Postdiscrimination generalization as a function of interresponse time*

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Following 20 sessions of variable-interval 20-sec reinforcement in the presence of a single 45-deg line-tilt stimulus, three pigeons were trained to discriminate between line tilts of 45 deg correlated with variable-interval 20-sec reinforcement and line tilts of 15 deg correlated with extinction. A generalization test along the line-tilt dimension was administered following a criterion discrimination performance. Gradients derived in terms of relative frequency of response as a function of line tilt indicated strong external stimulus control and exhibited clear peak shift. From the interresponse time (IRT) distributions generated for responding to each test stimulus, probability of response conditional upon IRT (IRTs/Op) was derived as a joint function of line tilt and IRT. The IRTs/Op functions for responses following IRTs in 0.2-sec-wide classes from 0.2 to 1.0 sec and for responses following IRTs in the interval of 1.0 to 2.0 sec were similar to the relative generalization gradients and also exhibited peak shift. Few IRTs were greater than 2.0 sec. External stimulus control was established over responses terminating IRTs both longer and shorter than 1.0 sec.

Stimulus control is assessed by measuring the change in response probability that results from a change in stimulus value. The generalization gradient obtained following free-operant, single-stimulus training (Guttman & Kalish, 1956) or discrimination training (Hanson, 1959) shows variation in rate or frequency of response. In the generalization test, response frequency is recorded in each test period (which is typically 30 sec in duration), and responses to the test stimulus are summed over all test periods. The problem with this particular method is that it gives no information about changes in rate of response that might occur within a test period. That is, although there may be variation in interresponse time (IRT), the defining characteristic of rate, such variation cannot be observed without dissecting the gross frequency measure. If there is variation in IRT within the test periods, it is possible that generalization is different for different classes of IRT. In other words, the exteroceptive stimuli control responses which occur after some IRTs, but do not control those responses which occur after other IRTs.

Blough (1963) presents data that suggest that stimulus generalization is different for different IRT classes. The IRT distributions for a pigeon's responses to each of several test wavelength stimuli (obtained following training with one stimulus value) showed that responses terminating short IRTs are the least affected by stimulus value. Blough (1963) concludes that "the gradient is produced mainly by a shift upward of the longer IRTs which leave the time of the short peaks relatively unaffected. It appears, as might be expected, that stimulus control is exerted over the responses following long IRTs; the thing that controls the occurrence of a

response with short IRTs is the preceding response [p. 243]."

Sewell and Kendall (1965) present similar data for a single pigeon tested along the dimension of auditory frequency. Again, it appeared that external stimulus control is exerted only over responses following long IRTs.

A more sensitive method of estimating the probability of response as a joint function of stimulus value and time since preceding response makes use of Anger's (1956) IRTs/Op statistic (Blough, 1969). Anger (1956) argues that because there are more opportunities for short IRTs than for long IRTs, the relative frequency of occurrence of a given IRT should be assessed in relation to the opportunity that the IRT may occur. In a given IRT class interval, the number of opportunities for an IRT is the number of IRTs in that interval plus the number of longer IRTs. Accordingly, the IRTs/Op statistic, or the number of IRTs in a class interval per opportunity in that class interval, estimates "the probability of response between x and y sec after the last response, given that S reaches x sec after the last response [Anger, 1956, p. 149]."

Blough (1969) describes wavelength generalization gradients plotted in terms of the IRTs/Op statistic, for different IRT class intervals. While the wavelength stimuli controlled response probability for IRTs greater than 1 sec, the gradients for IRTs smaller than 1 sec were flat. Thus the earlier conclusion was supported; only responses following long IRTs are controlled by external stimuli. Presumably, responses following short IRTs are controlled by response-produced or proprioceptive stimuli (Ray & Sidman, 1970).

In the experiments of Blough (1963, 1969) and Sewell and Kendall (1965), pigeons were trained to respond in the presence of a single stimulus value before testing for generalization. In the present experiment,

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Fig. 1. Relative line-tilt generalization gradients for individual Ss obtained following discrimination between line tilts of 45 deg (S+) and 15 deg (S-).

two-stimulus discrimination was established by scheduling reinforcement of a pigeon's responses in the presence of one stimulus value (45-deg line tilt) and extinction in the presence of a different value (15-deg line tilt). During subsequent testing for generalization along the line-tilt dimension, IRT distributions were generated. The training and testing procedures were kept as standard as possible (cf. Bloomfield, 1967; Hearst, 1969; Terrace, 1968).

METHOD

Subjects

Three experimentally naive white pigeons (University of Otago Medical School strain), between 1 and 2 years old, were maintained at 80% (± 10 g) of their free-feeding body weights. Water was always available in the individual living cages, and supplementary feeding ensured maintenance of the prescribed body weights.

Apparatus

Electromechanical relay circuitry, which controlled the experimental contingencies, was situated remote from the soundproofed and ventilated experimental chamber. Only one of three response keys of the interface (Grason-Stadler Model E6446-CA) was operative. The 2.0-cm-diam translucent response key was 9.8 cm to the right of center and 23.5 cm from the grid floor. A force of 12 g was sufficient to operate the key. An in-line digital display (Grason-Stadler Model E4580) was mounted behind the key, which could be transilluminated by a single 0.3-cm-wide white line on a dark surround, at any one of seven orientations to the horizontal, 0 to 90 deg in 15-deg steps (Grason-Stadler Stimulus Pattern 168, with brightness relationships reversed). Brightness of the line was 6.9 mV, as measured by an SEI photometer from 19 cm in front of the stimulus. The stimuli provided the only illumination in the dark chamber, except for the magazine light, which signaled 3-sec access to mixell grain. The response key was darkened during presentation. Response feedback was provided by a 33-msec stimulus offset at each response. Responses were recorded on impulse counters. During generalization testing, IRT distributions were generated by a Grason-Stadler multiple class time analyzer.

Procedure

Daily experimental sessions were conducted with each S. In Session 1, one bird (P63) was adapted to the chamber for 30 min, and two birds (P64 and P67) pecked spontaneously at a small black spot that was placed on the center of the key for the first three sessions only. For these two birds, each of 30 pecks in Session 1 was followed by reinforcement. In Session 2, P63 was magazine trained and shaped to keypeck, and each of the three

birds received 30 continuous reinforcements. In Sessions 3-7, responding was continuously reinforced (30 reinforcements per session). Reinforcement duration was always 3 sec.

In Sessions 8-27, responding was reinforced at variable intervals averaging 20 sec (VI 20 sec). The VI tape was constructed from an arithmetic progression employed by Catania and Reynolds (1968, p. 329). In this and other experiments conducted by the writer, cumulative response records indicated that this VI tape produced stable within-session response rates. In Sessions 8-27, 30-sec stimulus-on periods alternated with 10-sec blackout intervals, during which the chamber was dark and responses had no programmed consequence. Each session comprised 20 stimulus-on periods.

In all sessions (1-27) up to this stage, the response key was illuminated by the white line tilted at 45 deg to the horizontal.

Discrimination training began in Session 28. As in the previous single-stimulus training, 30-sec stimulus-on periods alternated with 10-sec blackouts. Responding in the presence of the 45-deg line (S+) was reinforced at variable intervals averaging 20 sec, while responding in the presence of the line tilted at 15 deg (S-) went unreinforced. Session duration was doubled to keep reinforcement density constant; 20 S+ periods alternated in succession with 20 S- periods according to a quasirandom order (Scully, Davies, & Amsel, 1970).

Discrimination training was continued until the relative proportion of responses to S+ was 80% or greater in a single session. On the day following attainment of this criterion, a generalization test was administered. The test was preceded by a "warm-up" on the original discrimination for four S+ and four S- periods; responding in these S+ periods was reinforced according to the previous VI 20-sec schedule. In the generalization test, conducted under conditions of extinction, 30-sec test periods alternated with 10-sec blackouts. During blackouts, the E recorded response frequency and IRT distribution for the preceding test stimulus. Seven blocks of seven test stimuli, from 0 to 90 deg in 15-deg steps, were randomly ordered in a Latin square design. Each bird received a different order of test stimuli.

RESULTS

Two birds (P63 and P67) required four sessions of discrimination training and one bird (P64) three sessions to meet the criterion of 80% responses to S+. The actual response proportions to S+ in the last session of discrimination were 86.51%, 85.05%, and 88.18% for Birds P63, P64, and P67, respectively. Only one bird (P63) showed clear behavioral contrast.

Figure 1 presents the relative generalization gradient for each S. The total numbers of responses made to all seven test stimuli were 906, 1,538, and 2,039 for Birds P63, P64, and P67, respectively. The right-hand column of Table 1 gives the total response frequency to each stimulus. Each point of the gradients in Fig. 1 represents

Table 1
Interresponse Time Frequency Distributions and Total Response Frequency for Different Values of Line Tilt

Line Tilt (Deg)	IRT Class Interval								Response Frequency
	0-0.2	0.2-0.4	0.4-0.6	0.6-0.8	0.8-1.0	1.0-2.0	2.0-3.0	3.0-	
S P63									
0	—	10	16	4	1	6	—	6	47
15	—	—	1	—	1	—	—	—	5
30	—	2	8	2	2	—	—	5	23
45	—	46	74	12	3	4	—	2	145
60	—	111	101	18	11	12	—	1	259
75	—	83	106	18	11	4	—	—	229
90	—	62	93	16	9	10	1	—	198
S P64									
0	—	5	8	1	—	1	—	13	34
15	—	—	2	—	—	—	—	5	12
30	—	11	1	—	2	2	—	26	49
45	—	164	58	14	7	14	1	9	274
60	—	248	79	26	16	5	1	4	385
75	—	297	83	13	16	18	2	2	438
90	—	180	96	11	21	27	1	3	346
S P67									
0	5	30	15	6	10	9	6	12	100
15	—	2	6	2	3	3	2	12	37
30	9	19	8	5	7	16	10	16	97
45	32	295	50	14	14	14	4	6	436
60	23	432	44	11	6	6	5	—	534
75	21	373	76	6	6	9	2	1	501
90	23	170	72	16	16	20	7	3	334

the total responses made to a given test value (in 3.5 min), expressed as a percentage of the total responses to all test values. Such relative gradients minimize individual differences in overall responding.

The gradients in Fig. 1 indicate clear stimulus control along the dimension of line orientation. Furthermore, peak shift is evident in every case; the mode of the gradient is located at some point (60 deg for P63 and P67, 75 deg for P64) other than the original S+ value of 45 deg. Peak shift is often regarded as a typical by-product of discrimination training (Terrace, 1972).

Table 1 presents IRT frequency distributions for responses to each test stimulus. Initially, the IRT distributions were recorded over 15, 0.2-sec-wide class intervals. A 16th class interval contained IRTs longer than 3.0 sec. IRTs in the 1.0- to 3.0-sec intervals were collapsed into two classes: 1.0-2.0 sec and 2.0-3.0 sec. IRTs were measured from the first response in each 30-sec test period; the time before that first response did not contribute towards an IRT. Therefore, the sum of IRTs per stimulus value in Table 1 does not equal the total response frequency per stimulus value (right-hand column). When IRTs were collapsed over all test stimuli, at least 90% of all IRTs for each S were 1.0 sec or smaller. Table 1 shows that there were very few IRTs in the 2.0-3.0-sec class interval. In the 0-0.2-sec interval, there were no IRTs for P63 and P64, and few for P67. Moreover, Table 1 shows that few IRTs were emitted in the presence of the 15-deg line tilt. In the IRT class greater than 3.0 sec, most IRTs occurred for the stimulus values of 0, 15, and 30 deg.

The IRTs/Op statistic was calculated for each test

value and each class interval by dividing the frequency of IRTs in each class interval in Table 1 by the total frequency of these and longer IRTs. If no response was made in a 30-sec test period, as was sometimes the case, the interval was not considered to provide an opportunity for an IRT since there was no response to define the beginning of an IRT. In addition, although the interval between the last response in a test period and the end of the test period sometimes constituted an opportunity for an IRT, it was not counted as such. IRTs/Op in the interval greater than 3.0 sec was always 1.0 (unless there were no IRTs in that interval), and class intervals in which there were no IRTs gave zero IRTs/Op.

Figure 2 shows IRTs/Op as a function of line orientation for each of five class intervals, 0.2-0.4 sec, 0.4-0.6 sec, 0.6-0.8 sec, 0.8-1.0 sec, and 1.0-2.0 sec. There were too few IRTs in the 2.0-3.0-sec interval to construct an IRTs/Op function. The irregularly high IRTs/Op values at 15 deg in the 0.4-0.6-sec and 0.8-1.0-sec classes for P63 can be attributed to the fact that only two IRTs contributed to these data points (see Table 1). Figure 2 shows that, for every IRT class interval, there was clear stimulus control by line orientation. Unlike Blough's (1969) data, these functions do not indicate absence of external control over responding following IRTs smaller than 1.0 sec. More interesting, perhaps, is the fact that most of the functions show a peak shift. In this and other respects, the IRTs/Op functions show close correspondence to the relative gradients of Fig. 1, which plot responding regardless of preceding IRT length.

Fig. 2. Probability of response conditional upon IRT as a joint function of line tilt and interresponse time.

DISCUSSION

The present result indicates that when generalization testing is preceded by discrimination training, stimulus control is established for responses following IRTs shorter than 1.0 sec as well as for responses following IRTs in the 1.0-2.0-sec class. Indeed, that reliable stimulus control functions with nonzero slope were obtained in terms of relative response frequency, coupled with the result that 90% of total IRTs were less than 1.0 sec, suggests that external stimulus control of responding following the very short IRTs is in fact possible. Although it is conceivable that responding was controlled by a certain amount of proprioceptive feedback, it is obvious that the intradimensional discrimination did establish strong external control.

The result of this study suggests a qualification of Blough's (1969) conclusion that "responses terminating IRTs of less than 1 sec will be less affected by stimulus value than by longer IRT responses [p. 97]." Stimulus control over responses terminating IRTs of less than 1.0 sec is at least as strong as the control over responses terminating longer IRTs. However, the present experiment differed from Blough's in several respects.

First, and perhaps most importantly, Blough (1963, 1969) trained his pigeons to respond in the presence of a single stimulus value, whereas the present experiment established two-stimulus discrimination before generalization testing. In the sense that postdiscrimination gradients are sharper than gradients obtained after single-stimulus training (Hanson, 1959; Switalski, Lyons, & Thomas, 1966), discrimination training results in a greater degree of external stimulus control, and possibly in a reduction of internal control (cf. Hearst, Koresko, & Poppen, 1964). Therefore, a wider range of IRTs comes under external stimulus control during discrimination training than in single-stimulus training. In addition, it is likely that responses terminating different IRTs are differentially reinforced during discrimination. That is, the responses following short IRTs in S+ are reinforced, whereas, as discrimination progresses and S- responding decreases to near-zero rates, responses following longer IRTs are associated with extinction in S-. Consequently,

IRTs/Op are high in the region of S+ and low in the region of S- for a relatively wide range of IRT classes (see Fig. 2).

Secondly, the value of the VI schedule employed in the discrimination and prior single-stimulus training of the present experiment was 20 sec, whereas Blough (1963) used a VI 4-min schedule. If, as Reynolds (1963) argues, response rate varies as a function of reinforcement rate, then an overall higher rate of response, and consequently a shorter mean IRT, are associated with the VI 20-sec schedule. Moreover, single-stimulus training with a VI 4-min schedule results in an overall flatter generalization gradient than does training with a VI 30-sec schedule (Hearst, Koresko, & Poppen, 1964). This result may also apply to postdiscrimination generalization, although the appropriate evidence is as yet unavailable.

Other differences between the previous and present experiments may have contributed to the different results. For example, Blough (1969) introduced a 0.6-sec response-contingent blackout in order to eliminate the very short IRTs, and reinforced the least frequent IRTs during training. Nevertheless, it is difficult to specify exactly what influence these factors would have on the degree of external control exerted over responses terminating different IRTs without further experimentation.

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