MAINTAINING RESPONDING DURING STIMULUS GENERALIZATION TESTING IN EXTINCTION¹

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Resistance to extinction and generalization gradients were studied following training with a long-adjusting-interval schedule. One large reinforcer occurred at the end of each daily training session. Sessions varied in length from 20 sec to 42.66 min, but were usually the latter. Repeated generalization tests were subsequently conducted for these subjects and subjects trained with a more conventional short-random-interval schedule. The long-adjusting-interval schedule produced generalization gradients that were not qualitatively different from those produced by the conventional procedure. However, the advantages of the long-adjusting-interval schedule are: (1) greater resistance to extinction both within and across generalization tests and (2) more stable gradient slopes within and across tests.

Reliable generalization gradients require consistent responding throughout presentations of test stimuli. The use of extinction during generalization testing is also important because presentations of reinforcement will most likely alter the slopes of generalization gradients. If reinforcement is still associated with the training stimulus and withheld in the presence of novel test stimuli, the gradients become sharper (Pierrel, 1958). On the other hand, if responses are reinforced in the presence of all the stimuli, spuriously flat gradients might be obtained.

The procedure developed by Guttman and Kalish (1956) solved some of these problems. Intermittent reinforcement during training increased resistance to extinction; consequently, many responses could be obtained in subsequent generalization tests conducted in extinction. Their procedure is not entirely satisfactory, however. Response rates decrease and gradient slopes change within test sessions; the gradients usually become steeper (*e.g.*, Friedman and Guttman, 1965) although occasionally flatter (*e.g.*, Reinhold and Perkins, 1955). The shape of the average gradient that results is difficult to interpret. The problems of reduced response rates and changing gradient slopes are especially acute when large numbers

of test stimuli are required, as in multi-dimensional stimulus generalization tests (*e.g.*, Eckerman, 1970).

Schuster and Gross (1969) devised a procedure that maintains responding without changes in gradient slopes. Their procedure involves interspersed training and test periods in each session.

The present paper reports a method for maintaining responding during testing without interspersed training involving reinforcement during the test sessions. Such test sessions followed training sessions with only one relatively large reinforcer at the end of each session; training session lengths varied from 0.33 min to 42.66 min. Results obtained under such a procedure were compared with those obtained under a more typical schedule of reinforcement in which 3-sec reinforcers followed responses on the average every 64 sec.

METHOD

Subjects

Six experimentally naive barren hen White King pigeons were housed in individual cages with grit and water always available. Feeding occurred at the end of each experimental session or once daily when sessions were not conducted so that at the start of each experimental session they would be at 70% of their free-feeding weight. Purina Pigeon Grains were used to maintain weight and served as the reinforcer.

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Apparatus

A Lehigh Valley Electronics pigeon test chamber #1519c was used with the houselight off and the window covered. Only one response key was operative; it consisted of a transparent plastic paddle behind a hole 2.4 cm (0.9 in.) in diameter. The response key was transilluminated by an Industrial Electronics Engineers, Inc. one-plane readout series #10 and GE 47 lamps, centered on the key. The remainder of the key was dark. Line angles from 0° (horizontal) to 90° (vertical) in 15° steps were available. White masking noise was provided by a Grason-Stadler noise generator and was presented through a speaker in the chamber. A fan provided ventilation and additional masking noise.

Scheduling, except during the first generalization test for each subject, was done automatically with solid state digital switching circuitry. During the first generalization test, stimuli were switched manually. Time, responses in the presence of each stimulus, and reinforcements were recorded with Sodeco electromechanical counters and Scientific Prototype Model 2-D cumulative recorders.

Procedure

Sessions were conducted five days per week. During Phase 1, through the use of standard operant-conditioning procedures, the six subjects (A-13, A-14, A-15, R-13, R-14, and R-15) were trained to eat from the food magazine and to peck the response key. When the key-peck response was established the subjects received 50 reinforcements each day on a continuous reinforcement (CRF) schedule. Reinforcement consisted of a 3-sec presentation of the food magazine accompanied by the magazine light. Throughout Phase 1, the key was transilluminated with a line at an angle of 45°. When a subject received 50 reinforcements in 5 min, Phase 2 was initiated. Phase 1 lasted for three or four sessions.

Phase 2 consisted of discrimination training. During this phase, the 45° line (S+) was presented until the subject responded and received a 3-sec reinforcer. Reinforcement was followed by 30 sec of extinction in the 90° line angle (S₋₁). At the end of the 30-sec period, S+ was again presented. Reinforcement was followed this time by 30 sec of extinction in

the 0° line angle (S₋₂). This cycle was repeated during each session until the subject had received 50 reinforcers, or 50 min had elapsed, whichever occurred first. This procedure remained in effect until nearly perfect discriminations had been formed (approximately 35 sessions). Phase 3 was then initiated.

During Phase 3, three of the six subjects (A-13, A-14, and A-15) were placed on an adjusting-interval (AI) schedule. This will be called the adjusting-schedule group. One reinforcer was delivered per session. Reinforcement continued to occur only in the presence of the 45° line. The order of stimulus presentation was 45°, 90°, 45°, 0° as before. This sequence was repeated throughout the session with stimulus changes occurring every 20 sec.

Reinforcement availability occurred at a predetermined time after the start of each session. During the first session on the adjusting schedule, reinforcement became available 20 sec after session onset. Thereafter, the time from session onset to reinforcement availability was doubled each day until a value of 10.66 min was reached. At this point, the criteria for doubling the time to reinforcement availability or maintaining it at its maximum value of 42.66 min were: (1) that visual inspection of the cumulative record of responses as a function of time revealed no period of relatively low rate in S+ and, (2) that the overall response rate in S+ for the session was at least 25 responses per minute. If the cumulative record revealed a period of relatively infrequent responding in S+ during Session *n*, the time to reinforcement was reduced for Session *n* + 1 so that reinforcement would occur during the portion of the session when the rate had previously been low; the time value was returned to the previous value for Session *n* + 2. If the response rate was less than 25 responses per minute, the time to reinforcement availability was returned to 20 sec for the next session and doubled on sessions thereafter as before.

When reinforcement became available, each response in the presence of the 45° line had a probability of 1/16 of producing reinforcement. The random-ratio schedule was superimposed on the adjusting-interval schedule in order to assure that reinforcement would be delivered at variable times after the onset of the S+.

Reinforcement consisted of one 2.33 to 2.66 min presentation of the food magazine accom-

panied by the magazine light, at the end of each session. Reinforcement duration varied randomly for reasons irrelevant to the experiment. During reinforcement, the magazine was dropped for 50 msec every 20 sec to redistribute the grain, assuring its presence in the eating cup.

Discrimination ratios, $S+ \text{ rate} / (S+ \text{ rate} + S- \text{ rate})$, were calculated for each $S-$ and for the $S-$ s combined, for each session. During this phase, some of the discrimination ratios began to decrease in one of the $S-$ s. It was noted that reinforcement occurred more frequently during an $S+$ presentation following this $S-$ than in an $S+$ presentation following the other $S-$. This accidental correlation between reinforcement and $S-$ s was reversed by changing the order of stimulus presentation to 45° , 0° , 45° , 90° , which tended to correct the poor discrimination ratios. Phase 3 lasted for approximately 117 sessions. Generalization test #1 was then administered.

For the remaining three subjects (R-13, R-14, and R-15), the reinforcement schedule in $S+$ was changed to a random-interval (RI) schedule (Farmer, 1963) during Phase 3. This will be called the random-schedule group. The discrimination ratios at the end of Phase 2 for the random schedule group were equivalent to those for the adjusting-schedule group. As with the adjusting-schedule group, reinforcement continued to occur only in the presence of the 45° line, the order of stimulus presentation remained as before, and stimulus changes occurred every 20 sec. Reinforcement consisted of a 3-sec presentation of the food magazine accompanied by the magazine light. For the first session on RI, the expected mean interval value was 8 sec (RI 8-sec); *i.e.*, the probability of reinforcement for the first response in each 4-sec time period in $S+$ was $1/2$. If the discrimination ratios did not decrease from their mean value for the last five sessions on CRF by more than 0.05, the schedule for the next session was RI 16-sec. If the discrimination ratios decreased by more than 0.05, the schedule remained RI 8-sec. The value of the schedule was raised in this fashion through the values of 16, 32, and finally 64. On the RI 64-sec schedule, the probability of reinforcement for the first response in each successive 4-sec period in $S+$ was $1/16$. The schedule remained RI 64-sec for the remainder of training. Phase 3 lasted for approximately 117 sessions. Generalization

test #1 was conducted at the termination of Phase 3.

Generalization test #1 for each group was preceded by 10 min of warmup exactly like training but with no reinforcement being presented to the adjusting schedule group. The test was conducted in extinction. During the test, the seven stimuli were presented randomly in blocks, each line angle appearing once in each block. Each stimulus remained on the key for 20 sec followed by a 10-sec timeout (period of complete darkness) during which stimuli were changed and the number of responses during the stimulus presentation recorded. When a subject failed to respond for two complete blocks of stimulus presentations or when 178.5 min had elapsed since the beginning of the test session, the test was terminated.

After test #1, the three random-schedule subjects and two of the adjusting-schedule subjects were given five sessions of training exactly like that immediately before testing. One subject (A-14) was eliminated from the adjusting-schedule group because of an experimental design error. The five subjects were then given generalization tests every other day with a training session occurring on days in between test days. These tests differed from the previous tests in that only a 20-sec warmup in $S+$ without reinforcement occurred, stimuli were changed and responses recorded automatically, there were no timeouts between stimuli, the same random order of stimulus presentation was used in every block in a given test, and each test was terminated after 42 min regardless of the subjects' behavior. The experiment was terminated after 28 tests per subject had been conducted. Testing for a subject was discontinued earlier if the subject failed to emit 50 responses in at least one of the stimuli during two consecutive tests.

RESULTS

Figure 1 shows a typical cumulative record for a discrimination training session on the adjusting schedule. The record was produced by Subject A-15 shortly before test #1. Reinforcement is shown only at the end of the record because it occurred only at the end of the session. The pauses in such records are usually $S-$ s. The response rate in the presence of $S+$, like that for a typical session with the RI

Fig. 1. Typical cumulative record produced during a training session on the adjusting schedule.

schedule, is high and stable throughout most of the session; however, there is some acceleration in response rate both at the beginning and at the end of the session.

Response rates before test #1 varied widely between subjects (range of approximately 30 to 140 responses per minute) but no consistent differences between groups were noted.

Table 1 shows the mean discrimination ratio (multiplied by 100) for the five sessions preceding test #1 and for the five sessions preceding test #2 for each of the six subjects. No systematic difference between groups appears to exist before either test.

Figure 2 shows the gradients for the first generalization test for the random-schedule group. The values on the ordinate were cal-

Table 1
Mean discrimination ratio X 100 preceding tests #1 and #2

Group	Subject	Mean Discrimination Ratio	
		Preceding Test #1	Preceding Test #2
Random schedule	R-13	77	95
	R-14	76	80
	R-15	83	79
Adjusting schedule	A-13	69	77
	A-14	76	
	A-15	80	90

Fig. 2. Percentage of maximum responses as a function of line angle for the first generalization test for the random-schedule group.

culated by dividing the total number of responses in each stimulus by the number of responses occurring at the maximum; the percentage at the maximum is therefore always 100. Line angle values appear on the abscissa. Broken lines represent, to the nearest approximation, the first one-third of the test, solid lines the last two-thirds. The numbers near the

gradients represent the absolute numbers of responses at maximum for the individual graphs; the upper number applies to the first one-third of the test and the lower number to the last two-thirds of the test. These gradients are irregular in shape. The peaks for the first one-third of the test for R-14 and R-15 are located at 60°, rather than at S+. The peaks of all other gradients are located at S+. Because the response rate decreased rapidly, the test for all random-schedule subjects lasted for less than 1 hr.

The gradients for the first 59.5 min of the first test for the adjusting-schedule subjects are shown in Figure 3. The format is the same as for Figure 2, but the graphs show only the data for the first 59.5 min of the test in order to make the size of the sample more comparable to that of the random-schedule subjects. Both gradients for Subject A-15 show a displacement in the peak from the 45° training S+ to 60°. All remaining gradients have peaks at S+. In general, the gradients are more regular and contain more absolute responses at maximum than those for the gradients for the random-schedule group, but are not qualitatively different. Gradients for the first one-third and last two-thirds of the test resemble one another to a greater extent than those for the random-schedule group.

The gradients for the entire first test for the adjusting-schedule group are shown in Figure 4, again using the same format as Figures 2 and 3. Again, both gradients for A-15 show peaks at 60° while the remaining gradients peak at S+. All of the gradients are quite regular. The first test for each adjusting-schedule subject lasted longer than 2 hr, which is more than twice as long as any first test for the random-schedule subjects.

Table 2 shows the percentage of total responses at the maximum of the gradients obtained from test #1 (Figures 2 through 4). An increase in the percentage from the first one-third of the test to the last two-thirds would indicate steepening of the gradients as a function of time in the test situation. The third column of the table shows the increase (+) or decrease (−) in this measure for each subject. All subjects in the random-schedule group show an increase of 8% or more. No subjects in the adjusting-schedule group show an increase of more than 5% in the first hour of testing; one shows a decrease. During the

Fig. 3. Percentage of maximum responses as a function of line angle for the first hour of the first generalization test for the adjusting-schedule group.

entire test for the adjusting-schedule subjects, none shows an increase of more than 8% and again one subject shows a decrease. Although the difference between groups is not great, the random-schedule subjects show slightly increasing gradient slopes as a function of time in the test while the adjusting-schedule subjects show less steepening or possibly no reli-

Fig. 4. Percentage of maximum responses as a function of line angle for the first generalization test for the adjusting-schedule group.

able steepening at all. The change in the area under the curves in Figures 2 through 4 presents a similar picture; the random-schedule gradients tend to increase slightly in steepness from the first one-third to the last two-thirds of the test and the adjusting-schedule gradients tend to maintain at a more constant steepness. While there is overlap in gradient steepness

Table 2

Percentage of total responses at maximum for first one-third and last two-thirds of test portion.

Group and Test Portion	Subject	% of Total at Maximum		Increase or Decrease in %
		First One-third	Second Two-thirds	
Random schedule—entire test	R-13	29	39	+10
	R-14	42	50	+8
	R-15	24	34	+10
Adjusting schedule—first 59.5 min	A-18	19	24	+5
	A-13	22	27	+5
	A-14	23	25	+2
	A-15	28	26	-2
Adjusting schedule—entire test	A-18	21	23	+2
	A-13	25	23	-2
	A-14	23	31	+8
	A-15	26	30	+4

between the two groups in the first one-third of the test, in the last two-thirds of the test the random-schedule group shows consistently steeper gradients than those for the adjusting-schedule group; this is true for both test portions shown for the adjusting-schedule group.

Figure 5 shows the number of responses at maximum for the random-schedule subjects in the repeated generalization tests. Two of the graphs show a decrease in responses at maximum as a function of repeated testing with fewer than 300 responses at maximum in most later tests. One subject met the criterion for terminating testing after six tests.

Figure 6 presents comparable data for the adjusting-schedule subjects. The two subjects show only slight decreases in response rate. The response rate of these subjects in test #1 (not shown) did not differ a great deal from those rates shown in the remaining tests. In the stimulus at which maximum responding occurred, Subject A-13 responded at a rate of 129 responses per minute in the first hour of test #1 and 111 responses per minute in test #2; a small decrease in responding may be indicated for this subject. Subject A-15 showed an increase in rate, responding at a rate of 109 responses per minute in the first hour of test #1 and 130 responses per minute in test #2. In general, decreases in rate over tests are small or nonexistent; response rates remain higher than those for the random-schedule subjects throughout repeated testing.

Fig. 5. Responses at maximum as a function of the number of tests for the random-schedule subjects. The data point for Subject R-15, test #10 is missing because of a failure in the recording apparatus.

Fig. 6. Responses at maximum as a function of the number of tests for adjusting-schedule subjects.

Figures 7 and 8 show the percentage of total responses at the maximum of the generalization gradient as a function of the number of tests for the random-schedule group and the adjusting-schedule group respectively. This function, again, is a rough measure of the sharpness of the generalization gradients generated in successive tests. An increase in this function indicates a sharpening of the gradients resulting from repeated testing while a decrease indicates flattening. Figures 7 and 8 also show the discrimination ratio (multiplied by 100), for both S—s combined, corresponding to the training sessions alternating with the

tests. Higher ratios indicate finer discriminations.

Comparison of Figures 7 and 8 with Table 1 shows that any major changes in the discrimination ratio, if such changes exist at all, occur before test #2. The ratios for all subjects but R-15 show an increase from the sessions preceding test #1 to the sessions preceding test #2, while subject R-15 shows a small decrease (Table 1). Thereafter, the ratio tends to be constant for all subjects (Figures 7 and 8). Subject A-13's discrimination ratios were somewhat variable. This subject occasionally showed a poorer discrimination ratio for 0°

Fig. 7. Percentage of total responses at maximum for the first one-third and the last two-thirds of the repeated generalization tests for random-schedule subjects. The figure also includes the discrimination ratio (multiplied by 100) for training sessions alternating with the tests. Data points from tests #14, #23, and #24 for Subject R-13, from test #10 for Subject R-15, and from the training session before test #3 for Subject R-15 are missing because of failures in the recording apparatus. All other missing training and test data points are due to the subjects' failures to respond.

than for 90°, which could not be attributed to stimulus sequencing; when this occurred, the deviation also tended to appear in the generalization gradients. Comparison of Figures 7 and 8 with Table 2 shows that generalization gra-

dient steepness changes very little from tests 1 to 2.

Figure 7 shows that, in spite of the fact that the discrimination ratio remains constant, Subject R-13 shows a definite sharpening of the

Fig. 8. Percentage of total responses at maximum for the first one-third and the last two-thirds of the repeated generalization tests for adjusting-schedule subjects. The figure also includes the discrimination ratio (multiplied by 100) for training sessions alternating with the tests. Data points from test #12 for Subject A-15 and from the training sessions before tests #2 and #8 for Subject A-15 are missing because of failures in the recording apparatus.

generalization gradient as a function of test number for both portions of the test, while Subject R-15 shows sharpening for at least the last two-thirds of the test. All random-schedule subjects show a tendency for the gradients in the last two-thirds of the test to be sharper and more variable than those for the first one-third. Figure 8 shows no gradient sharpening, either as a function of time within the test or as a function of test number, for the adjusting-schedule subjects.

To summarize, there seems to be no relationship between changes in the discrimination ratio and changes in gradient sharpness. The adjusting-schedule subjects have constant gradient slopes both within and across tests while the random-schedule subjects consistently show

an increase in gradient slope within tests and some tendency for an increase across tests.

DISCUSSION

The major point of interest is in the performance of subjects trained under a reinforcement schedule in which much longer periods of nonreinforcement occur than is typical. The random-interval-schedule group, with relatively short inter-reinforcement intervals, is used as a "typical" reference point with which the adjusting-interval-schedule group is compared.

The present experiment has shown that, while the long-adjusting-interval schedule produces generalization gradients that are not

qualitatively different from those produced by the more ordinary short-random-interval schedule, the use of the long-adjusting-interval schedule has the following advantages: (1) it produces greater resistance to extinction both within and across generalization tests and (2) it produces more stable gradients within and across tests. This difference is not attributable to differences in the amount of discrimination occurring on training days.

It was found that the adjusting-schedule subjects sometimes tended to develop relatively poor discriminations between the S+ and one of the S—s on training days. One source of the difficulty was in the stimulus sequencing and it is apparent that care must be taken to avoid presenting the reinforcer during an S+ presentation that consistently follows one particular S—. However, stimulus sequencing did not always account for the difficulty. A procedure to deal with this problem might be to return the subject to discrimination training with CRF in the S+, when needed, in order better to maintain the discrimination.

Discrimination training was not an essential part of the training procedure in the present experiment and both groups could just as well have been trained only in the presence of the 45° line. Discrimination training occurred in this case because generalization gradients with slopes greater than zero were desired and, without such training, line-angle generalization gradients are frequently flat. Had, for example, wavelength been used, such discrimination training would probably have been unnecessary. No discrimination training at all need be involved before generalization test #1

and, under the long-adjusting-interval schedule procedure, tests thereafter may involve discrimination training only to the extent that reinforcement may occur once in the presence of one training stimulus every other day and extinction may occur in the presence of several test stimuli on alternate days; this represents a minimal amount of discrimination training. The present results seem to indicate that an increase in discrimination will not occur under these conditions.

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