CONTRAST EFFECTS IN MAINTAINED GENERALIZATION GRADIENTS¹

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In Experiment I, pigeons were given equal reinforcement (variable-interval 1-min) for responding during randomized presentations of eight line-orientation stimuli. Then, only responding in the vertical orientation was reinforced. Stable generalization gradients soon formed and persistent behavioral and local (transient) contrast effects appeared. Local contrast effects were not a function of relative reinforcement frequency or of any other variable known to produce contrast. Instead, they were related to average response rates associated with each stimulus. Experiment II showed that local contrast effects represent increases and decreases in response rates relative to baseline responding, and that these effects are relative; a given stimulus might enhance responding during a subsequent presentation of one stimulus, but depress responding when followed by another. These data indicate that discrimination learning is not adequately described as the acquisition of excitatory properties by some stimuli and inhibitory properties by others. A more adequate account implies that stimuli exert both excitatory and inhibitory effects related to their value.

A multiple reinforcement schedule is comprised of two or more successively presented components; during each component a specific reinforcement schedule is in effect and a unique stimulus is present. Components may be alternated, randomly presented, or appear according to some other rule. Ferster and Skinner (1957, Chapter 10) stressed the independence of performances under the various components of a multiple schedule, but two forms of interaction among components have recently been reported: behavioral (sustained) contrast and transient contrast.

Behavioral Contrast

Reynolds (1961) demonstrated that overall responding in one component of a multiple schedule varies, depending upon the presence or absence of accompanying components providing more or less frequent reinforcement. Response rate in a variable-interval (VI) com-

ponent increases when the schedule in an alternated component is changed from VI to extinction (EXT) and decreases when this change is reversed. Reynolds called this effect "behavioral contrast", after Skinner (1938, p. 175), and suggested that it depends upon the relative frequency of reinforcement associated with a component. In a subsequent series of experiments employing schedules other than VI, he found the phenomenon to be a general effect accompanying successive discrimination.

Terrace (1963a) showed that behavioral contrast does not occur in a VI component if a special training procedure is used that prevents the occurrence of responding in an accompanying EXT component ("learning without errors"). He argued (1963a, 1963b, 1966) that behavioral contrast is an emotional effect arising from the aversiveness of stimuli correlated with unreinforced responding or simply with a reduction in response rate (*cf.* Skinner, 1938, p. 155).

Neither of these explanations deals adequately with behavioral contrast. Contrast occurs when relative frequency of reinforcement remains constant and other variables are manipulated. For example, contrast appears when response-contingent shock is added to an alternated component (Terrace, 1968) or when the schedule in this component is one that differentially reinforces low re-

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sponse rates (Reynolds and Limpo, 1968; Terrace, 1968). Conversely, contrast cannot be solely determined by the occurrence of unreinforced responding; for example, it appears when a VI component is alternated with time-out periods (Reynolds, 1961; Taus and Hearst, 1970).

Transient Contrast

A second type of interaction reported among components of a multiple schedule has been called "transient contrast" by Nevin and Shettleworth (1966). These authors found that the pattern of responding within one component of a multiple VI schedule was dependent upon the relative reinforcement frequency during the immediately preceding component. When relative reinforcement frequency in the preceding component was lower, responding was initially high and declined during the component. When the preceding component provided a higher relative frequency of reinforcement, responding was depressed at the beginning of the component. They showed that these effects (positive and negative transient contrast) were not dependent upon changes in response rates in a preceding component by reproducing them in the absence of responding in the preceding component.

Nevin and Shettleworth's effects were permanent, appearing at an intermediate stage of training, as were similar effects reported by Boneau and Axelrod (1962). However, these effects have also been reported during asymptotic (*i.e.*, steady-state) performance during multiple fixed-interval schedules (Catania and Gill, 1964; Staddon, 1969a). Staddon called his effects "transient contrast", since the pattern of responding during the FI components resembled the effects described by Nevin and Shettleworth. However, the persistence of the effects during multiple FI suggests that the label "transient" is not really appropriate here.

"Behavioral contrast" refers to changes in overall response rate in components and is measured over sessions. "Transient contrast", on the other hand, refers to a local effect, between successively presented components that may or may not be "transient" across sessions (*e.g.*, it appears to persist indefinitely during multiple FI). Since the effects discussed in the present paper are transient in the first sense

(*i.e.*, local), but not in the second, the term *local contrast* is used for these effects here.

Local (transient) contrast may appear as differences in overall response rate during a component or as differences in the "pattern" of responding during a component. The authors cited above stressed differences in the pattern of responding, but differences in overall response rates were also evident in their data. Local contrast appears in two forms: "positive local contrast", which appears as heightened overall responding *or* as responding that decreases during a component, and "negative local contrast", which appears as depressed overall responding *or* as a pattern of responding that increases during the component.

EXPERIMENT I

The investigation of contrast effects has concentrated on the search for some unique independent variable (*e.g.*, some property of reinforcement schedules) that can account for all instances of contrast. The search has so far been unsuccessful; the first experiment, which shows contrast interactions among components that differ only in the similarity of their associated stimuli to S+, suggests that an alternative approach may be necessary. This experiment assessed both behavioral contrast and local (transient) contrast among presentations of stimuli forming a maintained generalization gradient.

METHOD

Subjects

Six White Carneaux pigeons were maintained at 80% of their free-feeding weight throughout the experiment. Two birds (57 and 58) were experienced with multiple fixed-interval schedules; the remaining four (73, 17, 83, 76) had a varied training history.

Apparatus

The experimental chamber was a 13 by 13 by 13 in. (33 by 33 by 33 cm) box with a 0.6 in. (1.9 cm) translucent key mounted on one wall. A line orientation produced by a Tektronix Model 503 Oscilloscope was visible on the key. A lens with a focal length of 1 in. (2.54 cm) was mounted between the oscilloscope face and the key. It focused the image on the key. (The image was a line

orientation approximately 1.3 cm long and 0.5 mm wide as it appeared on the key.) The animal chamber and two-thirds of the oscilloscope were enclosed by a larger box 20 by 20 by 48 in. (51 by 51 by 122 cm) comprised of hollow 2 in. (5 cm) thick walls filled with sound-proofing materials. Reinforcement (3-sec access to mixed grain) was provided by a food magazine; the 2 by 2 in. (5 by 5 cm) aperture was located 2 in. (5 cm) below the key. The key display was extinguished during reinforcement but the 15-W fluorescent houselight remained lit. White noise and a ventilation fan masked extraneous noises; scheduling and recording equipment were located in an adjacent room.

Procedure

After one session of magazine and key training, training on the first condition began. Sessions consisted of presentations of eight line-orientation stimuli: 90° (vertical line), 78°, 66°, 54°, 42°, 30°, 18°, and 6°. Presentations lasted 1 min and were arranged in a fixed sequence of five blocks of 10, randomized within blocks. During each block, 90° appeared three times and each other orientation appeared once. In this experiment, no attempt was made to control for sequential relationships among presentations; *i.e.*, a given stimulus presentation was preceded and followed by whatever stimuli were dictated by the random sequence. Therefore, each stimulus was not necessarily preceded by every other stimulus. To facilitate control by stimuli on the key, "no-stimulus" periods appeared at the end of each block of stimuli. During these periods, pecking was never reinforced with food and no stimulus was present on the key. The length of the period was determined by a timer that reset with each key peck, thus prolonging the length of the period. The timer setting was initially 5 sec; this setting was increased to 20 sec during the first few sessions. It remained at this setting throughout the experiment. After a few sessions, responding during "no-stimulus" periods was negligible. The experiment consisted of two conditions.

1. VI-VI: Responding in all orientation stimuli was reinforced according to a VI 1-min schedule; the sequence of interreinforcement intervals was

based on the progression suggested by Flesher and Hoffman (1962).

2. VI-EXT: Responding was reinforced according to VI 1-min only when the 90° (vertical) orientation was present.

The number of sessions under each condition is shown in Table 1.

Table 1
Training Conditions

	Birds 57 and 58	Birds 73, 17, 83, and 76
VI-VI	22 sessions	23 sessions
VI-EXT	91 sessions	24 sessions

RESULTS

Only the data from the last five days of VI-VI and of VI-EXT are described here. The VI-EXT period represents VI-EXT Sessions 87 to 91 for Birds 57 and 58 and Sessions 20 to 24 for the remaining four birds.

Behavioral Contrast

Figure 1 shows individual gradients during the last five days of VI-VI and of VI-EXT for the six pigeons. Gradients were very stable during these periods. The shift to VI-EXT

Fig. 1. Individual gradients averaged over the last five sessions of the VI-VI and VI-EXT conditions.

generally increased responding in 90° (S+) and adjacent stimuli and decreased responding in stimuli more distant from 90°. This divergence of response rates is an instance of behavioral contrast, as defined by Reynolds (1961) and Bloomfield (1967).

Local Contrast Effects:

Pattern of Responding

Figure 2a shows responding in 78° as a function of the immediately preceding orientation. When preceded by 90°, response rate in 78° increased during the presentation (negative local contrast); when preceded by 18°, responding was initially elevated and decreased during the presentation (positive local contrast). Similar effects appeared during presentation of 66°, and, to some extent, during presentations of orientations more distant from 90°. Overall responding in more distant orientations was lower, and effects less orderly. For example, Figure 2b shows responding in 30° when preceded by presentations of 78° or 6°. Response rate in 30° was higher following presentations of 6°, but changes in the pattern of responding were small.

Local Contrast Effects:

Overall Level of Responding

Table 2 shows response rates in each orientation when preceded by 90° (S+) and when preceded by a stimulus more remote than itself from 90°. Data for 90°, 18°, and 6° are not shown, since comparisons could not be made for these orientations. Eighteen degrees was never preceded by 6°, the only orientation more remote from S+, while 90° and 6° were the extreme stimulus values.

In 27 of 30 cases, responding was greater when an orientation was preceded by one

more distant from 90° and lower when the preceding orientation was 90°. Thus, it appears that proximity to S+ determined these effects. It is difficult, however, to separate distance from S+ from average response rates, since the two were highly correlated. An exception to this rule was responding in 6° for Bird 73 and for Birds 57 and 58, the two animals that received the longest discrimination training (VI-EXT). Gradients for these birds (Figure 1) showed higher average re-

Fig. 2a. Responding during 15-sec periods in 78° following presentations of 90° and of 18° during the last five days of VI-EXT. Fig. 2b. Responding during 15-sec periods in 30° following presentations of 78° and of 6° during the last five days of VI-EXT.

Table 2

Responses per minute in each orientation as a function of the immediately preceding orientation (averaged data over last five days of VI-EXT)

Bird	78° after		66° after		54° after		42° after		30° after	
	90°	18°	90°	54°, 18°	90°	42°, 30°	90°	30°, 6°	90°	6°
57	82	96	58	83	38	59	27	38	12	21
58	77	111	38	74	17	38	12	33	8	31
76	101	104	65	140	57	89	27	55	14	54
73	87	90	70	77	47	57	24	52	24	37
17	77	74	39	50	13	36	8	6	3	10
83	100	98	82	110	63	77	47	58	38	42
Average	87	96	59	89	39	59	24	40	17	33

sponse rates in 6° than in 18° ; this difference was very reliable over sessions, particularly for Birds 57 and 58. Figure 3a shows the responding of these two birds during 6° when the preceding orientation was 66° and when it was 18° . If proximity to S+ determines the effect of the preceding stimulus, negative local contrast would be expected in 6° following both of these stimuli. The data are similar for the two birds; pronounced negative local contrast after 66° and *positive* local contrast after 18° . (For Bird 73, response rate in 6° was very low [<12 responses/min] and roughly constant following both 66° and 18° .)

Another example appears in Figure 3b, showing responding in 42° when preceded by 30° or by 6° . Average response rate in 30° was generally lower than in 6° for all birds (see Figure 1). Responding in 42° was consistently higher when the preceding orientation was 30° , rather than 6° .

The dependence of local contrast on average response rate during the preceding ori-

entation may mean that the effect of local response rate is sufficient to account for the effect. That is, the occurrence of a low response rate during an individual presentation of a component induces a comparatively high rate of responding in the following stimulus and a high response rate induces lower responding.

Responding was relatively constant in most orientations, particularly in extreme stimuli. In 54° and 42° , however, responding was variable enough to provide a suitable range of response rates to permit a test of this hypothesis. The effect of responding during individual presentations of 42° on subsequent presentations of 90° was assessed for Birds 57 and 58. Response rates in 42° varied from 0 to 73 per minute for Bird 57 and 0 to 38 per minute for Bird 58.

Figure 4 shows responding in 90° when preceded by a low response rate in 42° (0-12/min, Bird 57; 0-5/min, Bird 58) or a high response rate in 42° (18-73/min, Bird 57; 6-38/min, Bird 58). If anything, response rate in 90° appears to be positively related to response rate in the preceding stimulus rather

Fig. 3a. Responding during 15-sec periods in 6° following presentations of 66° and of 18° during the last five days of VI-EXT. Fig. 3b. Responding during 15-sec periods in 42° following presentations of 30° and of 6° during the last five days of VI-EXT.

Fig. 4. Responding of Birds 57 and 58 during 15-sec periods in S+ (90°) when the preceding stimulus was 42° . The pairs of curves represent occasions when responding during the previous presentation of 42° was more or less rapid (see text). Data were averaged over the last five days of VI-EXT.

than negatively related as would be required if local contrast were to be accounted for by moment-by-moment response rate interactions.

These examples indicate that average response rate in the preceding orientation, rather than proximity to S+, or local response rate, is the factor determining the form of responding during the subsequent presentation.

Form vs Overall Level of Responding

The preceding stimulus influences both the overall level of responding and its form during a subsequent presentation. In some cases both form and overall level are affected; thus, in Figure 2a, responding by Birds 57 and 58 is clearly higher in 78° when preceded by 18° than when preceded by 90°. Response rate also changed within each component: decreasing in the first case, increasing in the second. In other cases, differences in overall level of responding appear in the absence of clear differences in the form of responding (Figure 2b). Bird 57 (Figure 3a) provides an example of local contrast showing differences in the form of responding with virtually no difference in overall response rate.

As a rule, differences in overall response rates were more reliable than were differences in the form of responding. Both effects generally appeared during stimuli in which the rate of responding was relatively high; in stimuli further removed from 90°, differences in the form of responding were less clear, though differences in overall response rate were present.

DISCUSSION

These data show that although the average response rate in a stimulus on a maintained generalization gradient is a function of its distance from S+, the preceding stimulus presentation can influence both the rate and pattern of responding during an individual presentation.

Behavioral Contrast and Stimulus Generalization

Behavioral contrast is defined as a change in response rate in one stimulus resulting from a change in conditions in another stimulus, with the proviso that this change in response rate be in a direction away from that

occurring in the second stimulus (*i.e.*, rates diverge). In this experiment, the increase in responding in 90° following the shift from VI-VI to VI-EXT qualifies as behavioral contrast, because increased responding in this component was produced by a change of conditions (from reinforcement on VI to EXT) in the remaining stimuli.

However, responding also increased in orientations adjacent to 90° (*e.g.*, 78°, 66°). This change cannot be attributed to a change in the conditions of reinforcement associated with these stimuli (although there was a change), because the change is one that might be expected to decrease, rather than increase, response rate (*i.e.*, the change from VI 1-min to extinction). Moreover, if this change in conditions of reinforcement is disregarded for the moment, the increase in response rate in these components does qualify as contrast because it is associated with a change in the conditions of reinforcement in other components. On the other hand, this increase in response rate in stimuli adjacent to 90° may also plausibly be interpreted as owing to stimulus generalization: behavioral contrast acting directly only on responding in 90°, with the elevation in responding in adjacent stimuli being merely a by-product.

Carrying the generalization argument to extremes, it could be asserted that behavioral contrast occurred only between 90° and 6°. The increased response rates in 78° and 66° would then be due to generalization from S+ (90°), while the decreased responding in 54°, 42°, 30°, and 18° is due to generalization from 6°. It should be clear that the change in response rate in a particular stimulus, say 66°, can be attributed either to contrast, generalization, or both; there is no nonarbitrary way of deciding among these alternatives. Hence, these data suggest that there may be something wrong with the conceptual framework of which these terms are a part.

Local Contrast

Nevin and Shettleworth (1966) found that positive transient (local) contrast occurred in a VI component preceded by a component associated with less-frequent reinforcement and negative local contrast occurred in the same VI component when preceded by a component providing a higher frequency of reinforcement. Figure 2 in the present experiment

shows that these effects occurred among components that do not differ in reinforcement frequency; positive local contrast occurred in 78° when preceded by 18° , though both orientations were correlated with extinction. The pattern and level of responding in 30° differed when preceded by 78° or 6° , though food was never delivered for pecking in any of the three orientations.

Generally, responding was elevated when the preceding orientation was more distant from S+ (90°) and was depressed when preceded by a stimulus closer to 90° . Figure 3 shows that this effect was dependent upon average response rate in the preceding stimulus, reflected in height on the maintained gradient, rather than upon distance from S+ along the orientation dimension. Thus, positive local contrast occurred in 6° when preceded by 18° , an orientation closer to S+ than 6° but correlated with a lower average response rate. Similarly, responding in 42° was greater when preceded by 30° than by 6° , since average response rate in 30° was less than in 6° .

Nevin and Shettleworth's effects disappeared with training (lasting only a few sessions) and Pavlovian "induction" effects are also typically transient (although not invariably, see Pavlov, 1927, pp. 195-196). The comparable local contrast effects described here appeared to persist indefinitely, however. Possible reasons for this difference are discussed later.

EXPERIMENT II

Experiment I showed that local (transient) contrast interactions occur among presentations of stimuli forming a maintained generalization gradient and that these effects are predicted by average response rates. Responding was lower when the preceding stimulus was correlated with a higher average response rate and higher when the preceding stimulus was correlated with a lower average response rate.

The results of Experiment I suggested that local contrast effects are relative; *i.e.*, that the same stimulus may elevate responding in one stimulus and depress responding in another, relative to responding in the absence of contrast. To establish that effects are indeed relative, it is important to identify unequivocally

differences in response rates as increases and decreases relative to some baseline.

This experiment provided a baseline for assessing local contrast effects by including presentations of each stimulus preceded by itself. Thus, local contrast due to other stimuli could be compared with responding in the absence of contrast (*i.e.*, a stimulus preceded by itself).

This experiment differed from the first experiment in a second respect. In the first experiment, the presentation sequence of stimuli was fixed; here, the presentation sequence was changed every two days.

METHOD

Subjects

Five White Carneaux pigeons were maintained at 80% of their free-feeding weights throughout the experiment. All birds were experienced with maintained generalization gradients.

Apparatus

The apparatus was that described in Experiment I.

Procedure

Four presentation sequences of stimuli were used; they included either four stimuli (sequences 4-1 and 4-2) or three stimuli (sequences 3-1 and 3-2). The four-stimulus sequences consisted of presentations of 90° (vertical line), 66° , 42° , and 18° . These stimuli were randomized within four blocks of 17 presentations each, with the restriction that each stimulus preceded itself and each other stimulus once per block. The three-stimulus sequences were randomized within three blocks of 28. As in the four-stimulus sequences, each stimulus preceded itself and each other stimulus equally often (in this case, three times per block). In all sequences, blocks of stimuli were separated by 20-sec "no-stimulus" periods. As in Experiment I, responses during these periods were never reinforced with food, but reset the 20-sec timer, prolonging the period. Responding in 90° (S+) was reinforced with food according to a VI 1-min schedule, while responding in other orientations was never reinforced.

Bird 57, which had not been run for eight months, was trained for two sessions with 1-min presentations of 90° , reinforced accord-

ing to VI 30-sec, alternated with no-stimulus periods. These periods were initially 5 sec long and were gradually increased to 20 sec. The remaining birds were immediately exposed to the sequences.

Each bird was run for two consecutive sessions on each of the four sequences.

RESULTS

Local contrast effects observed during the second of the two days of the three-stimulus sequences are described here. Similar effects appeared during the four-stimulus condition, but the data were less orderly. There were no differences in behavior due to presentation sequence (*i.e.*, sequence 3-1 *vs* 3-2); therefore data were averaged within the three-stimulus condition.

Local Contrast: Overall Response Rates

Effects similar to those reported in Experiment I were observed. Table 3 shows responding as a function of the preceding stimulus during the three-stimulus sequences (90°, 54°, 18°).

If responding during a stimulus preceded by itself is a fair measure of baseline responding (*i.e.*, absence of contrast), then the preceding stimulus can cause an increase or decrease relative to baseline responding. Responding in 90° was elevated in 10 of 10 cases when preceded by 54° or 18°; responding in 54° was elevated when preceded by 18° (four of five cases) and depressed when preceded by 90° (four of five cases). Similarly, responding in 18° was depressed when preceded by 90° or by 54° (nine of 10 cases). The general rule that responding was elevated over baseline when the preceding stimulus was further removed from S+ and was depressed when the preceding stimulus was nearer S+ holds in 25 of 30 cases.

It should be noted that 54° elevated responding during subsequent presentations of 90° in all five birds; at the same time, 54° depressed responding in 18°. Thus, the same stimulus may have an enhancing or a depressing effect, depending on the stimulus that follows it.

Table 3

Responses per minute as a function of the preceding stimulus during the three-stimulus condition (Days 2 and 4)

Bird 57					Bird 58				
		Following Stimulus					Following Stimulus		
		18°	54°	90°			18°	54°	90°
Preceding Stimulus	18°	16	61	87	Preceding Stimulus	18°	14	48	55
	54°	13	55	86		54°	11	37	54
	90°	9	35	64		90°	10	38	47
Mean		13	50	79	Mean		12	41	52
Bird 119					Bird 72				
		Following Stimulus					Following Stimulus		
		18°	54°	90°			18°	54°	90°
Preceding Stimulus	18°	39	79	148	Preceding Stimulus	18°	20	61	70
	54°	37	85	148		54°	18	56	72
	90°	27	68	140		90°	22	55	56
Mean		34	77	145	Mean		20	57	66
Bird 76					Average Five Birds				
		Following Stimulus					Following Stimulus		
		18°	54°	90°			18°	54°	90°
Preceding Stimulus	18°	43	145	114	Preceding Stimulus	18°	26	79	95
	54°	40	106	105		54°	24	68	93
	90°	31	96	90		90°	20	58	79
Mean		38	116	103	Mean		23	68	89

Local Contrast: Pattern of Responding

The main effects of the preceding orientation on the pattern of responding during a presentation are shown in Figure 5. This figure shows response rate during successive 15-sec periods of the 1-min stimulus presentations. Responding when a stimulus was preceded by itself is compared with responding after presentations of other stimuli.

Positive local contrast (decreasing response rate during the presentation) occurred in 90° when preceded by 54° or by 18°, and in 54° when preceded by 18°. Negative local contrast (increasing response rate during the presentation) occurred in 54° when preceded by 90°, but was not clearly shown during presentations of 18° when preceded by 90° or by 54°. These effects were similar to those reported in Experiment I; here, they are shown as increases and decreases relative to baseline performance (stimulus preceded by itself).

DISCUSSION

If responding in a stimulus when preceded by itself is an adequate baseline (*i.e.*, showing absence of local contrast), then results here show that local contrast effects do represent elevations and depressions relative to baseline responding.

Results shown in Table 3 and in Figure 5 show that the same stimulus (54°) may enhance responding during subsequent presentations of one stimulus (90°) while depressing responding during subsequent presentations of another stimulus (18°). This effect appeared in both overall response rates and in the patterns of responding and shows that local contrast effects are relative, as was suggested in Experiment I.

In Experiment I, average response rate in the preceding stimulus predicted the contrast effect on the subsequent stimulus. Stimuli correlated with higher average response rates depressed responding during a subsequent stimulus (negative local contrast), while stimuli correlated with a lower average rate of responding produced an elevation in response during a subsequent stimulus (positive local contrast). This rule did not invariably hold during this experiment; Table 3 shows that Bird 76 responded at a higher average rate in 54° than in 90° (S+). The rule relating local contrast effects and average response

Fig. 5. Responding during 15-sec periods in stimuli presented during the three-stimulus condition (sequences 3-1 and 3-2) as a function of the immediately preceding stimulus. Data were averaged over the five animals during Sessions 2 and 4 of this condition.

rates described above would predict that responding in 90° would be depressed when preceded by 54° and that responding in 54° would be elevated when preceded by 90° for this animal. Table 3, however, shows that this did not occur; 90° depressed responding during subsequent presentations of 54°, while responding in 90° was elevated following 54°. Similar effects appeared in the data of several animals during the four-stimulus condition (not described here).

Thus, in this experiment, local contrast effects could be better predicted by similarity of stimuli to S+ than by average response rates; stimuli closer to S+ than a given stimulus produced negative local contrast when preceding that stimulus, while stimuli more remote from S+ produced positive local contrast. Examination of daily gradients showed that the short period of training used here was not sufficient for steady-state performance

to develop; in some cases, gradients clearly sharpened over sessions, particularly during the four-stimulus condition. Thus, the rule relating average response rates and local contrast may hold only during steady-state performance (*i.e.*, after the gradient has stabilized).

GENERAL DISCUSSION

When responding is equally reinforced (according to VI 1-min) during presentations of stimuli forming a maintained generalization gradient, an approximately flat, stable gradient results. If the reinforcement contingencies are then changed so that responses in only one stimulus value are reinforced, a steep and very stable gradient centered at or near S+ soon forms and two types of contrast effect appear.

Positive behavioral contrast (increase in response rate) occurs in S+; response rates also increase in stimuli adjacent to S+, an effect that could equally well be interpreted as due to behavioral contrast or due to stimulus generalization.

Local (transient) contrast occurs among presentations of all stimuli. These effects do not depend upon relative reinforcement frequency or any other variable known to produce contrast, but are predicted by average response rates correlated with stimuli, at least when the same sequence of stimuli is presented daily over a long period. Local contrast appears as differences in overall response rates, in the pattern of responding, or both. The effects represent increases and decreases in responding relative to baseline responding (*i.e.*, when a stimulus is preceded by itself). Local contrast effects are relative; the same stimulus may lead to a subsequent increase in response rate in one stimulus and to a depression in responding in another.

The Persistence of Local Contrast

Local contrast effects showed no sign of diminishing during these experiments; however, other studies (Boneau and Axelrod, 1962; Nevin and Shettleworth, 1966) found similar effects to be transient. Unlike the present experiments, their studies used only a few stimuli (two or three) and these stimuli were easily discriminable (*e.g.*, black circle with gap *vs* white key; red *vs* green key).

Either or both of these factors may be important in determining the persistence of the effects.

Local contrast effects (*i.e.*, the dependence of responding in a particular stimulus upon the preceding stimulus) and the final average response rates in individual stimuli (or the form of the stable generalization gradient) may depend upon different mechanisms. Local contrast requires only that, following a stimulus change, the animal discriminate whether the new stimulus is closer or farther away from S+. In these experiments, the stimuli were line orientations and all that was required was to detect whether the shift in tilt was toward or away from vertical (S+). If the discrimination is sufficiently easy, either because there are few stimuli to distinguish or because they are very dissimilar, it should soon be possible for the animal to respond on the basis of absolute similarity of stimuli. When this is possible, there is less need to rely on the transitions among stimuli in order to identify them, so local contrast disappears.

Catania and Gill (1964) reported results that bear on this point. These authors, using multiple fixed-interval schedules, found local contrast effects along the temporal dimension, as well as along a spatial dimension (a column of small lamps). The spatial contrast effects were transient, but when the stimuli were obscured, making them more difficult to discriminate, the contrast effects returned.

Similar reasoning may account for the persistence of local contrast in multiple fixed-interval schedules (Catania and Gill, 1964; Staddon, 1969a). Control of behavior under these conditions is primarily temporal; the animals learn to pause differentially as a function of the fixed-interval schedule in force, but discriminative stimuli signalling which component is in force are also important. Since both external and temporal stimuli are important, more stimuli must be judged than is the case in multiple VI, where only control by discriminative stimuli is involved. Since the increase in stimuli makes judgement more difficult, the transition among components remains a necessary cue for the identification of components and local contrast persists.

The possibility that local contrast may depend upon some property of the whole set of stimuli that are to be discriminated (*i.e.*, their number, similarity, *etc.*) may explain Pavlov's

difficulties in accounting for the analogous "induction" effects. Although he reported that these effects were usually transient, they were sometimes persistent and he was unable to find any single factor to account for these differences. If, as these results suggest, the effects are related to an animal's ability to remember a given stimulus in relation to the whole set of stimuli, *i.e.*, to some "gestalt" property of the stimulus set as a whole, then Pavlov's failure to find any single factor underlying the occasional persistence of induction effects is at least partially explained.

Properties of Interacting Stimuli

Several authors have attempted to account for both behavioral and local (transient) contrast by ascribing properties to discriminative stimuli; two alternative accounts will be discussed here.

The first alternative is a mechanism for local contrast proposed by Nevin and Shettleworth (1966) and by Williams (1965). These authors felt that transient (local) contrast was analogous to Pavlovian induction; they therefore suggested that Pavlov's (1927) account for induction could also explain local contrast. According to this view, the component stimuli in a multiple schedule (or, presumably, stimuli forming a maintained generalization gradient) become relatively excitatory or inhibitory. This process depends upon relative reinforcement frequency associated with a component, or upon other factors, such as the presence of electric shock. Positive and negative local contrast occur as the result of enhanced excitation following an inhibitory component and greater inhibition following an excitatory component.

The demonstration of an analogy between local contrast and Pavlovian induction is valuable in itself, since effects common to several paradigms are more informative than those specific to only one procedure. The establishment of an analogy does not mean, however, that Pavlov's account suffices to explain either phenomenon.

In dealing with local contrast, a distinction must be made between the sign of the effects (positive or negative) and properties ascribed to the stimuli that cause them. The effects themselves may be excitatory or inhibitory, since Experiment II showed that they represent increases and decreases in responding,

relative to baseline performance. Thus, there is some justification for calling negative local contrast an inhibitory effect and positive local contrast an excitatory effect, because this amounts to no more than providing labels for effects that are directly observed.

The Pavlovian model suggested by Nevin and Shettleworth goes further, however, since it also ascribes properties to the preceding stimulus, depending upon the sign of its aftereffect. Positive local contrast (an excitatory aftereffect) means that the preceding stimulus was "inhibitory", while negative local contrast (an inhibitory aftereffect) means the preceding stimulus was "excitatory". Thus, local contrast is explained by regarding stimuli "as possessing excitatory or inhibitory properties, in the sense of Pavlovian theory. . ." (Nevin and Shettleworth, 1966, p. 314).

The idea that a given stimulus is either excitatory, inhibitory, or neutral was accepted by Pavlov (1927) and has been adopted by others, such as Spence (1937), Hull (1943), and more recently, Rescorla (1969) and Hearst, Besley, and Farthing (1970). Thus, both Rescorla and Hearst *et al.*, discuss procedures for determining which property best describes a given stimulus. Data from the experiments described here make it doubtful that such a simple conception of extinction and inhibition will suffice to explain local contrast.

Experiments I and II show that this view requires that the same stimulus be both excitatory and inhibitory. For example, in Experiment I, responding in 90° following 66° was always high at the onset of the presentation and decreased with time in the presentation. Nevin and Shettleworth would describe this pattern of responding in 90° as positive local contrast and attribute it to enhanced excitation due to the preceding inhibitory stimulus (66°). Yet, when 66° preceded 6° (Figure 3a), responding in 6° began at a low level and increased during the presentation (negative local contrast). This effect would be interpreted as the inhibitory aftereffect of an excitatory stimulus (again 66°). Thus, 66° is at once excitatory and inhibitory, depending on effects shown during the following stimulus. Similar relative effects appear in Table 3 and Figure 5 from Experiment II, where 54° leads to elevated responding in 90° and to decreased responding in 18°.

The possibility that local contrast effects may be relative (*i.e.*, that the same stimulus may elicit responding in one stimulus while depressing responding in another) was recognized by Nevin and Shettleworth. However, in describing stimuli as "relatively" excitatory and inhibitory, they apparently failed to recognize the significance of the difference between "relative" and "absolute" excitation and inhibition. The latter is the traditional usage of the terms and is the sense in which Pavlov used them. The difference between relative and absolute excitation and inhibition is important and may be easily demonstrated by example.

Consider three stimuli, A, B, and C, and assume that presentations of A lead to negative local contrast (decreased responding) in B and C and that presentations of B lead to negative local contrast in C. Therefore, A is excitatory relative to B and C, while B is excitatory relative to C. Thus, the three may be ranked as relatively excitatory in the order A, B, C. Further assume (as should be the case) that presentations of C lead to positive local contrast (heightened responding) during subsequent presentations of B and A, while B leads to positive local contrast in A. Here, the stimuli may be ranked as relatively inhibitory in the order C, B, A. This account leads to a description of any one of the stimuli in one of two ways, depending on whether it is described according to its excitatory or inhibitory property. Whichever way it is described, the reference is to differences along a single dimension, not to the attribution of either excitatory or inhibitory properties to each stimulus in the traditional absolute sense of Pavlov and others.

One way in which excitation and inhibition accurately describe these stimuli is found in accounts that treat stimuli as having both excitatory and inhibitory effects. Both the conditioning theory of Konorski (1948) and the "neural unit" models of Békésy (1967) and Ratliff (1965) treat stimuli in this way (see also Staddon, 1969b). The neural unit model explains a variety of perceptual phenomena by assuming that stimulation of restricted regions of a receptive field has two effects: a zone of excitation centered on the stimulated region and an area of inhibition surrounding this area. Thus, every stimulus has both an excitatory and an inhibitory effect. Evidence

for this inhibitory effect is provided by the phenomenon of "lateral inhibition" (Hartline, 1949; Ratliff, 1965).

Since the present results make it clear that local contrast effects, at least, are relative, these combined inhibitory/excitatory models may provide a more faithful picture of the effects of discrimination training than traditional accounts in terms of contrast and generalization. In outline, such an account might run as follows: (1) Assume that animals order stimuli in terms of their value, where value is dependent upon a number of factors such as reinforcement rate, similarity to other valued stimuli, presence or absence of punishment, type of schedule associated with the stimulus, and perhaps other factors (*cf.* Hilgard and Bower, 1966; Staddon, 1969b; Premack, 1969). Average response rate in the stimulus might provide a useful index of value under many conditions (see Experiment I). (2) Assume that a given stimulus will exert both inhibitory and excitatory effects on stimuli that are "close" to it (in the sense of similarity, spatial and temporal proximity, *etc.*) and that these effects are directly related to its value. These interactions are conceived of as analogous to the inhibitory and excitatory interactions that take place across a sensory surface such as the skin, simple retinas, or the basilar membrane (*cf.* Békésy, 1967; Ratliff, 1965), so that a stimulus of value 10, say, will tend to inhibit responding in an adjacent stimulus of value 5, but will enhance responding in a stimulus of value 20. This kind of conceptualization, inexact and qualitative though it may be at the present stage of knowledge, represents a bridge between the relativistic effects of behavioral contrast, demonstrated in the present experiments, and similar perceptual effects such as brightness contrast, which also depends upon differences between stimuli rather than upon their absolute values.

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