LOCAL CONTRAST AND PAVLOVIAN INDUCTION¹

JOHN C. MALONE, JR.

UNIVERSITY OF TENNESSEE, KNOXVILLE

Two experiments examined the effects of number and similarity of stimuli on local contrast. In the first experiment, local contrast effects differed in magnitude as a function of the similarity among stimuli; greater positive local contrast appeared when stimuli were less similar, though this effect sometimes reversed for very dissimilar stimuli. In the second experiment, both positive and negative local contrast appeared transiently during the course of training a discrimination including two quite dissimilar stimuli. When two new stimuli were added, both effects reappeared in several cases. The effects remained when the discrimination was rendered more difficult by substituting a new stimulus very similar to one of the original pair. These and other data suggest that local contrast depends on the same factors that produce Pavlovian induction; in the absence of an alternative account, Pavlov's interpretation may be useful in suggesting further research that will help identify the mechanisms involved in both classical and operant discrimination learning.

Key words: multiple schedule, local contrast, Pavlovian induction, key peck, pigeons

One phenomenon considered by Pavlov to be essential evidence for his excitatory/inhibitory mechanism of discrimination learning was positive and negative induction. These terms refer to the facilitation of responding to an "excitatory" conditioned stimulus (CS) (e.g., one paired with food) when immediately preceded by an "inhibitory" CS (e.g., one presented in extinction) and the suppression of responding to an inhibitory CS preceded closely by an excitatory CS. Pavlov felt that these effects represented the aftereffects of excitatory and inhibitory processes; inhibition leads to increased excitation and excitation is followed by greater inhibition. Since the process appeared formally similar to the successive induction effects reported by Sherrington (1906) in his description of spinal cord function, Pavlov called his effects induction. The excitatory/inhibitory nature of induction seemed assured, since Sherrington had demonstrated that spinal induction depended on reciprocal excitatory/inhibitory processes. In-

duction effects have been carefully studied by Russian workers, since they view them as Pavlov did; that is, as essential characteristics of the formation of discriminations, and therefore of prime importance in the understanding of learning in general (cf. Razran, 1965).

The term induction became ambiguous with Skinner (1938); for him, induction meant generalization. This was based on the analogy with Sherrington's *simultaneous* induction. Skinner used "behavioral contrast" to refer to Pavlovian induction (or Sherrington's *successive* induction). Thus, Pavlovian induction means a divergence of response rates to stimuli correlated with reinforcement and nonreinforcement (Skinner's contrast), while Skinnerian induction means a convergence of response rates (Pavlovian "irradiation", or generalization). This difference in usage is extremely unfortunate, but it has nonetheless remained current.

Local contrast effects during operant discrimination training appear very similar to Pavlovian induction. These effects were first reported by Boneau and Axelrod (1962) and later by Catania and Gill (1964) and by Williams (1965). Nevin and Shettleworth (1966) provided the first careful examination of local contrast and emphasized the possible importance of these effects for interpretations of

¹This research was supported by a Biomedical Sciences Support Grant to the University of Tennessee, Knoxville and by grant number MH-24997 from the National Institute of Mental Health, USPHS. Reprints may be obtained from J. C. Malone, Department of Psychology, University of Tennessee, Knoxville, Tennessee 37916.

discrimination learning. Local contrast appears either as elevated operant responding during the initial part of a component of a multiple schedule when it is preceded by a component correlated with extinction or with a lower frequency of reinforcement (positive local contrast), or as lowered responding in the initial part of a component preceded by one providing more frequent reinforcement (negative local contrast). Nevin and Shettleworth called these effects *transient contrast*; besides bearing a strong resemblance to Pavlovian induction, like Pavlov's effects they appeared at an intermediate stage of discrimination training and usually disappeared after a few sessions. These authors suggested that this resemblance may mean a similarity of process and that Pavlov's account may be useful in dealing with both effects.

Nevin and Shettleworth also distinguished these effects from behavioral contrast (e.g., Reynolds, 1961), which may or may not depend on the same factors. Behavioral contrast refers to changes in responding in one component of a multiple schedule as the result of some change in conditions in an alternated component. Thus, response rate may increase in a variable-interval (VI) component as the result of adding an alternated component in which no reinforcement is provided. This effect is typically observed as a change in overall response rate occurring *across sessions*, while transient contrast appears among individual components and may be observed *within sessions*.

Malone and Staddon (1973) showed that "transient" contrast could be very durable under some conditions and suggested that the term *local contrast* was therefore more appropriate. Using a maintained generalization procedure, in which responding was reinforced in one line-orientation stimulus and extinguished in seven others, they found the effects to persist over several months. Negative local contrast (i.e., depressed response rates) appeared when any preceding orientation stimulus was correlated with a higher average response rate or was more similar to the stimulus in which reinforcement was provided, and positive local contrast (elevated response rates) occurred when the preceding stimulus was correlated with a lower average response rate or was more distant from S+. They pointed out that similar long-lasting effects were sometimes

found by Pavlov (1927, pp. 195-196) and were probably dependent on the difficulty of the discrimination. When very similar stimuli or a large number of stimuli are employed, local contrast may persist.

Local contrast may show the patterns described by Nevin and Shettleworth (i.e., increased or decreased response rates at the beginning of components) or may appear simply as overall increases or decreases in response rate in a component. Thus, negative local contrast may appear as decreased overall responding in a component relative to some measure of baseline responding, such as performance when a component is preceded by itself. Usually the pattern of responding within the component is similar to that described by Nevin and Shettleworth, but this is not essential. The distinguishing characteristic of local contrast is that it is observable during individual stimulus presentations.

Malone and Staddon also showed that local contrast represents *real* increases and decreases in responding, relative to baseline response rates (i.e., when a stimulus is preceded by itself). In addition, the effects were uncorrelated with *momentary* response rates during the preceding component; instead, the direction of the effects was related to relative distance from S+, which was normally reflected in *average*, rather than momentary response rates. Like Nevin and Shettleworth, Malone and Staddon pointed out the similarity of local contrast to Pavlovian induction, but expressed doubt that a literal interpretation of Pavlov's account could be useful in dealing with either effect. In my view, similarities between the two effects are of interest in themselves; Pavlov's account may, however, be useful in suggesting further points of similarity and in suggesting promising directions for further research.

If local contrast is analogous to Pavlovian induction, the factors that affect induction may affect local contrast. According to Pavlov's account (and that given by Konorski, 1948), induction reflects the growth of "excitatory and inhibitory neural processes" during discrimination (differentiation) training and shows several definite characteristics (Pavlov, 1927, Lec. XI):

1. Induction appears when some minimum intensity of excitation and inhibition have developed. Thus, it does not normally appear at the outset of training.

2. Inductive effects normally disappear when the excitatory/inhibitory processes stabilize (*i.e.*, the discrimination is complete).

3. The strength of the effects depends on the difficulty of the discrimination; a more difficult discrimination may lead to stronger induction.

4. Induction may be long-lasting or permanent if the discrimination is very difficult (1927, pp. 195-196).

5. Very strong excitation and very deep inhibition produce aftereffects of the same sign. For example, a very inhibitory stimulus may decrease rather than increase responding during a subsequent excitatory stimulus. Thus, induction would not occur if a discrimination is very well learned, whether due to prolonged training or due to the use of easily discriminable stimuli. This is, of course, the opposite of induction and was interpreted by Pavlov (and by Konorski, 1948) as the temporal generalization of excitation and inhibition.

The first characteristic, the delayed onset of the effects, was reported for local contrast by both Nevin and Shettleworth (1966) and Malone and Staddon (1973). The transient nature of the effects (characteristic two) was found to be true of local contrast by Nevin and Shettleworth, while Malone and Staddon's report of durable effects probably is an instance of the fourth characteristic. Characteristic three, the dependence of the strength of the effects on the discriminability of the stimuli, appears in the data reported by Malone and Staddon, but these authors made no reference to this effect in describing their data. The last-mentioned characteristic, a reversal of effects in a very well-learned discrimination, has not been reported for local contrast.

The experiments below provide further evidence for the similarity of local contrast and Pavlovian induction. Experiment I reproduces some of the data from the Malone and Staddon (1973) study, part of which were at that time presented without comment. Other data, not presented at that time, are included which suggest that local contrast, like Pavlovian induction, varies in strength with the discriminability of the stimuli producing the effects. In addition, data are presented from that study (which were not included in the published report) that provide information on the contribution of local contrast to behavioral contrast.

The second experiment describes the training of a simple discrimination between two line-orientation stimuli that was maintained until local contrast disappeared. At this point, the addition of two new stimuli for a few sessions caused a reappearance of local contrast, as did the addition of a stimulus very similar to the stimulus presented with reinforcement. One animal provided unexpected evidence for characteristic five above, the reversal of effects when a discrimination is very well established.

EXPERIMENT I

This experiment appeared as Experiments I and II reported by Malone and Staddon (1973). Table 3 from that paper is reproduced below as Table 1, since aspects of the data included there that are of interest here were not discussed at that time. Other data below (Table 2 and Figures 1 and 2) represent other results of that experiment that were not included in the original report.

METHOD

Subjects

Eight White Carneaux pigeons were maintained at 80% of their free-feeding weights throughout the experiment. All birds had a varied training history.

Apparatus

The experimental chamber was a 33 by 33 by 33 cm box with a 1.9 cm translucent key mounted on one wall. A line orientation produced by a Tektronix Model 503 oscilloscope was focused onto the key by a lens (focal length 2.5 cm) mounted between the oscilloscope face and the key. The image appeared on the key as a line orientation approximately 1.3 cm long and 15 mm wide. Between stimulus changes a 24-V dc battery connected to the horizontal input of the oscilloscope pushed the image off the key, preventing any obscuring effect from the previous stimulus. The animal chamber and two-thirds of the oscilloscope were enclosed in a larger soundproofed chamber measuring 51 by 51 by 122 cm. A food magazine located 5 cm below the key provided reinforcement (3-sec access to mixed grain). 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 re-

cording equipment was located in an adjoining room.

Procedure

After one session of magazine and key training, animals received extensive experience with eight line-orientation stimuli: 90° (vertical line), 78°, 66°, 42°, 30°, 18°, and 6°. Daily sessions were composed of 50, 1-min presentations, with VI 1-min reinforcement delivered in the presence of 90°.

Presentations were arranged in a fixed sequence of five blocks of 10, randomized within blocks. Ninety degrees appeared three times per block and each other orientation appeared once. Blocks of stimuli were separated by a 20-sec "no-stimulus" period. During these periods responses were never reinforced, but reset a 20-sec timer, prolonging the period. These periods were included to ensure that the animals attended to the stimuli on the key. Birds 57 and 58 received 22 sessions of equal VI 1-min reinforcement in all orientations, followed by 91 sessions in which responding was so reinforced only in 90°. Birds 73, 17, 83, and 76 received 23 sessions of VI in all stimuli and 23 sessions of reinforcement only in 90°.

In the second condition, presentation sequences included either three or four stimuli; two different presentation sequences were used in each case. The four stimulus sequences consisted of presentations of 90° (vertical line), 66°, 42°, and 18° 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 included 90°, 54°, and 18° orientations randomized within three blocks of 28. As in the four-stimulus sequences, each stimulus preceded itself and each other stimulus equally often (three times per block). In all cases, stimulus presentations lasted 1 min. Responding in 90° was reinforced according to VI 1-min, while responding in other orientations was never reinforced.

Bird 57, which had not been used for eight months, received two sessions of training with 90°, reinforced according to VI 30-sec, alternated with no-stimulus periods, which were increased in length from 5 to 20 sec over the two sessions. The other birds were immediately exposed to the sequences. Each bird was given two consecutive sessions on each of the four

sequences, the order of sequence presentation being different for each bird.

RESULTS

Local Contrast During the Eight-Stimulus Condition

The results of the first condition, described by Malone and Staddon (1973), showed that local contrast effects persisted over a prolonged period (at least up to 91 sessions) and that the direction of the effects (positive or negative) depended on relative proximity to 90°. In general, when the preceding stimulus was more similar to 90°, negative local contrast (decreased responding) occurred during a subsequent presentation, while an orientation less similar to 90° produced positive local contrast (heightened responding) during a subsequent presentation.

In addition, the magnitude of these effects was related to the similarity of the stimuli producing the effect. Figure 1 shows responding during 15-sec periods of the 1-min presentations of 90° when preceded by 78°, 42°, 30°, and 6° during the last five days of discrimination training (reinforcement only in 90°). The first three of these orientations preceded 90° three times daily; 6° preceded 90° twice per session. The remaining orientations (66°, 54°, 18°) preceded 90° only once per session and produced more variable effects.

Aside from Bird 17, where the preceding stimulus had little effect on responding in 90°, response rates during the first 15 sec of 90° increased when the preceding stimulus was further removed from that stimulus. This effect is most pronounced for Bird 58, where response rate in the first quarter of the component increased from 128 per minute after 78° to 132 per minute after 42°, 144 per minute after 30° to 172 per minute after 6°. For all animals, the average increase in first-quarter response rates during presentations of 90° following 6° over that following 78° was 21 responses per minute.

Similar effects appeared during other orientations; the *direction* of the effect (positive or negative) depended on the relative similarity of stimuli to 90°; the *magnitude* depended on the absolute similarity of any two stimuli. Reversals sometimes occurred, as was the case for Bird 76 in Figure 1. Response rates increased to a peak at 30° and were somewhat lower after 6°, the extreme orientation.

Fig. 1. Response rates during 90° following four other stimuli in Experiment 1. Response rates are shown during successive 15-sec periods of the 1-min stimulus presentation. Data were averaged over the last five sessions of discrimination training.

The nature of the presentation sequence did not allow a satisfactory evaluation of these effects, since every orientation was not preceded by every other. The lack of instances in which an orientation was preceded by itself (*i.e.*, appeared twice in succession) meant that there was no baseline to allow assessment of absolute changes in response rate. The second condition remedied this deficiency.

Local Contrast: Three- and Four-Stimulus Sequences

Local contrast effects observed during the second of the two days of each three-stimulus and four-stimulus sequence will be described. There were no differences in performance due to particular presentation sequence; therefore, data were averaged within the two stimulus conditions.

Tables 1 and 2 show overall response rates as a function of the preceding stimulus during the three- and four-stimulus conditions respectively.

Table 1 refers to the three-stimulus condition and shows quite clearly that the preceding stimulus leads to increased or decreased responding relative to baseline performance (*i.e.*, response rate when a stimulus is preceded by itself). If the preceding stimulus was more similar to 90°, subsequent responding is depressed; if the preceding stimulus is less similar to 90°, subsequent responding is elevated. This occurs in 25 of the 30 possible cases. In addition, the *degree* of elevation or depression depends on the preceding stimulus. In the averaged data for the five birds, baseline responding in 18° is 26 responses per minute; when 18° is preceded by 54°, responding is 24 per minute, and is reduced to 20 per minute when the preceding stimulus is 90°. Likewise, the elevation in responding in 90° is from 79 to 93 responses per minute when the preceding stimulus is 54° and rises to 95 per minute when 90° is preceded by 18°. For individual birds, the rule that responding in 18° is more suppressed when the preceding stimulus is 90°

Table 1
Responses per minute as a function of the preceding stimulus during Days 2 and 4 of the three-stimulus condition.

(Reproduced from Malone and Staddon, 1973)

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

than when it is 54° , and that responding in 90° is more elevated when the preceding stimulus is 18° than when it is 54° holds in eight of 10 cases. It is clearly invalidated in only one case (Bird 72; responding is higher in 90° after 54° than after 18°). Thus, local contrast is greater when the preceding stimulus is more dissimilar to the stimulus under consideration, at least under the conditions observed here.

Table 2 shows less clear, but similar results for the four-stimulus sequences. For example, response rate in 90° is generally elevated when the preceding stimulus is an orientation other than 90° (this holds in 13 of 15 possible cases). The degree of elevation during 90° is also greater when the preceding stimulus is 42° than when it is 66° (this holds in four of five cases; response rate is higher by an average of 11 responses per minute). Similarly, responding in 66° , which is elevated when the pre-

ceding stimulus is 42° or 18° (in eight of 10 cases), is *more* elevated after 18° than after 42° (this holds in four of five possible cases). Responding in 42° is depressed following presentations of 90° or 66° (in six of 10 cases) and is lower following 90° than following 66° (in three of five cases). Effects in 18° were less uniform; however, for three of the five birds, responding was lower in 18° when the preceding stimulus was 90° , rather than 66° or 42° .

One aspect of these data that did not appear in the three-stimulus condition is the frequent reversal in degree of elevation and suppression. For example, for Bird 57, responding in 90° was higher when preceded by 66° than by 90° , higher yet when preceded by 42° , and then considerably *lower* when preceded by 18° (this still represents an elevation relative to responding when preceded by another presentation of 90°). This occurs to some extent for Birds 57, 119, and 72.

Table 2

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

Bird 57						Bird 58					
		Following Stimulus						Following Stimulus			
		18°	42°	66°	90°			18°	42°	66°	90°
Preceding Stimulus	18°	16	37	79	84	Preceding Stimulus	18°	30	43	83	61
	42°	6	31	75	104		42°	31	34	76	61
	66°	9	24	73	96		66°	21	39	78	55
	90°	11	22	49	63		90°	18	43	59	48
Mean		11	29	69	87	Mean		25	40	74	56

Bird 119						Bird 72					
		Following Stimulus						Following Stimulus			
		18°	42°	66°	90°			18°	42°	66°	90°
Preceding Stimulus	18°	22	73	115	138	Preceding Stimulus	18°	21	45	67	58
	42°	39	62	152	168		42°	17	37	66	63
	66°	47	69	147	169		66°	18	33	61	60
	90°	31	39	112	145		90°	19	36	62	58
Mean		35	61	132	155	Mean		19	38	64	60

Bird 76						Average Five Birds					
		Following Stimulus						Following Stimulus			
		18°	42°	66°	90°			18°	42°	66°	90°
Preceding Stimulus	18°	25	84	141	110	Preceding Stimulus	18°	23	56	97	90
	42°	38	78	136	109		42°	26	48	101	101
	66°	39	90	133	83		66°	27	51	98	93
	90°	30	67	112	81		90°	22	41	79	79
Mean		33	80	131	96	Mean		25	49	94	91

Local Contrast and Behavioral Contrast

Figure 2 shows the effect of local contrast on overall response rates during the three- and four-stimulus conditions. Unfilled circles represent overall responding in a stimulus when preceded by itself; filled circles show responding when that stimulus is preceded by some

other stimulus. There is little overall effect in some cases, since those stimuli are preceded by both response-rate suppressing and response-rate facilitating stimuli. For example, in the three-stimulus condition, 54° is preceded by 18° , which enhances responding, and by 90° , which depresses responding; thus, the net effect is negligible. Responding in 90° is noticeably

Fig. 2. Maintained gradients during Days 2 and 4 of the three- and four-stimulus conditions. The pairs of gradients represent responding in a stimulus when preceded by itself (open circles) and when preceded by an orientation other than itself (closed circles).

affected; the effect of local contrast is to sharpen the gradient by increasing overall response rates in 90° and, to some extent, decreasing rates in 18°. The effect of local contrast on responding in 18° is much weaker; it clearly appears in only two of five cases. Similar effects occurred during the four-stimulus sequence. If only overall response rates were considered, such effects would normally be attributed to behavioral contrast and must under other conditions account for part of that effect.

DISCUSSION

Experiment 1 showed that local contrast depends on the average response rate in the stimulus under consideration and the average response rate in the immediately preceding stimulus. The effect is clearly dependent on *average*, rather than momentary response rates and this usually corresponds to the similarity of the stimuli involved.

If the amount of local contrast (whether positive or negative) depends on the similarity of stimuli producing the effect it would appear that the effect is greater when the stimuli are more dissimilar. Insofar as local contrast is similar to Pavlovian induction, this runs counter to Pavlov's observations of greater induction with more similar stimuli. It is possible, based on the data of Figure 1 and on performance during the four-stimulus sequence, that this effect reverses for extreme stimuli. This could mean that the difficulty of the discrimination used here was much greater than that typically used by Pavlov; a simpler task in which reversals were the rule would tend to support Pavlov's predictions.

Local contrast has an appreciable effect on overall response rates, particularly on the extremes of a continuum of stimuli. Strictly speaking, the elevations and depressions shown to result from local contrast in Figure 2 are not behavioral contrast effects, but such effects almost certainly account for much of what is usually interpreted as behavioral contrast (*cf.* Rachlin, 1973). This possibility is particularly likely, inasmuch as demonstrations of behavioral contrast typically employ only two components and therefore two stimuli, which would thus always represent the extremes of a continuum of similarity, and therefore local contrast would have a maximal influence.

EXPERIMENT II

Pavlov (1927) reported that induction effects were typically short-lived, as were the local contrast effects reported by Nevin and Shettleworth (1966). Malone and Staddon, who reported very durable local contrast, suggested that the longevity of the effects may depend on the difficulty of the discrimination, as reflected in the number and/or similarity of the stimuli to be discriminated. Nevin and Shettleworth used only a few stimuli (two or three) and these were quite discriminable (*i.e.*, key colors) while Malone and Staddon used eight stimuli that were difficult to discriminate (*i.e.*, line orientations separated by only 12 degrees). This possibility is strengthened by Pavlov's observation (1927, pp. 195-196) that induction effects were sometimes persistent and that this seemed to depend on the difficulty of the differentiation.

In this experiment, two widely-spaced line orientations were presented with reinforcement and extinction respectively and training was maintained long enough to allow the appearance and disappearance of local contrast. In a second phase, two new orientations were added (presented in extinction) to allow the re-instatement of local contrast. Finally, one of the orientations was replaced with one similar to that orientation presented with reinforcement. Any return of local contrast after its initial disappearance would provide evidence that the effect is in some way dependent on the difficulty of the discrimination (*i.e.*, the number and/or similarity of the stimuli to be discriminated).

METHOD

Subjects

Three experimentally naive Tumbler pigeons were maintained at 80% of their free-feeding weights throughout the experiment.

Apparatus

The experimental chamber was a 27 by 25 by 35 cm aluminum and Plexiglas box with a 1.9 cm transparent key mounted on one wall, centered 24 cm from the floor of the chamber. A Grason-Stadler Model A509-24 stimulus projector mounted behind the key provided line-orientation stimuli; line orientations were approximately 1.9 cm long and 3 mm wide as they appeared on the key. The experimental

chamber was enclosed in a larger box (86 by 61 by 61 cm) composed of 6.4-cm thick walls filled with soundproofing materials. Reinforcement (3-sec access to mixed grain) was available from the 5 by 6 cm magazine aperture located 8.9 cm below the key. The 6-W houselight and the key display were extinguished during reinforcement. The soundproofed box and a large ventilation fan masked extraneous noises; programming and recording equipment was located in an adjoining room.

Procedure

After magazine training, the birds were hand-shaped to key peck in the presence of a vertical (90°) line orientation on the key. They then received preliminary training in which 42, 1-min presentations of 90° , with responding reinforced according to VI-1 min, alternated with a 30-sec timeout period during which no reinforcement was available and each key peck reset the timer that governed the length of the timeout. Steady responding would thus increase the length of the timeout indefinitely. The length of the timeout was increased from an initial 5 sec to its final value over the first few sessions. As in Experiment I, these periods were included to ensure that the animals were attending to the stimuli on the key. This condition (90° , TO) was continued for 41 sessions to establish extremely stable responding to 90° before another stimulus was added.

During the next condition (90° , 60°) 1-min presentations of 90° , correlated with the same VI 1-min schedule, appeared with an equal number of 1-min presentations of a line orientation 60° from the horizontal, which was presented in extinction. Sixty-three presentations were randomized within three blocks of 21, with the restriction that each stimulus preceded itself and the other stimulus equally often and the same stimulus appeared no more than twice in succession. Ninety degrees appeared 32 times and 60° appeared 31 times. A 30-sec timeout period was inserted at the end of each block of stimulus presentations (*i.e.*, three times per session). This condition was continued for 39 sessions.

In the next condition (90° , 60° , 30° , 0°), 1-min presentations of 90° appeared with 1-min presentations of orientations 60° , 30° , and 0° from the horizontal. Reinforcement for responding in 90° continued according to the

same VI 1-min schedule, while the other orientations appeared in extinction. Stimulus presentations were randomized within four blocks of 17, with the same restrictions as the previous condition; each stimulus preceded itself and each other stimulus equally often and no stimulus appeared more than twice in succession. Timeout periods were included after the first three blocks of presentations. This condition was continued for six sessions.

The final condition (90° , 75° , 60° , 0°) was identical to the previous condition, except that an orientation 75° from the horizontal was substituted for the 30° orientation. Other aspects of the sequence were unchanged and training was continued for seven sessions.

RESULTS

Figures 3, 4, and 5 summarize the results of each condition for the three birds. Numbers in parenthesis refer to the sessions over which the data were averaged in each case. In all cases, responding is shown during successive 15-sec periods of the stimulus presentations.

90° , TO

At the end of this condition (upper-left panel of each figure), response rates were extremely stable in 90° for each bird. Response rates were uniform during successive 15-sec periods of the 1-min stimulus presentations for Birds 92 and 97; Bird 96 showed an increase in response rate during the 1-min period. This occurred during each of the three days comprising the averaged performance shown in the figure.

90° , 60°

The addition of 60° produced local contrast almost at once for Bird 92 and, to a lesser degree, for the other two birds. Averaged performance during Days 2 to 4 (Figures 3, 4, and 5) shows that Bird 92 responded at approximately 66 responses per minute during the first 15 sec of presentations of 90° preceded by itself (open circles) and at an average of 86 responses per minute when 90° was preceded by 60° (closed circles). This represents positive local contrast. Similarly, responding in 60° was lower when preceded by 90° than when preceded by 60° (negative local contrast). Bird 96 shows slight positive and negative local contrast; Bird 97's performance shows neither effect.

Fig. 3. Response rates during successive 15-sec periods of the 1-min stimulus presentations during Experiment II. Upper panel shows responding during 90° and 60° as a function of the preceding stimulus. The bottom panel shows similar data during the subsequent conditions. Numbers in parentheses refer to the sessions over which the corresponding data were averaged.

Fig. 4. Response rates during successive 15-sec periods of the 1-min stimulus presentations during Experiment II. Upper panel shows responding during 90° and 60° as a function of the preceding stimulus. The bottom panel shows similar data during the subsequent conditions. Numbers in parentheses refer to the sessions over which the corresponding data were averaged.

Fig. 5. Response rates during successive 15-sec periods of the 1-min stimulus presentations during Experiment II. Upper panel shows responding during 90° and 60° as a function of the preceding stimulus. The bottom panel shows similar data during the subsequent conditions. Numbers in parentheses refer to the sessions over which the corresponding data were averaged.

By Sessions 7 to 9, local contrast was clear for Birds 92 and 97. Response rate was initially higher in 90° following 60° (146 and 130 responses per minute respectively) than it was following 90° (108 and 106 responses per minute). Clear negative local contrast also appeared; it is noteworthy that these are the maximum local contrast effects observed and that in both cases response rate during 60° was still very high.

Bird 96 responded at high rates in 90° during these sessions, but response rate during 60° was virtually zero. Though slight local contrast had appeared earlier (Sessions 2 to 4) when responding in 60° was still high, by Sessions 7 to 9 there was not only no local contrast, but responding in 90° was considerably lower during presentations of 90° preceded by 60° (closed circles) than when it was preceded by 90° (open circles). This effect, which is in a direction opposite to local contrast, could only be viewed as an *induction effect*, in the sense that Skinner (1938) used the term (see Introduction).

By Sessions 28 to 30, Bird 92 still showed

clear positive local contrast in 90°; responding in 60° had decreased greatly and negative local contrast was absent. For Bird 97, responding had also decreased in 60° (and in 90°) and both positive and negative effects were absent. Bird 96 had earlier ceased responding altogether in 60° and continued to show "induction" effects in 90°; responding was lower following 60° than following 90°.

Sessions 37 to 39 (upper-right panel of each figure) represent sufficient training to abolish the effects in all animals. The only trace of local contrast appears in the data of Bird 97, where a slight negative effect appeared (responding in 60° was slightly lower following 90°). Bird 96 showed still lower response rates in 90° and responding in 60° remained absent.

With the addition of 30- and 0-degree orientations (lower-left panel of each figure) Birds 92 and 97 showed renewed local contrast effects. Bird 92 showed positive local contrast in 90°, with the greatest enhancement (an increase of almost 60 responses per minute) occurring after presentations of 0° and a slightly smaller (but still large) enhancement

following 60° and 30°. Bird 97 showed less-clear positive effects in 90°; local contrast did occur as an increase during presentations following 30° and 0°, but little effect appeared in presentations following 60°. Bird 96 showed increased response rates in 90° but, as was the case earlier, initial responding was *lower* following stimuli other than 90°. Perhaps significantly, this animal demonstrated virtually zero responding during orientations other than 90°.

During 60°, Bird 92 showed negative local contrast once again after presentations of 90° and a slight increase (positive local contrast) after presentations of 0°. Response rates were also decreased after 30°. For Bird 97, no clear effects due to the preceding stimulus appeared during 60°.

In 30°, Bird 97 showed heightened responding following 0° (positive local contrast) and the lowest response rates after 90° (negative local contrast). Little difference appeared during 0°, though the lowest response rates did appear after 90° and 60°.

It would be surprising, given the short period of training here (six days) to find clear effects in all stimuli. It is clear, however, that the addition of 30° and 0° re-instated local contrast among presentations of 90° and 60°, at least for Bird 92.

In the final condition, the substitution of 75° for 30° led to increased response rates in 90° for Bird 92; initial rates were highest following 0° and slightly lower after 60° and 75°. Bird 97 showed little effect in 90°; the most noticeable effect was a substantial decrease during presentations preceded by 0°. Bird 96 showed lower response rates when 90° was preceded by any other stimulus; responding during the first quarter of 75° was approximately the same as initial rates when 90° preceded itself.

Responding during 75° showed no clear differences as a function of preceding orientation except for Bird 92, which showed higher response rates after 60° and 0°. Likewise, there were no clear differences in 60° for Birds 96 and 97, though Bird 92 showed negative local contrast following 90° and an elevation following 0°. Responding in 0° was negligible for all birds.

Thus, the main effect of substituting 75° and 30° was to maintain whatever local contrast effects had been re-instated during the

previous condition and to foster *some* responding by Bird 96 in orientations other than 90°.

DISCUSSION

Local contrast may appear very soon after discrimination training is initiated; in this experiment, effects were evident by the second day. It is possible, of course, that the initial extended experience with 90° *versus* timeout was partially responsible for this.

As reported by Nevin and Shettleworth (1966), local contrast does not persist under some conditions. Present results, and those of Malone and Staddon (1973), suggest that the persistence of local contrast is partially dependent on the number of stimuli presented. When few stimuli appear, the effects are transient.

Local contrast is not simply a product of the alternation of periods correlated with higher and lower frequencies of reinforcement. When 90° was alternated with timeout periods, nothing like positive local contrast appeared in 90°, though the addition of a timeout period has been shown to produce behavioral contrast in an alternated VI component (Reynolds, 1961; Taus and Hearst, 1970). Local contrast did appear quite soon after 60° was introduced and remained strong only as long as substantial unreinforced responding occurred in 60°. This amounted to only a few sessions for Bird 96 and to over 30 sessions for the other two animals. This corresponds with Nevin and Shettleworth's observation that local contrast appears during an "intermediate" stage of discrimination training and seems to support Pavlov's contention that the effects (if they are analogous to Pavlovian induction) are somehow indicators of the process of discrimination; when the discrimination is complete, they disappear, and only induction (in Skinner's sense) appears.

This latter effect may apply to the performance of Bird 96. The only trace of local contrast for this bird appeared early in discrimination training and was gone by the seventh session. By that time, response rate was near zero in 60°, where it remained throughout the experiment (except for a few sessions after the addition of 75°). This may represent the response-suppressing aftereffect predicted by Pavlov's mechanism for discrimination learning (characteristic five discussed earlier). However, this account would have to allow for such

effects during the initial training period, when 90° was alternated with timeout, since responding in 90° showed a pattern similar to that observed throughout training. This is not entirely unreasonable; the only point at which local contrast (though slight) was observed in 90° was immediately after the introduction of 60°, as would be predicted by this account. After that, response rate was virtually zero in 60° and local contrast was replaced by the negative aftereffect of 60°. Thus, Pavlov's description of the process seems accurate; whether this means that 60° became excessively "inhibitory" is beside the point.

Data reported by Buck, Rothstein, and Williams (1975) support this possibility. These authors provided pigeons with VI 2-min reinforcement for responding in the presence of a triangle and then alternated this component with a red light correlated with extinction. For three of four birds, positive local contrast appeared in the VI component after a few sessions and faded as training progressed. However, the authors were puzzled to find that the predominant pattern of responding observed in the VI component during the VI-EXT condition was increased responding through the component, similar to the pattern shown by Bird 96. It is likely that the prior experience of their animals and the easy discriminability of the stimuli meant that the discrimination was virtually complete from the outset; no local contrast appeared and the pattern of responding observed was that which Pavlov specified would accompany an already established discrimination. No report of response rates during the extinction component was provided, but it is likely that little if any responding occurred, as was the case here for Bird 96.

The addition of two new stimuli, 30° and 0°, clearly led to a reappearance of positive and negative local contrast for Birds 92 and 97. Local contrast occurring between 90° and 60°, however, appeared only for Bird 92. The appearance of positive local contrast in 90° for Bird 97 following presentations for 30° and 0° does indicate that the identity of the interacting stimulus is important, as was shown in the preceding experiment. That is, local contrast did not reappear among presentations of 90° and 60°, but did appear among presentations of 90° and the new stimuli.

The substitution of 75° for 30°, rendering

the discrimination more difficult, produced little that was not evident in the preceding condition. Positive and negative effects persisted for Bird 92 and to some extent for Bird 97. These effects were really no more pronounced than they were in the preceding condition.

GENERAL DISCUSSION

The present data show that local contrast, like Pavlovian induction, varies in amplitude, depending on the stimuli associated with interacting components. Like Pavlovian induction, local contrast may reverse in sign during a well-learned discrimination. This appeared in Bird 96's data in Experiment II and may explain the results reported by Buck *et al.* (1975). Such reversals were well documented by Pavlov and by Konorski (1948), who attributed such effects to the extreme excitation and inhibition existing once a discrimination has been fully formed. Thus, a very inhibitory stimulus produces only inhibitory effects on performance during a subsequent stimulus. The fact that Bird 96 showed positive (and negative) local contrast only when nonzero responding occurred in stimuli presented without reinforcement agrees with Pavlov's and Konorski's observations, though it does not force their particular interpretations (*cf.* Malone and Staddon, 1973).

The contribution of local contrast to behavioral contrast is clearer in light of these data. Figure 1 shows that local contrast is probably not sufficient to account for behavioral contrast; in particular, it seems clear that negative local contrast is not great enough to account for negative behavioral contrast. In addition, it has been shown that behavioral contrast occurs when a VI component is alternated with timeout periods (*e.g.*, Reynolds, 1961; Taus and Hearst, 1970). Here, in Experiment II, it was evident that local contrast appeared *in addition to* whatever effects appeared as the result of alternating a VI component with timeout periods.

One point that bears emphasis is the fact that negative local contrast appears as reliably as positive local contrast. Several recent accounts (*e.g.*, Buck *et al.*, 1975; Schwartz, Hamilton, and Silberberg, 1975) treat local contrast only in its positive form. Surely the apparent symmetry of positive and negative

effects shown here and elsewhere (e.g., Nevin and Shettleworth, 1966) suggests that any account must deal with both effects. Similarly, it is difficult to believe that positive and negative effects may depend on two different mechanisms. For example, Rachlin (1973) suggested that positive local contrast may represent the addition of reinforcement-elicited responses (i.e., autopecks) to responses controlled by the reinforcement schedule in force, while negative local contrast owes to the effects of competing behaviors, which produce lower response rates. This is an ingenious treatment, which relates local contrast to other phenomena, but a survey of the properties of local contrast enumerated here and by Malone and Staddon (1973) argues against such an interpretation. In addition, if Pavlovian induction depends on the same mechanism that produces local contrast, then Rachlin's interpretation should apply to Pavlovian induction as well. It is conceivable that such an extension of his account could be accomplished, but it could not be done in a very straightforward way.

Rather than attempt to account for local contrast in this way or to use half of Rachlin's model and be satisfied with a plausible account for *positive* local contrast alone (Schwartz *et al.*, 1975) it may be useful to consider interpretations that deal more naturally with these and other interactions among behaviors. I have suggested elsewhere (Malone, 1975; Malone and Staddon, 1973) that the "neural unit" models of Békésy (1967) and Ratliff (1965), which have proved useful in dealing with a variety of sensory/perceptual phenomena, may be of some heuristic use.

The basic assumption of these models is that the activity of a sensory receptive unit is interpretable only if the activity of neighboring units is considered; interactions among units have been demonstrated both as spatial interactions occurring on a receptive surface and as temporal effects, similar to those described here.

The application of such a model to discrimination learning poses difficulties for some writers. Blough (1975), for example, referred to the neural unit model as a "tempting analogy"; although he had no specific objections to it, he felt more comfortable with traditional conditioning-based models. Despite some reluctance on the part of experimental psychologists to consider such a model seri-

ously, a view similar to Békésy's has a clear precedent in conditioning accounts of discrimination learning. None other than Pavlov proposed a model surprisingly like the neural unit to account for a variety of data.

In Pavlov's view, the formation of a discrimination may be represented by excitation and inhibition corresponding to cortical representations of reinforced and nonreinforced stimuli, surrounded by zones of inhibition and excitation, respectively. Whether such cortical representations really exist is irrelevant; the point is that a large number of phenomena observed by Pavlov made sense if one accepted this view. Such fields, with centers and surrounds of opposite sign, were adopted by Konorski (1948) and are formally indistinguishable from the neural unit model.

If, as the existence of local contrast and other data suggest, the strength of a conditioned reflex or a discriminated operant is not independent of the strengths of other behaviors, there is no reason not to take advantage of Pavlov's efforts to specify the rules governing such interactions. The alternative is to ignore some very pervasive effects or to devise *ad hoc* mechanisms to deal with every new interaction that is reported.

REFERENCES

- Békésy, G. v. *Sensory inhibition*. Princeton, N.J.: Princeton University Press, 1967.
- 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.
- Boneau, C. A. and Axelrod, S. Work decrement and reminiscence in pigeon operant responding. *Journal of Experimental Psychology*, 1962, **64**, 352-254.
- Buck, S. L., Rothstein, B., and Williams, B. A. A re-examination of local contrast in multiple schedules. *Journal of the Experimental Analysis of Behavior*, 1975, **24**, 291-301.
- Catania, A. C. and Gill, C. A. Inhibition and behavioral contrast. *Psychonomic Science*, 1964, **1**, 257-258.
- Konorski, J. *Conditioned reflexes and neuron organization*. Cambridge, Cambridge University Press, 1948.
- 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. and Staddon, J. E. R. Contrast effects in maintained generalization gradients. *Journal of the Experimental Analysis of Behavior*, 1973, **19**, 167-179.
- Nevin, J. A. and 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* (Tr. G. V. Anrep). New York: Dover, 1927.
- Rachlin, H. Contrast and matching. *Psychological Review*, 1973, **80**, 217-234.
- Ratcliff, F. *Mach bands: quantitative studies on neural networks in the retina*. San Francisco: Holden-Day, 1965.
- Razran, G. Russian physiologists' psychology and American experimental psychology. *Psychological Bulletin*, 1965, **63**, 42-64.
- Reynolds, G. S. Behavioral contrast. *Journal of the Experimental Analysis of Behavior*, 1961, **4**, 57-71.
- Schwartz, B., Hamilton, B., and Silberberg, A. Behavioral contrast in the pigeon: a study of the duration of key pecking maintained on multiple schedules of reinforcement. *Journal of the Experimental Analysis of Behavior*, 1975, **24**, 199-206.
- Sherrington, C. *The integrative action of the nervous system*. New Haven: Yale University Press, 1906.
- Skinner, B. F. *The behavior of organisms*. New York: Appleton-Century, 1938.
- Taus, S. E. and Hearst, E. Effect of intertrial (black-out) duration on response rate to a positive stimulus. *Psychonomic Science*, 1970, **19**, 265-267.
- Williams, D. R. Negative induction in instrumental behavior reinforced by central stimulation. *Psychonomic Science*, 1965, **2**, 341-342.

Received 23 September 1975.

(Final Acceptance 14 May 1976.)