*SIGNAL FREQUENCY AND SHOCK PROBABILITY
AS DETERMINANTS OF PROLONGED VIGILANCE
PERFORMANCE IN RHESUS MONKEYS¹*

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The effects of changing signal frequency on a prolonged vigilance task were investigated by systematically increasing the average inter-trial interval between successive signals. During a 6-hr watch, vigilance performance remained constant when the rate of signal presentation was 40, 20, and 10 per hour. When the rate of signal presentation was reduced to 7 or 4 per hour, marked decrements in detection performance were observed. Similar vigilance decrements occurred when the average rate of signals per hour was kept constant (10 per hour) and the probability of receiving a shock for missing a signal was systematically varied. The results of this study indicate the importance of reinforcement factors in the control and maintenance of vigilance performance.

Over the past two decades, a major focus of vigilance research has been the analysis of performance decrements under conditions requiring subjects to detect and report the occurrence of signals during extended observation intervals (Bergum and Klein, 1961; Jerison and Pickett, 1963; McGrath, Harabedian, and Buchner, 1968). Although such studies have been carried out with a wide variety of observation tasks under diverse experimental conditions, the results have been remarkably consistent. Observers are reported to show a decrement in the number of signals detected soon after the experiment begins (usually within the first half hour) and maintain this decreased detection level for the remainder of the session (Bergum and Klein, 1961; Jerison and Pickett, 1963).

The present report describes an experimental analysis of some of the conditions under which vigilance is maintained during a prolonged watch. Specifically, this work examined the effects of changing signal frequency and altering the probability of shock for missing signals upon the maintenance of a visual vigilance task in rhesus monkeys.

METHOD

Subjects and Apparatus

Two naive rhesus monkeys, each weighing approximately 5 kg at the start of the experiment, were restrained in primate chairs (Mason, 1958) enclosed in light-tight isolation

booths (Foringer), and maintained on a diet of Purina Monkey Chow with free access to water.

The stimulus used was a standard General Electric electroluminescent panel calibrated for intensity in a light-tight box using an Aminco photomultiplier microphotometer. The panel was mounted 4 in. (10 cm) from the monkey's face at eye level. A Kodak Wratten No. 96 (3.0 log units) neutral density filter was placed permanently in front of the lamp to produce a series of 30 equally spaced (0.20 log units) stimulus intensity values ranging between $1 \times 10^{-2} - 1 \times 10^{-7} \mu$ Lamberts.² Stimulus intensity was varied by changing the voltage across the electroluminescent panel. Voltage changes were made by switching the regulated line voltage through one or another of 30 series resistors according to the position of an add-subtract stepper (See Curran and Thomas, 1965).

A Foringer response lever mechanism mounted on the chair 12 in. (30 cm) in front of the monkey just above waist level provided for the recorded operant response. All scheduling and recording of the experiment was accomplished automatically and remotely by

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²In SI units of luminance, the μ Lambert is equivalent to 0.00318 cd/m².

means of a system of relays, timers, counters, recorders, and its associated switching circuitry.

In conducting the present research, the investigators adhered to the "Guide for Laboratory Animal Facilities and Care", as promulgated by the committee on Revision of the Guide for Laboratory Animal Facilities and Care of the Institute of Laboratory Animal Resources, National Academy of Science — National Research Council.

Procedure

Both monkeys were initially trained to press the response lever within 10 sec after the onset of the electroluminescent panel to avoid a brief electrical shock (Swinnen, Brady, and Powell, 1969) delivered through the neckplate and seat of the restraining chair. Stimuli were arranged with a probability generator and general purpose clock and scheduled to occur at an average interval of 1 min. When the avoidance performance stabilized at 90% correct detections or better for two consecutive 2-hr sessions, an adjusting avoidance procedure was introduced.

At the start of each experimental session, room and chamber lights were extinguished, stimulus intensity was attenuated to the middle of the range ($1 \times 10^{-4} \mu$ Lamberts) by remotely pulsing the add portion of the add-subtract stepper, and the monkeys were allowed 15 min to adapt to the dark. At the end of the 15 min, the first stimulus was presented. Responding within the 10-sec interval terminated the light, avoided the shock, and pulsed the add circuit of the add-subtract stepper, which decreased by 0.20 log units the intensity of the light scheduled for the next avoidance trial. Failure to respond within 10 sec in the presence of the light resulted in the delivery of a brief shock, and a pulse to the subtract circuit of the add-subtract stepper, which increased by 0.20 log units the intensity of the light scheduled for the next trial. Lever presses emitted in the absence of the stimulus light (*i.e.*, during the inter-trial interval) were gated through a probability generator and produced punishment on a 0.50 probability basis.

Signal trials were scheduled at random intervals during 7-hr daily experimental sessions with the number of signals per hour varied systematically. Five average signal fre-

quencies (40, 20, 10, 7, and 4 per hour) were studied for Monkey #3 and four average signal frequencies (40, 20, 10, and 7 per hour) were studied for Monkey #4. These average signal frequencies were studied in descending order over a series of more than 250 experimental sessions, with each signal frequency being presented at least 50 consecutive sessions. In addition to signal trials, noise trials were scheduled to occur at random intervals each hour. A noise trial was in all respects the same as a signal trial except that no voltage was applied across the stimulus lamp. The noise trials were included as "catch trials" to determine whether the monkeys' responding was being controlled by cues other than the stimulus light. Throughout the experiment, noise trials were scheduled to occur at the same frequency as signal trials (40, 20, 10, 7, and 4 per hour for Monkey #3; 40, 20, 10, and 7 per hour for Monkey #4).

Following the manipulation of signal frequency, the vigilance performance for each monkey was re-established at 10 signals per hour (10 noise trials per hour were also scheduled) and the probability of shock for missing a scheduled signal was varied systematically. As in the previous experiment, each detection decreased the intensity of the stimulus intensity scheduled for the next trial by 0.20 log units. Similarly, each miss increased the intensity of the stimulus scheduled for the next trial by 0.20 log units. Four shock probabilities (0.80, 0.60, 0.40, and 0.20 for Monkey #3; 0.70, 0.50, 0.40, and 0.20 for Monkey #4) were presented in descending order over a series of more than 100 experimental sessions with each shock probability value being presented for at least 25 consecutive sessions. Finally, the highest shock probability value for each monkey (0.80 for #3 and 0.70 for #4) was re-scheduled during seven consecutive 7-hr sessions to provide a replication of the baseline conditions.

RESULTS

Figure 1 shows modal stimulus intensities averaged over the last seven sessions at each of five signal frequencies for Monkey #3 and four signal frequencies for Monkey #4. Only session hours 2-7 are plotted on the figure, the first hour of each session being a "non-recorded warm-up".

Fig. 1. The effects of signal frequency on vigilance performance. Each data point represents the modal stimulus intensity averaged over seven sessions for each of the signal frequencies studied. Note that only hours 2 to 7 are plotted on the abscissa. The first hour was considered a warm-up and the data were therefore not included.

One should note that no vigilance decrement occurred during this warm-up period for either monkey at any of the signal rates presented. At signal frequencies of 40, 20, and 10 per hour, virtually no decrements in vigilance performance were observed over the 7-hr watch for either monkey, *i.e.*, on the average, both monkeys detected half the signals presented. At a signal frequency of seven per hour, both monkeys showed marked changes in vigilance performance. Stimulus intensities were higher and the number of signals detected decreased systematically over the course of the watch. The progressive decrement in performance shown in Figure 1 for Monkey #3 at four signals per hour and Monkey #4 at seven signals per hour appeared consistently throughout the course of the seven sessions averaged to provide these data.

Fig. 2. The effects of varying signal rate on inter-trial interval responding. Each data point represents the mean number of responses made between trials averaged over seven consecutive sessions.

Figure 2 shows the mean number of inter-trial interval responses averaged over the last seven sessions at each of five signal frequencies for Monkey #3 and four signal frequencies for Monkey #4. Both monkeys showed a systematic decrease in the number of responses made between trials as the number of signals per hour was reduced. The data plotted in Figure 2 indicate that the average number of

inter-trial interval responses per hour was approximately half the rate of signal presentations per hour. The number of responses to "catch trials" was unrelated to signals per hour. "Catch trial" responses ranged from 0 to 5 per session for both monkeys across all stimulus conditions.

Fig. 3. The effects of shock probability on vigilance performance. Each data point represents the modal stimulus intensity for the last 2 hr of the watch averaged over seven consecutive sessions.

Figure 3 shows modal stimulus intensities for the terminal 2 hr of each watch averaged over the last seven experimental sessions at each of four different shock probabilities, with signal frequency held constant at 10 per hour for each monkey. Marked increases in stimulus intensities and marked decreases in signal detections were found to be a function of decreasing probabilities of shock for detection failures. Replication of the high shock probability condition (*i.e.*, 0.80 and 0.70 for Monkeys #3 and #4 respectively) resulted in recovery of the indicated (star-labelled points in Figure 3) vigilance performance.

DISCUSSION

Methodologically, the observation task required of the monkeys is consistent with the operational characterization of vigilance cited in previous reports (Bergum and Klein, 1961;

Jerison and Pickett, 1963; Jerison, 1970) as a behavioral performance involving detection and report, during extended watch intervals, of signals scheduled to occur aperiodically, infrequently, and at near threshold levels. The experimental task can also be classified as a complex type of discriminative avoidance procedure, where the intensity of the discriminative stimulus depends upon the observer's detection performance. The present results suggest that the vigilance performance studied is a complex function of both signal frequency and shock probability. Since it is possible that the frequency of signals and possible frequency of shocks received may be confounded in this experiment, it is important to design further studies to help analyze the complex interaction of these two variables. One could, for example, study the effects of keeping signal intensity and shock probability constant while varying signal frequency on avoidance performance. Similarly, one could design an experimental situation where both signal frequency and shock probability are varied while the maximum number of shocks over conditions remains constant. The outcome of such an experiment would serve to clarify the relationship between shocks per hour and avoidance performance.

Inter-trial interval responding for both monkeys systematically decreased as the rate of signal presentations was reduced. Since the average number of responses between trials at 40, 20, and 10 signals per hour approximated the average number of detections per hour (20, 10, and 5) one might be led to the erroneous conclusion that the monkeys were attending to extra-experimental cues that were correlated with the onset of the stimulus. This hypothesis is quickly discarded though, when one notes that the number of responses occurring in the presence of "catch trials" ranged between 0 to 5 per session for both monkeys and was unrelated to the rate of signal presentations. In the jargon of the signal detection literature, the monkeys had very low "false alarm rates". Inter-trial interval responding must therefore be related to some variable that changed systematically with signal rate. The most likely variable is the average number of shocks received per hour.

At signal rates of 40, 20, and 10 per hour, both monkeys maintained an almost constant modal stimulus intensity over the entire ses-

sion (see Figure 1). They detected approximately 50% of the stimuli scheduled and missed approximately the same percentage. The data recorded during "catch trials" strongly suggest that the inter-trial interval responding is systematically related to the number of misses per hour, rather than to the number of detections. We therefore suggest that the majority of inter-trial interval responses most probably represent post-shock bursting resulting from shocks delivered when signals were missed.

The present findings with respect to the signal frequency parameter differ somewhat from past reports of marked increases in detection frequency as the rate of signal frequency increases (Deese and Ormand, 1953; Nicely and Miller, 1957; Jenkins, 1958; Hickey and Blair, 1959). Over the relatively wide range of signal presentation rates (10 to 40 per hour) no differences in detection performance were observed with either monkey, and significantly, no decrement in vigilance performance occurred during the prolonged 7-hr watch at these rates of signal presentation. Only when the rate of signal presentations was reduced to seven per hour or less did such performance decrements appear.

That the maintenance of a highly effective vigilance performance over the broad range of signal frequencies observed in this study may be attributable, at least in part, to reinforcement contingencies is suggested by the findings related to independent manipulation of shock probability. Systematic increases in modal stimulus intensity were found to be related to scheduled decreases in the probability of shock for missing a signal. With signal presentation rates of 40, 20, and 10, and shock probability at or near 1.0, the overall frequency of reinforcement remained relatively high. With signal presentation rates of only four to seven per hour or shock probabilities below 0.80 however, the absolute frequency of reinforcing events appears to have been reduced below the level necessary to maintain vigilance performance without decrements. This interpretation takes into account not only the findings of Holland (1958) relating the probability of observing responses to the schedule of signal presentations, but also takes into consideration the possible effects of added information provided by feedback shocks for missed signals.

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