REINFORCEMENT OF SPACED RESPONDING IN A SIMULTANEOUS DISCRIMINATION¹

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Pigeons were exposed to three stimuli simultaneously with responses reinforced according to differential-reinforcement-of-low-rate schedules. Responses to one stimulus (the positive stimulus) that were spaced appropriately resulted in food presentation. The variables manipulated were the time parameter of the schedule (5, 10, 20, 30 sec) and the consequences of responding to the other two stimuli (the negative stimuli). The percentage of the total responses that occurred to each stimulus was independent of the schedule value but was dependent on the consequences of responding to the negative stimuli. If responses to both reset the schedule timer, responding was confined largely to the positive stimulus. If responses to neither had scheduled effects, the birds were more likely to respond to those stimuli. Responding to one negative stimulus could be selectively attenuated by having responses to that stimulus alone reset the timer. With the schedule time value held constant, the absolute rate of responding to the positive stimulus was either stable or decreased with maintained exposure; it did not change as a function of increases or decreases in responding to the negative stimuli. Rather than interacting and affecting each other, responses to the three stimuli were controlled independently by their relation to reinforcement. There was no evidence that responses to the negative stimuli mediated the spacing of responses to the positive stimulus.

The prevailing schedule of reinforcement has been found to influence the accuracy of matching-to-sample (Dews, 1963; Ferster, 1960) and the shape of generalization gradients (Hearst, 1965; Hearst, Koresko, and Poppen, 1964; Thomas and Switalski, 1966; Zeiler, 1969). Data from simultaneous discrimination procedures (a special case of concurrent schedules in which two or more stimuli appear simultaneously and responses to one are correlated with a schedule of reinforcement while responses to others are correlated with extinction), however, have not revealed that stimulus control depends on the schedule used to produce and maintain responding. Nevin (1967) found equal accuracy when responses to one of two stimuli produced food according to discrete-trial analogues of either fixed-ratio or fixed-interval schedules. Zeiler (1968, 1970) found responding to be confined almost entirely to the stimulus correlated with reinforcement when responses to one of three

stimuli resulted in food presentation according to free-operant fixed-ratio or fixed-interval schedules.

The present study extended the analysis of reinforcement schedules in simultaneous discriminations by investigating differential-reinforcement-of-low-rate (DRL) schedules. In a DRL schedule, a reinforcing event occurs when a response follows the preceding response by more than the time specified by the parameter value. Such schedules were of particular concern, because in successive discriminations they produced less stimulus control (flatter generalization gradients) than did any other (Hearst, *et al.*, 1946; Zeiler, 1969). The essential aspect of simultaneous discriminations is that the subject is free to respond to any of two or more stimuli at any time, but responses to only one result in a reinforcing event (*e.g.*, food). With a DRL schedule, responses to one stimulus that are spaced appropriately in time are followed by food presentation. The effects of responses to the other stimuli may be manipulated. Two possibilities are: (1) they could have no scheduled effect at all, that is, they could be completely irrelevant with respect to the presentation of food; or (2) they could be treated similarly to

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nonreinforced responses to the positive stimulus in that they start the DRL interval anew. The present procedures investigated both of these alternatives.

METHOD

Subjects

Three White Carneaux pigeons were maintained at 80% of their free-feeding weights. None of the birds had participated in experiments previously.

Apparatus

Three translucent 0.8-in. (2 cm) diameter response keys (R. Gerbrands Co.), each operated by a minimum force of 12 g (0.12N), were mounted 3 in. (7.6 cm) apart, center-to-center. A 2-in. (5.1 cm) square aperture below the middle key provided occasional access to Purina Pigeon Checkers, the food used as the standard diet. White light illuminated the aperture, and the keys were dark during the 4-sec magazine cycles. Continuous white noise masked extraneous sounds.

All of the keys could be transilluminated with pairs of white, red, blue, or green 7-w lamps. Either all three keys were white, or each was a different color (red, blue, or green). The location of the colors changed after food presentations with the six possible spatial orders of the three colors occurring according to a repeating mixed sequence of 48 steps. Occasionally, two successive steps established the same spatial order.

Procedure

The five sessions conducted per week lasted until each bird received 30 food presentations or until time requirements necessitated termination. Sessions in which 30 reinforcements did not occur lasted from 2 to 16 hr as time permitted.

Acquisition of stimulus control. Initially the keys were white, and a response on any operated the feeder. The schedule was then changed to differential-reinforcement-of-low-rate (DRL): the first response on any key separated from the preceding response on any key by at least the time period specified produced food. Throughout the experiment, the interval was also initiated by the end of a feeder cycle. Responses occurring before the end of the specified interval reset the DRL timer.

The initial DRL value was 5 sec, but it was then raised abruptly to 10 sec for Bird 121, 20 sec for Bird 125, and 30 sec for Bird 122 and was maintained at those values for 22 sessions.

In the next 42 sessions, the keys were transilluminated with the red, blue, and green lights, and the birds obtained food according to the DRL schedule for responding to one of the three colors. This color, referred to as the positive stimulus or S+, was green for Bird 121, red for Bird 122, and blue for Bird 125. Only responses to S+ affected the DRL schedule: responses to S+ separated by at least the DRL value specified produced food, and responses to S+ before the end of the interval reset the timer. Responses to the other two stimuli (the negative stimuli, or S₁- and S₂-) had no scheduled effects. The DRL value was the same as in the last 22 sessions with the white keys.

Stimulus control and DRL value: reset only on S+ responses. Counting the first schedule with the three colors described above, each bird was studied with four different DRL values. Schedules were changed periodically so that each bird had DRL 5-sec, DRL 10-sec, DRL 20-sec, and DRL 30-sec schedules. The criterion for changing schedules was that there be a minimum of 18 sessions, that visual inspection revealed stable cumulative records, and that the percentage of the total responses in the last five sessions that occurred to S+ was within five points of that for each of the preceding two blocks of five sessions with no consistent direction of change. All birds were studied on a schedule until the last bird stabilized. Table 1 shows the sequence of schedules and the number of sessions for each bird. Throughout, responses to S+ separated by at least the time specified by the DRL value produced food; responses to S+ separated by shorter times began the DRL interval anew. Responses to the two negative stimuli had no scheduled effects.

Stimulus control and DRL value: reset on all responses. In the next set of conditions, the DRL timer reset on responses to S₁- and S₂- as well as on S+ responses occurring before the end of the DRL interval. Hence, responses to S+ that resulted in food presentation were separated from responses to any stimulus by at least the DRL value. Each bird had the four different DRL values as shown in Table

Table 1
Sequence of Conditions, Response Rate, and Reinforcement Frequency

Bird 121			Bird 122			Bird 125			Sessions
Condition	Resp/ sec ^a	Reinf/ hour	Condition	Resp/ sec ^a	Reinf/ hour	Condition	Resp/ sec ^a	Reinf/ hour	
1. DRL 10-sec	0.26	108	1. DRL 30-sec	0.13	13.8	1. DRL 20-sec	0.37	1.7	42
Reset S+	0.18		Reset S+	0.13		Reset S+	0.32		
2. DRL 30-sec	0.24	1.6	2. DRL 5-sec	0.15	188	2. DRL 10-sec	0.82	71.0	27
Reset S+	0.21		Reset S+	0.14		Reset S+	0.24		
3. DRL 20-sec	0.44	1.4	3. DRL 10-sec	0.29	45.5	3. DRL 5-sec	0.67	125	36
Reset S+	0.29		Reset S+	0.17		Reset S+	0.41		
4. DRL 5-sec	0.35	300	4. DRL 20-sec	0.37	15.2	4. DRL 30-sec	0.30	1.5	29
Reset S+	0.24		Reset S+	0.16		Reset S+	0.22		
5. DRL 5-sec	0.23	375	5. DRL 20-sec	0.15	23.4	5. DRL 30-sec	0.21	1.3	18
Reset S+, S ₁ -, S ₂ -	0.22		Reset S+, S ₁ -, S ₂ -	0.15		Reset S+, S ₁ -, S ₂ -	0.21		
6. DRL 20-sec	0.29	0.8	6. DRL 10-sec	0.17	57.7	6. DRL 5-sec	0.34	167	24
Reset S+, S ₁ -, S ₂ -	0.28		Reset S+, S ₁ -, S ₂ -	0.17		Reset S+, S ₁ -, S ₂ -	0.34		
7. DRL 30-sec	0.18	2.3	7. DRL 5-sec	0.20	250	7. DRL 10-sec	0.27	31.0	23
Reset S+, S ₁ -, S ₂ -	0.18		Reset S+, S ₁ -, S ₂ -	0.20		Reset S+, S ₁ -, S ₂ -	0.27		
8. DRL 10-sec	0.12	181	8. DRL 30-sec	0.15	2.0	8. DRL 20-sec	0.26	2.2	22
Reset S+, S ₁ -, S ₂ -	0.12		Reset S+, S ₁ -, S ₂ -	0.14		Reset S+, S ₁ -, S ₂ -	0.26		
9. DRL 20-sec	0.33	3.3	9. DRL 20-sec	1.06	21.4	9. DRL 10-sec	0.64	79.0	25
Reset S+	0.26		Reset S+	0.20		Reset S+	0.19		
10. DRL 20-sec	0.37	18.3	10. DRL 20-sec	0.19	5.3	10. DRL 10-sec	0.32	71.4	20
Reset S+, S ₂ -	0.16		Reset S+, S ₂ -	0.16		Reset S+, S ₂ -	0.24		
11. DRL 20-sec	0.09	50.0	11. DRL 20-sec	0.42	14.2	11. DRL 10-sec	0.14	188	23
Reset S+, S ₁ -	0.08		Reset S+, S ₁ -	0.16		Reset S+, S ₁ -	0.14		
12. DRL 20-sec	0.10	50.0	12. DRL 20-sec	0.19	7.6	12. DRL 10-sec	0.16	188	27
Reset S+, S ₂ -	0.09		Reset S+, S ₂ -	0.18		Reset S+, S ₂ -	0.16		
13. DRL 20-sec	0.13	65.2	13. DRL 20-sec	0.58	19.2	13. DRL 10-sec	0.16	214	20
Reset S+	0.09		Reset S+	0.18		Reset S+	0.16		
14. Extinction			14. Extinction			14. Extinction			18

^aUpper number of each pair is the combined response rate to the three stimuli. The lower number (italicized) is the response rate to S+ alone.

1. The criteria for schedule changes were as described above.

Analysis of the reset conditions. A series of conditions was then designed to examine the effects of holding the DRL schedule constant while the timer did or did not reset on S- responses. Birds 121 and 122 had a DRL 20-sec schedule, and Bird 125 had a DRL 10-sec schedule. These values had produced the highest percentage of responses to a negative stimulus in Conditions 1 to 4.

First, responses to the negative stimuli did not reset the timer: this was a replication of the procedure of Conditions 1 to 4. Next,

responses to S₂- (red for Bird 121, blue for Bird 122, green for Bird 125) reset the timer, and responses to S₁- had no scheduled effects. The functions of the stimuli then were switched: responses to S₁- reset the timer while responses to S₂- had no effects. Next, the timer again reset on S₂- responses and responses to S₁- were irrelevant. Finally, neither responses to S₁- nor S₂- responses had scheduled effects. The criteria for changing conditions were the same as in the earlier conditions.

Extinction. The experiment concluded with 18 sessions, each of 2-hr duration, in which

Fig. 1. Percentage of total responses occurring to S+ in the first condition of differential reinforcement. The first point is for the first session; subsequent points are the percentages computed over successive blocks of three sessions.

there were no food presentations. The stimuli changed positions every 2 min.

RESULTS

Acquisition of Stimulus Control

The birds first were exposed to the red, blue, and green stimuli after their behavior had stabilized under DRL schedules; the initial adjustment to DRL occurred with white keys. Figure 1 shows the percentage of the total responses occurring to S+ in the first session and in successive blocks of three sessions. The three birds emitted over 50% of the responses to S+ in the first sessions. Subsequently, all had sessions with over 90% of the responses occurring to S+. Bird 121 revealed the most fluctuation, with S+ responses ranging from 42% to 94% of the total. The percentage of S+ responses generally increased with continued training.

Stimulus Control and DRL Value

The birds were first exposed to the four DRL values when responses to the negative

stimuli had no scheduled effects. The percentage of the total responses occurring to S+ in the last five sessions of each condition revealed the degree of stimulus control produced; the higher the percentage, the more differential responding with respect to the stimuli and hence the greater control by S+. There was no orderly relation between the percentage of S+ responses and DRL value for any bird. The percentages were ordered as follows. Bird 121: 30-sec (88%), 10-sec (68%), 5-sec (68%), 20-sec (67%); Bird 122: 30-sec (97%), 5-sec (95%), 10-sec (58%), 20-sec (44%); Bird 125: 20-sec (86%), 30-sec (73%), 5-sec (62%), 10-sec (29%). Neither were there clear order effects. As shown in the first four points of Figure 2, Bird 122 had a decreasing percentage of S+ responses over the first four conditions, but the other two birds had different patterns. At the end of the fourth condition, the three birds were emitting 73% or fewer of the total responses to S+.

In Conditions 5 to 8, the DRL timer reset on responses to the negative stimuli. This

Fig. 2. Percentage of total responses occurring to each stimulus in the last five sessions of each condition. The legends at the top of the figure indicate the responses that reset the DRL timer.

meant that these responses were always separated from food presentation by at least the time interval specified by the DRL schedule. Figure 2 shows that the percentage of responses to S+ rose to between 96% and 100% of the total and remained at that level through Condition 8. In Conditions 5 to 8, as in Conditions 1 to 4, there was no systematic relation between DRL value and the percentage of responses to S+; in fact, there were minimal differences among the four DRL schedules.

The change in the distribution of responses to the three stimuli in conditions 5 to 8 may have been due either to the change in the consequences of responses to the negative stimuli or to the prolonged exposure to differential

reinforcement. To determine which of these factors was responsible, the schedule that had produced the lowest percentage of S+ responses in Conditions 1 to 4 (Birds 121 and 122: DRL 20-sec; Bird 125: DRL 10-sec) was reinstated. As in Conditions 1 to 4, responses to the negative stimuli in Condition 9 had no scheduled consequences. Figure 2 shows that the percentage of S+ responses decreased to 80% for Bird 121, to 19% for Bird 122, and to 30% for Bird 125. Therefore, the distribution of responses to the three stimuli was determined by the consequences of S- responses and not by prolonged experience. A substantial percentage of the total responses occurred to either or both S₁- and S₂- only if such re-

sponses did not result in resetting the DRL timer.

To analyze further the relation between the consequences of responses to S_1- and S_2- and stimulus control, the consequences were manipulated while the DRL schedule was held constant. Figure 2 shows the percentage of responses occurring to each stimulus when responses to both stimuli were irrelevant (Conditions 9 and 13), when responses to S_2- reset the timer and responses to S_1- were irrelevant (Conditions 10 and 12), and when responses to S_1- reset the timer and responses to S_2- were irrelevant (Condition 11).

All of the birds revealed stable behavior under each condition, although two (Birds 121 and 125) revealed metastability (Staddon, 1965). Their behavior stabilized each time a condition was imposed, but the stable behavior was not identical to that occurring when the condition had been imposed previously. Bird 125 illustrated this metastability the most clearly. In Conditions 9 and 10, Bird 125 responded to the negative stimulus that did not reset the timer (both S_1- and S_2- in Condition 9, S_1- in Condition 10). However, after Condition 10 eliminated S_2- responses and Condition 11 eliminated S_1- responses, responding in Conditions 12 and 13 was confined largely to $S+$.

Bird 122 was affected by every condition. This bird rarely responded to S_1- under any condition. However, whenever responses to S_2- did not reset the timer, Bird 122 responded to that stimulus more often than to $S+$. This represented what Staddon (1965) called true stability as contrasted with metastability.

In summary, the consequences of responding to the negative stimuli determined how responses were distributed. At least 96% of the responses occurred to $S+$ when responses to the two negative stimuli reset the DRL timer. If those responses had no scheduled consequences, the relative frequency of $S-$ responses increased to highs ranging from 33% to 81% of the total in the different birds. If responses to one $S-$ reset the timer, the birds had a low percentage of responses to that stimulus. Every condition that produced a relatively large percentage of responses to an $S-$ allowed those responses to occur in close temporal contiguity to food presentation. If such contiguity was not permitted (and in

Fig. 3. Rate of responding to each stimulus under the seven conditions having the same DRL schedule. For Bird 121, these were Conditions 3, 6, 9, 10, 11, 12, 13 in Table 1; for Bird 122, they were Conditions 4, 5, 9, 10, 11, 12, 13; for Bird 125, they were Conditions 2, 7, 9, 10, 11, 12, 13. The compressed order shown on the abscissa is as follows. 1: Reset $S+$; 2: Reset $S+$, S_1- , S_2- ; 3: Reset $S+$; 4: Reset $S+$, S_2- ; 5: Reset $S+$, S_1- ; 6: Reset $S+$, S_2- ; 7: Reset $S+$.

some cases when it was), responding was confined largely to $S+$.

Response and Reinforcement Rate

Table 1 shows that neither the rate of responding to $S+$ nor to the three stimuli combined had an orderly relation to DRL value when the timer did not reset on responses to the negative stimuli. When the timer did reset on responses to S_1- and S_2- , Birds 122 and 125 declined in rate as the DRL value increased. Bird 121, in contrast, responded at the highest rate under the DRL 20-sec schedule and the lowest rate under the DRL 10-sec schedule.

Figure 3 shows the response rate in the seven conditions involving the same DRL schedule (Birds 121 and 122: DRL 20-sec; Bird 125: DRL 10-sec) but different consequences of $S-$ responses. Responses to an $S-$ occurred at a substantial rate only if they did not reset the

timer. Every instance of elevated response rate to an S— occurred when responses to that stimulus had no consequences.

For Birds 121 and 125, the rate of responding to S+ tended to decrease with successive conditions; note that the Conditions labelled 1, 3, and 7 in Figure 3 were all the same, but that the rate to S+ decreased from one to the next. Bird 122 had a nearly constant S+ rate under all conditions. This stability (for Bird 122) or fairly steady decrease (for Birds 121 and 125) occurred despite substantial fluctuations in the rate of responding to either S₁— or S₂—. These data suggest that the response rate to S+ was independent of the rate of responding to the other stimuli. The various manipulations affected the overall rate, but the S+ rate depended upon the DRL value either in conjunction with or independent of how long the birds had been exposed to it. This was also the case even immediately after a transition from one condition to another: the rate of responding to S+ was not disturbed in the first session of the next condition despite the newly changed consequences of S— responses and the attendant change in responding to either or both S₁— and S₂—. The response rate to S+ in the first session was always within the range encompassed by the S+ rates in the last five sessions of the preceding condition.

One possible basis for responding to the negative stimuli would be if such responding resulted in more efficient behavior, that is, if it helped the pigeons to space their responses to S+ appropriately (*c.f.*, Laties, Weiss, and Weiss, 1969). However, Table 1 shows that the frequency of reinforcement was not influenced systematically by whether or not responses to the negative stimuli reset the timer. The absence of consistent changes in reinforcement frequency that were correlated with changes in stimulus control suggests that responses to S₁— and S₂— in Conditions 1 to 4 and 9 to 13 did not occur because they increased the frequency of reinforcement. Another measure of reinforcement density is the probability of reinforcement, that is, the number of reinforced responses divided by the total number of responses. Whether the denominator was the number of responses to all three stimuli or the number of responses to S+, the probability of reinforcement (and reinforcement frequency as well) was inversely related to DRL

value but not systematically related to the percentage of the total responses that occurred to S+. The probabilities (either per response or per S+ response) ranged from highs of 0.37 to 0.45 under DRL 5-sec to lows of fewer than one food presentation per 1500 responses at DRL 30-sec, independent of the consequences of responses to the negative stimuli. There was no evidence, therefore, that responses to those stimuli served as mediating behavior that in some way increased the efficiency of DRL performance.

Extinction

Figure 4 shows the overall rate of responding and the percentage of responses occurring to each stimulus in the 18 sessions of extinction. Response rate declined with successive sessions, although for Birds 121 and 125 extinction initially increased rate. Rate decrement did not yield corresponding decrements in stimulus control. The percentage of the total responses occurring to S+ never fell below 68% after Session 1. Bird 122 came to respond almost exclusively to S+, while Bird

Fig. 4. Percentage of total responses occurring to S+ (filled points) and overall rate of responding (open points) in each session of extinction. The first point is for the data of the last session under a DRL schedule.

121 ranged around 80% and Bird 125 ranged between 80% and 100%.

DISCUSSION

The degree of control over responding by the stimulus terminally correlated with food presentation depended on the consequences of responding to the other stimuli. If the responses were irrelevant in the sense of having no scheduled consequences, the birds frequently responded to those stimuli; if the responses were relevant in that they reset the DRL timer, the birds confined their responses almost exclusively to the positive stimulus.

The behavior occurring when responses to the negative stimuli reset the DRL timer showed that differential reinforcement according to a DRL schedule can produce a high level of stimulus control, in fact a level comparable to that observed previously with fixed-ratio and fixed-interval schedules (Zeiler, 1968, 1970). The decrement in stimulus control found with DRL schedules in successive discriminations by Hearst, *et al.*, (1964) and Zeiler (1969) did not characterize simultaneous discriminations. Instead, responses were confined to the stimulus terminally correlated with food presentation as long as nonreinforced responses to all of the stimuli reset the DRL timer. Perhaps the decreased stimulus control in successive discriminations stems from the fact that only responses to S+ have had any consequences in those experiments.

Another similarity under all schedules that have been investigated with simultaneous discriminations is that stimulus control does not decline when the probability of responding declines. Nevin (1967) and Zeiler (1968, 1970) found that although various manipulations lowered the number of responses occurring with fixed-ratio and fixed-interval schedules, stimulus control by the stimulus previously or currently correlated with food presentation remained high. In the same vein, stimulus control by the positive stimulus was not weakened during the extinction phase of the present experiment when response rate decreased. In fact, the birds either immediately or eventually emitted a higher percentage of responses to the previously positive stimulus than had occurred in the preceding condition when such responses were followed by food presentation.

The major schedule-dependent effect in si-

multaneous discriminations appears to be related to the consequences of responses to stimuli other than the one terminally correlated with food presentation. With fixed-ratio and fixed-interval schedules, as long as only one stimulus is correlated with either food presentation or with a conditioned reinforcer, responses to the other stimuli can occur at any time without affecting stimulus control (Zeiler, 1968, 1970). Although they can occur, they appear infrequently and then rarely in close contiguity with reinforcement. The DRL schedule, in contrast, produces a high degree of control by the positive stimulus reliably only if responses to negative stimuli cannot occur in close temporal contiguity with food presentation. In this respect, DRL schedules seem to resemble variable-interval schedules (Catania and Cutts, 1963).

Experiments with DRL schedules conducted to study collateral behavior, rather than stimulus control, have also found that animals will respond to a stimulus having no scheduled relation to food presentation (Bruner and Revusky, 1961; Schwartz and Williams, 1971; Zuriff, 1969). Why these responses should occur is unclear. The present data show that they need not result in increased reinforcement frequency or probability, nor do they appear to affect the rate of responding to the positive stimulus, as might be expected if they came to mediate a temporal discrimination. (See Laties, *et al.*, 1969 for a critical discussion of mediation of temporal control by collateral behavior.) Instead, the independence between the rate of responding to the positive stimulus and the rate of responding to the negative stimuli suggests that the two types of responses are controlled separately and may have no essential relation to each other (except for the fact that they are physically incompatible and cannot occur simultaneously). McMillan's (1969) data support this hypothesis. Two stimuli were present, and responses to one produced food according to a DRL schedule. McMillan varied whether or not food presentation also required responses to the second stimulus. When required, responses to the second stimulus occurred; when not required, they disappeared. The relation of each response to reinforcement determined the frequency of the responses. Even though responses to the second stimulus must have occurred early in training and would have

facilitated the spacing of responses to the first stimulus, if they were not required they were not maintained.

The wholly predictable aspect of stimulus control under DRL schedules is that if responses to the positive stimulus are reinforced while responses to other stimuli reset the DRL timer, responses are confined to the positive stimulus. If responses to the other stimuli have no scheduled effects, the responses may or may not occur. A degree of unpredictability also characterizes response rates under DRL schedules: the irregular relation between response rate and the time parameter of the schedule found in the present experiment replicated that found by Staddon (1965). Staddon went on to show that the source of the irregularity is that response rate at a particular DRL value depends both on the pigeon's history and on the prevailing schedule. Although the rate becomes stable under each exposure to a given DRL value, the rate on the next exposure to that value can change depending on what other DRL schedules have been interpolated. Thus, under some conditions, metastability occurs with respect to response rate as well as with respect to stimulus control when spaced responses to a stimulus produce food.

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