JOURNAL OF THE EXPERIMENTAL ANALYSIS OF BEHAVIOR 1969, 12, 897-903 NUMBER 6 (NOVEMBER)

REINFORCEMENT OF EYE MOVEMENT WITH CONCURRENT SCHEDULES[1]

STEPHEN R. SCHROEDER AND JAMES G. HOLLAND

UNIVERSITY OF NORTH CAROLINA AND UNIVERSITY OF PITTSBURGH

Human macrosaccadic eye movements to two areas of a four-dial display were conditioned by concurrent variable-interval schedules of signals. Reinforcers (signals) were delivered to the two right-hand dials on one schedule and to the two left-hand dials on another, independent schedule. The use of a changeover delay between crossover eye movements and reinforcement had the effect of changing the pattern of scanning from fixating four dials in succession or in a Z-shaped pattern to scanning vertically the dials on either side with fewer crossovers. In the presence of a changeover delay, subjects matched relative eye-movement rates and relative reinforcement rates on each schedule. Rate of crossover eye movements, with a changeover delay in effect, was also inversely related to the difference in reinforcements arranged by the concurrent schedules. The results suggest that for stimuli whose critical components are arranged spatially, conditioned eye movements play an important part in selective stimulus control.

There is a growing body of evidence that macrosaccades, *i.e.*, large saltatory eye movements, play an important part in the way information is selected from visually presented material. Gould and Schaffer (1967) showed that subjects on pattern recognition tasks look longer at patterns they are looking for, comparing details between a given pattern and a memorized standard pattern rather than searching in a holistic manner. Kaplan and Schoenfeld (1966) and Teichner and Price (1966) showed that eye-movement patterns are related to learning to verbalize rules for spatial distribution of information relevant to the solution of problems presented visually. Mackworth and Morandi (1967) showed that subjects, when gazing at photographs, look mostly at the informative elements of the pictures. Mackworth, Kaplan, and Metlay (1964) and Schroeder and Holland (1968*a*) showed that eye-movement rates are correlated with signal rates on vigilance tasks.

Recent experiments with monkeys (Berger, 1968) and with humans (Schroeder and Holland, 1968*b*) indicate that macrosaccades are operant observing responses subject to reinforcement contingencies. When eye movements were specifically reinforced according to simple or complex reinforcement schedules in these experiments, the resultant pattern of eye-movement rates was parallel to that of traditional bar-pressing responses associated with schedules of food reinforcement.

The question of how eye movements are controlled by reinforcement is relevant to the study of attention involving differential responding to spatial stimulus configurations. Differential reinforcement of line of sight may be related to the discriminability of the stimulus components. One of the simpler cases would be the differential rate of fixations to two different areas of a display with signal (reinforcement) frequency varying for the two areas.

This situation is analogous to concurrent schedules in more usual operant conditioning situations (*e.g.*, Catania, 1966). With concurrent variable-interval (VI) schedules, reinforcements are scheduled independently on two response keys. Subjects usually match relative response rate on each key to the relative reinforcement rate available on each VI schedule if a changeover delay (COD) is used (Herrnstein, 1961). Relative rate here refers to the proportion of the response or reinforcement rate on one key to the total response or reinforcement rate on both keys (see Catania, 1963). A COD is some specified delay between a switch from one key and the next available reinforcement on the other key.

[1]This research was supported by OE Contract No. 4-10-58. Reprints may be obtained from Stephen Schroeder, Department of Psychology, University of North Carolina, Chapel Hill, North Carolina 27514.

In the present experiment, looking into two dial areas was considered comparable to responding on two keys as discussed above. The analogy was tested by examining the effects of variables (COD duration, relative reinforcement rate, and reinforcement disparity) which have been found to affect concurrent performances in other situations (Findley, 1958; Herrnstein, 1961, 1964; Catania, 1963; Catania and Cutts, 1963; Reynolds, 1963; Brownstein and Pliskoff, 1968).

METHOD

Subjects

Six undergraduates from the University of Pittsburgh (one male, five females) all had normal vision and were naive with respect to the task and apparatus.

Apparatus

From a distance of 28 in. (71.1 cm) the subject viewed a display of four 0.25 in. (0.63 cm) by 1.0 in. (2.5 cm) ammeter dials (Fig. 1) positioned in a square arrangement 5.5 in. (13.9 cm) apart center to center (11° visual angle). Pointer deflections served as signals (reinforcers). The subject had two buttons available: one for resetting pointers on the two right-hand dials, one for the two left-hand dials. Pressing a button indicated detection of a signal and reset the pointer. False positives, *i.e.*, pressing when there was no signal, had no response consequences.

Eye movements were recorded by a Mackworth Eye-Movement Camera (Polymetric Company) that used the corneal reflection technique. The camera consisted of three subsystems: (1) a table-mounted optical system for obtaining the location of the corneal reflection; (2) a television camera and monitor; and (3) a Massey-Dickinson television digitizer, which locates the corneal reflection and assigns to it an X, Y coordinate in a 15° by 15° (visual angle) matrix. This information was then transferred through a buffer to standard electromechanical counters and cumulative recorders. One cumulative recorder recorded fixation frequency on the two right-hand dials and one recorded fixation frequency on the two left-hand dials. Sodeco counters recorded frequency of fixations on each dial and crossover eye movements between the left- and right-hand dials over sessions. Reinforcement was arranged independently for each concurrent schedule with standard relay equipment.

The subject, experimenter, camera, and eye-movement recording system were housed in a normally lighted, air conditioned room. All electromechanical scheduling and recording apparatus was in an adjoining room.

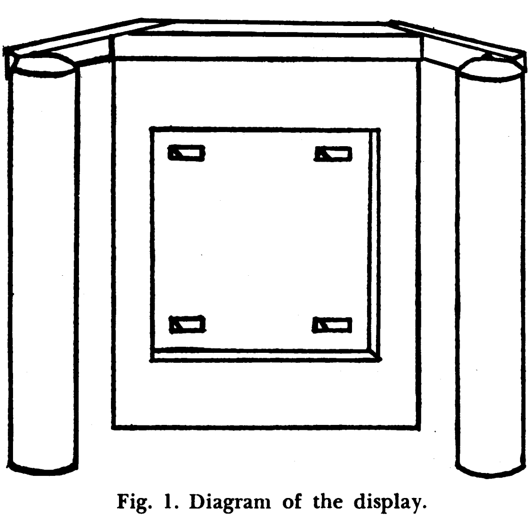

Fig. 1. Diagram of the display.

Procedure

The subject's task was to monitor the display of four dials and report by pressing an appropriate switch any deflections of a needle. Pressing the switch reset the needle. Signals for the two dials on the left were scheduled by one VI timer and signals for the two dials on the right were scheduled by a second, independent, concurrently operating VI timer.

An eye-movement response was defined as intrusion of the corneal reflection into an area representing the 4° by 4° display area containing an individual dial. The initial "look" was the response; another response was recorded only when the subject looked out of that area and back into it or into another dial area.

When a signal was scheduled for one set of dials, a 36-point stepping switch determined whether the upper or lower dial would provide the signal. The dial sequence was chosen from a table of random numbers. This procedure encouraged shifting of fixations between the two dials on one side and reduced the likelihood of staring at one dial and waiting for the pointer to deflect. If a subject were fixating a dial when the signal occurred, staring and not shifting his fixations might be reinforced. In this respect the present procedure differed from the standard situation where reinforcement is not available until the response is made.

The COD was timed from the first fixation after a changeover. All reinforcements scheduled to occur before the COD were held until the end of the COD and then delivered. The COD began to time anew every time a changeover occurred, so that no changeover could be reinforced with zero delay.

Looking up and down between two dials on the same side was considered equivalent to responding on a single key in more typical operant procedures. Looking horizontally or diagonally between dials was defined as a changeover, analogous to switching from one key to another in typical concurrent schedules.

Twelve interreinforcement intervals were chosen for each reinforcement schedule from a table of random numbers so as to range from 1 sec to double the average interval for each schedule. For example, for the one-signal-per-minute schedule, 12 intervals ranging from 1 to 120 sec but averaging 60 sec were used. This cycle of 12 intervals was repeated throughout the session, with the sequence of intervals within a cycle changed for each repetition according to a counterbalanced design. The average intervals were 9, 20, 30, 60 sec, corresponding to the 6.7, 3.0, 2.0, 1.0 signals-per-minute schedules (see Table I).

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

> "This is a device for measuring pupil size. It works like this: a light shines off your left eye into this set of lenses and prisms. The camera picks up the reflection and records it.
>
> "To make the system focus on your eye properly, your head must be in the same position all the time or errors are recorded. To help keep your head still we use a bite plate with dental wax on it. (Make an impression for the subject here.) When this dries, I'll fasten it to the apparatus and you simply bite into it during the experiment and that holds your head relatively still. I can compensate for small head movements by adjusting these calibration cranks.
>
> "Now your job is to watch these dials for pointer deflections. If a pointer on either dial on the right side deflects, you reset it by pressing this button in your right hand. If one of the pointers deflects on the left side, press the button in your left hand. The object of the game is for you to detect as many deflections as you can. I will give you a hint: there is a way for you to optimize the number of pointer deflections you receive.
>
> "Any questions now?"

Procedural questions were answered. Subjects were given no further verbal feedback until the end of the experiment when they were paid at $3.00 an hour.

Subjects served for one 25-min session per day five days a week for a maximum of 10 sessions; the length and the number of the sessions were limited because subjects found the task very uncomfortable and boring.

Previous work with the present task and apparatus revealed that subjects were reluctant to serve more than four or five sessions. Therefore, all subjects were given a hint in the instructions (*i.e.*, they could optimize the number of reinforcements received) with a view to disrupting more speedily the initial tendency to scan the dials in succession or in a Z pattern. Also, relatively short VI schedules were used to maintain adequate eye-movement rates. Under these conditions reasonably stable reinforcement rates developed by the end of the first session.

Table 1 gives the different sequences of reinforcement rate and COD duration received by each subject.

RESULTS

Data from the final session of each sequence for each subject were used for analysis. Table 1 shows the obtained reinforcement, response, and changeover rates for each subject in each treatment combination. Rates were calculated by dividing the total number of responses on the right-hand dials or the left-hand dials or changeovers by the number of minutes in the session. The obtained reinforcement rates of some subjects failed to reach their scheduled rates. This occurred mostly on schedules with a high reinforcement density. Nevertheless, the eye-movement rates to the two sides

Table 1

Sequences of scheduled reinforcement and COD contingencies (Columns 1-5) and obtained reinforcement, eye-movement response and changeover rates (6-11). A scheduled COD of 0.0 sec refers to no COD.

	Scheduled					*Obtained*					
Subject	*No. of Sessions*	*Reinf./ Min on Right*	*Reinf./ Min on Left*	*Total Reinf./ Min*	*COD (Sec)*	*Reinf./ Min on Right*	*Reinf./ Min on Left*	*Total Reinf./ Min*	*Resp./ Min on Right*	*Resp./ Min on Left*	*Change-overs/ Min*
MC	3	6.7	1.0	7.7	2.5	6.6	0	6.6	71	3.7	1.5
	1	1.0	6.7	7.7	2.5	0	6.7	6.7	3.9	94	3.9
	3	6.7	1.0	7.7	1.0	4.0	1.0	5.0	76	19	17
	3	6.7	1.0	7.7	0.0	4.0	1.0	5.0	69	50	57
GS	3	6.7	1.0	7.7	2.5	6.7	0	6.7	67	7	6.7
	1	1.0	6.7	7.7	2.5	0	6.7	6.7	3	72	3.7
	3	6.7	1.0	7.7	1.0	5.0	1.0	6.0	65	13	6.3
	3	6.7	1.0	7.7	0.0	4.0	1.0	5.0	69	45	42
RM	3	6.7	1.0	7.7	0.0	6.7	1.0	7.7	44	35	41
	3	6.7	1.0	7.7	1.0	2.1	0.8	2.9	65	55	68
	3	6.7	1.0	7.7	2.5	5.4	1.0	6.4	102	14	5.8
SR	3	2.0	2.0	4.0	0.0	1.8	2.0	3.8	39	39	40
	3	2.0	2.0	4.0	1.0	2.0	2.0	4.0	37	31	30
	4	2.0	2.0	4.0	2.5	1.7	1.8	3.5	29	34	16
SB	5	6.7	2.0	8.7	1.0	6.0	1.8	7.8	75	23	20
	5	2.0	1.0	3.0	1.0	1.5	0.75	2.25	70	31	16
DM	5	3.0	3.0	6.0	1.0	2.9	3.0	5.9	37	37	27
	4	1.0	1.0	2.0	1.0	1.0	0.8	1.8	43	32	20

matched closely the obtained reinforcement rates in most cases with a COD present.

Matching Relative Eye-Movement Rates to Relative Reinforcement Rates

Figure 2 shows how subjects matched relative eye-movement rates to relative reinforcement rates under three COD durations (no COD or a COD of 1 or 2.5 sec). Subjects contributed two points to each curve for each condition in which they served, one point for relative responses to the two right-hand dials, one for the two left-hand dials. The poorest matching occurred with no COD (Fig 2*a*). When no COD was present, matching also decreased as the disparity between reinforcement rates to the two concurrent schedules increased.

The best matching occurred with a COD of 1 sec (Fig. 2*b*), with one exception. This subject (RM) was first exposed to the task with no COD. During this time, she developed a rapid rate of horizontal scanning. Each horizontal or diagonal eye movement to dials constituted a changeover. When the 1-sec COD was introduced, she increased her changeovers, even though they resulted both in a drastic decrease in her reinforcement rate from 7.7 per min to 2.9 per min and in poor matching. However, when the COD was increased to 2.5 sec, she matched (Fig. 2*c*) and her reinforcement rate returned to 6.4 per min.

Good matching also occurred with a COD of 2.5 sec (Fig. 2*c*), but another interesting result was found. Two subjects (MC and GS) began the task with a long COD (2.5 sec), and both essentially extinguished responding to the schedule that dispensed fewer reinforcements. Table 1 shows that they produced no reinforcement on the left-hand dials. In the next sessions the reinforcement schedules on the dials were reversed. No reinforcement and very few fixations on the right-hand dials occurred. However, when the COD was changed to 1 sec, they matched.

Effect of COD Duration on Changeover

Catania (1966, pp. 215-220) noted that the use of a COD is related to a reduction in changeovers from one key to another. Figure 3 confirms this result for the present eye-movement experiment with one exception. It will be remembered that subject RM had developed a high changeover rate that was enhanced when the COD was changed from 0 to 1 sec.

In general, however, when subjects began the task with no COD and the COD was increased to 2.5 sec, better matching accompanied an increase in COD. Those subjects who began the task with a long COD (2.5 sec) changed over very little; their matching im-

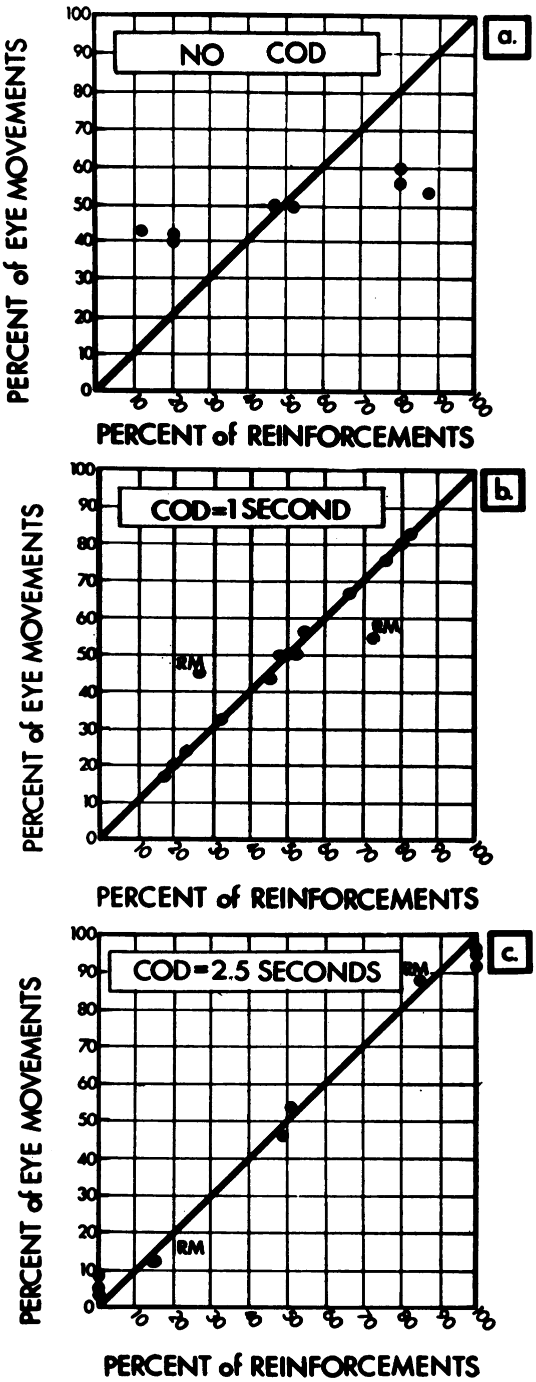

Fig. 2. Relative eye-movement rate as a function of relative reinforcement rate for two COD durations and no COD.

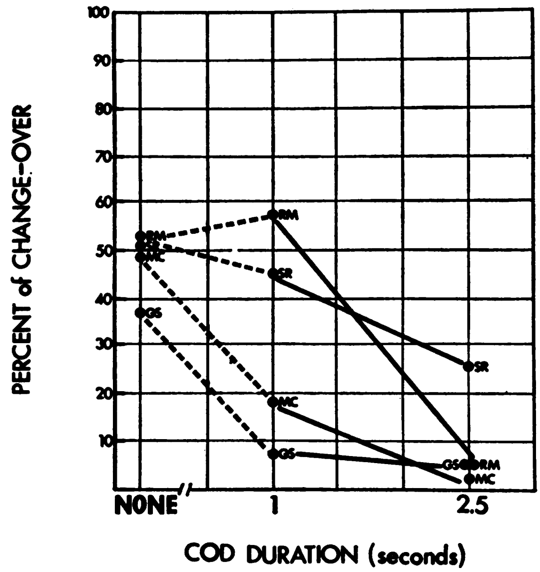

Fig. 3. Percentage of changeovers (horizontal or diagonal eye movements) as a function of COD duration. Subjects RM, MC, GS received 6.7 reinforcements per minute on one schedule and one reinforcement per minute on the other. SR received two reinforcements per minute on both schedules.

proved when the COD was reduced to 1 sec and became much worse when the no-COD condition was introduced.

Interaction of COD and Reinforcement Disparity

The change in COD had a large effect on changeovers when the disparity between the two concurrent reinforcement schedules was large, but little effect when the two schedules arranged equal numbers of reinforcements (Fig. 4). Similarly, Herrnstein (1961) found changeovers to decrease as a function of the difference between the per cent of reinforcements on each of two keys in a concurrent scheduling task only when a COD was used. Each point in Fig. 4 represents the percentage of changeovers for one subject for no COD or CODs of 1 or 2.5 sec. Even though the points in the figure are scattered, due to restrictions in procedure and individual differences, it appears that Herrnstein's results are confirmed. With no COD, reinforcement disparity had little effect; but when a COD was present, reinforcement disparity tended to decrease changeovers. Subject RM's changeovers with 1-sec COD were again atypical in this figure for reasons discussed previously.

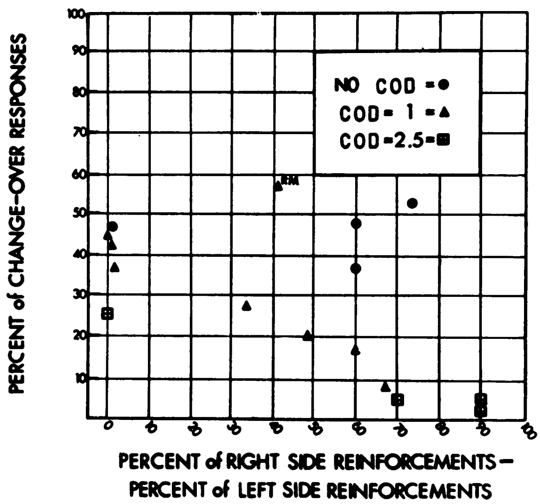

Fig. 4. Percentage of changeovers as a function of reinforcement disparity. Each point is the percentage of total responses that were changeovers for one subject in one of the COD conditions.

DISCUSSION

The present experiment confirmed previous findings (Berger, 1968; Schroeder and Holland, 1968 *a*, *b*) that macrosaccades behave as operant observing responses. Furthermore, the results suggest that the general findings of concurrent scheduling also apply to concurrent eye movements in humans.

As was expected, subjects matched relative eye-movement rates to relative reinforcement rates. Several variables affected the matching, the most important of which was the presence of a changeover delay. From Fig. 2*a* it appears that the absence of a COD is most telling as the disparity between reinforcement rates on the concurrent schedules increases. This result probably reflects the fact that subjects, when scanning this display, initially adopted a stereotyped eye-movement pattern, looking at each dial in succession or scanning with a Z-shaped pattern or its reverse (Schroeder and Holland, 1968*a*). Relative response rates matched relative reinforcement rates only after this pattern was replaced by vertical scanning on either the left-hand dials or the right-hand dials with few changeovers (horizontal or diagonal eye movements). With no COD, eye movements in any of the three directions were reinforced. Since the response was not very effortful and the pointers remained deflected until the subjects detected them and reset them, disparity in the reinforcement schedules was not sufficient to break subjects' predominant search pattern.

Excellent matching occurred with a COD present (Fig. 2*b*, *c*). The inverse relationship between COD duration and changeover rate (Fig. 3) has also been reported with concurrent scheduling studies using animals (Herrnstein, 1961; Shull and Pliskoff, 1967; Brownstein and Pliskoff, 1968). A similar relationship between changeover rate and the difference between the relative rates of reinforcement obtained from the concurrent schedules was found by Herrnstein (1961) and Brownstein and Pliskoff (1968).

Catania and Cutts (1963) reported poor matching by humans on a button-pressing task with concurrent VI extinction schedules. With no COD, subjects responded on the extinction schedule sometimes more than twice as much as on the key with the VI schedule. CODs eliminated this superstitious responding, but some subjects required long CODs (up to 15 sec) to accomplish extinction. This result contrasts with the present results of good matching with a COD of 1 sec and near extinction on the VI 1-min schedules by MC and GS when they began the experiment with a COD of 2.5 sec.

These differences are probably due to differences in task and procedure. Subjects in the experiment by Catania and Cutts (1963) performed a paced button-pressing task where subjects were to pace their presses to a flashing light (100 per min). Since their subjects received only a single session, relative response rates may have been less stable than those in the present experiment. For instance, all present subjects could describe the procedure after the experiment, whereas many of the subjects used by Catania and Cutts (1963) had difficulty describing the task.

The present experiment demonstrated that concurrent scheduling variables affect eye movements to spatial locations. Since line of sight is involved in the selection of components of spatial stimulus configurations, the conditioning of eye movements plays an important role in choice selection. For instance, Schroeder and Holland (1968*a*) and Mackworth *et al.* (1964) showed that, in a vigilance situation, the speed of shifting fixations was related to the number of signals detected regardless of signal rate. Schroeder (1969) has shown that, in a simple discrete-trial discrimination task, subjects learn to ignore redundant stimuli according to their relevance to the critical stimulus. These results, together with the present results, suggest that operant control of eye movements plays an important part in establishing stimulus control and can be a powerful tool for assessing functional properties of stimuli.

REFERENCES

Berger, R. J. Operant conditioning of eye movement in the monkey. *Journal of the Experimental Analysis of Behavior*, 1968, **11**, 311-320.

Brownstein, A. and Pliskoff, S. Some effects of relative reinforcement rate and changeover delay in response-dependent concurrent schedules of reinforcement. *Journal of the Experimental Analysis of Behavior*, 1968, **11**, 683-688.

Catania, A. C. Concurrent performances: reinforcement interaction and response independence. *Journal of the Experimental Analysis of Behavior*, 1963, **6**, 253-263.

Catania, A. C. Concurrent operants. In W. K. Honig (Ed), *Operant behavior: areas of research and application*. New York: Appleton-Century Crofts, 1966. Pp. 213-270.

Catania, A. C. and Cutts, D. Experimental control of superstitious responding in humans. *Journal of the Experimental Analysis of Behavior*, 1963, **6**, 203-208.

Findley, J. D. Preference and switching under concurrent scheduling. *Journal of the Experimental Analysis of Behavior*, 1958, **1**, 123-144.

Gould, J. D. and Schaffer, A. Eye-movement parameters in pattern recognition. *Journal of Experimental Psychology*, 1967, **74**, 225-229.

Herrnstein, R. J. Relative and absolute strength of response as a function of frequency of reinforcement. *Journal of the Experimental Analysis of Behavior*, 1961, **4**, 267-272.

Herrnstein, R. J. Secondary reinforcement and rate of primary reinforcement. *Journal of the Experimental Analysis of Behavior*, 1964, **7**, 27-36.

Kaplan I. and Schoenfeld, W. Oculomotor patterns during solution of visually presented anagrams. *Journal of Experimental Psychology*, 1966, **77**, 447-451.

Mackworth, N. and Morandi, A. J. The gaze selects informative details within pictures. *Perception and Psychophysics*, 1967, **2**, 547-551.

Mackworth, N., Kaplan, I., and Metlay, G. Eye movement during vigilance. *Perceptual and Motor Skills*, 1964, **18**, 397-402.

Reynolds, G. On some determinants of choice in pigeons. *Journal of the Experimental Analysis of Behavior*, 1963, **6**, 53-59.

Schroeder, S. Selective eye movements to simultaneously presented stimuli during discrimination. *Perception and Psychophysics*, 1969 *in press*.

Schroeder, S. and Holland, J. G. Operant control of eye movements during human vigilance. *Science*, 1968, **161**, 292-293. (*a*)

Schroeder, S. and Holland, J. G. Operant control of eye movements. *Journal of Applied Behavior Analysis*, 1968, **1**, 161-166. (*b*)

Shull, R. and Pliskoff, S. Changeover delay and concurrent schedules: some effects on relative performance measures. *Journal of the Experimental Analysis of Behavior*, 1967, **10**, 517-527.

Teichner, W. and Price, L. Eye aiming behavior during the solution of visual patterns. *Journal of Psychology*, 1966, **62**, 33-38.

Received 20 February 1969.