CONCURRENT SCHEDULE CONTROL OF HUMAN VISUAL TARGET FIXATIONS¹

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Operant conditioning techniques were applied to the study of how target fixations are controlled by the probability of signal occurrence. In a standard vigilance setting, gaze at three illuminable volt meters was monitored by a Mackworth television eye camera with automatic recording capability. Gaze at a given meter produced illumination of the meter, and signals (deflections of the needle on the meter) were scheduled as intermittent consequences of this response. Target fixations were thus placed under the control of concurrent variable-ratio, differential-reinforcement-of-low-rate, and fixed-interval schedules in normal adult volunteers.

Holland (1957) demonstrated that the phenomenon of human vigilance may be studied experimentally by considering observing behavior as an operant that is reinforced by presentation of the signal. The studies of Mackworth and Mackworth (1958) made the quantitative recording of human eye movements possible in a relatively normal perceptual situation by introducing closed-circuit television into the corneal reflection ophthalmograph. These two contributions were combined by Schroeder and Holland (1968*a, b*, 1969) in studies that demonstrated that human eye movements can be brought under the schedule control of signal presentation in a vigilance situation. Rosenberger, Fischman, and Goldiamond (1969), also using the Mackworth apparatus, demonstrated that color of the background and direction of gaze may both be used as discriminative stimuli in this reinforcing control.

Frazier and Bitetto (1969), using a modification of the original Holland vigilance paradigm, demonstrated concurrent schedule control over manual observing responses. The present experiments were designed to combine the achievements of Frazier and Bitetto (1969) with those of Schroeder and Holland (1968*a, b*, 1969), and thus demonstrate control over looking behavior by different types of schedules operating concurrently.

Materials and Methods

The Mackworth television eye marker camera used in this experiment and diagrammed in Figure 1 has been described in detail elsewhere (Rosenberger *et al.*, 1969). Briefly, light emanating from a point source is reflected off the subject's cornea and photographed by a closed-circuit television camera as he sits with his head fixed and views a target at a distance of 26 in. (36 cm). With proper calibration, the position of the corneal reflection image on the television monitor screen will reflect the position of the subject's gaze with an error of one degree over a 20-degree field.

For the present experiments, an automatic recording capability similar in its function to that described by Schroeder and Holland (1968*a, b*, 1969), but different in structure, was added. The present apparatus consisted of 120 photoelectric cells arranged in a matrix of 12 by 10 overlying the tube of the video monitor. The outputs of these cells were appropriately amplified to provide the voltage transition needed to drive standard 12-V logic packages. The outputs were also connected to a 12 by 10 matrix of digibit indicator lights to allow for visual calibration. The photocell outputs were also gated through an oscillator with the outputs of the two television cameras to allow the circuit to distinguish between the left and right eye. However, for these experiments, the movements of only the left eye were monitored.

The target of gaze consisted of three illuminable voltage meters (Lafayette Catalogue No.

¹This study was supported in part by Program Project Grant Number HD 05124 from the National Institute of Child Health and Human Development. Reprints may be obtained from the author, Box C, Waverley, Massachusetts 02178.

Fig. 1. Diagram of Mackworth television eye camera apparatus, with automatic photocell recording matrix overlying the video monitor screen.

5410) each 2 in. (5 cm) square, arranged in an equilateral triangle, each side of which subtended a visual angle of 11° (Figure 2). In the center of this triangle was a small red bulb used for calibration. The apparatus was so arranged that whenever the bulb was illuminated by the experimenter, responses from the photoelectric cells were disallowed.

Gaze at a given meter, that is, within an area 4.8° wide and 3.2° high on the target display, caused that meter to be illuminated for 1 sec, and was recorded as a response on a Gerbrands C-3 cumulative recorder. There was a separate cumulative recorder for each meter. Minimum deviation from the meter area required to establish a new fixation was 1.6° (dimensions of the square area on the video monitor covered by a single photocell). Only the onset of gaze was recorded as a response, and it was thus necessary to look away from a given meter and back at it for a second response to be recorded.

Signals consisted of deflection of the indicator needle on one of the meters. This deflection subtended a visual angle of 2° at the pointer tip. A signal was presented simulta-

neously with meter illumination for the full duration of 1 sec, after which time the needle automatically reset. Presentation of the signals was scheduled as an intermittent consequence of gaze at a given meter. For meter No. 1 at the lower left-hand corner of the triangle,

Fig. 2. Diagram of the target display. The pointer on meter 1 is shown deflected (signal).

a presentation of one signal for an average of every 10 looking responses (VR 10) was used, as arranged by a probability generator. For meter No. 2, at the top of the triangle, a signal was presented at every looking response only if no looking response had occurred within the previous 10 sec (DRL 10-sec). For meter No. 3, at the lower right-hand corner of the triangle, signals were presented as a consequence of looking responses at a fixed interval of 1 min (FI 1-min).

Subjects were normally intelligent young adult volunteers of both sexes. Ten subjects were studied for as many as thirty 10-min training sessions each. The 10-min sessions were conducted in groups of three, separated by 5-min rest periods. No more than three sessions occurred on a given day.

At the beginning of the first training session, the following instructions were read to each subject:

This is an experiment to study the effects of sleep deprivation. Your task will be to look at the three meters on the screen in front of you. As you look at a meter it will light up, enabling you to see the needle clearly. Sometimes when the meter lights up the needle will deflect, other times the needle will not deflect. On the aluminum box there are three buttons which correspond to the three meters. When one of the needles deflects, press the appropriate button to record your signal detection. You must press the button as rapidly as possible for the detection to be

Fig. 3. Acquisition of concurrent schedule control in a single subject over 23 sessions. Blips on the cumulative recorder represent signal presentation. Blips on the event pens represent correct detections. The three cumulative records arranged in vertical rows show the cumulative looking response rates on meters one through three (top to bottom).

Fig. 4. Acquisition of concurrent schedule control in a second normal subject.

counted. It will not count after the light goes off (one second).

The object of the task is for you to detect and record as many deflections as possible in a ten-minute period. After each ten-minute period you may rest for five minutes. In order for the equipment to run smoothly, you must hold your head as still as possible. The plastic bite bar will help you. When the red light in the center of the screen comes on, look at it and hold your gaze as steady as possible. You must look at the red light only when it is on. The rest of the time you may look where you please. If at anytime you are unable to turn on a meter by looking at it, signal me with your left hand.

"Remember: Detect and record as many signals on the three meters as possible. There is a most efficient way to do this, and you should try to find out what it is."

Subjects were paid for their performance at a flat rate of \$3.00 per block of three 10-min sessions. Total time investment per block was between 45 and 50 min. They were not in fact sleep deprived for these experiments. This variable was introduced during later studies.

The recording of observing responses on the cumulative recorders was inaudible to the subject. However, correct detections were counted on a Sodeco print-out counter, the operation of which was plainly audible.

RESULTS

Of the six subjects who completed at least six training sessions, all achieved some degree of schedule control over looking behavior, as defined by a recognizable difference between any two of the three cumulative records in a single session. Control by the fixed-interval schedule proved to be by far the most difficult of the three to achieve. Control by the other two schedules was relatively constant and reliable.

Figure 3 documents the acquisition of schedule control in a single subject over twenty-three 10-min sessions. The cumulated response on each of the three cumulative records for a given session represents gazes at the appropriate meter. Blips on the cumulative record represent signal presentations. Blips on the event pen represent correct detections. During Session 2, the time pattern of responses to the

three meters was rather similar. Over the succeeding sessions, an increasing degree of differentiation among the three records occurred. Specific schedule control was seen in the final session.

Figure 4 shows a similar acquisition of schedule control in a second subject. A somewhat different but nonetheless recognizable pattern is seen.

Figure 5 illustrates an experiment performed in a third subject after acquisition of schedule control to demonstrate specificity of control. The sessions depicted were all performed during the same hour, separated by 5-min rest periods. During the first session, typical schedule control is illustrated. Between the first and second sessions, the subject was told that schedules would be altered in some way for the succeeding two sessions, but the alteration was not specified. In fact, the DRL schedule was altered from 10 to 5 sec. Control

Fig. 5. An experiment with a single subject demonstrating specific schedule control in four 10-min sessions, all on the same day. At the double line, the DRL interval on meter 2 was changed from 10 to 5 sec.

by the new schedule is demonstrated within the first 4 min of the second session at point "a", without appreciable effect on the other two schedules except for a slight decrease in rate. There was in fact a slight increase in reinforcement density by the third session.

DISCUSSION

The present studies differ in several procedural respects from those reported by Schroeder and Holland (1968*a, b*, 1969). In particular, the present studies tied specific reinforcement schedules to specific meters, all of which were available for signal presentation at the same time. Schroeder and Holland (1968*a, b*) provided convincing evidence of multiple schedule control; also (1969) they demonstrated concurrent control by two separate VI schedules. The present studies provide, as far as is known, the first demonstration of concurrent control by different schedules over looking behavior in various directions.

In the FI schedules, the characteristic "fixed-interval scallop" does not appear in very many of the intervals. Schroeder and Holland (1968*b*) obtained somewhat better, although not entirely consistent, FI performance in a multiple schedule arrangement. There are several possible reasons for the present difficulty. First, it must be remembered that in the vigilance paradigm, signal presentation functions as a conditioned reinforcer, and it is well recognized that FI schedules are among the most sensitive to changes in the power of the reinforcer. Since under the present experimental conditions the signal appeared for only 1 sec, and had to be detected during that time, it is possible that the undetected signals appearing on the FI meter in Figure 3 (Sessions 1 and 4) were not seen, and thus did not function to reinforce fixations on the FI schedule.

To test this possibility, an additional experiment was conducted with Subject D.I. in which the apparatus was arranged so that when a signal appeared on meter 3, the pointer remained deflected until it was reset by the detection response. No change was seen in

either the efficiency of detection or the cumulative frequency of target fixations on this meter after 12 sessions.

The more probable cause of the inconsistent FI performance of the present subjects was that in this particular concurrent schedule situation, fewer than 10% of the total reinforcements were obtainable on the FI meter. Furthermore, in these experiments, no limited hold was imposed for signal presentation once the interval had timed out. Thus, there was little incentive for anticipation responding near the end of the interval.

Of the various reinforcement contingencies heretofore studied with eye movements, concurrent schedules seem more typical of those imposed by the natural visual environment. In fact, they rather closely approximate special life situations such as vehicle instrument panels. This paradigm may thus be expected to provide a useful tool for studying the effects of both display and physiologic variables on human eye movement behavior.

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Received 26 March 1973.

(Final Acceptance 4 June 1973.)