JOURNAL OF THE EXPERIMENTAL ANALYSIS OF BEHAVIOR 1980, 34, 263-272 NUMBER 3 (NOVEMBER)

LOCAL CONTRAST AND MAINTAINED GENERALIZATION

JOHN M. HINSON AND JOHN C. MALONE, JR.

DUKE UNIVERSITY AND THE UNIVERSITY OF TENNESSEE, KNOXVILLE

Pigeons received variable-interval reinforcement for key pecking during presentations of horizontal and vertical line-orientation stimuli, while pecks during five intermediate orientations were extinguished. Lowest peck rates were observed during presentations of negative stimuli adjacent to the positive orientations while peck rate during 45 degrees (the intermediate negative orientation) was relatively high, i.e., there were negative contrast shoulders. When peck rates were manipulated in the positive orientations, peck rate in neighboring orientations changed in the opposite direction. Contrast shoulders faded after prolonged training. A second type of contrast, local contrast, was correlated with similarity of preceding stimulus and different average peck rates during different stages of the discrimination process. The data suggest that sequential local contrast accompanying the formation of a discrimination contributes to the form of generalization gradients. Blough's model of stimulus control predicts the changes in gradient form described here, but may not accurately depict the underlying processes responsible for gradient form.

Key words: local contrast, dimensional contrast shoulders, maintained generalization, line orientation, key peck, pigeons

Stimulus generalization is a key explanatory concept in psychology. Hull (1943) and Spence (1936, 1937), as well as Skinner (1938), included generalization as one of the cornerstones of conditioning along with primary and secondary reinforcement. Spence's durable model for discrimination learning most fully exploits the concept of stimulus generalization. This model hypothesizes that an algebraic summation of underlying generalization gradients of excitation and inhibition around reinforced and nonreinforced stimuli is sufficient to explain phenomena characteristic of discrimination learning, such as transposition.

Spence's model, which uses stimulus generalization as its explanatory principle, stresses the static aspects of stimulus control. This emphasis is reflected in common techniques for assessing stimulus control, such as the method introduced by Guttman and Kalish (1956). The Guttman-Kalish technique consists of using stimulus pretraining with reinforcement, followed by a test. During the test, several stimulus values appear along with the training value(s), and reinforcers are not available for responding to any stimuli. The test stimuli are supposed to act as probes to reveal the form of the underlying generalization gradient. Individual empirical gradients can be mapped in this way to allow predictions about the form of responding under different pretraining conditions.

Data derived from this extinction-test procedure suggest the inadequacy of Spence's model. The most notable findings are the absence of hypothesized additivity of underlying gradients in the empirical postdiscrimination gradient (e.g., Honig, Thomas, & Guttman, 1959; Kalish & Guttman, 1957; 1959) and the presence of positive and negative peak shift (e.g., Guttman, 1965; Hanson, 1959). Although ad hoc gradients can be devised to fit many cases, findings from the extinction-test procedure place severe limitations on the usefulness of Spence's model (e.g., Hanson, 1959). The virtues and failings of Spence's model are detailed in Mackintosh (1974) and Rilling (1977).

As opposed to the Guttman-Kalish technique, which is designed to reveal the form

---

This research was supported by grant number MH-29774 from the National Institute of Mental Health to John C. Malone, Jr. We thank Norman Guttman and J. E. R. Staddon for their helpful comments. Reprints may be obtained from J. M. Hinson, Department of Psychology, Duke University, Durham, North Carolina 27706, or J. C. Malone, Department of Psychology, University of Tennessee, Knoxville, Tennessee 37916.

of static underlying generalization gradients, the maintained generalization procedure, first used by Pierrel (1958), provides an approach to the dynamic processes underlying stimulus control. The maintained generalization procedure involves daily sessions in which stimuli correlated with various conditions of reinforcement are successively presented. This procedure allows tracking of empirical gradients over time, permitting firmer inferences concerning the *development* of stimulus control than is possible with massed-extinction tests (see Blough, 1969; Malone, 1974; Malone & Staddon, 1973).

Using a maintained generalization procedure, Reynolds (1961) presented pigeons with several positive and negative stimuli drawn from a stimulus continuum obtained by rotating an isosceles triangle. The response rates of the birds were typically highest during positive stimuli adjacent to negative stimuli, and lowest during negative stimuli adjacent to the positive set. Analogous results have been reported by Catania and Gill (1964) using a column of lamps as a stimulus continuum, Farthing (1974) and Malone (1975) using a line-tilt continuum, and Blough (1975) using a hue continuum. These "contrast edge effects" or "dimensional contrast shoulders" (Essock & Blough, 1977) are similar to peak shift and do not follow in a straightforward manner from Spence's model (cf. Farthing, 1974; Malone, 1975).

In addition to dimensional contrast shoulders, maintained generalization procedures have also revealed the presence of local (transient) contrast (Malone & Staddon, 1973; Nevin & Shettleworth, 1966). Local contrast refers to the sequential after-effects of stimuli presented in successive-discrimination procedures. Positive local contrast is enhanced responding during a stimulus when it is preceded by a stimulus correlated either with less frequent reinforcement or with a lower overall rate of responding. The symmetrical effect, i.e., negative local contrast, is suppressed responding, relative to baseline, when the preceding stimulus is correlated either with more frequent reinforcement or with a higher overall rate of responding. Both effects may be large, doubling or halving baseline response rate as a function of stimulus sequence. Local contrast is pervasive in discrimination learning (e.g., Mackintosh, 1974); it represents the operant analogue of Pavlovian induction (Malone, 1976).

Given the inadequacy of Spence's static model to explain phenomena such as dimensional contrast shoulders, and given the pervasiveness of dynamic phenomena such as local contrast, it is prudent to investigate the relationship between local contrast and dimensional contrast shoulders. The experiment described below investigated changes in the form of the maintained generalization gradient and local contrast during the development of a discrimination along a line-tilt continuum.

Pigeons' key pecks were reinforced only during two extreme orientations and extinguished during five intermediate orientations. Local contrast among the negative stimuli followed the pattern that would be expected if each stimulus had been correlated with a different reinforcement frequency, instead of the same (zero) frequency. Transitions from a stimulus maintaining a higher average peck rate to a stimulus maintaining a lower rate resulted in negative local contrast, whereas transitions from a stimulus maintaining a lower peck rate to a stimulus maintaining a higher peck rate resulted in positive local contrast, despite equivalent reinforcement conditions.

The form of local contrast changed in orderly ways during training. Early in training, local contrast in negative stimuli was *stimulus-specific* (cf. Malone & Staddon, 1973); that is, the magnitude of local contrast varied directly with similarity of orientation. The greatest suppression occurred when the preceding stimulus was most similar. Later in training, the direction and magnitude of local contrast were determined by average response rates. During this period of training, negative contrast shoulders appeared. After extended training, local contrast disappeared as did the negative contrast shoulders. Thus, changes in local contrast paralleled changes in the form of the overall gradients.

METHOD

Subjects

Six White Carneaux pigeons were reduced to 80% of their free-feeding weights. All birds had several months' prior experience pecking white keys on the wall and floor of a different chamber, with reinforcement provided by fixed-ratio, differential-reinforcement-of-low-rates, or differential-reinforcement-of-other-behavior schedules. This unpublished research did not involve discrimination training among stimuli or between spatial location of keys. One bird was dropped from the present experiment for failure to show stable baseline responding.

Apparatus

The experimental chamber was a 33 by 33 by 40 cm steel and Plexiglas box enclosed in a larger soundproof box. A Grason-Stadler stimulus projector mounted behind the transparent pecking key provided line-orientation stimuli. The key was centered over a 3 by 2.4 cm magazine aperture. Reinforcement consisted of 3-sec access to mixed grain. During reinforcement the 6-W houselight and the stimulus on the key were extinguished. The soundproofed box and a large ventilation fan masked extraneous noises. Programming and recording equipment was in an adjacent room.

Procedure

Seven line-orientation stimuli (0° [horizontal], 15°, 30°, 45°, 60°, 75°, and 90° [vertical]) appeared during successive 30-sec presentations. Pecking during 0° and 90° was reinforced according to a variable-interval (VI) 30-sec schedule; pecking during all other stimuli was extinguished. Each session consisted of 108 stimulus presentations arranged in eight blocks. At the end of each block the keylight was turned off. During these dark-key components, responding was never reinforced and each peck reset a 30-sec timer that controlled the duration of the component. This procedure was used to facilitate control by line stimuli on the key; all animals stopped responding during the dark-key components within two sessions. The line stimuli were arranged randomly within blocks with the restriction that each stimulus precede all stimuli, including itself, approximately equally often. Some stimuli appeared more often than others. Line tilts 0°, 15°, 30°, and 60° appeared daily in 16 components while 45°, 75°, and 90° appeared in 14 components. One of the former four stimuli always preceded the dark-key components. Due to the large number of components and their quasi-random order, the animals showed no discrimination of this difference. The stimulus sequence remained unchanged throughout all conditions of the experiment.

The order of conditions was as follows:

Condition I. (Sessions 1-32) All stimulus presentations lasted 30 sec and each stimulus preceded itself and all other stimuli twice.

Condition II. (Sessions 33-47) Components of 0° were shortened to 10 sec and components of 90° were lengthened to 50 sec. This manipulation was based on the finding that decreasing the duration of a VI component increased key-peck rate in that component (Hinson, Malone, McNally, & Rowe, 1978; Shimp & Wheatly, 1971). Pecks in 0° and 90° were still reinforced according to VI 30-sec. Pecks during all other stimuli continued to be extinguished; the duration of the extinction components remained 30 sec.

Condition III. (Sessions 48-149) The duration of all stimuli was returned to 30-sec, as in Condition I.

The main dependent variable was pecking rate during presentations of the nonreinforced stimuli. Condition II, in which the durations of the two reinforced components were changed in opposite directions, was intended to determine the effect of changed average response rates during the reinforced components on peck rates in the extinction stimuli.

RESULTS

Condition I. Figure 1 shows data for individual birds. For each bird, the upper left panel represents maintained generalization gradients averaged across five days of training for Condition I (days 28-32) and Condition III (days 73-77). In Condition I, Birds 52 and 67 pecked about equally in the VI stimuli 0° and 90°, Bird 61 pecked more rapidly in 90° than in 0°, while Birds 57 and 66 pecked more rapidly in 0° than 90°; the only large difference between 0° and 90° was 34 pecks/min for Bird 66. Peck rates for all birds in the negative stimuli, 15°, 30°, 60°, 75°, generally decreased with increasing angular difference from the VI orientations. The most striking feature of these gradients was the relative peak in response rate at 45°, the negative orientation equidistant from the positive pair. This peak in the gradient represents a *negative contrast shoulder*.

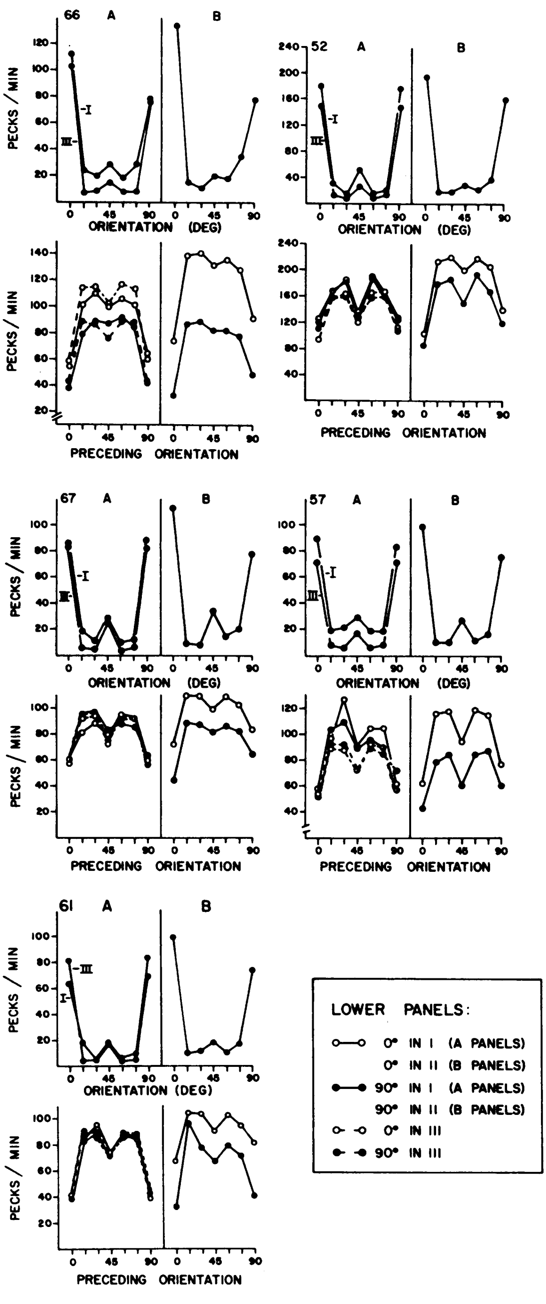

Fig. 1. For each bird, the upper two panels display maintained generalization gradients over Conditions I, II, and III, and the lower two panels display response rate in the first 10 sec of 0° and 90° as a function of the preceding stimulus, corresponding to the upper panels. See text for details.

Below the overall gradients of Figure 1 are displayed peck rates during the first 10 sec of the positive components, 0° and 90°, as a function of the preceding component. (See the legend in Figure 1.) This representation maximizes the effect of local contrast, which is usually most evident during the initial part of the component. For all birds, local contrast functions mirrored generalization gradients of average response rate, being M-shaped where the overall gradients were W-shaped.

Condition II. Shimp and Wheatley (1971), Todorov (1972), and Hinson et al., (1978) found that the VI response rate could be increased by decreasing the duration of the VI component. Condition II examined changes in maintained generalization gradients and local contrast when 0° was shortened to 10-sec components and 90° was lengthened to 50-sec components.

In Figure 1, the upper right panel for each bird shows the maintained generalization gradient averaged over the last five sessions of Condition II. Peck rate increased for all birds during the shortened VI stimulus, 0°; it changed little, or decreased slightly, during the lengthened VI stimulus, 90°. Increases in 0° ranged from a low of 10 pecks/min for Bird 57 to a high of 30 pecks/min for Bird 66. The degree of increase was not correlated with baseline peck rate.

The lower right panels of Figure 1 again represent peck rate in the first 10 sec of 0° and 90° as a function of the preceding stimulus. Peck rate in 0° was generally elevated relative to Condition I, regardless of the preceding stimulus. An important change during this condition is in the relative standing of 15° (nearest to 0°) and 75° (nearest to 90°). For 4 of 5 birds, in succeeding 0° components, the 15° components produced slightly greater positive local contrast, relative to 75°, than they did in Condition I. Analogous, though smaller, changes in positive local contrast occurred in 90°. As in Condition I when response rates stabilized, so in Condition II average peck rate in the preceding stimulus well predicted the magnitude of positive local contrast; this was exemplified in the effects that 15° and 75° produced in the positive stimuli that followed them.

Condition III. Component durations in 0° and 90° were changed back to 30 sec as in Condition I. The upper left panels in Figure

1 show maintained generalization gradients for this period. These gradients show about the same relationships among stimuli as in Condition I, but absolute response rates in the extinction stimuli were lower. The functions describing local contrast in 0° and 90° in Condition III (lower left panels; see legend) were like those found in Condition I. Magnitude of positive local contrast was, again, well predicted by average peck rate in the preceding stimulus. As in Condition I, the different negative stimuli affected gradient form as would stimuli correlated with different frequencies of reinforcement. The relative peak in response rate in 45° was correlated with less positive local contrast in 0° and 90° components that followed 45° than in VI components that followed other extinction stimuli. Thus the increased peck rate in 45° functioned comparably to an increase in reinforcement to reduce the magnitude of positive local contrast in the ensuing VI components.

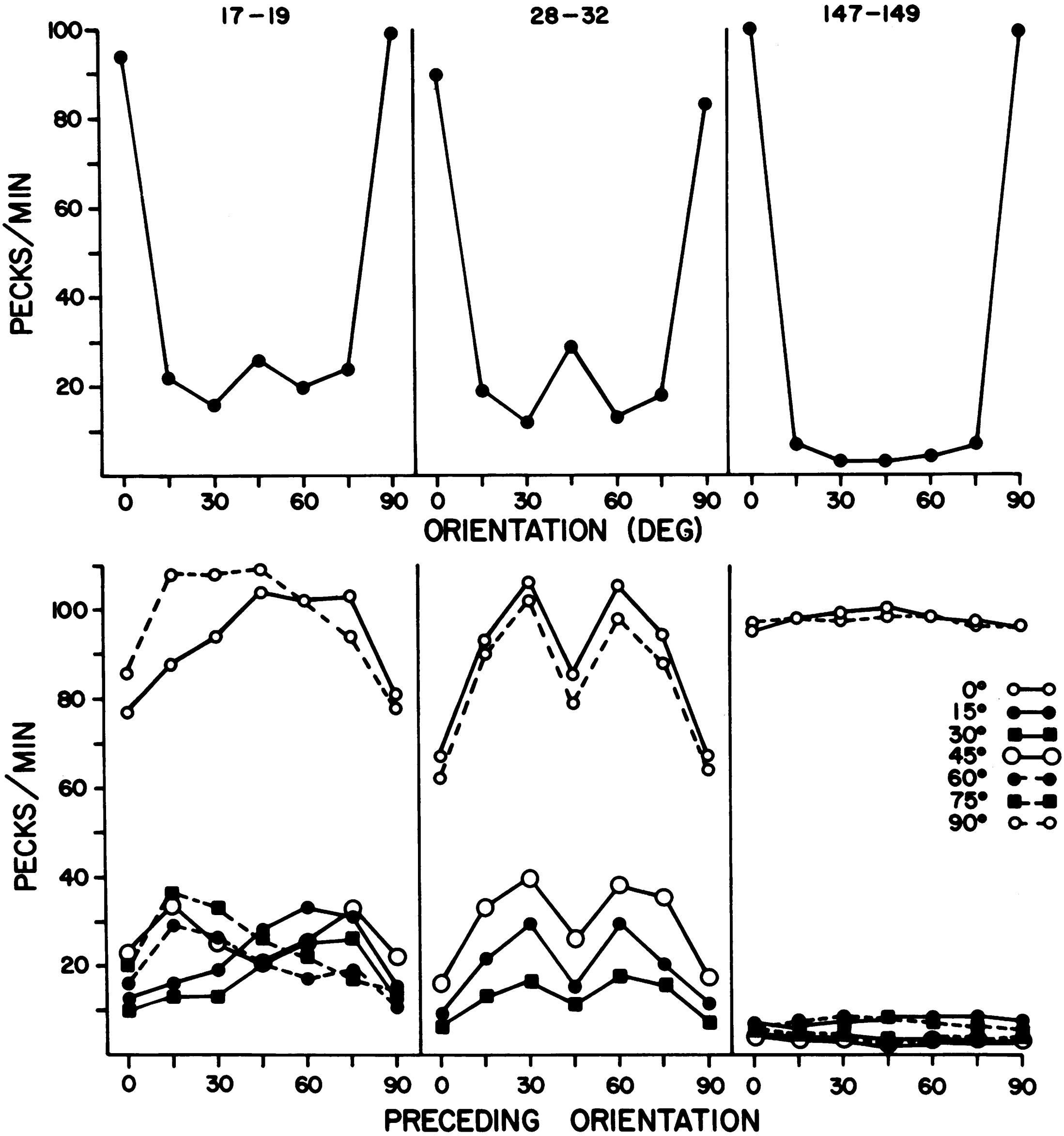

Fig. 2. Upper panels display maintained generalization gradients for the days indicated averaged across all animals. Lower panels display response rate for each stimulus as a function of the preceding stimulus, corresponding to the upper panels. See text for details.

Table 1
Response rate in each stimulus as a function of the preceding stimulus over Days 17 to 19 of Condition I in Experiment I. See text for details.

	Following Stimulus								*Following Stimulus*						
Preceding Stimulus	*0°*	*15°*	*30°*	*45°*	*60°*	*75°*	*90°*	*Preceding Stimulus*	*0°*	*15°*	*30°*	*45°*	*60°*	*75°*	*90°*
Bird 52								*Bird 57*							
0°	130	6	7	16	16	20	134	*0°*	68	16	12	27	24	36	81
15°	167	12	13	30	31	37	186	*15°*	66	21	13	26	42	48	90
30°	179	18	14	24	29	36	184	*30°*	75	26	12	24	34	38	89
45°	180	34	29	18	29	30	185	*45°*	95	39	21	20	21	26	89
60°	181	36	32	20	22	24	180	*60°*	96	48	29	22	12	28	86
75°	182	32	33	27	20	18	164	*75°*	94	44	23	28	18	20	72
90°	134	8	8	14	12	11	129	*90°*	79	17	14	26	10	24	66
Bird 61								*Bird 66*							
0°	53	8	3	27	8	12	56	*0°*	59	10	15	21	16	8	63
15°	57	10	4	32	20	29	73	*15°*	64	18	23	47	38	30	98
30°	62	14	5	24	23	28	75	*30°*	69	22	17	34	34	29	98
45°	68	20	12	20	18	24	74	*45°*	72	25	20	29	28	24	96
60°	70	25	18	28	14	18	70	*60°*	70	28	26	36	24	19	92
75°	72	23	22	38	18	12	65	*75°*	73	27	28	43	29	17	88
90°	50	8	6	25	5	7	52	*90°*	55	12	10	23	22	10	73
Bird 67								*Average Five Birds*							
0°	74	25	14	23	14	22	94	*0°*	77	13	10	23	16	20	86
15°	84	21	12	35	14	38	93	*15°*	88	16	13	34	29	36	108
30°	85	13	17	21	11	33	96	*30°*	94	19	13	25	26	33	108
45°	104	20	16	20	11	27	101	*45°*	104	28	20	21	21	26	109
60°	95	28	21	19	12	22	86	*60°*	102	33	25	25	17	22	102
75°	92	27	24	31	11	18	79	*75°*	103	31	26	33	19	17	94
90°	87	28	25	24	7	20	70	*90°*	81	15	13	22	11	14	78

Extended training. The major feature of the generalization gradients of Figure 1 was the relative peak in response rates at 45°; this feature of the gradients was still apparent after 80 sessions. With further training, this peak diminished and U-shaped gradients appeared (see Figure 2). Just as local contrast mirrored the gradient form in the earlier conditions, so with extended training, local contrast disappeared when U-shaped gradients appeared.

The parallel course of development of gradient form and local contrast suggests several possibilities. Local contrast could be caused by dimensional contrast shoulders evident in the global gradient, or both could be due to another discriminative process. A third possibility is that local contrast produces the global gradient form. To evaluate this third suggestion, data from three different periods in training are presented in Figure 2. The upper panels represent maintained generalization gradients averaged across all birds for days 17-19 (before response rates had stabilized), days 28-32 (a period of stable gradient form), and days 147-149 (extended training and eventual gradient form). (Bird 67 was discontinued after 90 sessions due to illness.) The lower panels of Figure 2 present peck rate in each stimulus as a function of the preceding stimulus for the training period indicated. Tables 1-3 contain local contrast data for individual birds over the same periods.

In the first panel of Figure 2 (early in training), the W-shape is just beginning to appear in the overall gradient, and at this stage all birds showed local contrast that was *stimulus-specific,* i.e., similarity in angle between preceding and current stimulus best predicted the magnitude of local contrast. For example, peck rates in 15° or 30° and in 60° or 75° were low when the preceding negative stimulus was similar (15°, 30° and 60°, 75°, respectively) and much higher when the preceding stimulus was more distant. When the preceding stimulus was one of the VI pair, 0° or 90°, peck rate was consistently lower. It is possible that in the case of preceding VI components the effect of similarity was outweighed by some inhibitory after-effect of food

Table 2

Response rate in each stimulus as a function of the preceding stimulus averaged over the last five days of Condition I in Experiment I. See text for details.

		Following Stimulus									*Following Stimulus*						
		0°	*15°*	*30°*	*45°*	*60°*	*75°*	*90°*			*0°*	*15°*	*30°*	*45°*	*60°*	*75°*	*90°*
	Bird 52									*Bird 57*							
Preceding Stimulus	*0°*	120	12	10	25	14	12	122	*Preceding Stimulus*	*0°*	60	8	5	15	10	13	58
	15°	155	30	16	51	22	28	157		*15°*	85	23	12	34	22	20	91
	30°	179	43	22	61	28	47	179		*30°*	103	29	17	45	30	37	96
	45°	124	21	15	42	17	19	113		*45°*	79	14	9	20	16	12	80
	60°	180	46	29	64	24	43	178		*60°*	90	20	14	31	25	36	81
	75°	154	32	24	54	19	25	148		*75°*	81	18	12	30	21	18	77
	90°	123	14	10	22	9	10	121		*90°*	60	10	4	17	12	9	57
	Bird 61									*Bird 66*							
Preceding Stimulus	*0°*	39	8	2	10	3	4	35	*Preceding Stimulus*	*0°*	58	8	6	16	10	13	42
	15°	68	17	6	17	6	7	76		*15°*	90	21	17	27	17	31	71
	30°	79	22	7	23	8	12	78		*30°*	93	25	22	28	20	33	81
	45°	66	13	2	16	4	7	56		*45°*	84	17	19	24	15	38	69
	60°	78	24	6	24	8	12	73		*60°*	96	27	24	30	23	32	78
	75°	67	12	7	25	9	10	72		*75°*	92	15	19	26	20	26	68
	90°	36	7	2	8	2	3	40		*90°*	62	12	12	18	13	11	41
	Bird 67									*Average Five Birds*							
Preceding Stimulus	*0°*	57	9	6	13	7	8	54	*Preceding Stimulus*	*0°*	67	9	6	16	9	10	62
	15°	68	16	12	34	10	10	77		*15°*	93	21	13	33	15	19	90
	30°	77	27	14	38	15	19	76		*30°*	106	29	16	39	20	30	102
	45°	70	12	10	28	8	7	77		*45°*	85	15	11	26	12	15	79
	60°	82	28	14	39	12	14	82		*60°*	105	29	17	38	19	25	98
	75°	74	25	15	39	12	10	79		*75°*	94	20	15	35	16	18	88
	90°	56	10	5	18	4	5	61		*90°*	67	11	7	17	8	8	64

delivery itself. (We were unable to separate extinction components on the basis of whether the preceding VI component did or did not have a food delivery. However, the account is plausible since ordinal ranking of peck rate in extinction stimuli preceded by VI stimuli was correlated with similarity.) In any case, peck rate in the extinction stimuli was strongly affected by the similarity of the preceding orientation.

Consider the local contrast curves for 15° and 30°, and for 60° and 75° early in training. The curves for 15°/30° increase as they approach 90°; the curves for 60°/75° increase as they approach 0°. Each of these pairs presents half of an M-shape, reflecting increasing distance from 0° (15°/30° curves) or from 90° (60°/75° curves). The curve for 45° approximates their summation; the end points are not as low and there is an elevation on either side of 45°. The 45° stimulus thus appears to be at an optimal distance to benefit from dissimilarity from both 0° and 90°. Since local contrast at this stage of training is best predicted by similarity, it is plausible to argue that the peak in response rate at 45° in the global gradient is produced by local contrast during the formation of the discrimination.

During the period of training represented in the second panels of Figure 2, response rates have stabilized and the gradient form shows little visible change for weeks. At this point, as noted earlier, local contrast is no longer predicted by similarity of preceding stimulus, but rather by average response rate. The M-shaped local-contrast curves in the lower middle panel of Figure 2 perfectly mirror the form of the overall gradient above. The higher the peck rate maintained by a stimulus, the lower the rate in the following stimulus. Given that local contrast, based on similarity, had earlier produced the gradient form, local contrast now based on average response rate would serve to maintain the W-shaped gradient.

The third panels of Figure 2 show data from extended training. The upper right panel shows that at this stage, the relative peak at 45° (the negative contrast shoulder) is entirely absent from the generalization gradient. Peck rates in the extinction stimuli are highest in

Table 3
Response rate in each stimulus as a function of the preceding stimulus averaged over the last three days of training in Experiment I. See text for details.

	Following Stimulus						
Preceding Stimulus	0°	15°	30°	45°	60°	75°	90°
Bird 52							
0°	130	7	5	6	5	6	128
15°	135	3	4	3	5	4	132
30°	134	4	4	3	4	7	133
45°	135	4	3	3	3	6	130
60°	131	6	3	4	3	6	129
75°	131	6	4	4	2	5	128
90°	132	7	6	6	6	5	131
Bird 61							
0°	78	7	2	3	2	6	82
15°	82	7	3	2	2	8	83
30°	83	8	3	2	2	8	80
45°	82	9	2	1	2	9	83
60°	79	8	2	2	1	7	84
75°	79	10	2	2	2	8	81
90°	79	7	2	3	4	7	80
Bird 57							
0°	80	8	4	3	5	6	85
15°	83	10	5	3	5	7	84
30°	85	11	5	3	4	9	83
45°	86	10	5	3	5	9	84
60°	84	10	6	2	3	8	86
75°	84	9	4	4	6	7	87
90°	79	7	3	2	3	7	85
Bird 66							
0°	90	4	3	4	2	6	92
15°	92	5	3	4	2	7	91
30°	94	7	3	3	4	7	91
45°	95	3	2	2	3	7	93
60°	96	7	2	2	3	6	93
75°	95	6	3	2	2	4	89
90°	93	5	2	2	4	4	89
Average Five Birds							
0°	95	7	4	4	5	7	97
15°	98	6	4	3	4	7	98
30°	99	7	4	3	4	8	97
45°	100	8	3	2	3	8	98
60°	98	8	3	3	3	7	98
75°	97	8	3	3	3	6	96
90°	96	7	3	3	4	5	96

15° and 75°, the stimuli most similar to the VI pair, although the absolute rates in all extinction stimuli are consistently low. The lower right panel also shows that local contrast is absent. There is no longer a discernible effect of the preceding stimulus on the peck rate in subsequent stimuli.

DISCUSSION

These data add to previous accounts showing that the formation of a discrimination is not adequately described by the Spence model or by any account that assumes discrimination learning depends simply upon interacting static gradients of excitation and inhibition. Over the period of training described here, the most striking features of behavior were dimensional contrast shoulders and local contrast.

Blough (1975) has proposed a dynamic model of stimulus control that couples a psychophysical similarity function, akin to the Spence generalization gradient, with a variation on the Rescorla-Wagner model of conditioning (Rescorla & Wagner, 1972). Blough specifically designed his model to account for dimensional contrast shoulders. In fact, in computer simulations we have found that with appropriate choice of parameter values, many of the results reported here fit Blough's model, including the eventual disappearance of dimensional contrast shoulders. Blough's dynamic model explains what the classic Spence model cannot. We shall not discuss the model in detail, since our aim is neither to refute nor confute the model. However, a shortcoming of the model worth mentioning is that it is essentially an "outcome" model that may not accurately reflect the processes leading to these outcomes. Blough's model does not yield the local contrast effects described here. Further, Blough's (1975) failure to simulate the *magnitude* of dimensional contrast shoulders by parameter manipulation may well be due to failure to recognize the contribution of local contrast. Similarly, earlier suggestions (e.g., Catania & Gill, 1964; Malone & Staddon, 1973) that a "neural-unit" model fashioned on the formal processes described by Bekesy

(1967) might account for data such as these are also called into question by the time-dependent nature of local contrast.

Farthing (1974) reported dimensional contrast shoulders using a line-orientation continuum. His pigeons pecked at the highest rates during VI stimuli bordering a set of extinction values. Negative shoulders did not appear, probably owing to a floor effect, since key pecking to all extinction stimuli was extremely low. The positive contrast shoulders persisted for over two months, but after 60 to 80 sessions they were displaced by Spencian gradients; the highest peck rates then occurred in VI stimuli most distant from the extinction set. Catania and Gill (1964) similarly found that their contrast shoulders faded with continued training but they were able to reinstate them in several ways, all of which rendered the discrimination more difficult. For example, the dimensional-contrast effects returned if a plastic plate covered the 16 lamps that served as a stimulus continuum, thus making them less discriminable.

Why should contrast shoulders fade with training and why should obscuring the stimuli restore them? Perhaps low stimulus discriminability leads to local contrast, which in turn produces contrast shoulders. Malone (1976) found that local contrast that had disappeared would return if the stimuli were made more similar and thus less discriminable. He suggested that this could account for the occasional indefinite persistence of induction which puzzled Pavlov (1927).

The crucial question is whether local contrast produces contrast shoulders, accentuates differences produced in other ways, or is merely the outcome of the same discriminative processes that produce contrast shoulders. Our data show that early in training local contrast is *stimulus-specific;* that is, the magnitude of local contrast is greatest when the preceding stimulus is most similar to the current stimulus. This stimulus-specificity may account for decreased response rate in extinction stimuli adjacent to a VI stimulus. Though local contrast sometimes depends on stimulus similarity (e.g., Mackintosh, 1974; Malone, 1976), it was not previously known to depend on the stage of training. (Malone's [1976] effects were present after prolonged training, but the discrimination was a difficult one.) Given that the form of the gradient (contrast shoulders) had already been determined by local contrast, later in training that form would be maintained and accentuated by local contrast that is dependent upon average response rates. Why local contrast should act in this time-dependent manner is a question still to be answered.

The data presented here argue for the importance of sequential processes in determining overall gradient form in maintained-generalization procedures. The importance of sequential effects has also been noted in several studies employing the Guttman-Kalish technique. For example, Honig et al. (1959) found that massed extinction of responding during a stimulus in discrimination training was insufficient to produce peak shift, and Donahoe, McCroskery, and Richardson (1970) reported that mixed presentations of positive and negative stimuli were necessary to produce peak shift. These authors suggested that Pavlovian induction (i.e., local contrast) is important in discrimination learning. Further, Ellis (1970) concluded that discrimination training must include stimulus sequences of positive stimuli preceded by negative stimuli in order for peak shift and contrast to appear in the post-discrimination gradient. Ellis went on to suggest that sequential dependencies could be incorporated into Bush and Mosteller's (1955) linear operator model (the basis of the Rescorla-Wagner and Blough models) by using different operators for different sequences of stimuli.

If Blough's model were extended to take local contrast into account it would become more similar to Konorski's (1948) model for discrimination learning. Konorski explained Pavlovian induction (which is analogous to local contrast) by assuming the existence of "subliminal reflexes" dependent upon shared elements of CS+ and CS−. In brief, presentation of a CS+ elicited tendencies both to respond and not to respond. This "subliminal" tendency not to respond found expression during a subsequent CS−, leading to suppressed responding. A similar sublimal CS+ response during CS− was held to produce enhanced responding during the following CS+. Such subliminal tendencies depended upon response strength associated with CS+ and CS− and upon their similarity.

While the Blough model seems useful, a treatment including sequential effects, which may be responsible for overall gradient forms and which, at the least certainly contribute to them, promises a more nearly complete account. This may involve incorporating local contrast into the Blough model, or the development of an independent model based upon sequential effects. In either case, these processes should play an important role in theories of stimulus control.

REFERENCES

Von Bekesy, G. *Sensory inhibition*. Princeton, N.J.: Princeton University Press, 1967.

Blough, D. S. Generalization gradient shape and summation in steady-state tests. *Journal of the Experimental Analysis of Behavior*, 1969, **12**, 91-104.

Blough, D. S. Steady state data and a quantitative model of operant generalization and discrimination. *Journal of Experimental Psychology: Animal Behavior Processes*, 1975, **104**, 3-21.

Bush, R. R., & Mosteller, F. *Stochastic models for learning*. New York: Wiley, 1955.

Catania, A. C., & Gill, C. A. Inhibition and behavioral contrast. *Psychonomic Science*, 1964, **1**, 257-258.

Donahoe, J. W., McCroskery, J. H., & Richardson, W. K. Effects of context on the postdiscrimination gradient of stimulus generalization. *Journal of Experimental Psychology*, 1970, **84**, 58-63.

Ellis, W. R. Role of stimulus sequences in stimulus discrimination and stimulus generalization. *Journal of Experimental Psychology*, 1970, **83**, 155-163.

Essock, S. M., & Blough, D. S. Effects of stimulus spacing on steady state gradients of inhibitory stimulus control. *Animal Behavior and Learning*, 1977, **5**, 174-176.

Farthing, G. W. Behavioral contrast with multiple positive and negative stimuli on a continuum. *Journal of the Experimental Analysis of Behavior*, 1974, **22**, 419-425.

Guttman, N. Effects of discrimination formation on generalization. In D. Mostofsky (Ed.), *Stimulus generalization*. Stanford: Stanford University Press, 1965.

Guttman, N., & Kalish, H. I. Discriminability and stimulus generalization. *Journal of Experimental Psychology*, 1956, **51**, 79-88.

Hanson, H. M. Effects of discrimination training on stimulus generalization. *Journal of Experimental Psychology*, 1959, **58**, 321-334.

Hinson, J. M., Malone, J. C., McNally, K. A., & Rowe, D. W. Effects of component length and of the transitions among components in multiple schedules. *Journal of the Experimental Analysis of Behavior*, 1978, **29**, 3-16.

Honig, W. K., Thomas, D. R., & Guttman, N. Differential effects of continuous extinction and discrimination training on the generalization gradient. *Journal of Experimental Psychology*, 1959, **58**, 145-152.

Hull, C. L. *Principles of behavior: An introduction to behavior theory*. New York: Appleton-Century Co., 1943.

Kalish, H. I., & Guttman, N. Stimulus generalization after equal training on two stimuli. *Journal of Experimental Psychology*, 1957, **53**, 139-144.

Kalish, H. I., & Guttman, N. Stimulus generalization after training on three stimuli: A test of the summation hypothesis. *Journal of Experimental Psychology*, 1959, **57**, 268-272.

Konorski, J. *Conditioned reflexes and neuron organization*. Cambridge: Cambridge University Press, 1948.

Mackintosh, N. J. *The psychology of animal learning*. New York: Academic Press, 1974.

Malone, J. C. The effect of number of stimuli on the steady-state generalization gradient: A test of the summation hypothesis. *Journal of Experimental Psychology*, 1974, **102**, 729-732.

Malone, J. C., Jr. Stimulus-specific contrast effects during operant discrimination learning. *Journal of the Experimental Analysis of Behavior*, 1975, **24**, 281-289.

Malone, J. C., Jr. Local contrast and Pavlovian induction. *Journal of the Experimental Analysis of Behavior*, 1976, **26**, 425-440.

Malone, J. C., Jr., & Staddon, J. E. R. Contrast effects in maintained generalization gradients. *Journal of the Experimental Analysis of Behavior*, 1973, **19**, 167-179.

Nevin, J. A., & Shettleworth, S. J. An analysis of contrast effects in multiple schedules. *Journal of the Experimental Analysis of Behavior*, 1966, **9**, 305-315.

Pavlov, I. P. *Conditioned reflexes: An investigation of the physiological activity of the cerebral cortex*. (G. V. Anrep trans.). London: Oxford University Press, 1927.

Pierrel, R. A generalization gradient for auditory intensity in the rat. *Journal of the Experimental Analysis of Behavior*, 1958, **1**, 303-313.

Rescorla, R. A., & Wagner, A. R. A theory of Pavlovian conditioning: Variations in the effectiveness of reinforcement and nonreinforcement. In A. H. Black & W. F. Prokasy (Eds.), *Classical conditioning II: Current research and theory*. New York: Appleton-Century-Crofts, 1972.

Reynolds, G. S. Contrast, generalization, and the process of discrimination. *Journal of the Experimental Analysis of Behavior*, 1961, **1**, 289-294.

Rilling, M. Stimulus control and inhibitory processes. In W. K. Honig & J. E. R. Staddon (Eds.), *Handbook of Operant Behavior*. Englewood Cliffs, N.J.: Prentice-Hall, 1977.

Shimp, C. P., & Wheatley, K. L. Matching to relative reinforcement frequency in multiple schedules with a short component duration. *Journal of the Experimental Analysis of Behavior*, 1971, **15**, 205-210.

Skinner, B. F. *The behavior of organisms*. New York: Appleton-Century Co., 1938.

Spence, K. W. The nature of discrimination learning in animals. *Psychological Review*, 1936, **43**, 427-449.

Spence, K. W. The differential response in animals to stimuli varying within a single dimension. *Psychological Review*, 1937, **44**, 430-444.

Todorov, J. C. Component duration and relative response rates in multiple schedules. *Journal of the Experimental Analysis of Behavior*, 1972, **17**, 45-49.

Received September 13, 1979
Final acceptance June 13, 1980