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REINFORCEMENT CONTINGENCIES MAINTAINING COLLATERAL RESPONDING UNDER A DRL SCHEDULE[1]

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Two-key conjunctive schedules were studied with one key (food key) under a differential-reinforcement-of-low-rate 20-sec schedule, while the consequences of responding on another key (collateral key) were varied. When food depended not only upon a food-key interresponse time in excess of 20 sec, but also upon the occurrence of one or more collateral-key responses during the food-key interresponse time, the rate of collateral-key responding was low and food-key interresponse times rarely exceeded 20 sec. When collateral-key responses could produce a discriminative stimulus correlated with the availability of food under the DRL schedule, the discriminative stimulus functioned as a conditioned reinforcer to maintain higher rates of collateral-key responding, and the spacing of food-key responses increased. If the occurrence of the discriminative stimulus was independent of collateral-key responses, the rate of collateral-key responding was again low, but the spacing of food-key responses was still controlled by the discriminative stimulus. Both the conditioned reinforcer and the explicit reinforcement contingency could maintain collateral-key responding, but the adventitious correlation between collateral-key responses and the delivery of food could not maintain very much collateral-key responding. The pattern of responding on the food-key was determined to a much greater extent by the correlation between the discriminative stimulus and the delivery of food than by the pattern of responding on the collateral key.

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Collateral behavior, first observed by Wilson and Keller (1953), often has been considered to mediate (Segal-Rechtschaffen, 1963; Laties, Weiss, Clark, and Reynolds, 1965) the spacing of responses under schedules that selectively reinforce long interresponse times (DRL schedules). Originally, the purpose of the present experiments was to establish collateral behavior on an operandum, as Segal-Rechtschaffen (1963) did, in order to study the relationship between collateral behavior and the spacing of responses on a second key reinforced according to a DRL schedule. However, this objective became of secondary im-

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portance when it was discovered that the procedures separated the roles of explicit, adventitious, and conditioned reinforcement in maintaining collateral behavior.

Under all of the two-key conjunctive schedules studied, DRL 20-sec was scheduled on one key (food key), while the response requirements on the other key (collateral key) during the food-key interresponse time were varied. Under some schedules, a collateral-key response was required during the food-key interresponse time before food-key responses could produce food. These schedules measured the combined effects of explicit and adventitious reinforcement contingencies in maintaining collateral-key responding. When the explicit contingency was eliminated the role of the adventitious contingency could be studied in isolation. Under other schedules, collateral-key responses produced a discriminative stimulus correlated with availability of food under the DRL schedule. Under these schedules, the discriminative stimulus came to function as a conditioned reinforcer. By comparing patterns of collateral-key responding under schedules where collateral-key responses produced a discriminative stimulus with schedules where the discriminative stimulus was independent of collateral-key responding, or where no discriminative stimulus could be produced, the function of the discriminative stimulus as a conditioned reinforcer could be studied.

METHODS

Subjects

Two male White Carneaux pigeons, weighing 475 to 625 g with free access to food and water, were food-deprived to 80% of their free-feeding body weights, and maintained at these weights for the duration of the experiments. Both birds had been trained to peck a key under various schedules of food presentation and had some experience with a two-key DRL schedule; they had not been used in any experiments for about nine months before the present one.

Apparatus

The experimental chamber, after Ferster and Skinner (1957), was sound attenuating. Two translucent, plastic pigeon keys, 20 mm in diameter, were mounted on a false wall inside the experimental chamber about 9 cm apart and 18 cm above the chamber floor. One key could be transilluminated by either white or green lamps (collateral key) and the other by red lamps (food key). A feedback relay behind the wall operated whenever 15 g of force was applied to either key. Centered between the two keys at a point about 4 cm above the floor of the chamber was a rectangular opening through which a pigeon could gain 3-sec access to grain. The chamber was illuminated by a 25-w bulb and white noise was present at all times. Scheduling and recording apparatus were housed in a different room from the one containing the experimental chamber.

Procedure

Sessions were 30 min in duration. The two birds were retrained to peck the food key, which was always red, and then were exposed to one session during which every response on the food key produced food. In the second and third sessions, delivery of food was made contingent upon one or more responses on the collateral key, which was white, followed by a response on the food key. Responses on the collateral key never produced food directly. The collateral-key contingency remained in effect, while the minimum reinforced interresponse time (IRT) on the food key was gradually increased to 20 sec. In subsequent experiments, the DRL 20-sec schedule on the food key was held constant, while the contingencies on the collateral key were varied. The schedules to which the birds were exposed and the order of exposures are outlined in Table 1.

RESULTS

Responding under a DRL 20-Sec Schedule with a Collateral Response Required on a Second Key (No-Stimulus Schedule or NS Schedule)

The purpose of this experiment was to assure that at least some of the behavior occurring during the IRT on a food key under a DRL schedule could be measured objectively. This was accomplished by requiring that one of the collateral responses during the food-key IRT be pecks on a collateral key. Therefore, the food key was under a DRL 20-sec schedule, but before a food-key response could produce food, at least one response had to be made on the collateral key during the food-key IRT. This schedule is referred to as the

Table 1

Summary of Schedules Investigated

Schedule	Food Key Contingency	Collateral Key Contingency (To "Set Up" Food)	Conditions Producing Stimulus Change on Collateral Key	Sessions on Schedule	
				Bird 284	Bird 337
No-stimulus schedule (NS)	DRL 20 Red Key	One or more responses during food-key IRT	Key always white, no programmed change	35-62	63-90
Optional response-produced-stimulus schedule (ORPS)	DRL 20 Red Key	Same as NS schedule	First response after 20-sec IRT on food key changes color from white to green	7-34	35-62
Clock-stimulus schedule (CS)	DRL 20 Red Key	Same as NS schedule	Key changes color from white to green automatically after 20-sec IRT on food key	63-90	7-34
Response-produced-stimulus schedule (RPS)	DRL 20 Red Key	One or more responses after 20-sec IRT on food key	First response after 20-sec IRT on food key changes color from white to green	104-131	103-130
CS, no collateral response required	DRL 20 Red Key	None	Same as CS	91-97	Not tested
ORPS, no collateral response required	DRL 20 Red Key	None	Same as ORPS	98-103	Not tested
NS, no collateral response required	DRL 20 Red Key	None	Same as NS	Not tested	91-97
NS, no collateral response required, no collateral-key light	DRL 20 Red Key	None	White key light turned off, no stimulus change	Not tested	98-102

no-stimulus schedule (NS schedule) since no stimulus change was scheduled as a result of collateral-key reponses.

Both birds were exposed to the NS schedule for 28 sessions in the order shown in Table 1. Performance was stable over approximately the final 10 sessions. Figure 1 shows IRT frequency distributions in 4-sec class intervals for the food key and the total number of collateral-key responses during each food-key class interval, averaged over the final five sessions under the NS schedule.

For both birds, IRT distributions peaked in the fourth class interval (12 to 16 sec) with a smaller peak in the first class interval (0 to 4 sec). Neither bird terminated many IRTs longer than 20 sec, so food rarely was delivered. Similar short spacing of responses has been reported for pigeons under conventional DRL schedules (Reynolds and Catania, 1961; Reynolds, 1964; Staddon, 1965). The few IRTs longer than 20 sec usually produced food (22 of 25 times for Bird 284, and 38 of 42 times for Bird 337, over the last five sessions), since the birds usually pecked the collateral key at least once during the food-key IRT.

Figure 1 also shows that collateral-key responses occurred with greatest frequency in the class interval just before the peak of the IRT distribution (8 to 12 sec) and in the same class interval as the peak of the IRT distribution (12 to 16 sec). These data suggest that collateral-key responses immediately preceded food-key responses.

Bird 284 had about a one-to-one ratio of collateral-key responses to food-key responses. Since a one-to-one ratio matched the minimum requirement of the NS schedule, it is not likely that adventitious correlation of food delivery with collateral-key responses maintained this bird's collateral-key responding. Bird 337 made more collateral-key responses than required by the schedule. These "extra" collateral-key responses might represent unextinguished responses from a previous schedule (see Table 1). However, the rate of collateral-key responding was quite stable

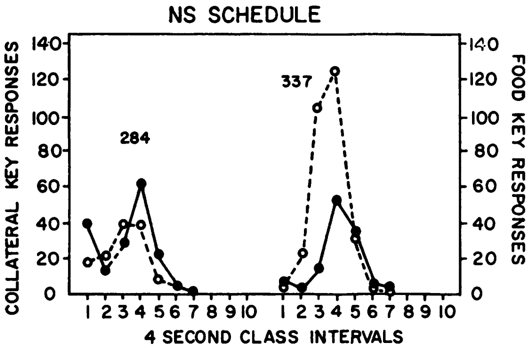

Fig. 1. Interresponse-time and collateral-key frequency distributions for both birds under the NS schedule. Each point represents the number of responses (food key is the solid line with closed circles, and collateral key is the broken line with open circles) occurring at each class interval, averaged over the last five sessions under the NS schedule. Each class interval is 4-sec wide, and food becomes available at the beginning of the sixth class interval.

for Bird 337 over the final 10 of 28 sessions under the NS schedule, and since there was a temporal relationship of collateral-key to food-key responses, the "extra" collateral-key responses probably were maintained by their adventitious correlation with food delivery. However, the IRT distributions were similar for both birds despite differences in the rate of collateral-key responding.

Elimination of the Collateral-Response Requirement from the NS Schedule (Bird 337). Turning off the Collateral-Key Light (Bird 337)

The purpose of these experiments was to determine if collateral-key responding could be decreased by removing the collateral-key contingency from the NS schedule and later decreased further by turning off the collateral-key light, and finally to determine what effects these manipulations had on the patterns of food-key responding. Table 2 shows that when the collateral-key requirement was eliminated from the NS schedule, the rate of collateral-key responding decreased during the first session. Over the remaining six sessions collateral-key responding continued to decrease (not shown).

Table 2 shows also that the decreased rate of collateral-key responding under the NS schedule without a collateral-response requirement was accompanied by a flattening of the food-key IRT distribution, and a higher frequency of food delivery. In the sense that temporal discrimination is reflected by a peak in the IRT distribution during the fourth and fifth class intervals (8 to 16 sec), performance deteriorated when the collateral-key requirement was eliminated; however, in the sense that more reinforcements occurred, performance improved.

After seven days under the NS schedule without a collateral-key contingency, the collateral-key light was turned off for five sessions. Turning off the collateral-key light further decreased collateral-key responding, which was again accompanied by a flattening of the food-key IRT distribution (not shown). Thus, both methods of eliminating collateral-key responses were accompanied by a flattening of the food-key IRT distribution and an increased frequency of food delivery.

Responding under a DRL 20-Sec Schedule, Where Required Responses on a Collateral Key Can Produce a Discriminative Stimulus Correlated with the Availability of Food under the DRL Schedule (Optional-Response-Produced-Stimulus Schedule or ORPS Schedule)

The purposes of this experiment were to see if a discriminative stimulus, correlated with the availability of food under the DRL schedule and produced by collateral-key responses, could reinforce collateral-key responding, and to determine if the response-produced discriminative stimulus could control the pattern of food-key responding. The food-key schedule was DRL 20-sec, and reinforcement again was contingent upon one or more collateral-key responses during the food-key IRT (as under the NS schedule). In addition, the first collateral-key response occurring after a 20-sec IRT on the food key changed the color of the collateral key from white to green. Under this schedule, food-key responses could produce food (assuming an IRT in excess of 20 sec) in the presence of either a white or a green collateral-key light. If all collateral-key responses occurred before the 20-sec food-key IRT, the food-key response would produce food in the presence of a white collateral-key light (exactly as under the NS schedule; see Table 1). However, a collateral-key response after 20 sec without a food-key response produced the discriminative stimulus. In so far

Table 2

Changes in the pattern of responding when the collateral-key requirement was removed from the NS schedule. Data represent the last session before the collateral-key requirement was eliminated from the NS schedule for Bird 337 and the first session after the collateral-key requirement was eliminated.

4-Sec Class Interval	*IRT Frequency Distribution*		*Frequency Collateral-Key*	
	NS Schedule	*NS-No Collateral*	*NS Schedule*	*NS-No-Collateral*
1	5	5	3	8
2	3	14	23	36
3	14	27	103	50
4	54	30	134	50
5	32	25	35	29
6	7	15	3	6
7	1	3	1	2
8	0	3	0	1
9	0	0	0	0
10	1	0	2	0

as obtaining food was concerned, production of the discriminative stimulus on the collateral key was optional; hence, this schedule will be referred to as the optional-response-produced-stimulus schedule (ORPS schedule).

Both birds were exposed to 28 sessions under the ORPS schedule. Figure 2 shows frequency distributions of IRTs on the food key in 4-sec class intervals and the number of collateral-key responses during each class interval, averaged over the last five sessions under the ORPS schedule.

The IRT frequency distributions of both birds peaked in the fifth class interval (16 to 20 sec), with a secondary peak in the first class interval (0 to 4 sec). The shape of the IRT distribution under the ORPS schedule was bimodal, as under the NS schedule, but under the ORPS schedule the distribution was shifted one class interval to the right (closer to reinforcement), and many more food-key responses were reinforced. Thus, adding the discrimination stimulus after collateral-key responses clearly increased the spacing of food-key responses. Nevertheless, the major proportion of food-key responses terminated IRTs of less than 20 sec, and did not produce food. The failure of the discriminative stimulus to exert better control over food-key responding was probably because food-key responses could produce food in the absence of the discriminative stimulus, which would strengthen the tendency to make food-key responses at short IRTs when the collateral key was white.

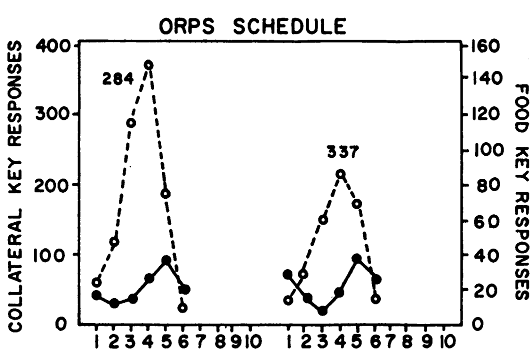

Fig. 2. Interresponse-time and collateral-key frequency distributions for both birds under the ORPS schedule. Each point represents the number of responses (food key is the solid line with closed circles, and collateral key is the broken line with open circles) occurring at each class interval, averaged over the last five sessions under the ORPS schedule. Each class interval is 4-sec wide, and food becomes available at the beginning of the sixth class interval.

Only rarely did IRTs greater than 20 sec terminate without the delivery of food because no collateral-key responses were made. For Bird 337, 131 of 132 IRTs longer than 20 sec terminated with food, while 113 of 116 IRTs longer than 20 sec terminated with food for Bird 284 (summed over the last five sessions). Unfortunately, the recording methods did not permit a determination of the proportion of times food delivery occurred in the presence of the white collateral-key light, relative to the green collateral-key light.

Figure 2 shows that the rate of responding on the collateral key was many times higher under the ORPS schedule than under the NS schedule (Fig. 1), indicating that the stimulus change on the collateral key also functioned as a conditioned reinforcer to maintain collateral-key responding.

Collateral-key responses occurred with greatest frequency in the class interval (12 to 16 sec) just before the class interval (16 to 20 sec) where food-key responses occurred with greatest frequency. Such data suggest that the rate of collateral-key responding was highest just before a food-key response, a suggestion supported by the cumulative-response records of Fig. 3.

Elimination of the Collateral-Response Requirement from the ORPS Schedule (Bird 284)

This experiment sought to determine whether or not the conditioned reinforcer could maintain collateral-key responding when food delivery was no longer dependent upon collateral-key responses. Immediately before this experiment, Bird 284 had been under a schedule that eliminated collateral-key responding completely (see Table 1). Under the ORPS schedule without a collateral response requirement, the number of collateral-key responses increased from 0 to 62 responses during the first session, to 154 during the second session, and to 192 during the third session. These data were a further indication that the green collateral-key light was a conditioned reinforcer, capable of establishing responding in the absence of a scheduled food contingency.

Responding under a DRL 20-Sec Schedule Where Collateral-Key Responses Must Produce a Discriminative Stimulus Correlated with the Availability of Food before a Food-Key Response Can Be Reinforced (Response-Produced-Stimulus Schedule or RPS Schedule)

Under the ORPS schedule, the spacing of food-key responses was not as efficient as expected, and it was suggested that this was because food-key responses could produce food both with and without collateral responses producing the discriminative stimulus. Therefore, the ORPS schedule was modified so that at least one collateral-key response was required after 20 sec without a food-key response before a food-key response could produce food. Since the first collateral-key response after a 20-sec IRT on the food-key also produced a discriminative stimulus for the availability of food under the DRL schedule, food could be delivered only after collateral-key responses had produced the discriminative stimulus. Since the discriminative stimulus was no longer an optional event in the sequence leading to food, this schedule was called the

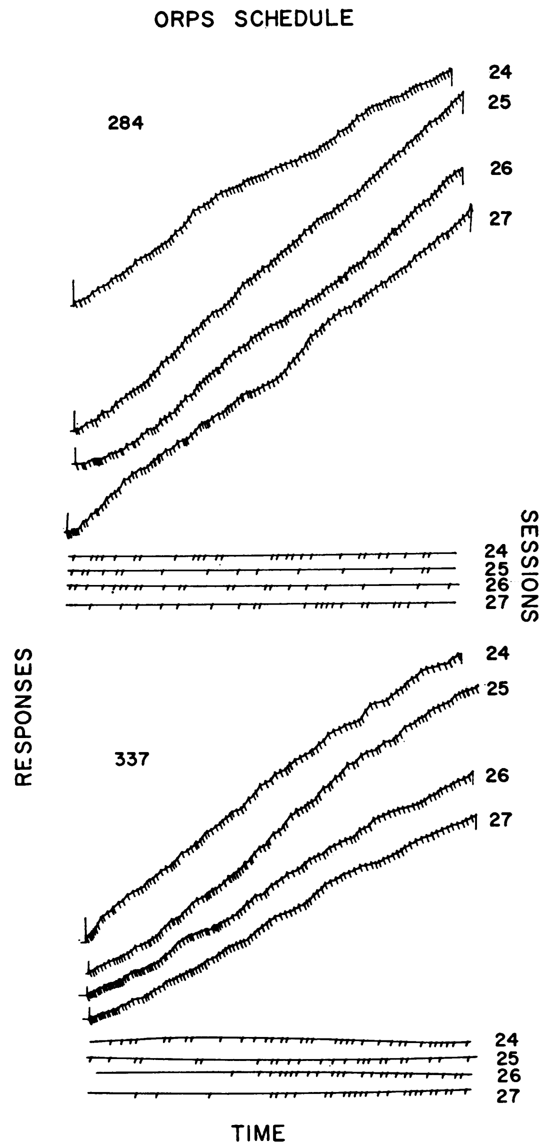

Fig. 3. Cumulative-response records of performances of both birds during four of the last five sessions under the ORPS schedule. Ordinate: cumulative number of collateral-key responses (left axis) and session number (right axis). Abscissa: time. Diagonal offsets of the pen on the horizontal lines indicate delivery of food. Diagonal offsets of the pen on the cumulative response lines indicate food-key responses.

response-produced-stimulus schedule (RPS schedule).

Both birds were exposed to the RPS schedule for 28 days, although behavior had stabilized after 18 days. Distributions of IRT frequency for the food key and the number of collateral-key responses in each class interval have been averaged over the final five sessions under the RPS schedule in Fig. 4.

Figure 4 shows that almost all IRTs on the food key were terminated during the sixth class interval (20 to 24 sec) and produced food. The near optimal spacing of food-key responses under the RPS schedule strongly suggests that the closer spacing of responses under the ORPS schedule resulted from the reinforcement of some food-key responses in the presence of the white collateral-key light. The tendency to respond on the food key in the presence of the white collateral-key light might have generalized to shorter IRTs which could not terminate in food delivery.

The rate of responding on the collateral key was much higher under the RPS schedule than under any other except the ORPS schedule, the rate under the RPS schedule being only slightly higher than under the ORPS schedule. This slight increase in rate was correlated with a more frequent production of the conditioned reinforcer under the RPS schedule.

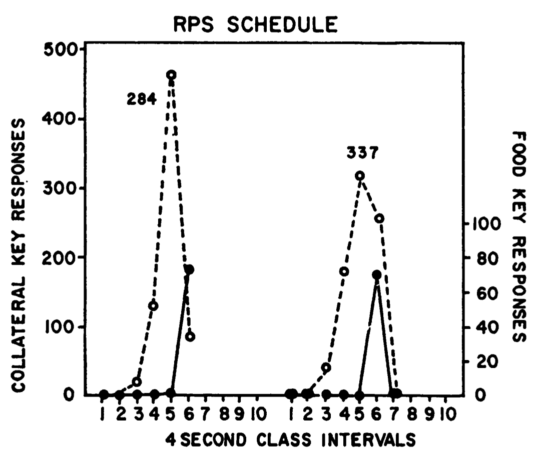

Fig. 4. Interresponse-time and collateral-key frequency distributions for both birds under the RPS schedule. Each point represents the number of responses (food key is solid line with closed circles, and collateral-key is broken line with open circles) occurring at each class interval, averaged over the last five sessions under the RPS schedule. Each class interval is 4-sec wide and food becomes available at the beginning of the sixth class interval.

If premature food-key responses did not occur under the RPS schedule, the green collateral-key light was scheduled according to a 20-sec fixed interval. Figure 5 shows that a fixed-interval pattern (a pause followed by an increased rate of responding) of collateral-key responding developed. By shaping a fixed-interval pattern of collateral-key responding, the conditioned reinforcer controlled responding in the same manner as other reinforcers.

Responding under a DRL 20-Sec Schedule Where a Discriminative Stimulus Is Presented Automatically (Clock-Stimulus Schedule or CS Schedule)

The purpose of this experiment was to determine if the discriminative stimulus for the

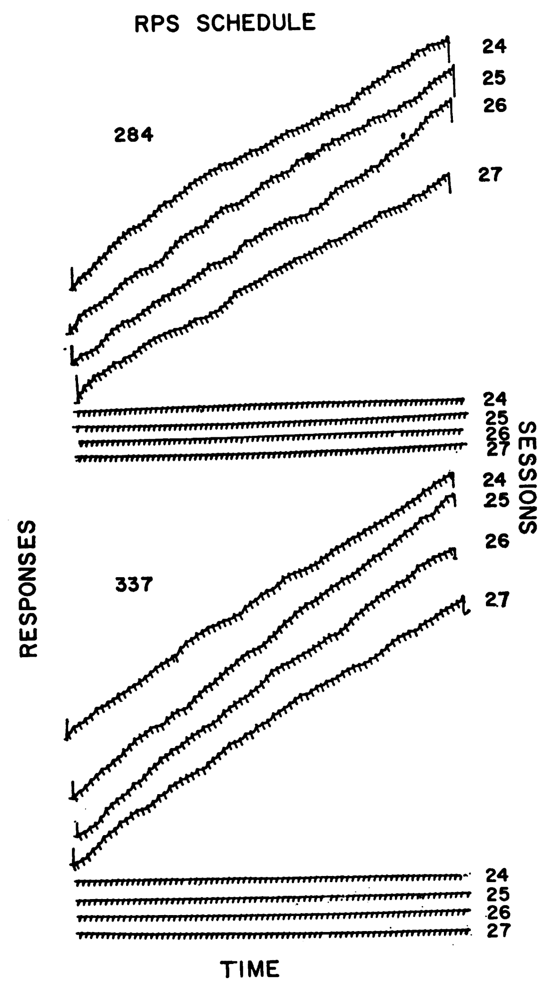

Fig. 5. Cumulative-response records of performances of both birds during four of the last five sessions under the RPS schedule. Recording as in Fig. 2.

availability of food under the DRL schedule could maintain collateral-key responding when it was independent of collateral-key responses, and to determine to what extent the discriminative stimulus controlled the pattern of food-key responding under these conditions. The schedule requirements were identical with those of the NS schedule (one collateral response was required during a food-key IRT greater than 20 sec, see Table 1), except that after 20 sec without a food-key response, the color on the collateral key changed automatically from white to green. By analogy with the terminology used to describe fixed-interval schedules with time-correlated stimuli (Ferster and Skinner, 1957), the present schedule was designated as the clock-stimulus schedule (CS schedule). Food-key IRT frequency distributions in 4-sec class intervals and the number of collateral-key responses in each class interval have been plotted in Fig. 6.

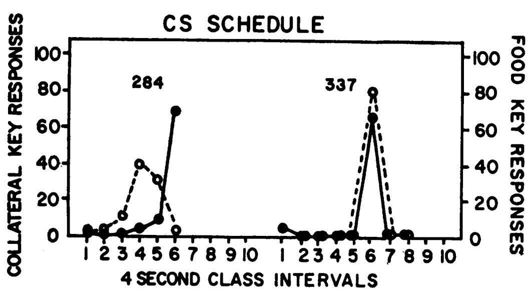

Fig. 6. Interresponse-time and collateral-key frequency distributions for both birds under the CS schedule. Each point represents the number of responses (food key is the solid line with closed circles, and collateral key is the broken line with open circles) occurring at each class interval, averaged over the last five sessions under the CS schedule. Each class interval is 4-sec wide and food becomes available at the beginning of the sixth class interval.

Under the CS schedule the food-key IRT frequency distribution peaked in the sixth class interval (20 to 24 sec) and the frequency of IRTs in all other class intervals was very low. Thus, automatic presentation of the discriminative stimulus correlated with the availability of food exerted about the same degree of control over food-key responding as occurred under the RPS schedule. Despite the efficient spacing of food-key responses under the CS schedule by both pigeons, Bird 284 produced only 225 reinforcements following termination of 359 IRTs on the food key that were longer than 20 sec. Therefore, during many IRTs longer than 20 sec, Bird 284 did not make collateral-key responses. For Bird 337, reinforcement almost always occurred after termination of IRTs longer than 20 sec (315 out of 321 times).

The rate of collateral-key responding under the CS schedule was quite low, lower even than under the NS schedule (Fig. 1). Although the ratio of collateral-key responses to food-key responses was about one-to-one for both birds, the temporal relationship of collateral-key to food-key responses was different for each bird under the CS schedule. Bird 284, which failed to make collateral-key responses during some IRTs, made collateral-key responses most often during the fourth and fifth class intervals (12 to 20 sec). During some IRTs, Bird 284 must have made several collateral-key responses and during other IRTs, no collateral-key responses at all. Figure 6 shows that Bird 337 did not respond until the discriminative stimulus appeared and then pecked the collateral key and the food key in sequence. The green collateral-key light appears to have served as a discriminative stimulus for both food-key and collateral-key responding for Bird 337, rather than as a conditioned reinforcer. Thus, the evidence indicates that the green collateral-key light controlled the pattern of food-key responding, but it had little effect as a conditioned reinforcer for collateral-key responding when it was not response-contingent.

Elimination of the Collateral-Response Requirement from the CS Schedule (Bird 284)

After 28 days under the CS schedule, the collateral-key requirement was eliminated for Bird 284. By the seventh day under the CS schedule without a collateral-key contingency, collateral-key responses no longer occurred. These results suggest that under the CS schedule, collateral-key responding was maintained almost entirely by the requirement that at least one collateral response was necessary during the food-key IRT before food could be produced.

DISCUSSION

At least three reinforcement contingencies might have contributed to the maintenance of collateral-key responding during these experiments. First, under some of these schedules collateral-key responses were required before food could be delivered under the DRL schedule. Second, collateral-key responses in excess of the one required by most schedules might be strengthened by adventitious correlation with the reinforcer if they occurred in close temporal proximity to it. Third, under some schedules collateral-key responding produced a discriminative stimulus for the availability of food under the DRL schedule, and such stimuli are potential conditioned reinforcers (Kelleher and Gollub, 1962). By varying the consequences of responding on the collateral key, the role of each of these contingencies in maintaining collateral-key responding could be determined.

Under the NS schedule, where only one collateral-key response was required, the extent to which the rate on the collateral key exceeded the rate on the food key probably reflected the degree to which collateral-key responding was maintained by adventitious correlation with food delivery. This contingency maintained responding under the NS schedule in only one of the two birds (Bird 337). When the collateral-key contingency was eliminated under the NS schedule for this same bird, a low rate of collateral-key responding was maintained after seven sessions, providing some evidence that adventitious correlation between collateral-key responding and food delivery might be maintaining a limited amount of responding. However, the failure of collateral-key responding to occur at a higher rate than food-key responding under the NS schedule for Bird 284, the failure of collateral-key responding to be maintained in excess of the schedule requirements under the CS schedule in both birds, and the rapid extinction of collateral-key responding when the collateral-key requirement was eliminated from the CS schedule (Bird 284), all indicate that adventitious correlations played a relatively small role in maintaining responding on the collateral-key. Collateral-key responding observed under these schedules must have been maintained largely by the requirement that collateral-key responses had to occur before food could be obtained under the DRL schedule.

Under the ORPS and RPS schedules, collateral-key responses could produce a stimulus correlated with the availability of food (after a food-key response). That this stimulus also came to function as a conditioned reinforcer of collateral-key responding when it was response-produced is suggested by the high rate of responding under the RPS and ORPS schedules. Further, the fixed-interval patterns of responding, seen especially under the RPS schedule, indicated that the conditioned reinforcer maintained responding in a manner similar to that of unconditioned reinforcers.

A second question upon which these experiments bear is the degree to which the pattern of food-key responding was controlled by the discriminative stimulus and by the pattern of responding on the collateral key. Under the RPS and CS schedules, practically all food-key responses terminated IRTs between 20 and 24 sec. Under both of these schedules, food-key responses were reinforced only in the presence of a green collateral-key light. However, under the CS schedule the green collateral-key light occurred automatically, while under the RPS schedule it was response-produced. That the rate of collateral-key responding was much higher under the RPS schedule, while the food-key patterns were much the same under both schedules, suggests that the pattern of food-key responding was controlled much more by the discriminative stimulus than by the responses which occurred during the food-key IRT.

Under variations of the ORPS schedule, the discriminative stimulus did not exert as much control over the pattern of food-key responding as under the other schedules where a discriminative stimulus was available. This was probably because food could be obtained under ORPS schedules in the absence of the discriminative stimulus. Nevertheless, spacing of responses on the food key was considerably better under the ORPS schedule than it was under the NS schedule, where no discriminative stimulus was scheduled.

Removing the collateral-key requirement from the NS schedule provided inconclusive evidence as to whether or not collateral-key responding could mediate food-key responding in the absence of a scheduled discriminative stimulus. When collateral-key responding was decreased by extinguishing it, or by turning off the collateral-key light, the IRT distribution on the food key was flattened, indicating a disruption of the temporal pattern of responding. However, this disruption resulted in a higher frequency of reinforcement, which might be interpreted as an improved performance.

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