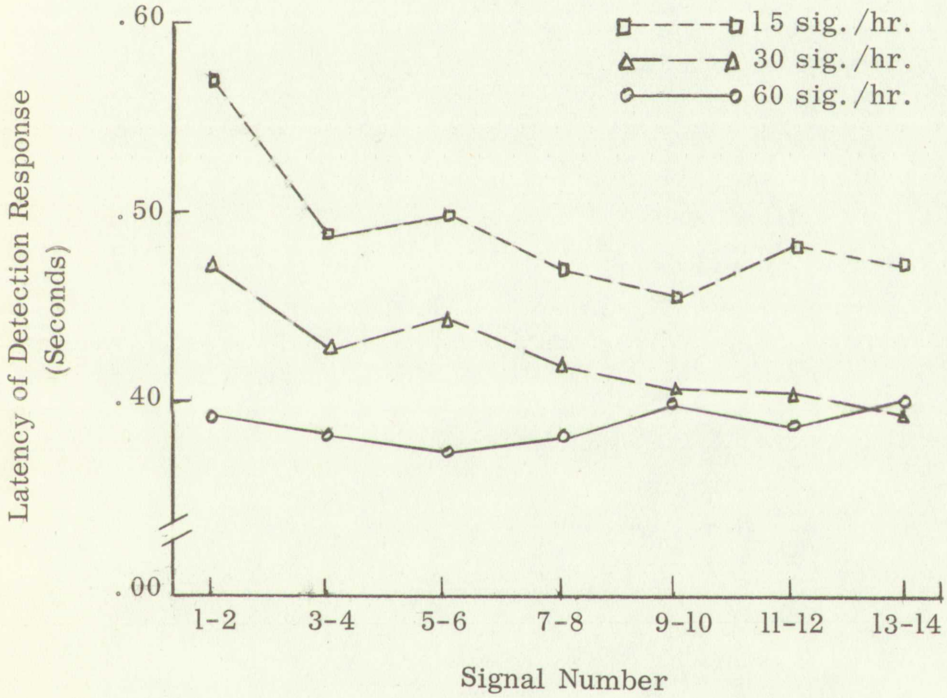


Fig. 2.--Detection performance in the passive observation condition as a function of signal rate. Each point is the mean latency of 18 Ss at two signals.

of critical signals have been averaged to show the trends with greater clarity. Generally speaking, detection performance is found to be better with higher rates of signal presentation. However, the mean latency of response was found to progressively decrease with the low (15 sig./hr.) and medium (30 sig./hr.) signal rates, while remaining roughly constant throughout the test period with the high signal rate (60 sig./hr.). Thus, at the end of the test period, performance was essentially equivalent in the medium and high rate conditions, but still somewhat inferior in the low rate condition. Whether the asymptotic levels of performance would be equal for all three rates is not clear. A much more lengthy test period would be required to answer this question.

Since the effects of signal rate appear greatest at the first two critical signals and tend to dissipate during the remainder of the test period, the above results must be due largely to schedule differences in the first 4 to 8 min. of the task. On their face, such results do not seem to be extremely plausible, as one would tend to expect the differences to be small at the beginning of the test period, and to increase as greater portions of the schedules were experienced. A number of alternative explanations appear possible; these will be treated in the discussion.

The analysis of variance of the latency data for the passive observation condition is shown in Table 6. Despite the small numerical magnitude of the rate effects discussed above, the statistical reliability of these effects was confirmed by the significant Signal x Rate interaction. However, the main effect of rate was not quite significant as $F = 3.26$ was required at $P = .05$.

The analysis shown in Table 6 also revealed the presence of a significant sex difference, and Signal x Variability x Sex interaction. The mean response latencies for male and female Ss were 0.40 sec. and 0.47 sec., respectively. While quite small, this sex difference agrees with that found in the practice period. This difference is also evident in Fig. 3, which shows the significant interaction. Only four of the twenty-one female means shown in Fig. 3 are found to be smaller than male means at the same signal numbers.

Despite grouping of means at successive pairs of critical signals, the trends shown in Fig. 3 are quite variable. With respect to the variability conditions, there is a definite, but numerically small tendency for detection

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TABLE 6

ANALYSIS OF VARIANCE OF RESPONSE LATENCIES IN THE TEST PERIOD FOR THE PASSIVE OBSERVATION CONDITION

| Source | df | Sum of Squares | Mean Square | F |
|---|---|---|---|---|
| Rate (R) | 2 | 1.339077 | 0.669539 | 3.19 |
| Variability (V) | 2 | 0.432015 | 0.216008 | 1.03 |
| Sex (S) | 1 | 0.965005 | 0.965005 | 4.60* |
| R x V | 4 | 0.363563 | 0.090891 | $<1$ |
| R x S | 2 | 0.355996 | 0.177998 | $<1$ |
| V x S | 2 | 0.002764 | 0.001382 | $<1$ |
| R x V x S | 4 | 0.454648 | 0.113662 | $<1$ |
| Subjects | 36 | 7.560262 | 0.210007 | -- |
| Signal (Sig) | 13 | 0.365830 | 0.028141 | 3.99*** |
| Sig x R | 26 | 0.313623 | 0.012062 | 1.71* |
| Sig x V | 26 | 0.206218 | 0.007931 | 1.12 |
| Sig x S | 13 | 0.068286 | 0.005253 | $<1$ |
| Sig x R x V | 52 | 0.442804 | 0.008515 | 1.21 |
| Sig x R x S | 26 | 0.213407 | 0.008208 | 1.16 |
| Sig x V x S | 26 | 0.333817 | 0.012839 | 1.82** |
| Sig x R x V x S | 52 | 0.462127 | 0.008887 | 1.26 |
| Subjects x Sig | 459 | 3.237253 | 0.007053 | -- |
| Total | 746 | 17.116695 | | |

*$P < .05$
**$P < .01$
***$P < .001$

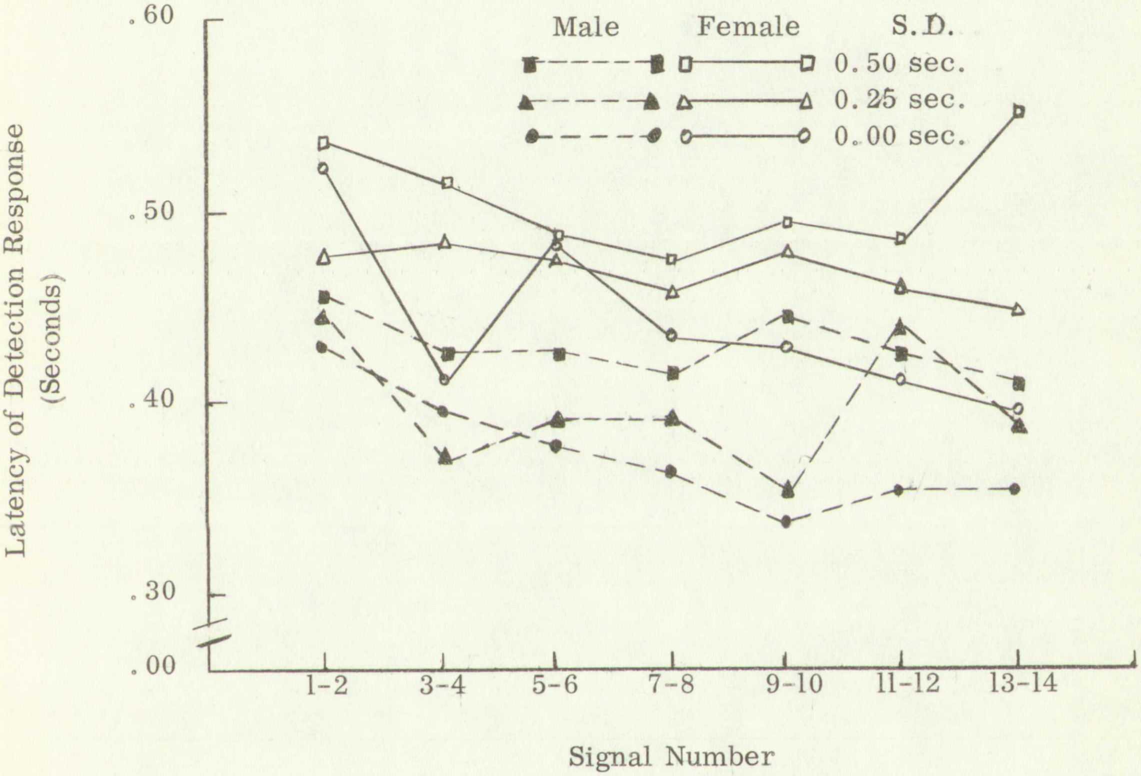


Fig. 3.--Detection performance in the passive observation condition as function of intersignal interval variability and sex. Each point is the mean latency of 9 Ss at two signals.

performance to be superior with lesser degrees of variability. In addition, detection performance tends to show greater improvement during the test period with schedules of lesser variability. Since the differences in these variability effects for the two sexes appear to be caused by a few disparate means which occur rather adventitiously, one is led to regard the three-way interaction as a Type I error. The variability effects shown in Fig. 3 suggest that the Signal x Variability interaction should have been significant, and would have been if the few disparate means had not disturbed the above trends.

In order to show the Signal x Variability interaction more clearly, the data for the two sexes were combined in Fig. 4. Although the differences are small, it is quite obvious that they are in favor of the lower degrees of variability. Furthermore, the differences tend to increase as the test period progresses, as one would expect. While the effect is not as great as that for signal rate, intersignal interval variability also appears to affect detection performance in the passive condition.

Schedule Effects in the Active Condition: The effects of signal rate on detection performance in the active observation condition are shown in Fig. 5. When this figure is compared with Fig. 2 it is evident that little or no relationship exists between detection performance in the active and passive observation conditions. It may be, on the one hand, that the extreme variability of the active data merely "washes out" effects as small as those shown in Fig. 2. On the other hand the observing response procedure may have introduced extraneous effects which, while reliable themselves, overbalance the effects of signal rate. In Fig. 5 there is some tendency for performance to improve in the early part of the test period, to decline abruptly at about the middle of the period, and then to slowly improve to the original level at the end.

The analysis of variance of latency data from the active condition tended to support the former over the latter explanation. For the overall test of the differences among the treatments the F was 1.32 (df = 17, 36). Even less suggestive of reliable effects was the overall test of differences in trend among the treatments; the F for Signal x Treatments was 0.87 (df = 221, 445). Further breakdown of these effects for specific sources was similarly unfruitful. Finally, the test of the overall trend shown in Fig. 1 yielded F = 1.14 (df = 13, 445) which

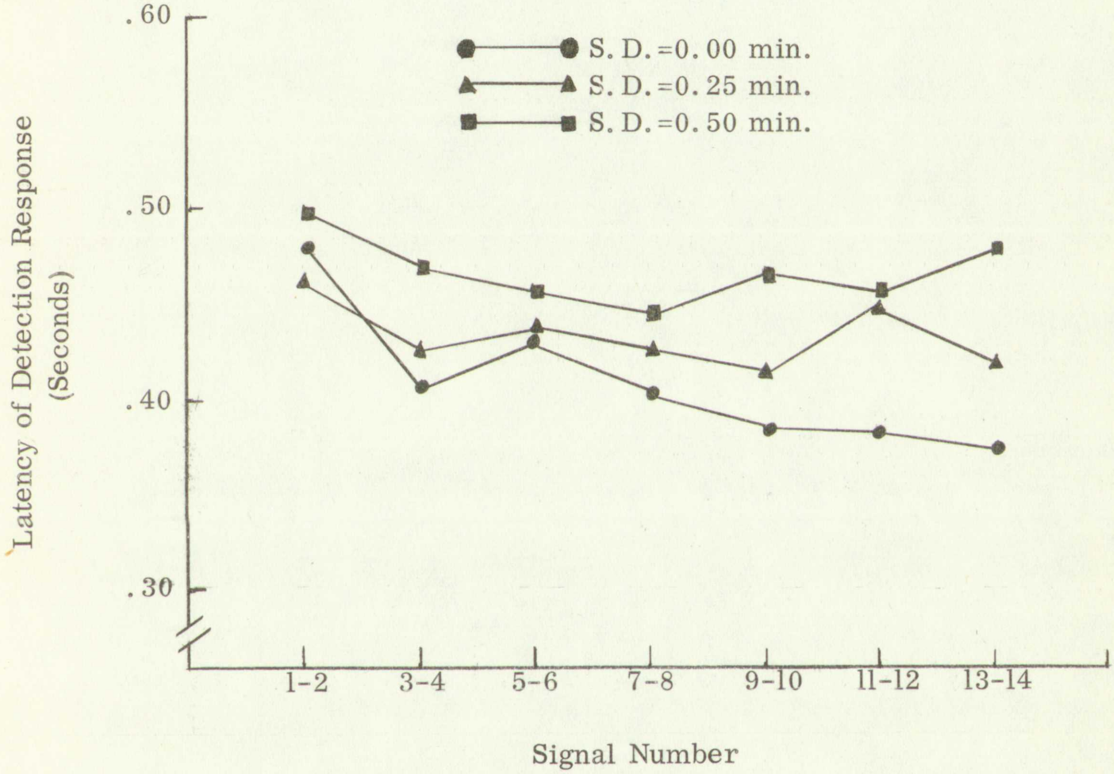


Fig. 4. --Detection performance in the passive observation condition as a function of intersignal interval variability. Each point is the mean latency for 18 Ss at two signals.

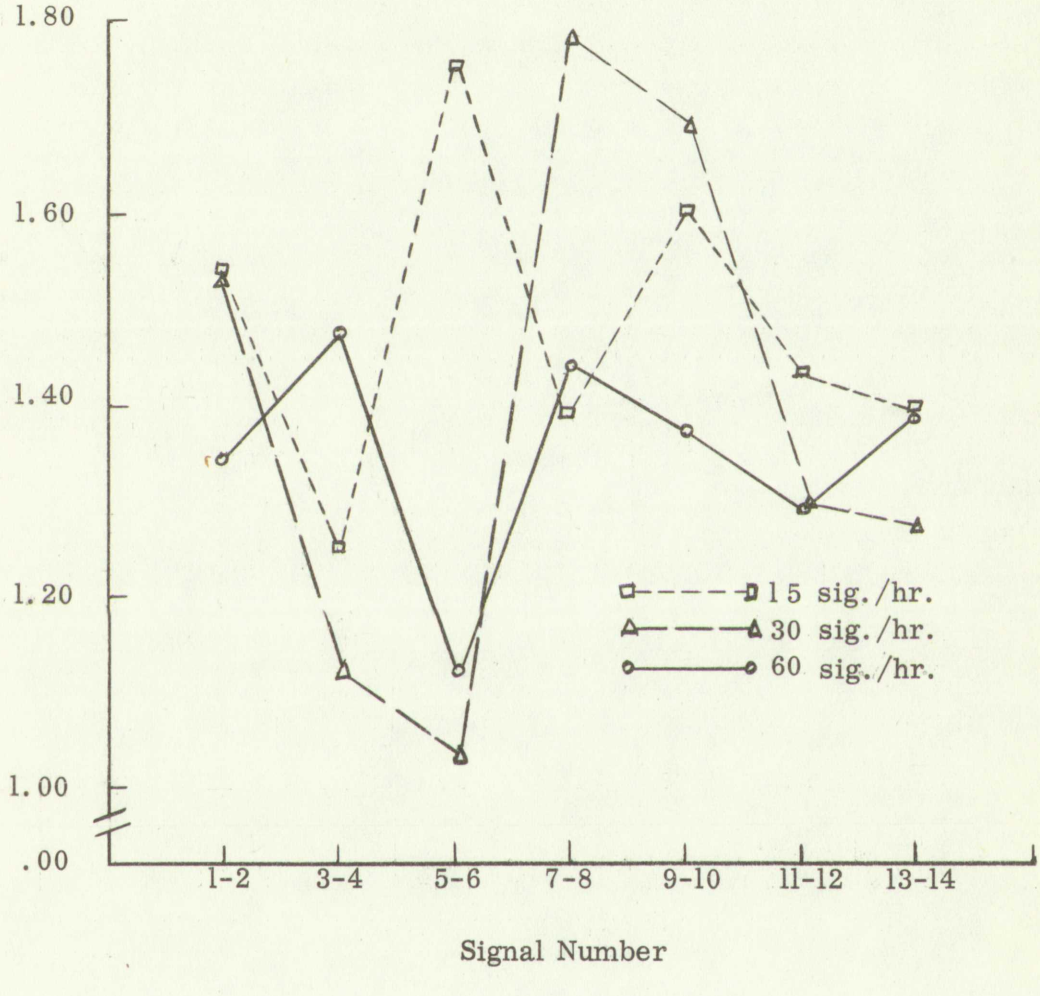


Fig. 5.--Detection performance in the active observation condition as a function of signal rate. Each point is the mean latency of 18 Ss on two signals.

was also not significant. Thus, we must conclude that the only statistically reliable aspect of detection performance in the active observation condition was its variability. Apparently, the variability was sufficiently great to obscure all effects of the independent variables.

Observing Response Results: Since detection performance was not similar in the active and passive observation conditions, a detailed examination of observing behavior in the active condition did not appear to be useful as a means of illuminating the nature of vigilance. However, it was still necessary to investigate the relationship between observing response rate and detection performance in the active condition alone, so as to verify Holland's (1958) findings. The indicant of observing behavior used in this comparison was the mean number of observing responses per second, averaged over the entire test period for each S. The median response latency at critical signals was used as a measure of detection performance for each S. The median was used since it would not be biased by the extreme scores.

Inspection of a scatter-plot of the rate and latency data revealed a curvilinear relationship between the two variables. This curvilinearity was eliminated when rate was plotted against the logarithm of latency. Correlation coefficients were then determined between observing response rate and log median latency for both male and female Ss. The resulting Pearson rs were -.696 for the males, and -.639 for the females. Both rs are statistically significant with $P < .001$. The correlation for both males and females combined was -.647, also significant with $P < .001$. Thus, observing response rate appears to be a predictor of detection performance in the active observation condition. This finding supports that of Holland (1958), despite the use of a different criterion of detection performance in his experiment. While the present experiment employed latency as a response measure, Holland employed percent of signals detected. The generality of the above relationship is thus reinforced.

## CHAPTER V

## DISCUSSION

Vigilance Decrement: A significant decline in detection performance was not obtained in either the active or passive observing conditions. In fact, a small but significant overall improvement in performance occurred in the passive condition. The results of the passive condition generally agree with recent findings of Bergum and Lehr (1962). These investigators also used a meter display without the observing response procedure and found no evidence of a performance decrement as indexed by latency of response. Data on percent of signals detected were also obtained since transient signals were employed. While detection percentages for successive time periods were not reported, the overall level was about 95%, which obviously leaves little room for a decrement with this measure.

Although Bergum and Lehr did not find an improvement in response latencies, this may have been due to averaging of latencies within successive 15-min. periods. If the data of the present experiment were similarly grouped, little overall evidence of an improvement in performance would have been observed. The slight difference in results also might have been due to different signal magnitudes used in the two studies. The signal of the present experiment was a $45^{\circ}$ deflection of the pointer from the null position; in the Bergum and Lehr experiment a $15^{\circ}$ deflection was used. Since performance improved with a $45^{\circ}$ signal and remained constant with a $15^{\circ}$ signal, a decrement in performance might be found if a signal of less than $15^{\circ}$ were used. At least, if a performance decrement is to be demonstrated at all with a meter display, the results of the two studies suggest that a signal of less than $15^{\circ}$ must be employed.

It may be, as Bergum and Lehr suggest, "... that the null-meter task *as it is presently constituted* is not a suitable vehicle for vigilance research." A decrement in detection performance is the defining characteristic of the vigilance problem. If experimental results are to apply to the solution of this problem, they must be obtained in a situation where a decrement is demonstrable.

# CHAPTER V

## DISCUSSION

*Vigilance decrement.* A significant decline in detection performance was not obtained in either the active or passive observing conditions. In fact, a small but significant [illegible] improvement in performance occurred in the passive condition. The results of the passive condition generally agree with recent findings of Bergum and Lehr (1962). These investigators also used a meter display without the observing response procedure and found no evidence of a performance decrement as indexed by latency of response. Data on percent of signals detected were also obtained since frequent signals were employed. While detection percentages for successive time periods were not reported, the overall level was about 99%, which obviously leaves little room for a decrement with this measure.

Although Bergum and Lehr did not find an improvement in response latencies, this may have been due to averaging of latencies within successive 15-min. periods. If the data of the present experiment were similarly grouped, little overall evidence of an improvement in performance would have been observed. The slight difference in results also might have been due to different signal magnitudes used in the two studies. The signal of the present experiment was a 45° deflection of the pointer from the null position; in the Bergum and Lehr experiment a 15° deflection was used. Since performance improved with a 45° signal and remained constant with a 15° signal, a decrement in performance might be found if a signal of less than 15° were used. At least, if a performance decrement is to be demonstrated at all with a meter display, the results of the two studies suggest that a signal of less than 15° must be employed.

It may be, as Bergum and Lehr suggest, ". . . that the null-meter task as it is presently constituted is not a suitable vehicle for vigilance research." A decrement in detection performance is the defining characteristic of the vigilance problem. If experimental results are to apply to the solution of this problem, they must be obtained in a situation where a decrement is demonstrable

If a decrement cannot be obtained in a task, performance may be insufficiently sensitive to variables which are important to the control of the vigilance decrement in general, or overly sensitive to variables which do not, in general, affect the vigilance decrement. That is, independent variables which are necessary and sufficient for the production or elimination of a performance decrement may not be the same variables which control the overall level of monitoring performance. Thus, the present experimental results may actually be more pertinent to the general topic of reaction time than to that area of attention research known as vigilance.

The failure of a performance decrement to appear in the active observation condition of the present experiment is superficially at variance with the results of Holland (1958). The performance of 39% of his Ss remained at a constant level while they detected 99% of all signals, and the remaining 61% of the Ss showed a performance decline with a total detection percentage of 80%. Thus, there was a vigilance decrement for the total group and an overall detection level of 86%. The lack of similar results in the active condition may be traced to the use of response latency as the dependent variable, and the fact that response latency is not subject to the ceiling effect involved in the percentage measure.

In the observing response procedure, signal detection is directly dependent on the momentary observing response rate present at the time of signal occurrence. If no key depressions are made when a transient signal appears, the signal will not be observed and not detected. If a persistent signal is used, the response latency will depend on the duration of the nonobserving period. Since part of Holland's Ss showed a decline in response rate, the percentage of signals detected naturally declined. The remainder of Holland's Ss showed an increase in response rate, but the percentage measure was at a near 100% level to begin with, and remained constant. An increase in the level of detection performance cannot be shown when the percentage measure is the sole criterion of vigilance, and is near the 100% level at the beginning of the task.

In the active condition of the present experiment, however, E observed increases or decreases in response rate similar to those described above, but which were accompanied by concomitant increases and decreases in detection

If a decrement cannot be obtained in a task, performance may be insufficiently sensitive to variables which are important to the control of the vigilance decrement in general, or overly sensitive to variables which do not, in general, affect the vigilance decrement. Thus, independent variables which are necessary and sufficient for the production or elimination of a performance decrement may not be the same variables which control the overall level of monitoring performance. Thus, the present experimental results may actually be more pertinent to the general topic of reaction time than to that area of attention research known as vigilance.

The failure of a performance decrement to appear in the active observation condition of the present experiment is superficially at variance with the results of Holland (1958). The performance of 25% of his Ss remained at a constant level while they detected 99% of all signals, and the remaining 75% of the Ss showed a performance decline with a total detection percentage of 80%. Thus, there was a vigilance decrement for the total group and an overall detection level of 85%. The lack of similar results in the active condition may be related to the use of response latency as the dependent variable, and the fact that response latency is not subject to the ceiling effect involved in the percentage measure.

In the observing response procedure, signal detection is directly dependent on the momentary observing response rate present at the time of signal occurrence. If no key depressions are made when a transient signal appears the signal will not be observed and not detected. If a persistent signal is used, the response latency will depend on the duration of the nonobserving period. Since part of Holland's Ss showed a decline in response rate, the percentage of signals detected naturally declined. The remainder of Holland's Ss showed an increase in response rate, but the percentage measure was at a near 100% level to begin with, and remained constant. An increase in the level of detection performance cannot be shown when the percentage measure is the sole criterion of vigilance, and is near the 100% level at the beginning of the task.

In the active condition of the present experiment, however, E observed increases or decreases in response rate similar to those described above, but which were accompanied by concomitant increases and decreases in detection

performance. Since the increases and decreases in performance would tend to balance out when averaged together, no overall improvement or decline was obtained in the active condition. According to this interpretation, the active condition would have shown a decrement if the percentage measure had been obtained, and Holland's experiment would not have shown an overall decrement in performance if latency of response had been used as the dependent variable. Evidence for this interpretation comes from the increase in variance of response latencies in the active condition between the practice and test periods. Such an increase in variance would naturally follow if a portion of the Ss showed an increase in response latencies, while the remainder showed a decrease.

Signal magnitude may have played an additional role in the difference between the active condition and Holland's experiment. While Holland did not report the precise angular displacement used, it may have been several times smaller than $45^{\circ}$. However, the contribution of this factor to the difference in results is probably small unless Holland used a signal of less than $15^{\circ}$, in view of Bergum and Lehr's results discussed above.

Effect of Observing Response Procedure: The results of the present experiment do not support the validity of Holland's observing response procedure as a means of investigating vigilance phenomena. That is, the behavior which is presumably measured by this technique appears to be altered by the technique itself. In both the practice and test periods, detection performance was much more variable in the active than the passive condition. Furthermore, the variability was sufficiently extreme to totally obscure - in the active condition - the effects of independent variables which were observed in the passive condition. The present results cannot be regarded as completely conclusive, however, since no decrement in detection performance was observed. It may be that effects in the passive condition would be paralleled by similar effects in the active condition despite the increase in variability, if the two conditions were compared in a decremental vigilance task. However, such results do not appear likely when it is remembered that a decrement was observed by Holland, and not observed by Bergum and Lehr, even though both studies used percent detections as a dependent variable.

performance. Since the [illegible]

balance out when averaged [illegible]

obtained in the active [illegible]

conditions would have shown [illegible]

obtained, and Holland's [illegible]

in performance of latency [illegible]

Evidence for this interpretation [illegible]

latencies in the active [illegible]

increase in variance would [illegible]

increase in response latencies, [illegible]

Signal magnitude may [illegible]

between the active condition [illegible]

report the precise angular [illegible]

smaller than 90°. However, the [illegible]

results is probably small [illegible]

of Bergum and Lehr's results [illegible]

Effect of Observing Responses [illegible]

periment do not support the [illegible]

as a means of investigating [illegible]

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The present results cannot be [illegible]

since no decrement in detection [illegible]

effects in the passive condition [illegible]

active condition despite the [illegible]

compared in a decremental [illegible]

likely when it is remembered [illegible]

not observed by Bergum [illegible]

tions as a dependent variable.

The extreme variability of detection performance in the active condition would appear to result primarily from the dependence of detection performance on the momentary response rate present at the time of signal occurrence. While a sizable correlation was found between overall detection performance and overall response rate, the correlation would have been even higher if the average momentary rate at times of signal occurrence had been used. At least, E's informal observations of the S's behavior would suggest this finding. The result of such a dependence was essentially to superimpose variations in response rate upon variations in detection performance.

Not only were differences among individuals increased in this way, so also were differences within individuals. As noted in the discussion of the vigilance decrement, the response rates of some Ss in the active condition apparently increased while the rates for others decreased, with consequent increases and decreases in detection performance. This not only would result in a larger estimate of variance between Ss, but also lead to an even more striking increase in the estimate of variance within Ss. Such results were found in the data for the test period. Since the within Ss variance was extremely small in the passive condition, similar increases and decreases in detection performance apparently did not occur in this condition.

In addition to overall increases or decreases in response rate, in the active condition the E also observed that the momentary rates of many Ss were quite variable. Such fluctuations in momentary rate would further magnify intra-individual differences. All in all, then, Holland's observing response procedure is found to produce detection performance which is neither reliable nor valid in the study of vigilance.

Effect of Signal Rate: The results of the present experiment agree with the results of other studies (Deese and Ormond, 1953; Ellis and Ahr, 1960; Jenkins, 1958; Kappauf and Powe, 1959) which show superior detection performance with higher rates of signal presentation. However, the differences in the present study were found to be large at the start of the test period, and to progressively decrease throughout. The usual finding has been quite the opposite. The peculiarity of such results suggests that the basic process involved in the present effects of signal rate may be somewhat different than that involved

in previous results. This suggestion is reinforced by the fact that the present results occur in the presence of improvement rather than decline in detection performance.

An expectancy hypothesis proposed by Deese (1955) has been widely used to account for the effects of signal rate on detection performance. This position assumes that an S gradually builds up an "expectancy," with regard to the future patterning of signal occurrences, out of past experience with the signal schedule. The S's momentary level of vigilance is then a reflection of his momentary "expectancy" that a signal will occur. Since Ss can predict short intervals of time better than long ones, performance is therefore superior with high signal rates. If the Ss of the present experiment were acquiring such "expectancies" which would permit improved prediction of future signals, the "expectancies" in different rate groups would have tended to be more similar at the beginning of the test period than at the end. Thus, the differences in performance would have been small at the beginning and larger at the end. Since the actual results were quite the opposite, such an expectancy hypothesis appears to have little validity in the present experiment.

An operant conditioning theory such as that proposed by Holland (1958) does not appear to be any more useful than an expectancy theory in this instance, since both theories would appear to make similar predictions as to the relative magnitude of initial and final differences. The operant conditioning theory assumes that detection performance is a direct function of observing response rate, and that signal detection serves to reinforce the emission of observing responses. Since reinforcement is more frequent with high signal rates, high response rates are produced. Thus, high signal rates result in superior detection performance. However, operant conditioning is typically a gradual process, with maximal differences between reinforcement schedules being shown in the "steady states" achieved after several hours of conditioning. Thus, differences in performance produced by different signal rates would be expected to increase rather than decrease, as the task progressed.

Another hypothesis might be that the improvement shown in the present experiment was merely "response learning," i.e., learning how to make a rapid detection response. While reaction time has been found to improve with

practice (Blank, 1934; Hovland, 1936; Miles, 1936), such improvement has always been very small and very gradual, requiring many practice trials. The present results do not appear to conform to such a pattern. The major portion of the improvement was found to be complete after only a few detection responses; in the high rate condition, asymptote was approximately reached prior to the first critical signal at which performance was measured. In addition, one would expect the asymptotes to be the same for all rate groups. While not entirely conclusive, the data did suggest that this was not the case.

The data do indicate, however, that the improvement in reaction time was related to the massing of detection responses, rather than their absolute number. Close examination of Fig. 5 reveals that some 18 to 20 signal detections were required to bring the performance of the medium rate condition to about that achieved in the high rate group after only 4 to 8 detections. Furthermore, 7 to 8 signal detections in the low rate group were required to reach the level of performance attained after 2 to 4 detections in the medium rate condition. For such results, warm-up would appear to be the most appropriate explanatory mechanism.

Apparently a temporary "preparatory set" or "motor readiness" was acquired in some degree whenever a detection response was made. This warm-up of the motor adjustments necessary for a rapid detection response tended to reduce response latency. Since warm-up is cumulative, detection performance progressively improved with the number of detection responses. But warm-up also tends to dissipate as a function of time, so that the rate at which warm-up was completed was an inverse function of the mean intersignal interval. With the low rate condition, nearly all of the warm-up dissipated during the average interval. While a point of equilibrium was reached between the acquisition and dissipation of warm-up, the process was never completed. Thus, performance in this condition tended to reach an asymptotic level which was inferior to that of the remaining rate conditions.

While most experimenters have failed to report warm-up in the vigilance situation, this can usually be attributed to the grouping of data over broad intervals of time. In addition, the usual vigilance decrement would tend to overbalance the small effects of warm-up. Another factor could be the extensiveness of the training period used. Most studies have given rather extensive

practice, with numerous signals occurring in a short period. Warm-up would thus tend to be completed prior to the test period. The major significance of the warm-up interpretation, however, would appear to be the implication that signal rate, *per se*, has no effect on detection performance *in the absence of vigilance decrement*. That is, if warm-up were properly controlled in the present task, no effect of signal rate would be obtained. This implication appears to be a fruitful basis for further research.

*Effect of Schedule Variability*: Although no evidence for overall effects of the variability conditions were obtained in the passive observing condition, effects did turn up in a significant three-way interaction involving signals and sex. However, the contribution of sex in this case was rejected as a Type I error, in favor of an interpretable Signal x Variability interaction. Performance in the three variability conditions appeared to show comparable warm-up effects at the beginning of the task, and the differences between the variability levels were small. However, greater degrees of improvement during the test period were found with lesser degrees of variability. Thus, the differences between the variability conditions were larger at the end of the task, and were clearly related to the "predictability" of the signal schedules.

Such results are equally interpretable by the expectancy or operant conditioning theories, and may have some generality to situations involving performance decrements. In contrast to the effects of signal rate, the variability effects appear to represent the influence of intersignal interval variability *per se* on detection performance. The results are not inconsistent with the hypothesis that schedule variability, rather than signal rate, has been the prepotent factor responsible for the effects attributed to signal rate in previous experiments. However, the variability effects were of small numerical magnitude and no statistical significance, so that only very tentative conclusions can be drawn. Furthermore, similar effects remain to be demonstrated in a decremental vigilance task. Support of the experimental hypothesis must await further research on this issue.

While no evidence of a rate-variability interaction was obtained in the present experiment, there were only 6 *Ss* assigned to each schedule in the passive condition. Thus, the present experiment was probably of inadequate precision to demonstrate the existence of such an interaction.

Sex Differences in Performance: In both the practice and test periods evidence was obtained that reaction latency is somewhat shorter for males than females. However, the differences tended to be small, and were not found to interact with other experimental variables, except for the possible Type I error discussed above. Although the direction of the difference agrees with previous findings (Bellis, 1933; Elliott and Loutitt, 1938; Seashore and Seashore, 1941), the present results would appear to be of significance only from a methodological standpoint. Apparently it is not legitimate to use both males and females in vigilance research without including sex as a variable in the statistical analysis, if latency of response is used as the dependent variable. If sex is not included in the analysis, the sex difference will be included in the error variance and will reduce the precision of the experiment.

## CHAPTER VI

## SUMMARY AND CONCLUSIONS

The present experiment was designed to assess the independent effects of signal rate and intersignal interval variability on performance in a visual monitoring task. In addition, the effects of the observing response procedure devised by Holland (1958) were investigated.

Nine signal schedules were used combining signal rates of 15, 30, and 60 signals per hour, with intersignal interval S. D. s of 0.00, 0.25, and 0.50 min. Two observing conditions were employed with each schedule, for a total of eighteen experimental conditions. The active observing condition involved Holland's (1958) observing response procedure. In this condition, the Ss were required to depress a key to permit observation of the monitoring display. In the passive observing condition, this response was not required for continuous observation of the display. One hundred and eight undergraduate students of psychology were used as Ss with three male and three female Ss randomly assigned to each experimental condition.

The vigilance task was similar to that used by Holland (1958). The signal to be detected appeared on a meter display as a deflection from the null position. The S was provided with two keys; one was depressed to recenter the pointer while the other provided a brief flash of light illuminating the meter display. Since the meter was placed behind one-way glass, and the Ss were in semi-darkness, the display could not be observed unless illuminated. In the passive condition, the display was continuously illuminated and the flash key was not used.

Scheduling of signal presentations and recording of S's observing and detection responses was accomplished by means of standard switching and recorder units in use in operant research. The latency of each detection response was measured by a Standard Laboratory Timer. In addition to response latencies, rates of observing response obtained in the active condition were used in the analysis of the results.

The following conclusions were suggested by the experimental results:

1. Unless a decrement in detection performance can be obtained with signals of small magnitude, the meter display does not appear to be appropriate for vigilance research. Decrements with this display have only been obtained when the observing response procedure has been used along with percent detections as the dependent variable.

2. Holland's observing response procedure produces a marked increase in the variability of detection performance, both between and within Ss. The variability is sufficiently extreme to obscure effects on detection performance which are otherwise obtained.

3. In the absence of an overall performance decrement, signal rate appears to affect detection performance largely through warm-up of the detection response. High signal rates produce faster warm-up so that detection performance is superior with such rates in the early part of the task.

4. Although of small magnitude and statistical insignificance, the effects of intersignal interval variability on detection performance suggest that detection performance is increasingly superior with low degrees of variability as the task progresses.

5. No evidence is found of an interaction between signal rate and schedule variability. However, the absence of a decrement and the small sample used may have obviated such a finding.

6. Detection performance in the active condition appears to depend directly on the momentary rate of observing response. This dependence is partially reflected in a sizable correlation between log median latency and average response rate.

7. There is some indication that male Ss have shorter reaction latencies than female Ss. The sex variable is of little general experimental significance, however, since it does not appear to interact with other variables.

The present conclusions with regard to the effects of signal rate, intersignal interval variability and, to some extent, the effects of the observing response procedure, must be regarded as tentative until they can be confirmed in a vigilance task which involves the characteristic decrement in detection performance.

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# APPENDIX I

## Plates Showing Apparatus

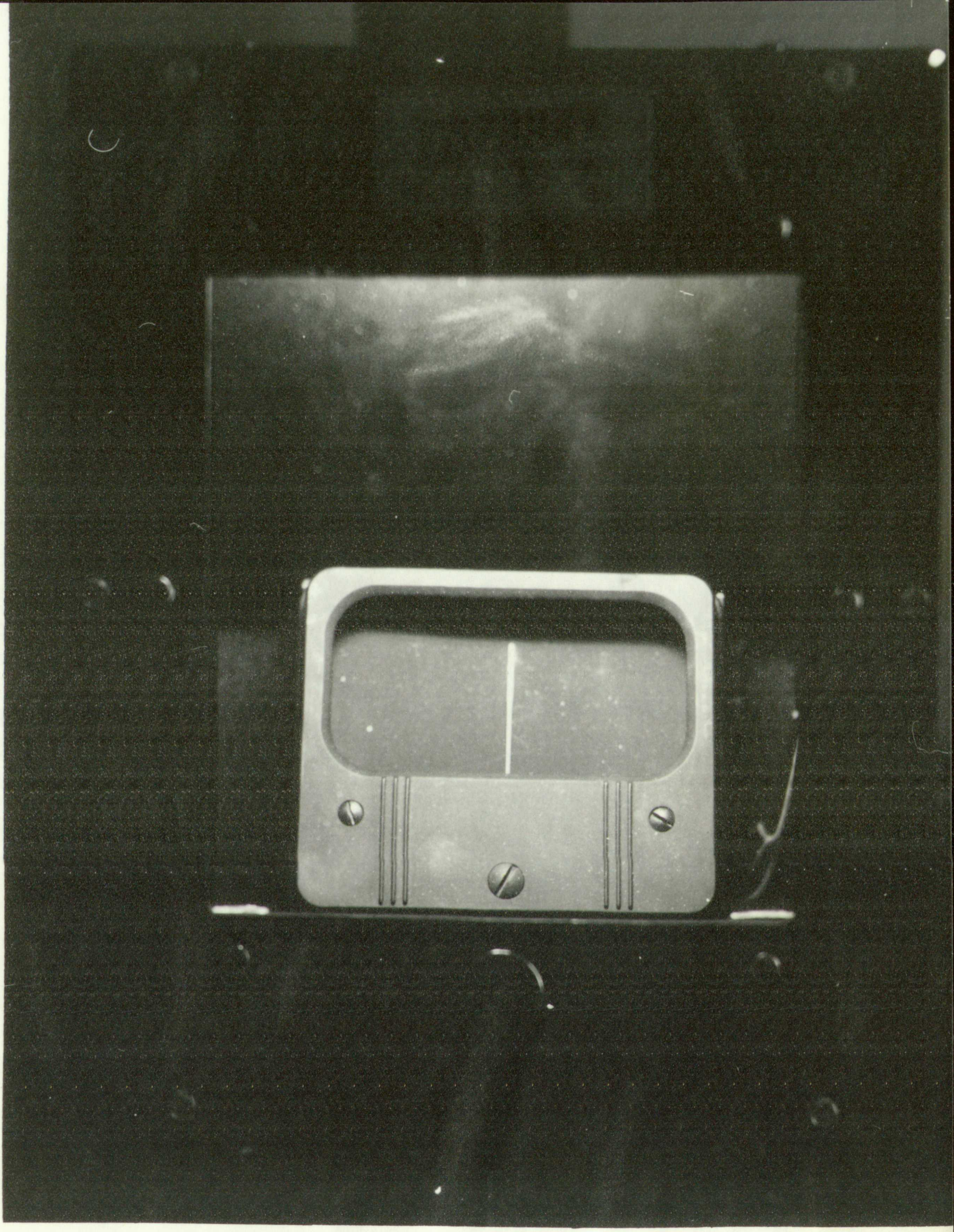

Plate 1. The illuminated vigilance display, as seen by the Ss.

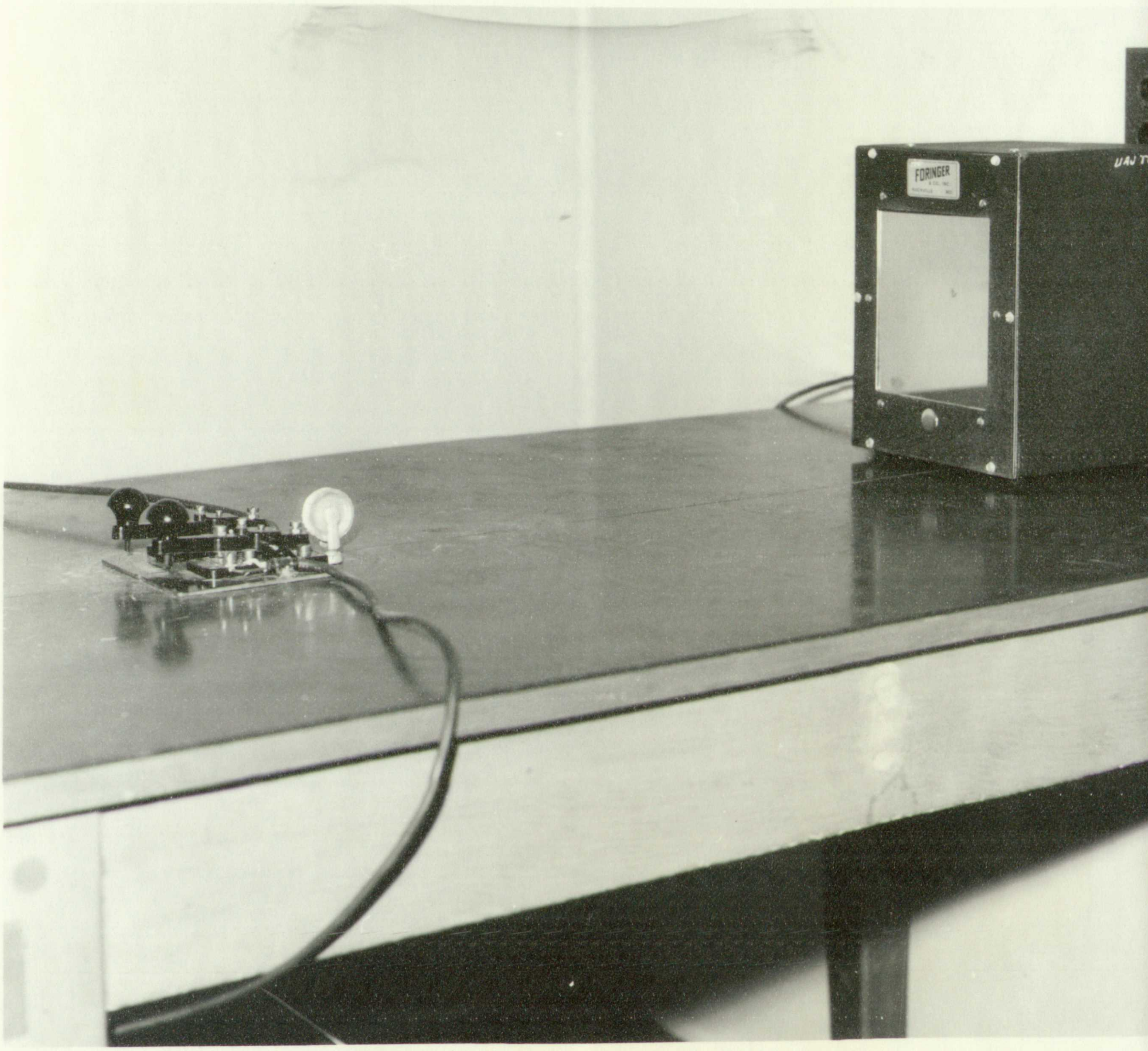


Plate 2. Arrangement of the display box and response keys in S's cubicle.

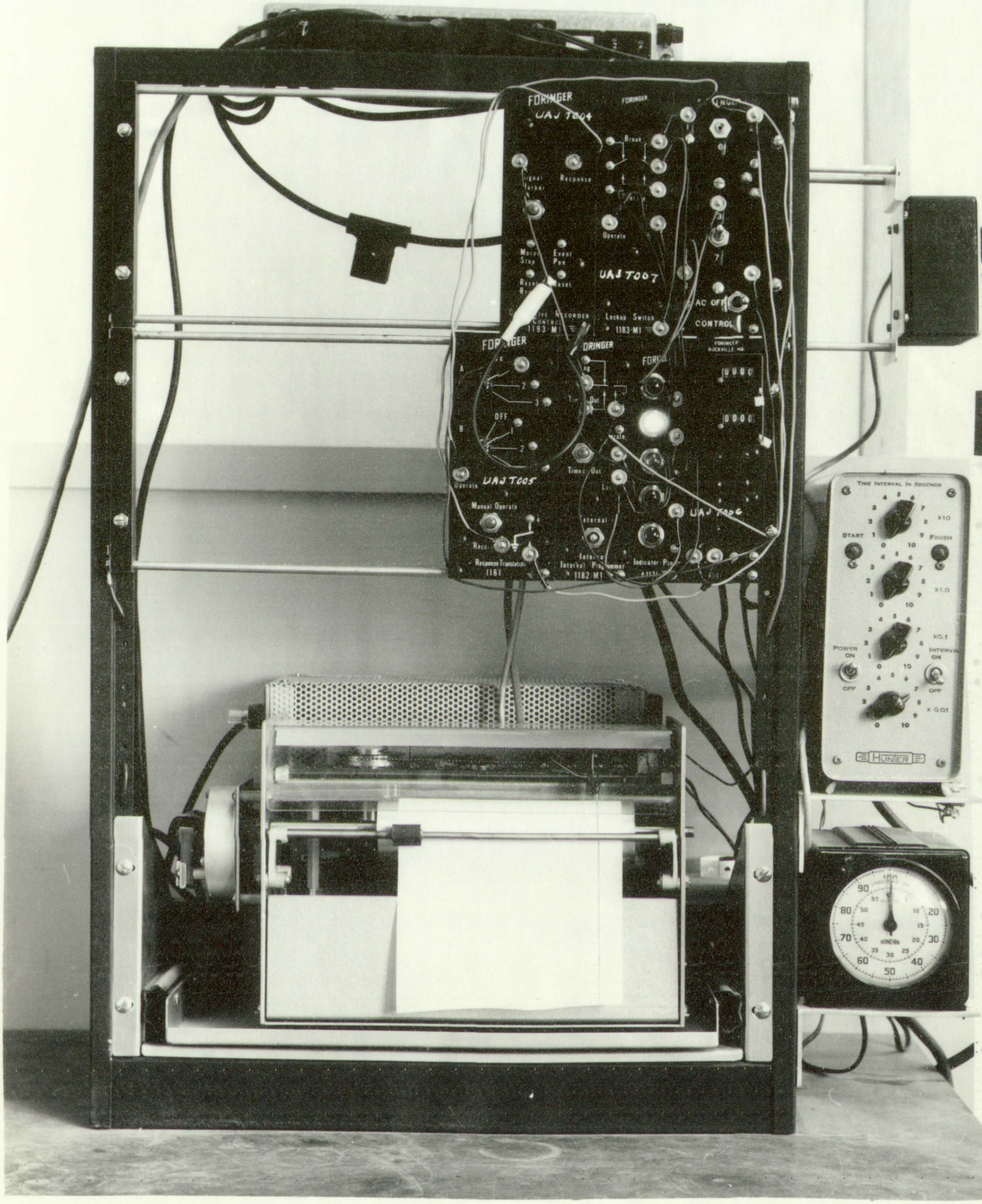


Plate 3. Programming and recording apparatus located in E's cubicle.

APPENDIX D

INSTRUCTIONS [illegible]

Inside the box in front of you is a [illegible] with [illegible] pieces. Whenever you press the right [illegible] it will [illegible] an "answer" [illegible] and you [illegible]

[illegible]

When it [illegible]

[illegible] to know [illegible]

[illegible]

There [illegible]

but want to [illegible]

[illegible]

this function [illegible]

[illegible]

Now we [illegible]

response is [illegible]

so that the [illegible]

press the light [illegible]

[1] The parenthetical [illegible] the [illegible]

[illegible] condition.

APPENDIX II

INSTRUCTIONS TO SUBJECTS *

Inside the box in front of you is a meter with a pointer. (Whenever you press the right hand key, a light will flash on inside the box and you will be able to see into it for a short time. Try it once.) Usually the pointer will be straight up, but occasionally it will move off center to about a 45$^{o}$ angle. When it moves off center, it can be reset by pressing the left hand key. Your job is to keep the amount of time the pointer is off center to an absolute minimum, by resetting it as quickly as possible whenever it goes off center.

There is one more thing which is also important. You must use only your left hand to press the left key (and your right hand to press the right key). Now, do you understand what you are supposed to do? Good. We will start with a little practice session, so you can see how everything works. The light will flash off (on) once as a signal for you to start. Any questions?

(One min. practice period)

Now we will begin the regular experiment. Remember that your only purpose is to reset the pointer as quickly as possible after it goes off center, so that the amount of time it remains off center is a minimum. (How fast you press the light key is entirely up to you.) Any questions?

* The parenthetical statements were only read to the Ss in the "active" observation condition.

MILLERS FALLS
EZERASE
COTTON CONTENT

**IMPORTANT!**

Special care should be taken to prevent loss or damage of this volume. If lost or damaged, it must be paid for at the current rate of typing.