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EFFECTS ON CONCURRENT PERFORMANCES OF A STIMULUS CORRELATED WITH REINFORCER AVAILABILITY[1]

STANLEY S. PLISKOFF AND DONALD GREEN

UNIVERSITY OF MAINE, ORONO AND UNIVERSITY OF KANSAS

A multiple schedule was arranged in which each component consisted of two, concurrent variable-interval schedules of reinforcement. A changeover-key procedure was used, and the components of the multiple schedule were distinguished (initially) by the color of the changeover key. During one component of the multiple schedule, the availability of a reinforcer arranged by one of the variable-interval schedules was marked by an exteroceptive stimulus, provided that that variable-interval schedule was not at the time assigned to the main key. During the other component of the multiple schedule, no reinforcer-correlated stimuli were ever presented. During the latter component of the multiple schedule, the distribution of responses and time for the concurrent variable-interval schedules suggested control by the distribution of reinforcements. During the former component, most main-key responses were emitted on the key in the presence of which reinforcer-correlated stimuli were presented. Changeover rate in the presence of that key color was depressed. The discriminative control over the changeover was easily established and was reversible.

One method for arranging concurrent schedules employs a single operandum, the main key (Findley, 1958). The schedules operate simultaneously, assign reinforcement independently, and each schedule is associated with a distinct exteroceptive stimulus. Only one schedule at a time is assigned to the operandum, but a response (or responses) on a second operandum, the changeover key, alternates the schedule assignment and stimulus. A reinforcer arranged by one of the schedules is produced by a response only when the appropriate schedule is assigned to the main key. Hence, the organism typically responds on each of the schedules, changing over fairly often from one to the other.

Most analyses of concurrent performances consider the changeover to be an operant. As such, it should be subject to control by experimental variables otherwise found to control operant behavior. Little has been done to study the variables that explicitly control the changeover, with the exception of the classical delay of reinforcement (Perin, 1943). In the context of concurrent schedules, the changeover delay (Herrnstein, 1961) specifies a minimum delay between a changeover and the occurrence of scheduled reinforcement. The greater the delay, the lower the changeover rate (Shull and Pliskoff, 1967).

The present experiment explored for the changeover (and for the distribution of responses and time on concurrent schedules) another well-established method for controlling the distribution in time of an operant, *viz.*, the correlation of a stimulus with the availability of reinforcement, or discriminative control.

With concurrent variable-interval schedules, the correlation of a stimulus with reinforcement is interesting only when the reinforcer is arranged by the schedule of a concurrent pair momentarily ignored by the organism. A changeover is thereby required for a response to produce the reinforcer, and the changeover should come under discriminative control by the stimulus, since a response following a changeover in the presence of the stimulus is certain to be reinforced, and a response following a similar changeover in the absence of the stimulus will not be reinforced. While that arrangement has not been studied in its own right, it has been used for other purposes by Catania (1963) and by Rachlin and Baum (1969). In those experiments, responding became largely restricted to the main-key color in the presence of which stim-

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uli marked reinforcers available by responding on the alternative schedule.

METHOD

Subjects

Two experimentally naive, male Silver King pigeons (HD5 and HD6) served and were maintained at approximately 80% of free-feeding weights.

Apparatus

The experiment was performed with a standard Grason-Stradler two-key front wall (Model E 1184JA) mounted in a plywood box. Each of the keys could be transilluminated from behind by colored light. A peck of about 15 g (0.147N) force was required to operate a key, and each operation produced a sharp, feedback click from a relay mounted behind the front wall. The main key was on the right, the changeover key on the left. Routine electro-magnetic equipment was employed to control the experiment and to record data.

The variable-interval (VI) schedules of reinforcement were arranged by means of Gerbrands tape pullers, which operated at 1 mm per second. The sequences of intervals, specified as average minimum interreinforcement durations, were arithmetic with the interval of longest duration equal to twice the average. Each sequence consisted of 11 intervals in quasi-random order.

Procedure

After magazine training with HD5 and HD6, there were two sessions during which each of 60 pecks operated the feeder and alternated the color of the main key between blue and red (B and R in Table 1). There followed four sessions during which reinforcers were arranged by a single VI 3-min schedule, with key colors alternating as before.During these sessions, the changeover key was darkened and inactivated.

A multiple schedule, which served as the basic design of the experiment, was then introduced. *Each component of the multiple schedule itself consisted of two concurrent VI schedules of reinforcement.* At this stage of the experiment, the components of the multiple schedule were distinguished only by the color of the changeover key. During one component, which served as the "No-Stimulus" component, the changeover key was transilluminated with green light; during the other component, the "Stimulus" component, it was transilluminated with yellow light. Components of the multiple schedule alternated every 15 min, except as noted in Table 1.

During the No-Stimulus component of the multiple schedule (NS in Table 1) no exteroceptive stimulus was ever correlated with the availability of a reinforcer. During the Stimulus component (designated S), an exteroceptive stimulus was sometimes, depending upon the experimental condition, correlated with the availability of a reinforcer arranged by one of the VI schedules. Whenever such an exteroceptive stimulus was scheduled, it appeared just as the reinforcer was arranged, but only provided that the other VI schedule was at that time assigned to the main key; otherwise no stimulus appeared. In summary, one component of a multiple schedule consisted of routine concurrent VI schedules; during the other component, reinforcers arranged by one of the VI schedules were signalled provided that VI schedule was not assigned to the main key. No changeover delay was used.

The experiment consisted of 13 conditions. Each is numbered and identified in Table 1; the number of sessions devoted to each is indicated also.

The first condition was described above; the components of the multiple schedule each involved concurrent VI 3-min schedules, and no exteroceptive stimuli appeared. Exteroceptive stimuli were introduced during the second condition. For the Stimulus component of the multiple schedule, *i.e.,* when the changeover key was yellow, a stimulus—the illuminated houselight at the upper right of the front wall—appeared (only) when (a) the main key was blue, and (b) the alternative VI schedule, which was associated with the main key when red, arranged a reinforcer. The third condition was the same as the second, except that the changeover key flashed at a rate of 56/min in order to increase the stimulus contrast between the two components of the multiple schedule.

The fourth condition reversed the third condition with respect to points (a) and (b) above: only when the main key was red could an exteroceptive stimulus occur, thereby marking the availability of a reinforcer for a peck on the blue key.

Table 1

Response, time, and changeover frequency data averaged over the final five sessions of each experimental condition. NS represents the No-Stimulus component of the multiple schedule, and S represents the stimulus component; CO represents changeovers. Time data are in seconds. The presence and absence of added stimuli are indicated along with the multiple concurrent schedules (*mult conc*) for each condition.

	Time (*NS*)		*Time* (*S*)		*Resp* (*NS*)		*Resp* (*S*)		*CO*	
Bird	*B*	*R*	*B*	*R*	*B*	*R*	*B*	*R*	*NS*	*S*
	1. *Mult Conc* VI 3-min VI 3-min: No Stimuli (25 Sess)									
HD5	1703	1672	1518	1618	1213	1043	1086	1015	1136	935
HD6	1740	1698	1717	1682	1157	1171	1136	1151	1436	1342
	2. *Mult Conc* VI 3-min VI 3-min: During(S), Stimuli When Main Key is Blue (27 Sess)									
HD5	1618	1401	2381	486	922	864	1278	269	770	259
HD6	1809	1588	1989	1198	1014	1086	1118	679	1345	1061
	3. Same As (2): But CO Key Light Flashes 56/min (19 Sess-See Note 1)									
HD5	1745	1468	2270	546	692	696	903	175	625	229
HD6	1775	1549	2650	175	1106	1345	1986	89	1425	113
	4. *Mult Conc* VI 3-min VI 3-min: During (S), Stimuli When Main Key is Red (49 Sess-See Note 2)									
HD5	1485	1724	620	2370	880	1128	328	1575	1273	502
HD6	1618	1789	115	2521	1196	1576	57	1965	1275	71
	5. Same As (4): But *Mult Conc* VI 1-min VI 1-min (19 Sess)									
HD5	532	542	147	755	285	332	59	443	438	103
HD6	498	564	89	850	377	473	37	765	405	50
	6. Same As (4): *ie,* Return to *Mult Conc* VI 3-min VI 3-min (34 Sess)									
HD5	1668	1785	497	2401	918	1122	257	1618	1463	442
HD6	1513	1592	124	2653	1266	1331	72	1978	1041	76
	7. Same As (4):But *Mult Conc* VI 0.5-min VI 0.5-min (37 Sess-See Note 3)									
HD5	248	295	109	367	113	134	37	238	143	59
HD6	273	257	84	381	228	258	45	389	183	58
	8. Same As (4): *ie,* Return to *Mult Conc* VI 3-min VI 3-min (17 Sess)									
HD5	1473	1684	238	2475	983	1188	96	1525	967	158
HD6	1733	1473	93	2653	1832	1452	45	2395	1228	59
	9. *Mult Conc* VI 1-min VI 3-min: During (S), Stimuli When Main Key is Red (27 Sess-See Note 4)									
HD5	967	554	161	1216	750	293	56	545	385	59
HD6	984	691	107	1233	1019	663	43	907	658	54
	10. Same As (9): But *Mult Conc* VI 0.5-min VI 3-min (26 Sess)									
HD5	611	234	169	670	484	123	69	259	166	84
HD6	604	387	147	667	575	275	67	351	375	58
	11. Same As (9): But *Mult Conc* VI 0.25-min VI 3-min (34 Sess)									
HD5	310	74	326	70	214	37	286	20	73	26
HD6	312	102	196	155	406	75	221	76	106	34
	12. Same As (9): But *Mult Conc* VI 3-min VI 0.25-min (31 Sess)									
HD5	112	352	54	415	40	205	19	299	61	36
HD6	226	297	52	430	233	342	38	560	146	38
	13. Same As (4, 6, and 8): *ie,* Return to *Mult Conc* VI 3-min VI 3-min (15 Sess)									
HD5	1635	1475	359	2375	1193	902	157	1703	841	213
HD6	1719	1455	83	2590	1638	1357	38	2010	970	54

Table Notes: (1) During Component NS of the multiple schedule, the CO key was transilluminated with green light; during Component S, with yellow light. For the first 12 sessions of Condition 3, the green CO key flashed; for the final seven sessions, the yellow CO key flashed. The change was accompanied by no shift in performance, transient or otherwise. (2) Between the twenty-eighth and twenty-ninth sessions of Condition 4, there intervened 15 sessions during which a fixed ratio was scheduled to produce a changeover. Eleven sessions at FR 10 were followed by four at FR5. (3) During the final 14 sessions of this condition (only), the components of the multiple schedule alternated every 8 min. (4) During the initial four sessions of this condition, the components of the multiple schedule alternated every 15 min; from the fifth session on, including Conditions 10, 11, and 12, they alternated every 12.5 min. During Condition 13, they alternated every 15 min. During Conditions 9, 10, and 11, the VI 3-min was scheduled for the red main key; during Condition 12, for the blue main key.

The fifth through eighth conditions were similar to the fourth regarding the reinforcer-correlated stimulus, but the VI schedules were varied as shown in the table; note that within each of those conditions, both VI schedules of a concurrent pair were equal. Conditions nine through 12 were similar, except that the VI schedules of the pairs were unequal, with one of them always VI 3-min. The final condition, 13, repeated the fourth condition.

Experimental sessions were conducted daily, and each session was terminated after 60 reinforcements. A grain mixture served as the reinforcer, and the duration of the feeder operation varied from 3 to 6 sec depending on weight trends. The grain was illuminated by white light; the rest of the chamber was darkened during feeder operation.

RESULTS

The results of the experiment are presented in Table 1 and Figures 1 and 2.

Table 1 shows data averaged over the final five sessions of each experimental condition for each of the two pigeons. Time spent in the presence of each key color, blue (B) and red (R), is shown in addition to the number of responses with respect to each color. The time and response data are presented separately for each component of the multiple schedule, when reinforcer-correlated stimuli were never presented (NS) and when they were sometimes presented (S). Finally, the column labelled CO shows changeover frequencies. The calculations yielding Figures 1 and 2 were made from the data contained in the table. Only the calculations for one of the birds, HD5, are shown in the figures; similar figures for the second bird provide no new information.

Figure 1 shows the distribution of the main-key responses (per cent on the blue key) for the first 12 conditions of the experiment. Each condition is denoted by a number; the numbers are keyed to the experimental conditions numbered in Table 1.

(*a*) *Conditions 1 through 4.* Condition 1 involved no stimuli, and the percentage of pecks on the blue key was close to 50% during each component of the multiple schedule. The result represents the even distribution of responses expected when VI schedules of the same average interreinforcement interval arrange reinforcement for each VI of a concurrent pair. In the second condition, a stimulus was presented during the Stimulus component; it appeared only when the main key was blue and a reinforcer was available for the

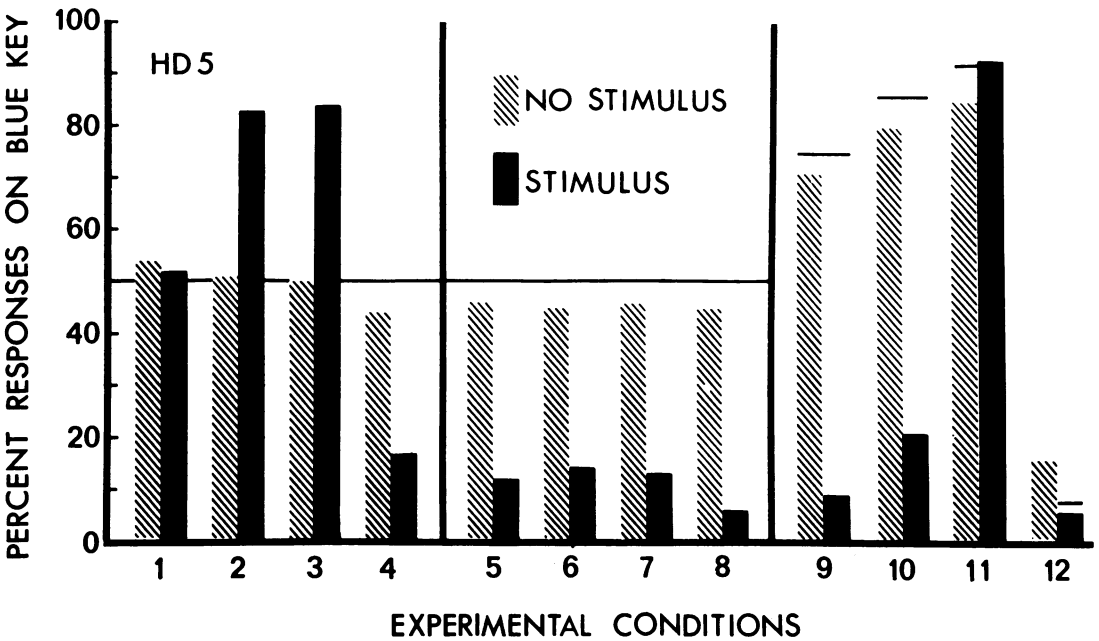

Fig. 1. Per cent responses on the blue key during the Stimulus and No-Stimulus components of the multiple schedule. The experimental conditions numbered on the horizontal axis are keyed to Table 1.

next peck on the red key. The percentage of responses on the blue key during the Stimulus component rose to 83%; the percentage during the No-Stimulus or control component remained very close to 50%. The third condition was the same as the second, except that the light for the changeover key flashed, a procedure introduced expressly for HD6. Bird HD6 showed for the second condition a percentage of responses on the blue key of 48% during the No-Stimulus component but only 62% (as compared with HD5's 83%) during the Stimulus component. Since the distinction between the components of the multiple schedule might have been inadequate—only the changeover keys were a different color, while the pigeon spent most of its time several inches to the right near the main key—the flashing key was introduced. There was no change from Condition 2 for HD5, but HD6 now dstributed 96% of its responses on the blue key during the Stimulus component.

Condition 4 served as a control for the result obtained in Conditions 2 and 3. If the presentation of the reinforcer-correlated stimuli when the main key was blue was responsible for the increase in the percentage of pecks on the blue key, then a reversal of the stimulus-reinforcer relation should reverse that outcome. In Condition 4, a stimulus was presented when the main key was red and only when a reinforcer was available for a peck on the blue key. Figure 1 shows that the preference during the Stimulus component changed from the blue key in the earlier conditions to the red key in the fourth condition. Bird HD5 emitted 17% of its responses on the blue key, and HD6 emitted only 3%. There was some induction of that effect to the No-Stimulus component; HD5 emitted 44% of its responses on the blue key during the No-Stimulus component of the fourth condition as compared with 50% during the third; HD6 shows similar (but less) induction.

(*b*) *Conditions 5 through 8.* As indicated in Table 1, the VI schedules were varied in this sequence of conditions, but they were equal within each condition. Conditions 6 and 8 were the same as Condition 4 above, *i.e.,* VI 3-min schedules were arranged; VI 1-min schedules were used in Condition 5 and VI 0.5-min in Condition 7. Figure 1 shows no systematic effect resulting from the varying of the VI schedules.

(*c*) *Conditions 9 through 12.* During three conditions, the schedule associated with the red main key remained VI 3-min while that associated with the blue key was changed to VI 1-min to VI 0.5-min to VI 0.25-min, with the final condition reversing the eleventh, *i.e.,* VI 3-min for the blue key and VI 0.25-min for the red key.

The horizontal markers at ordinates of 0.75 for Condition 9, 0.86 for Condition 10, and 0.92 for Condition 11 indicate the percentages of responses that would be expected on the blue key if those percentages approximated the percentages of reinforcers expected by responding on that key (Herrnstein, 1961). It is clear that during the No-Stimulus condition, the percentages move in the direction of approximation; the increase from Condition 9 through 11 is monotonic, but actual response percentages fell below the expected by about 5% for Bird HD5. Bird HD6 showed deviations that were larger: about 15% in Conditions 9 and 10 and 8% in Condition 11. However, even Bird HD6 displayed a monotonic increase in the percentage of responses on the blue main key as the mean interreinforcement interval on that key decreased. During the Stimulus component of the multiple schedule, Conditions 9 and 10 show an increase in the percentage of responses on the blue key, but the differences between the actual percentages and those required for approximation to the expected reinforcement percentages are large. Bird HD6 shows a similar result but even more extreme. During Condition 11, both birds showed evidence of reasonable approximation of response to reinforcer percentage during both the No-Stimulus and Stimulus conditions; Bird HD6, however, fell short by 18% during the Stimulus component but only by 8% during the No-Stimulus component. Evidently the change in the VI schedule associated with the blue key from VI 0.5-min (Condition 10) to VI 0.25-min (Condition 11) was sufficient to counteract the effect of the added stimuli while the main key was red.

Condition 12 reversed Condition 11, and Bird HD5 showed a preference reversal during both components of the multiple schedule. Bird HD6 showed a similar reversal during the Stimulus component, but it emitted 41% of its responses on the VI 3-min schedule (blue key) during the No-Stimulus component. That re-

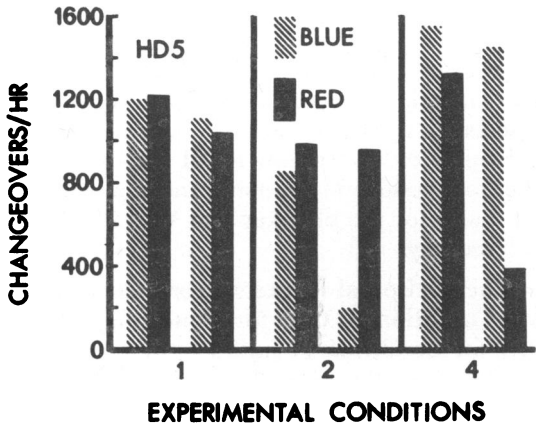

Fig. 2. Changeovers per hour in the presence of the blue and red main keys during the Stimulus and No-Stimulus components of the multiple schedule. The experimental conditions numbered on the horizontal axis are keyed to Table 1.

sult is considerably at variance with its performance during Condition 11, when 16% of its responses were emitted on the VI 3-min schedule (red key).

The final condition of the experiment, number 13 in Table 1, is not plotted in Figure 1. It reinstated the procedures of Condition 4, and similar results were obtained.

Figure 2 shows changeover rates during Conditions 1, 2, and 4. Each of those experimental conditions is represented by two pairs of histogram bars. The left pair for each condition shows changeovers per hour in the presence of the blue (hatched bar) and red (solid bar) main keys during the No-Stimulus component of the multiple schedule. The right pair of bars shows changeovers per hour for the two keys during the Stimulus component.

The left pair of bars for Condition 1 shows equal changeover rates, about 1200 changeovers per hour, in the presence of the blue and red main keys during the No-Stimulus component. The right pair of bars also shows approximately equal changeover rates, about 1000 per hour, during the Stimulus component. Since no exteroceptive stimulus was associated with reinforcement availability during Condition 1, the No-Stimulus and Stimulus components were identical except for the color of the changeover key.

The changeover rates for the blue and red main keys were again approximately equal during the No-Stimulus component of Condition 2. The difference shown amounts to 131 changeovers per hour. During the Stimulus component, a stimulus appeared when the main key was blue and the VI schedule associated with the red main key arranged a reinforcer. The changeover rate in the presence of the blue key was depressed, while that in the presence of the red key was about the same as during the No-Stimulus condition. Condition 4 represented a control for Condition 2; the stimulus-reinforcer availability relation was changed from the VI schedule associated with the red key to that associated with the blue key. The changeover rates for the two key colors during the No-Stimulus component differed by 215 changeovers per hour, and during the Stimulus component, by 1075 changeovers per hour. In contrast with Condition 2, the lower changeover rate was in the presence of the red key. The data for the second bird, HD6, show the same relationships as graphed and described for HD5.

DISCUSSION

Little is known about the discriminative control of the changeover. Informal observations in the laboratory suggest that a changeover is highly likely immediately after reinforcement, when the probability of another arranged by the same arithmetic variable-interval schedule is low. In other words, changeovers often come under the discriminative control of reinforcers.

In the present experiment, an arbitrary exteroceptive stimulus was employed to study discriminative control over the changeover. Discriminative control was established without difficulty and was characterized by a "preference" for the key color in the presence of which stimuli were provided, denoting the availability of reinforcement on the alternative schedule. Although the distribution of reinforcers was even for the two schedules, the preference reached values of 85% to 90% of the responses and time. Significant preferences were virtually absent in the alternative component of the multiple schedule, where no discriminative control was arranged. Similar effects were obtained when the VI schedules of the concurrent pairs were changed from VI 3-min to VI 1-min and to VI 0.5-min.

An interesting result was obtained during the final set of conditions (9, 10, 11 in Table 1

and Figure 1). One of the schedules was always VI 3-min, while the other was varied from VI 1-min to VI 0.5-min to VI 0.25-min. The birds tended toward matching (Herrnstein, 1961; Catania, 1966) during the component of the multiple schedule in which no exteroceptive stimuli were presented; as the proportion of reinforcers produced by pecking on the blue key increased, so did the percentage of responses on that key. When stimuli correlated with reinforcement for pecking the blue key were presented when the key was red, however, there was no approximation to matching until the schedule associated with the blue key was VI 0.25-min. Evidently, a sufficiently high rate of reinforcement for responding on the blue key overcame discriminative control by stimuli presented while the red key was red, and the preference for the blue key equalled that obtained in the control component of the multiple schedule where no stimuli were presented. The final result was reversible, at least for one of the birds, as shown during Condition 12.

The effect of discriminative control on changeover rate is straightforward (Figure 2). The changeover rates were approximately equal in the presence of the two key colors during the control component of the multiple schedule. When stimuli were presented during the other component, the changeover rate was depressed in the presence of the key color associated with the presentation of stimuli, *i.e.*, blue in Condition 2 and red in Condition 4. It was relatively unchanged in the presence of the other key color.

We became interested in determining whether the tendency to remain in the presence of a particular key color during the stimulus component of the multiple schedule was accompanied by a greater than otherwise tendency to depart the other key color following reinforcement for a peck on that key color. For three sessions during the eighth condition of the experiment, a polygraph recorded the occurrence of reinforcers and subsequent changeovers. Measurements taken on the tapes showed no difference between the average elapsed time between a reinforcement and a changeover from the blue key color for the two components of the multiple schedule (t-test for correlated means). Evidently, the added stimuli depressed changeover rate in the presence of one of the key colors without increasing changeover rate in the presence of the other, where changeovers were discriminatively controlled by the reinforcer.

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