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OPERANT CONTROL OF EYE MOVEMENTS[1]

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In a monitoring situation eye movements were required in order for signals to be presented. Detection of signals was the reinforcement. A multiple schedule of fixed-interval reinforcement, differential reinforcement of low rate, and fixed-ratio reinforcement was established for eye movements. Results demonstrated that an eye movement can act as an operant controlled by its consequences. Operant control of eye movements has important implications for human factor analysts concerned with "attention".

It has often been suggested that the apparent selectivity of stimuli (often included under the general name of attention) results from responses or lack of responses which make the stimuli available (Dardano, 1965; Kelleher, 1958; Kelleher, Riddle, and Cook, 1962; Wyckoff, 1952, 1954). These observing responses have been suggested (Holland, 1957) to be like any other instrumental response subject to the principles of operant behavior. In this context observing responses are responses, the performance of which results in presentation of the conditioned reinforcing stimulus. That is, if a subject has been trained to make a response following the onset of a discriminative stimulus, that stimulus will strengthen another response which precedes its onset. This latter response is called an observing response only as a convenience to indicate that its reinforcement is the detection of the discriminative stimulus (*c.f.* Kelleher and Gollub, 1962). Holland (1958) showed that an arbitrary observing response of pressing a key for a brief flash of light is reinforced by detections of signals. Various simple schedule effects were shown using this form of reinforcement, and evidence was provided that the observing responses could account for classical vigilance phenomena.

Observing responses for visual stimuli would include head orientation, eye movements, accommodation, and perhaps even more subtle and as yet unidentified responses. These precurrent responses may account for some or all of the apparent stimulus selection in simple and complex discrimination learning tasks. Moreover, these responses are followed by the stimuli they produce, and therefore might well be operants controlled by these stimuli acting as reinforcers. The present study attempted to demonstrate operant control of one such "natural" observing response, saccadic eye movements.

METHOD

Subjects

Three male undergraduates from the University of Pittsburgh were used. They had normal vision and were naive with respect to the present task.

Apparatus

Signals were displayed on four 0.25-in. by 1-in. ammeter dials (*i.e.*, a retinal angle of 0.5° by 2°) equidistant from one another in a square arrangement 5.5 in. apart (11° center to center) and 28 in. from the subject. These dials were mounted on a 7.5-in. square steel panel attached to a black plywood stage. A picture of a sensuous girl sitting wrapped in a bedsheet was in the center of the display, surrounded by four green lights positioned in a diamond shape equidistant from each other and from the center of the display (see Fig. 1). The picture gave the subject something to look at besides the dials and thereby aided in lowering initially high baseline eye-movement rates. Incandescent reflectors illuminated the display from the sides.

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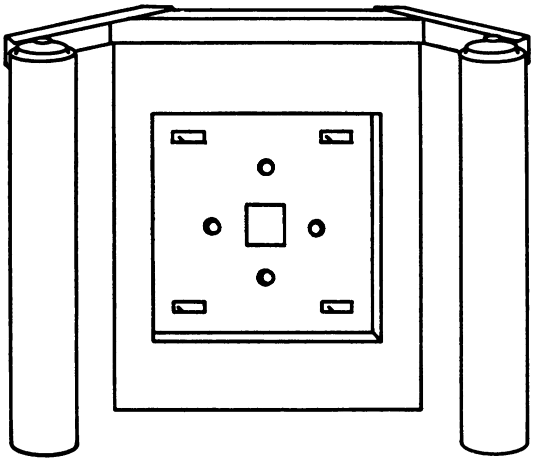

Fig. 1. Diagram of the display.

Signal presentation (pointer deflection) was controlled automatically by standard relay equipment. The subject pressed a button to report when he detected that one of the four pointers on the ammeter dials was deflected. Only one pointer at a time deflected. All button presses were recorded on an Esterline-Angus event-recorder. Distribution and sequence of signals on the four dials were equal and random.

Recording of eye movements was accomplished by a Mackworth Eye Movement Camera, Model v-1164-2 (Polymetric Company). This system (Mackworth and Thomas, 1962) consisted of the following basic subsystems: (a) visual apparatus which used the corneal reflection technique; (b) a closed-circuit TV camera and 8-in. monitor screen; (c) a Massey-Dickinson Television Digitizer which locates the brightest image in the television camera's field of view (*i.e.*, the corneal reflection) and assigns to this image an X and Y coordinate to indicate its position. There are 15 available X and 15 available Y positions, giving 225 locations (*i.e.*, a matrix subtending a visual angle of 15° by 15°). Information is digitized once per television frame, at a rate of 60 complete digitizations per second.

Records of eye movements were kept on the Esterline-Angus recorder, a Gerbrands Cumulative Recorder, and a photorecording device consisting of banks of counters, timers, and a camera with a timed shutter release. The cumulative recorder thus gave rate of shifting fixations over sessions, the photorecorder gave accumulated frequency and duration of fixations over periods within a session, and the Esterline-Angus gave duration of each fixation on each dial, detection latencies, and false positives (button presses when signals were absent). The subjects, camera, display, and experimenter were located in a semi-darkened, air-conditioned room. All relay and recording equipment was in an adjoining room.

Procedure

The subject was seated in a dental chair which was adjusted to make him as comfortable as possible. He then received the following instructions:

> "This is a device for measuring pupil diameter. There is some indication in the literature that pupil diameter changes as you solve a problem. The camera works like this: as you monitor the display a light shines off your eye through this set of lenses into a closed-circuit TV system. To make this system work properly, it is necessary for you to keep your head and posture as still as possible. A very small movement of your head or arms can cause large errors in measurement. To help you hold your head still we have a bite board with dental impression compound on it. (Make an impression for subject.) You will discover that you can find a pretty comfortable position after a while.
>
> "Your job then is to watch these dials for deflections of a pointer and find the problem in this display. Whenever a pointer deflects, press this button as fast as you can; that will reset the pointer. That's all you have to do.
>
> "Since it is important for you to complete the entire experiment, you will be paid after it is completely over. Once we begin the experiment, please do not ask me any questions about it or discuss it with others until we are finished. You may notice me fooling around back here occasionally, but just ignore me. I have to check the equipment to see that it is running properly. Any questions now?"

Each subject was given one 40-min session per day, five days a week. At the end he was paid a lump sum at $2.00 an hour.

Since the eye-movement response rates initially were high, a schedule of reinforcement designed to differentially reinforce a low rate (DRL) was first employed. During the DRL period, signals occurred only after a 10-sec period with no looks at dials. Pilot work showed that subjects often started the task with very fast eye-movement rates. After the rate of behavior became stabilized under this schedule the subject was informed that a new problem was being initiated. He was then given brief experience (one or two sessions) on a fixed-ratio schedule of reinforcement, in which a signal occurred after each 45 looks at dials (FR 45). The same procedure was repeated on a fixed-interval schedule of reinforcement, in which a signal occurred contingent on a look, every 2 min after the last detection regardless of the subject's intervening eye movements. The DRL 10-sec, FR 45, FI 2-min schedules of reinforcement were then presented together in a multiple schedule which was run until the rates stabilized. Each component of the multiple schedule was associated with the illumination of one of the dim green lights in the middle of the display. The components appeared in a regular series. The duration of each component was 4 min.

An eye movement was defined as the intrusion of the corneal reflection in a 4° by 4° square area surrounding each corner dial. As long as the reflection stayed in one area, it was scored as one response. A new eye-movement response was scored only if the subject looked out of that area and back into it or into another dial area. Thus, the subject had to make four fixations to observe the whole display, or what might functionally be considered one observing response. The size of the signal area was chosen to minimize errors due to minor shifts in calibration. Although the apparatus is accurate to 1° when it digitizes eye fixations, pilot work showed that calibration shifts shortly after a given session begins. Therefore, it was necessary for the experimenter to make continuous minute adjustments in calibration to minimize the loss of data. The choice of 4° was based on an eye-movement study by Gould and Schaffer (1965), who found that the eye-marker indicates a general area on the retina, averaging about 4°, in which accurate perception occurs; *i.e.*, the subjects need not fixate a target dead-center to perceive it accurately.

RESULTS

In every case the reinforcement schedule in effect came to control the rate of shifting of fixations into the dial areas. Figures 2, 3, and 4 show the final sessions of each subject on the DRL 10-sec and *mult* FI 2-min DRL 10-sec FR 45 schedules. Each of these records for the multiple schedule begins with two FI 2-min components followed by 4 min of DRL 10-sec and the next 4 min of FR 45. This pattern repeats throughout the record. Subject PA reached stable performance in 13 sessions; BH, 11; and EE, 8. These records are similar to those found both in the observing response studies of Holland (1958) with humans and in studies of operant conditioning of animals (Ferster and Skinner, 1957).

The behavior of subject BH reflected the DRL schedule of reinforcement by the end of the first session. The behavior of the other subjects took a few more sessions to stabilize. Their low response rates had to be shaped by first reinforcing looks of 6 sec or more at the picture in the center; duration of the fixation necessary to cause reinforcement was then gradually increased to 10 sec. Subjects BH and EE have typical DRL performance, including the occasional short bursts of responding reported by Sidman (1956).

The pen was deflected when a signal was presented and reset when the detection key was pressed; therefore longer interresponse times resulted in periods with the pen deflected, as seen in records for EE and BH. Subject PA's response rate was somewhat higher. This was apparently correlated with his tendency of occasionally waiting the appropriate 10 sec, pressing the detection button before scanning the dials, then running off a few bursts of eye movements.

On the multiple schedule, each subject usually showed an obvious and dramatic shift from FI to DRL to FR performance, although interresponse times in the FR and FI components occasionally appear somewhat irregular. This "graininess" may reflect interaction between schedules and the fact that at least four fixations were required to make one sweep of the display. In the FR component, brief pauses occur after each reinforcement, although they are so brief as to be difficult to see after photographic reduction of the record.

Typical FI scallops are shown in the records for each of the subjects. However, in several cases the change in the stimuli associated with the different components of the schedule appeared to go undetected. When the subject is

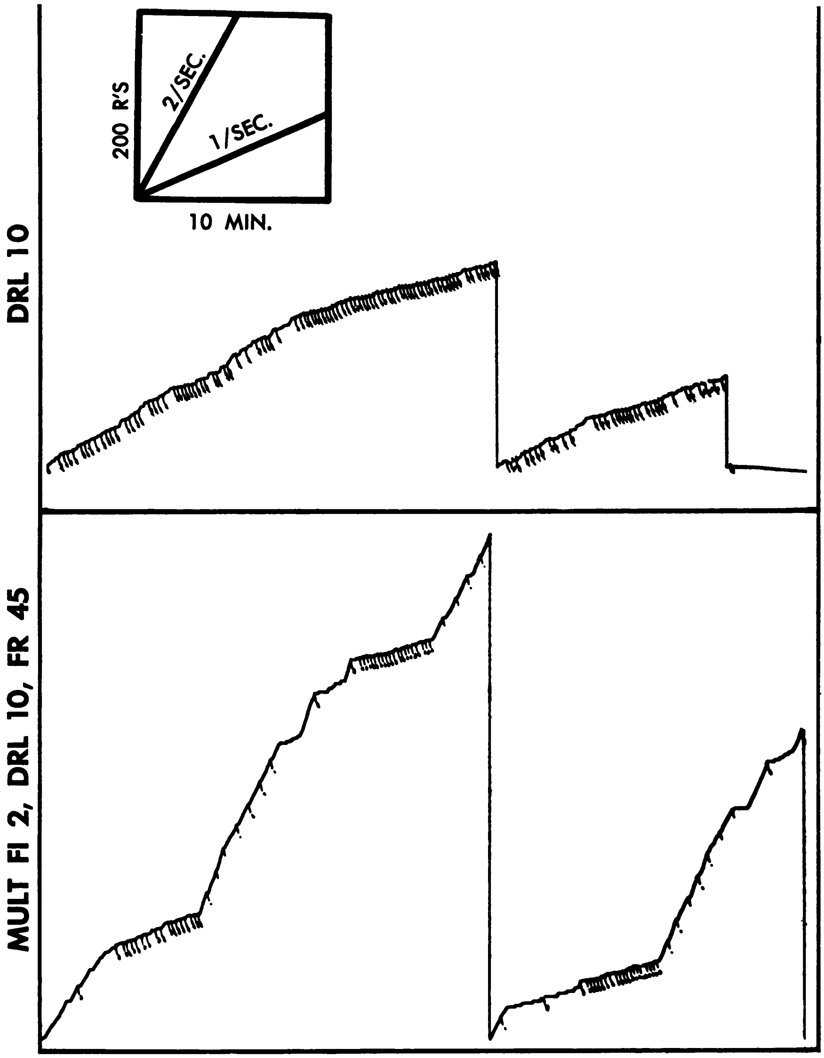

Fig. 2. Cumulative response records of Subject PA's final sessions on DRL 10-sec and *mult* FI 2-min, DRL 10-sec, FR 45 schedules. Pips on the curves are signal detections.

rapidly scanning the corner dials on an FR schedule the dim lights in the central area are especially likely to be ineffective. This may explain why in some FI components the higher response rate associated with FR continues briefly before the FI scallop begins (as in the third and fifth FI component in Fig. 2, the third and seventh components in Fig. 3, and the seventh in Fig. 4). This effect is similar to that found in a mixed schedule in which no stimulus is associated with different components of the schedule (Ferster and Skinner, 1957). The two atypical intervals in Fig. 2 (fifth and sixth) may also reflect a failure of control by the stimuli associated with the FI component, since the response pattern closely resembles that found in the DRL component.

Relative frequency of fixating at each of the four dials was also examined to check if bias for looking at a particular dial might affect the results. All three subjects divided their fixations about evenly between the four dials. The mean frequency of each respective dial on the DRL schedule was 115, 107, 108, 104; for the multiple schedule it was 497, 483, 481, 478. Similarly, no incorrect reports of signals were made (i.e., no false positives), and only a few looks at signals without reports occurred (an average of one on the final DRL and 15 on the multiple schedule sessions). It thus appears that eye movement rates were under the influence of the signal schedules alone.

DISCUSSION

The results confirm the earlier finding (Holland, 1958) that signal detections reinforce responses which precede the detection. Gross saccadic movements of the eyes behave much like the observing response of key-pressing, in that they are operants reinforced by producing the stimulus.

Besides being of great theoretical interest, stimulus selectivity is of special importance to human factors analysts concerned with vigilance performance, *e.g.*, human watch-keeping and quality control. Stimulus selectiveness has also been of great interest to educators, particularly with respect to teaching reading skills as well as in the field of programmed instruction. In the past, attention has been used in a negative sense to explain situations in which a stimulus or some element of a stimulus does not reliably control a response; or it is defined as some inferred process or state of the organism (*e.g.* Broadbent, 1965). The present observing response technique, on the other hand, permits a direct quantitative assessment of attentive behavior. Eye-movement systems are becoming popular in the fields of advertising, human engineering, and applied medicine (Young, 1963), where they are successfully being used to assess selectivity of stimulus elements.

While fixating may not always imply "seeing", it is nevertheless reasonable to assume, as Kelleher (1958) remarks, that if a subject makes a response that makes discrimination possible, he is attending to it. This should surely be true of eye movements with respect to visual discriminanda. It seems possible that eye-movement variables like frequency, duration, and distance between fixations might afford a more direct behavioral means of assessing degree of attention than has thus far

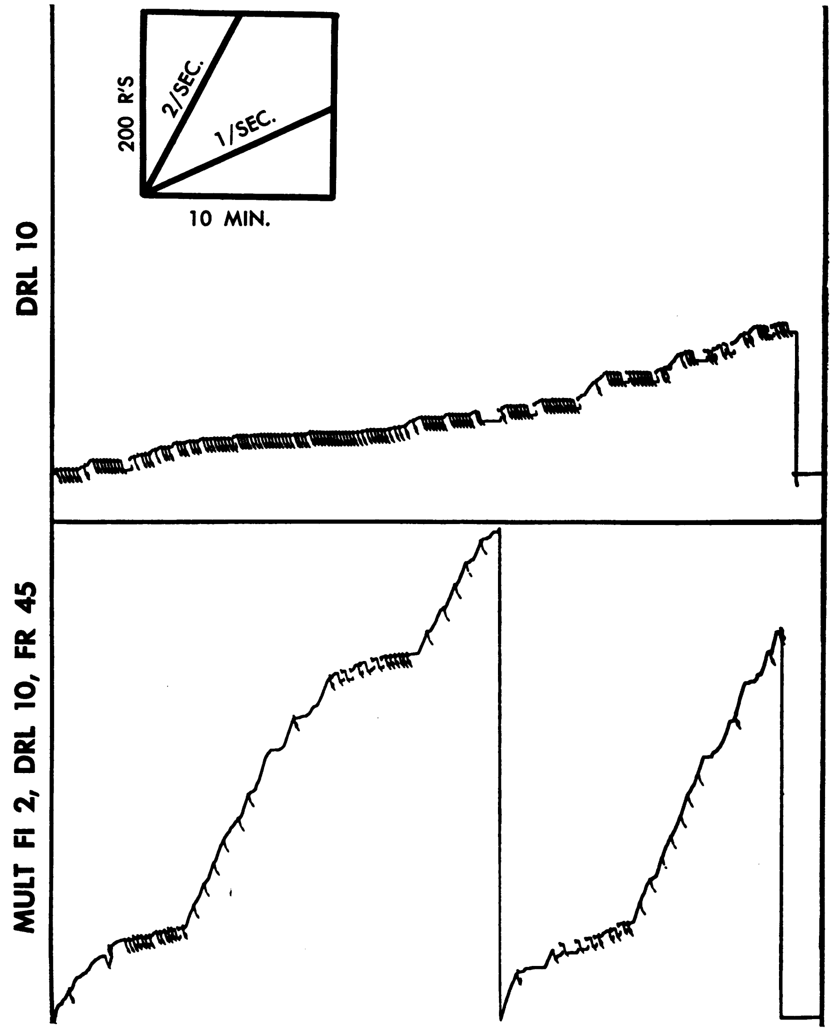

Fig. 3. Cumulative response records of Subject EE's final sessions on DRL 10-sec and *mult* FI 2-min, DRL 10-sec, FR 45.

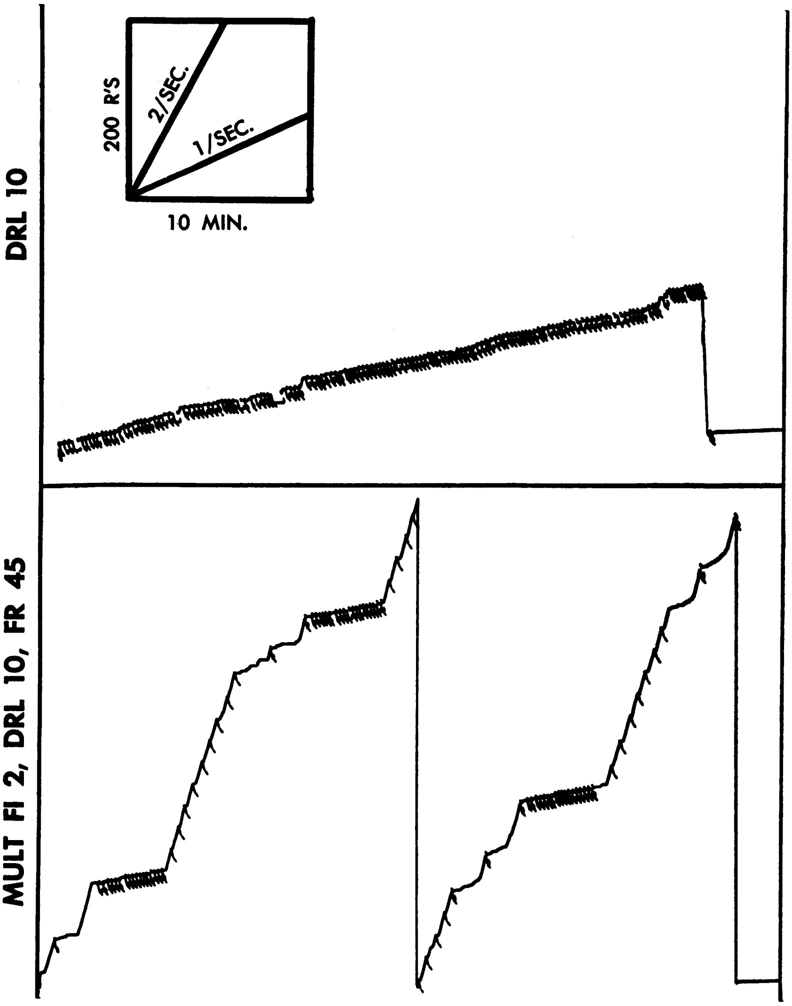

Fig. 4. Cumulative response records of Subject BH's final sessions on DRL 10-sec and *mult* FI 2-min, DRL 10-sec, FR 45.

been possible. The present experiment also suggests that these responses are subject to the same laws of reinforcement as other responses, and therefore the abundant findings of operant research may be useful in explaining many of the phenomena of "attention".

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