DIFFERENTIAL REINFORCEMENT AND STIMULUS CONTROL OF NOT RESPONDING[1]

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Pigeons were trained to respond with equal variable-interval reinforcement in the presence of a white key and also a white key with a vertical line. They were then trained not to respond to the vertical line by extinguishing the response or by reinforcing its non-occurrence at various frequencies. During training, the rate of key-pecking in the presence of the white key, maintained by a constant variable-interval schedule of reinforcement, depended on the frequency of reinforcement in the presence of the line. When lines of different orientations were presented in a generalization test, birds trained with extinction responded more to other orientations than to the vertical line, whereas those trained with high frequencies of reinforcement for not responding tended to respond equally at all line orientations. Intermediate frequencies of reinforcement gave mixed results.

When a pigeon is exposed successively to two stimuli, S_1 and S_2, where S_1 is correlated with intermittent reinforcement of key-pecking and S_2 is correlated with extinction, the following effects are reliably observed. First, the average rate of responding in the presence of S_1 increases as the response rate in S_2 decreases. This is known as positive contrast (Reynolds, 1961a). In addition, the response rate in the presence of S_1 is highest immediately after exposure to S_2 (Catania and Gill, 1964). This is termed positive transient contrast (Nevin and Shettleworth, 1966), to distinguish it from the sustained contrast effect identified by Reynolds. Second, generalization gradients along the S_1–S_2 continuum have an elevated peak that is displaced away from S_2, relative to the gradient obtained after training with S_1 alone. This effect is termed peak shift (Hanson, 1959). Finally, a generalization gradient about S_2 along a continuum orthogonal to the S_1–S_2 dimension shows increases in responding at stimulus values re-

mote from S_2, indicating that S_2 controls "not-responding" in much the same way as S_1 controls responding (Honig, Boneau, Burstein, and Pennypacker, 1963). This gradient may be taken as defining the inhibitory function of S_2 (Jenkins, 1965), and is known as a gradient of inhibition.

Terrace (1966a, b) has demonstrated that neither contrast effects, nor peak shift, nor gradients of inhibition are observed after special discrimination training with little or no responding in S_2. He has therefore argued that these effects depend on the occurrence and gradual elimination of unreinforced responding in S_2. On the other hand, Reynolds (1961a) has shown that a discrimination may be formed without contrast if food reinforcement is given in S_2, contingent on the non-occurrence of key-pecking (a procedure known as DRO, an abbreviation for "differential reinforcement of other behavior"). In one portion of his study, pigeons were trained to respond equally on identical variable-interval schedules in S_1 and S_2, and were then trained to respond differentially by changing the S_2 schedule to extinction or DRO. Contrast occurred with extinction in S_2, but not with DRO. From data presented by Reynolds (1960), it is clear that there was a substantial amount of unreinforced responding in the presence of S_2 during training with DRO, indeed, only slightly less than with extinction. Reynolds argued, therefore, that the usual

sustained contrast effect in S_1 depended on non-reinforcement in S_2, rather than the reduction of rate *per se*. In a related study, Nevin and Shettleworth (1966) used DRO to show that positive transient contrasts depend also on differences in reinforcement frequency, rather than differences in response rate.

Reynolds (1961a) employed a DRO 50-sec schedule, *i.e.*, food was presented after 50 sec without a response, so that the maximum frequency of reinforcement was 72 food presentations per hour. Extinction, of course, provides zero reinforcements per hour. Presumably, the magnitude of the contrast effect in S_1 is continuously related to the frequency of reinforcement in S_2, as shown by Catania (1961) in a concurrent reinforcement procedure. To the extent that contrast and gradients of inhibition are intimately linked, as they appear to be in Terrace's (1966b) work, one may expect that increases in the frequency of reinforcement for not responding in S_2 will reduce or eliminate contrast effects in S_1 and, concomitantly, the steepness of gradients of inhibition about S_2. The present experiments investigated this possibility.

EXPERIMENT 1

METHOD

Subjects

Four experimentally naive male White Carneaux pigeons were maintained at 80% of their free-feeding weights, ± 15 g.

Apparatus

A standard operant conditioning chamber was equipped with a single translucent response key, a house light, and a grain magazine. Reinforcement consisted of 3-sec access to the illuminated grain magazine. The response key remained lighted during reinforcement. Stimuli were projected on the back of the key by a multiple stimulus projector (Grason-Stadler # E4580-155). The stimulus S_1 was a uniform white light, and S_2 was a white light of the same luminance with a vertical black line, $\frac{1}{16}$-in. wide, superimposed on it. Four other available line orientations were 22.5°, 45°, 67.5°, and 90° from vertical. Standard relay equipment was in an adjacent room. Data were recorded on counters and a cumulative recorder.

Procedure

Preliminary training consisted of adaptation to the chamber, magazine training, and shaping to peck the white key. The birds were allowed about 200 regular reinforcements over several sessions. The birds were then given two sessions of exposure to variable-interval (VI) 1-min reinforcement with S_1 and S_2 alternating irregularly on the key.

The final procedure, which was instituted after this preliminary training, consisted of a 15-session training cycle as follows:

(a) *Equal reinforcement of key-pecking in S_1 and S_2.* Either S_1 or S_2 was projected on the key for 2.5 min. At the end of this period, there was a 3-sec timeout, during which the key was dark, followed by another presentation of S_1 or S_2. A session consisted of 16 presentations of each stimulus in a sequence randomized with the restriction that S_1 and S_2 appeared equally often, and that S_1 followed an S_1 presentation as often as an S_2 presentation. A 2.5-min warmup period, alternating randomly between S_1 and S_2 from session to session, preceded the collection of data. A single arithmetic VI 3-min tape ran continuously during both S_1 and S_2, but stopped during the 3-sec timeout. The 2.5-min timer stopped during reinforcement, so that access to grain did not affect the duration of exposure to the stimuli. A reinforcement made available but not collected in any period was cancelled. This procedure was in effect for the first four sessions of each training cycle.

(b) *Differential reinforcement in S_1 and S_2.* The equal reinforcement procedure was changed in only one respect: key-pecking was never reinforced in S_2, while the VI 3-min schedule in S_1 was maintained. In S_2, reinforcement was delivered contingent upon the non-occurrence of pecking. If the subject did not peck the key in S_2, a variable-interval tape ran continuously, and delivered reinforcement whenever it was scheduled. Each time the subject pecked the key, the tape stopped for 10 sec. Thus, a reinforcement could never occur within 10 sec of a response. This schedule will be designated VI DRO. Each subject was trained for 10 sessions with extinction, or a VI DRO schedule with an average interreinforcement interval of 3, 1, or $\frac{1}{3}$ min in S_2.

(c) *Generalization testing.* In the fifteenth and final session of the cycle, the birds were

given 20 min of training on the differential reinforcement schedule to which they were exposed in (b). Then, a generalization test was run, in which each of the five line orientations was projected on the key for 1-min periods, separated by 3-sec timeout. Ten blocks of five exposures each were given, with the order of the orientations randomized within each block. S_1 was never presented, and there was no reinforcement at any time after the first 20-min warmup.

Each of the four subjects was exposed to each of the four differential reinforcement schedules in a different order. A fifth training cycle was given to replicate the first for each bird. The order of treatments is summarized in Table 1.

Table 1

Order of exposure to various differential reinforcement schedules for individual subjects. The reinforcement schedule in S_1 was always VI 3-min; the schedule in S_2 is given below.

Train-ing Cycle No.	Bird Number			
	479	481	482	483
1	EXT	VI ⅓ DRO	VI 1 DRO	VI 3 DRO
2	VI ⅓ DRO	VI 3 DRO	EXT	VI 1 DRO
3	VI 1 DRO	EXT	VI 3 DRO	VI ⅓ DRO
4	VI 3 DRO	VI 1 DRO	VI ⅓ DRO	EXT
5	EXT	VI ⅓ DRO	VI 1 DRO	VI 3 DRO

Except for a few days between training cycles, sessions were conducted daily if the birds were within 15 g of their 80% weights. Commonly, a bird being trained with VI ⅓ DRO in S_2 would exceed this weight criterion. When this occurred, the other birds were not run but were fed in their home cages in order to keep the spacing between sessions the same for all subjects.

RESULTS

Changes in Behavior during Differential Reinforcement

The effects of the various differential reinforcement schedules on responding in the presence of S_1 and S_2 are summarized in Fig. 1. Each bird's rate of responding in each session was normalized by dividing by the rate in the final session of training with equal reinforce-

ment. These normalized rates were then averaged across subjects for each schedule of reinforcement in S_2, including replications. The schedule of reinforcement in S_2 had marked effects on responding in S_1: rates increased with extinction in S_2, and decreased with VI ⅓ DRO in S_2, while the intermediate schedules had intermediate effects. The rate of elimination of responding in S_2 was also affected by the schedule of reinforcement: all three VI DRO schedules effected a more rapid elimination of responding, and resulted in lower asymptotes, than did extinction. These
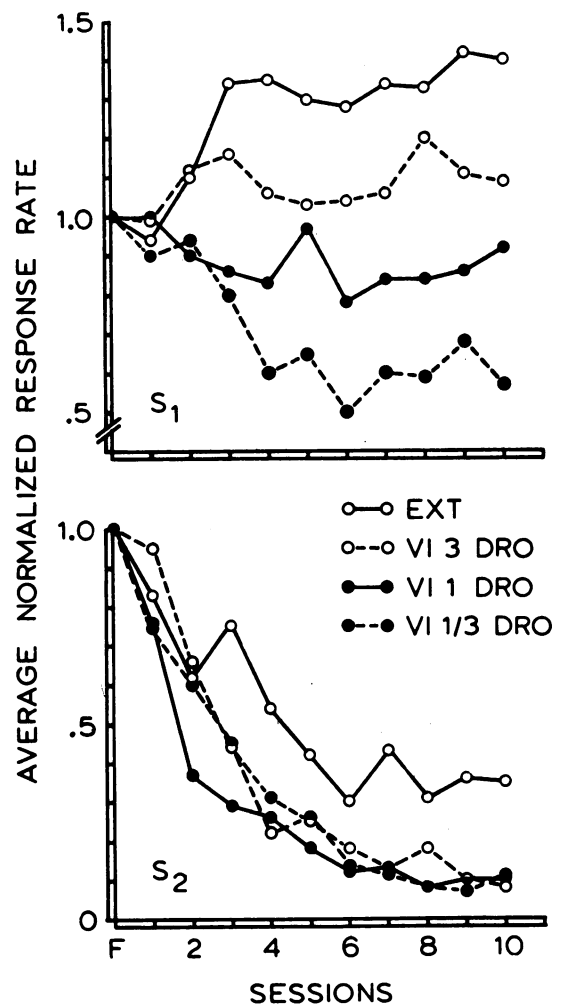

Fig. 1. Averaged normalized rate in S_1, correlated with a VI 3-min schedule of reinforcement, and S_2, correlated with various frequencies of reinforcement for not responding, over the course of 10 sessions of training. Rates were normalized with respect to the final session of training with VI 3-min in both stimuli (designated session F).

results precisely replicate the findings of Reynolds (1961a), and extend them by demonstrating a systematic effect of DRO reinforcement frequency on response rate in S_1.

For each subject, the average response rates in the presence of S_1 and S_2 during the final three sessions of equal reinforcement and differential reinforcement training are shown in Table 2. The numbers of reinforcements actually obtained per hour during these sessions are tabulated also. Examination of the table shows that approximately equal numbers of reinforcements occurred during equal reinforcement training, but that response rates in S_2 were usually lower than in S_1. Response rates in S_1 always increased when extinction was scheduled in S_2. The increases tended to be smaller with VI 3 DRO, and were inconsistent across subjects with VI 1 DRO. All subjects exhibited decreases in response rate when VI ⅓ DRO was scheduled in S_2. The rate of responding in the presence of S_2 tended to remain higher with extinction than with any of the VI DRO schedules in S_2. Note that the replication data for one subject in each condition are similar to the initial determina-

tions except for generally elevated rates. Thus, the average relative rates plotted in Fig. 1 are representative of the untransformed data for individual subjects.

Responding in S_1 was examined for transient contrast effects by subdividing each 2.5-min period into 30-sec segments, exclusive of reinforcement time. Responses in each 30-sec segment were cumulated and averaged for the last three sessions on each differential reinforcement procedure (excluding replications). Figure 2 shows the time course of responding in S_1 within 2.5-min periods after exposure to S_2 or S_1. Performances of each subject are presented in each panel, according to the schedule of reinforcement in S_2 during the first four training cycles. The data are most simply summarized by noting that responding in S_1 after exposure to S_2 is more variable than is responding after exposure to S_1. Only Bird 482 exhibits a clear transient increase after S_2 correlated with extinction, while all subjects exhibit transient low rates after S_2 correlated with VI ⅓ DRO. Thus, this procedure generally failed to isolate positive transient contrasts.

Table 2

Responses per minute in the presence of S_1 and S_2 for the final three sessions of equal reinforcement, and the final three sessions of differential reinforcement on the various S_2 schedules. The actual numbers of reinforcements per hour are also tabulated. The sequence of exposure to each schedule is indicated for each bird.

| S_2 Schedule	Bird No.	Training Cycle No.	Equal RFT				Differential RFT			
			Resp/Min		RFT/Hr		Resp/Min		RFT/Hr	
			S_1	S_2	S_1	S_2	S_1	S_2	S_1	S_2
EXT	479	1	53.3	43.5	21.0	13.0	80.0	15.1	22.5	0
	479	5	105.4	67.6	22.5	21.5	127.0	21.8	21.5	0
	481	3	61.4	53.3	22.0	20.0	70.1	18.0	23.0	0
	482	2	36.3	33.4	22.0	21.0	67.6	7.2	22.0	0
	483	4	40.6	25.1	20.0	19.5	69.1	18.4	20.0	0
VI 3 DRO	479	4	71.4	44.4	21.5	22.0	70.7	0.9	20.5	18.5
	481	2	32.9	29.1	20.5	22.5	52.9	2.7	21.0	15.0
	482	3	61.9	40.9	18.0	23.5	66.2	7.2	22.0	11.0
	483	1	40.9	40.2	14.5	15.0	52.5	11.2	20.5	8.0
	483	5	51.0	38.4	22.5	19.0	70.9	2.8	22.5	16.0
VI 1 DRO	479	3	73.5	57.3	22.0	20.0	47.2	5.0	22.0	43.0
	481	4	76.2	70.0	18.5	23.0	35.9	1.1	21.5	58.5
	482	1	27.4	29.6	20.5	16.5	31.2	2.3	21.5	49.0
	482	5	52.1	46.0	19.5	24.0	62.2	1.7	22.5	52.5
	483	2	45.4	32.3	22.0	19.0	48.7	11.6	21.0	19.5
VI ⅓ DRO	479	2	70.2	55.7	19.5	22.0	29.4	1.8	21.0	181.0
	481	1	17.1	10.1	15.0	16.5	15.9	2.5	19.0	166.0
	481	5	60.2	57.4	21.5	21.5	34.6	0.9	20.5	190.0
	482	4	62.6	36.6	23.0	19.5	42.9	3.4	23.5	158.5
	483	3	58.5	43.8	21.5	22.0	27.2	3.8	20.5	153.5
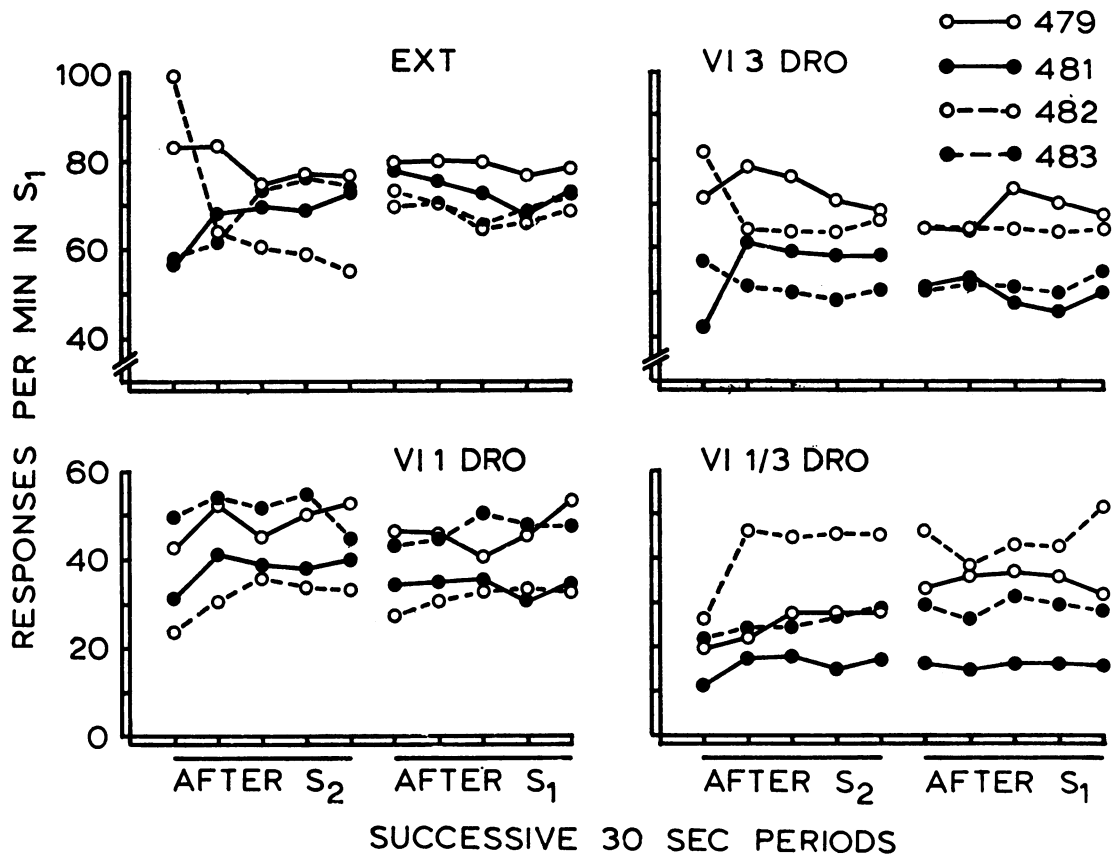
Fig. 2. Rate of responding in successive 30-sec periods of S_1 following exposure to S_2 or to S_1. Data are averaged for individual subjects over the final three sessions of exposure to each schedule of reinforcement in S_2.

Generalization Gradients for Responding in S_2

The numbers of responses made by each subject in the presence of each of the five line orientations, after training on the four schedules, are presented in Fig. 3. All gradients taken after extinction in S_2, though shallow and not entirely orderly, exhibited a tendency for responding to increase as the line orientation changed progressively away from 0 degrees (S_2). In particular, every subject responded more at 90 degrees than at 0 degrees. This tendency became less clear as the reinforcement frequency for not responding in S_2 increased, and disappeared altogether when the subjects received VI ⅓ DRO in S_2. The replication gradients were lower and less orderly than the initial gradients in all conditions. Only Bird 479, trained with extinction in S_2, responded more at 90 degrees than at 0 degrees in the replication.

Relative gradients were calculated for each subject by dividing the number of responses in the presence of each line orientation by the total responses during the test. Replications were averaged within subjects, and then averages were calculated across subjects for each schedule of reinforcement in S_2. The resulting average relative gradients are presented in Fig. 4. The trend parallels that displayed in Fig. 1 for responding to S_1. That is, extinction in S_2 produced inhibitory control by S_2, and contrast in S_1; VI ⅓ DRO produced neither effect; and the intermediate schedules produced weak or inconsistent effects. The average relative gradient after extinction replicated the gradients reported by Honig *et al* (1963). In both studies, there was slightly more than twice as much responding to 90° as to 0°.

To determine whether the individual differences in gradient slope after a given DRO schedule were related to other aspects of behavior, various measures of gradient slope
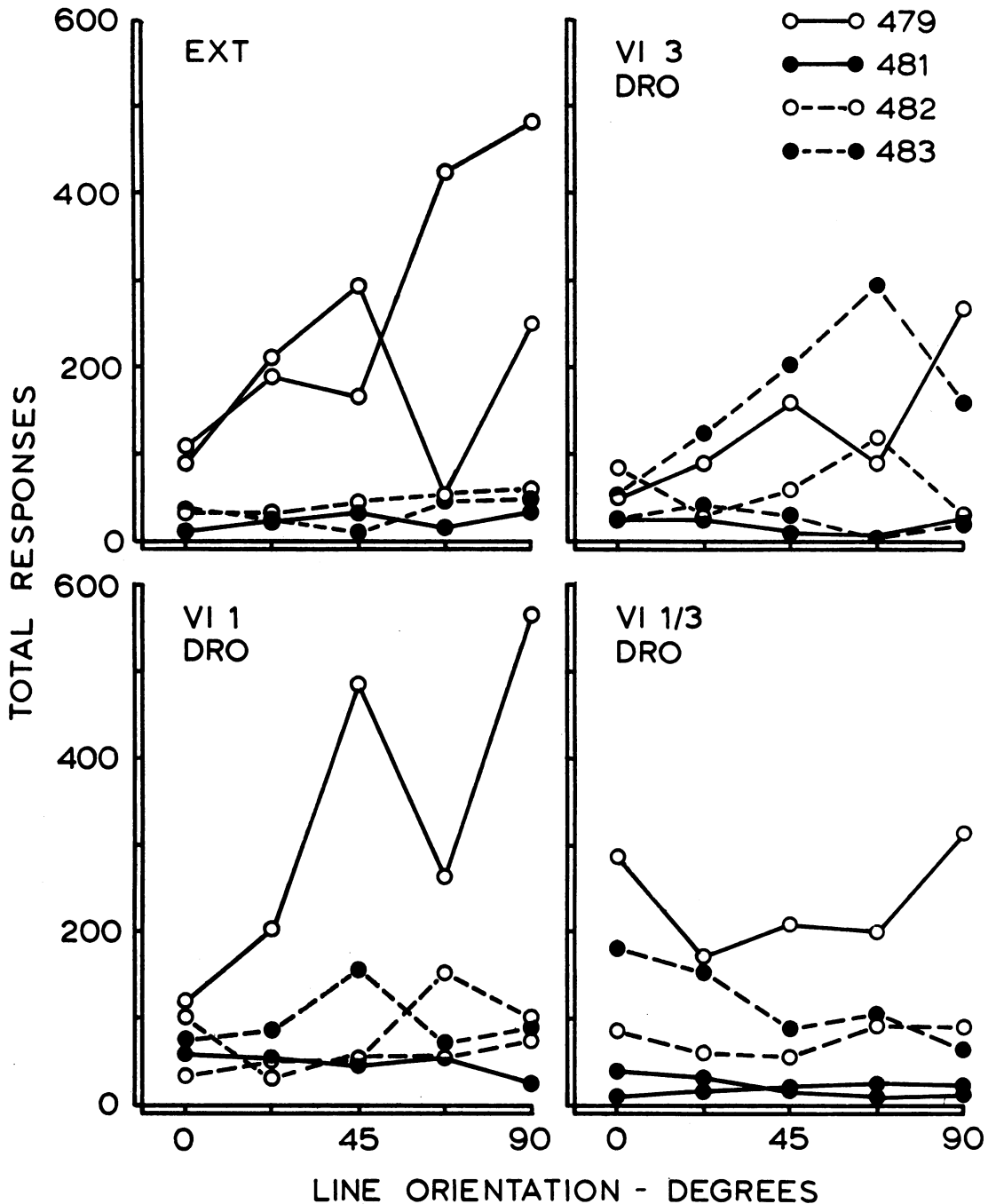
Fig. 3. Absolute numbers of responses at each of five line orientations presented in a generalization test following training with each schedule of reinforcement in S₂. Each orientation was presented for ten 1-min periods without food reinforcement.

were examined in relation to performance during differential reinforcement. There was no evidence that the extent of inhibitory control was correlated across subjects with either sustained or transient contrast effects in S_1, total responses to S_2 during differential reinforcement, or the rate of responding to S_2 at the end of training.
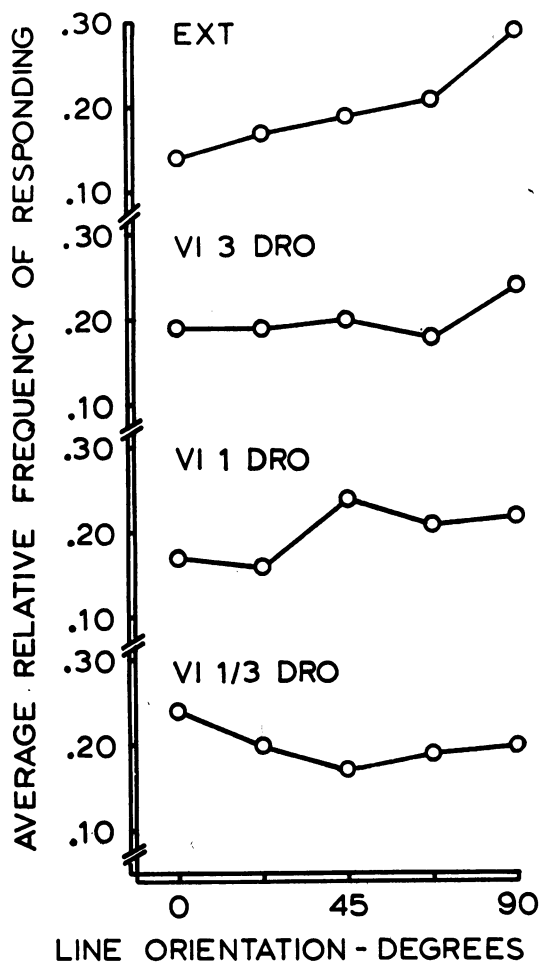
Fig. 4. Average relative frequency of responding at each of five line orientations following training on each schedule of reinforcement in S_2.

DISCUSSION

The design of Exp. 1 differed from previous studies of generalization of inhibition in that each subject was tested for inhibitory control by S_2 several times, after different schedules of reinforcement in S_2. The gradients seemed to become somewhat less orderly with repeated testing, perhaps because of the accumulating history of reinforcement for key-pecking in S_2 during the four equal reinforcement sessions in each training cycle. It is possible that this feature of the experiment obscured any inhibitory control, that may have developed during DRO training. Another possible confounding factor is that subjects receiving frequent reinforcement in the presence of S_2 could use the occurrence of reinforcement itself as a cue for

not pecking. This may have shifted their attention away from the key, or established patterns of movement in the chamber that reduced effective exposure to S_2. To attempt to control for these factors, a second experiment was performed with independent groups of subjects and a reinforcement schedule designed to insure attention to S_2, by presenting reinforcement on a DRO contingency only at the end of an S_2 period.

EXPERIMENT 2

METHOD

Subjects

Eight male White Carneaux pigeons were maintained at 80% of their free-feeding weights, ±15 g. Birds 484, 485, 486, and 487 had been exposed to S_1 and S_2 of the present experiment in a discrete-trials procedure for about 25 sessions; this experiment was terminated because it generally failed to establish differential responding. Birds 320, 349, 429, and 430 had a prolonged history of exposure to a discrete trials procedure with blue and green key lights.

Apparatus

As in Exp. 1.

Procedure

Since all subjects had a history of reinforcement for key-pecking, no preliminary training was required. The birds were placed directly on the final procedure, which consisted of three phases, as in Exp. 1:

(a) *Equal reinforcement in S_1 and S_2.* Either S_1 or S_2 was projected on the key for 10 sec, in a random sequence similar to that of Exp. 1. An arithmetic VI 1-min schedule ran continuously during presentations of both stimuli. If a reinforcement had been made available during the 10-sec period, the key remained lighted until the first peck to occur after 10 sec from stimulus onset, which was reinforced with 3-sec access to grain. If a reinforcement had not become available, the key light was turned off at the end of 10 sec with no contingency on responding. Responses during the 10-sec period had no scheduled consequences. Following either reinforcement or non-reinforcement, the key remained dark for 3 sec before the next stimulus presentation,

and the VI tape stopped. This procedure was in effect for 5.5 sessions, where each session consisted of sixty-four 10-sec periods, with 32 presentations of each stimulus.

(b) *Differential reinforcement in S_1 and S_2.* In the middle of the sixth session, the procedure was changed so that 10 sec had to elapse without a peck before S_2 ended, while the S_1 schedule remained as described above. For the EXT group (320, 349, 484, and 486), S_2 always ended with a 3-sec timeout. For the DRO group (429, 430, 485, and 487), a VI ⅓-min program ran continuously during S_2, and S_2 ended with a 3-sec presentation of grain if a reinforcement had become available during that S_2 period. If the subjects discriminated perfectly and never responded in S_2, about half the S_2 periods would end with reinforcement. If they responded fairly often, increasing the duration of S_2, the probability of reinforcement at the end of S_2 would increase, since the VI schedule would have a longer opportunity to make reinforcement available. However, the average frequency of reinforcement per unit time in S_2 would decrease. The purpose of this procedure was to insure equivalent exposure to S_2 for both groups, insofar as possible, by preventing the DRO subjects from using reinforcement as a cue. The EXT and DRO groups experienced conditions closely analogous to the EXT and VI ⅓ DRO schedules in Exp. 1, except that stimulus presentations were brief, and the duration of S_2 was contingent on responding. This procedure remained in effect for seven full sessions following the half session during transition from equal reinforcement to differential reinforcement. Each session still consisted of 32 presentations of each stimulus, but the session length was now variable, depending on the rate in S_2.

(c) *Generalization testing.* The test for inhibitory control by S_2 was continuous with the final session of differential reinforcement. Food reinforcement was discontinued, and each of the five line orientations was projected on the key for 10-sec periods, separated by 3 sec with the key dark. Sixty blocks of five exposures were presented, with the order of orientations randomized within blocks. S_1 was never presented after testing began, and the duration of exposure to the stimuli was not influenced by the amount of responding in their presence.

Experimental sessions were conducted on consecutive days throughout the course of training, since the birds were always within 15 g of their 80% body weights.

RESULTS

Since this procedure was somewhat unusual, detailed data on acquisition will be presented. During the equal reinforcement phase, several birds exhibited slightly lower rates in S_2 than in S_1, but there did not seem to be any systematic dependency on the subjects' prior histories. In the first half of the transition session, rates were generally high and similar in both stimuli. With the transition to differential reinforcement, rate in S_2 decreased similarly for all eight birds, and no consistent differences were evident across groups. Total responses to S_2 over the course of 7.5 sessions of differential reinforcement training ranged from 503 to 3028 for the EXT birds, and from 1139 to 1322 for the DRO birds. Total time spent in S_2 over the same period ranged from 61.6 to 82.3 min for EXT, and from 60.0 to 80.3 min for DRO. On the average, the elimination of behavior in S_2 was nearly identical in the two conditions. The final rate of reinforcement per unit time spent in S_2 was about 2.60 rft/min for all DRO birds; this value is quite close to the average of 2.83 rft/min obtained on the VI ⅓ DRO schedule in Exp. 1. Two of the four EXT birds exhibited contrast in S_1; the two which did not had unusually high rates for pigeons on interval schedules of reinforcement. All four DRO birds exhibited substantial rate reductions in S_1, three of the four within the first half session of training. Analysis of the data indicated that these decreases were partly attributable to pauses in S_1 periods after reinforcement at the end of a preceding S_2. The acquisition data are summarized for individual subjects in Fig. 5. In general, the major aspects of performance during differential reinforcement in Exp. 1 were replicated.

Generalization gradients for responding to various line orientations are shown in Fig. 6. Bird 349 responded only four times during the generalization test (all four at 90°); its data are not included. Birds 320, 484, and 486 all exhibited shallow but orderly inhibitory gradients after EXT in S_2. It is interesting to note that all three responded more at 0° than at
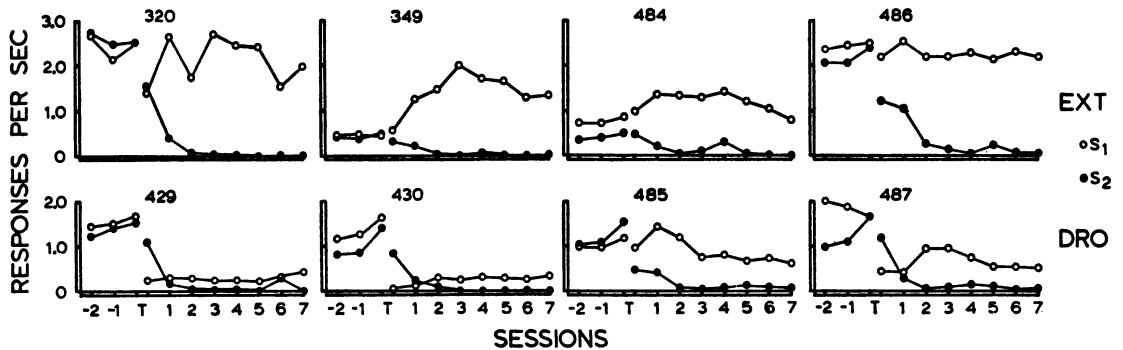
Fig. 5. Rate of responding to S_1 and S_2 during the final two sessions of equal reinforcement, transition to differential reinforcement, and seven subsequent sessions of differential reinforcement. Data are presented for individual subjects according to whether they never obtained food at the end of S_2 (EXT), or obtained food intermittently if no response had occurred for 10 sec (DRO).

22.5° or 45°. The relative gradients for these three birds are substantially identical. Birds 429, 430, 485, and 487 gave gradients which tended, if anything, to decrease at orientations remote from 0°.
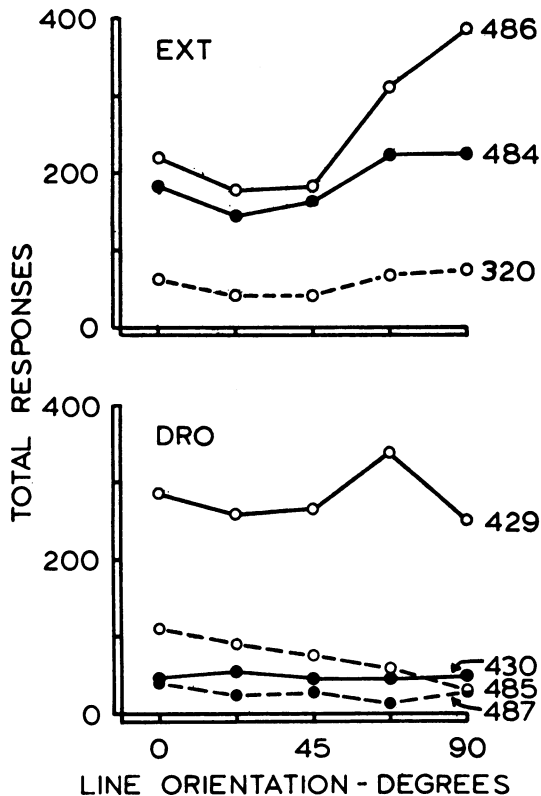

Fig. 6. Absolute numbers of responses at each of five line orientations following training with EXT or DRO in S_2. Each orientation was presented for sixty 10-sec periods without any contingency on responding or food reinforcement. No data are presented for Bird 349, which responded only four times.

The average relative gradients for these groups are presented for comparison in the top panel of Fig. 7. Although it is evident that extinction in S_2 established only rather weak control of not responding, the DRO schedule produced none at all. The difference between the EXT and DRO gradients was quite comparable to that between EXT and VI $\frac{1}{3}$ DRO in Exp. 1. To show this, the percentage of responses made to each orientation following
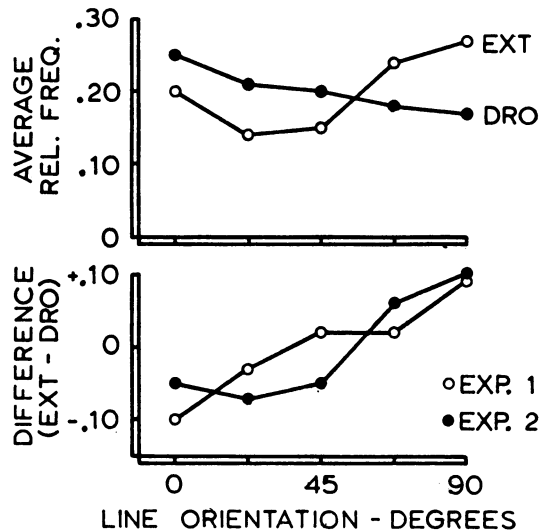

Fig. 7. Upper panel: average relative frequency of responding at each of five line orientations following training with EXT or DRO in S_2. Lower panel: differences between the average relative frequencies of responding at each of five line orientations after training with EXT and VI $\frac{1}{3}$ DRO in Exp. 1, and after EXT and DRO in Exp. 2. In both cases, the average relative frequency of responding at each orientation following DRO training was subtracted from the average relative frequency of responding following EXT.

DRO training was subtracted from the percentage following EXT, as given by the average relative gradients from both experiments. These difference gradients are plotted in the lower panel of Fig. 8, indicating the similarity of the two sets of data. Thus, the differences in stimulus control of not responding effected by DRO and extinction in these two quite different procedures were substantially identical.

DISCUSSION

The generalization gradients obtained in these experiments suggest that the elimination of behavior in the presence of a stimulus (S_2) is not by itself a sufficient condition for the stimulus control of not responding. The use of a DRO contingency led to elimination of behavior similar to that effected by extinction, yet if DRO reinforcement was frequent, there was no evidence of inhibitory control. Neither was there any evidence of positive contrast when frequent reinforcement for not responding was scheduled in S_2; indeed, response rates in S_1 decreased under these conditions.

These findings are at variance with Terrace's (1966a, b) formulation of the role of response elimination in discrimination learning. He has proposed that contrast and gradients of inhibition depend on the reduction of response rate in S_2. It appears that the frequency of reinforcement must also be taken into account. It also appears that Terrace's errorless training procedures and frequent DRO reinforcement have a good deal in common: neither procedure gives rise to positive contrast effects, nor to stimulus control of not responding.[3] The gradients obtained after errorless training (Terrace, 1966b) differ from

the present gradients in one important respect: there was no responding at any stimulus value after errorless training, but there was substantial responding after DRO training. However, the amount of responding did not vary along the S_2 continuum.

Nevin and Shettleworth (1966) showed that positive transient contrast occurred after exposure to a stimulus correlated with extinction, but not after exposure to a stimulus correlated with DRO, although both controlled near-zero response rates. The present study generally failed to demonstrate positive transient contrast in S_1. One possible reason for this failure is that the phenomenon tends to disappear with continued training (Nevin and Shettleworth, 1966). The conditions of the present study, which exposed single subjects to various reinforcement schedules over a long period of training, were probably not optimal for the isolation of such an effect. Nevertheless, it should be noted that positive transient contrast is functionally similar to sustained contrast, as measured by average response rates, and to gradients of inhibition, in that all three effects depend on extinction, and are not observed during discrimination training without errors, (Terrace, 1966a, p. 320) or with reinforcement for not responding.

This paper has used the term "contrast" in its generally accepted sense: a change in rate in S_1 under constant reinforcement conditions, correlated with an opposed rate change in S_2. Bloomfield (1967) has recently argued that contrast should be defined in terms of reinforcement frequencies instead. He arranged multiple schedules with a constant VI 1-min schedule in one component (S_1), and either fixed-ratio (FR) or differential reinforcement of low rate (DRL) schedules in the other component (S_2). He found that equivalent changes in the frequency of reinforcement in S_2 had similar effects on response rate in S_1, regardless of whether the S_2 schedule led to high rates on FR or low rates on DRL. The present finding of a systematic dependency of rate in S_1 on the frequency of reinforcement in S_2 with different DRO schedules in S_2 is precisely consistent with Bloomfield's results.

To demonstrate this consistency, the relation between the rate of responding in S_1 and the relative frequency of reinforcement obtained in S_1 was determined from the data of Exp. 1, and from Bloomfield's (1967) data.

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[3]A recent paper by Yarczower, Dickson, and Gollub (1968) suggests that this equivalence extends to the peak shift. They report that generalization gradients obtained after discrimination training with *tand* VI 30-sec DRL 4-sec in the presence of 550 nm, and DRO 10-sec in the presence of 570 nm, had maxima at 550 nm and did not differ from control gradients obtained after training with 550 nm only. However, comparable training with extinction in the presence of 570 nm produced peaks at 540 nm (Yarczower *et al*, 1966). Similarly, Terrace (1964) trained pigeons with VI 1-min reinforcement in the presence of 580 nm, and either standard extinction or errorless training in 540 nm. Generalization gradients were shifted away from 540 nm after extinction, but not after errorless training.

For the data of Exp. 1, presented in Table 2, response rates in S_1 for the final three sessions were averaged within subjects for replications, and then averaged across subjects for the four differential reinforcement conditions. The resulting average response rates are plotted in Fig. 8 as a function of the average relative frequency of reinforcement. The latter measure was calculated for each subject by dividing the number of reinforcements obtained in S_1 by the sum of reinforcements in S_1 and S_2. Note that this is identical to the relative rate of reinforcement, since S_1 and S_2 were of the same duration and occurred equally often. The resulting relative frequencies of reinforcement were averaged in the same way as response rates. The average rate of responding in S_1 during equal reinforcement training, the mean of the first column of data in Table 2, is included at a relative frequency of reinforcement of 0.50, with a circle around the point.

Bloomfield's (1967) data for multiple VI DRL schedules (presented in his Fig. 1) were transformed into this form by grouping the data points into five sets, ranked according to reinforcements obtained in the DRL component, averaging, and plotting in Fig. 8 as a function of the average relative frequency of reinforcement obtained in the VI component.
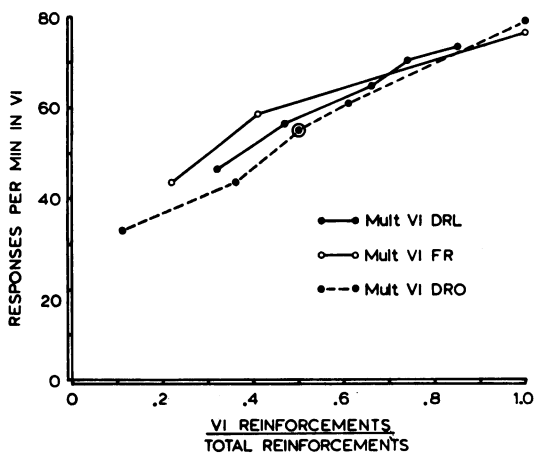

Fig. 8. Response rate in a constant variable-interval (VI) component of a multiple schedule, as a function of the proportion of reinforcements obtained in the VI component when the reinforcement schedule in the other component varied. The function for *mult* VI DRL is taken from Bloomfield (1967), Exp. 1. The function for *mult* VI FR is taken from Reynolds (1961*b*), Series 1. The function for *mult* VI DRO is taken from Exp. 1 of this report.

This estimation procedure was checked by replotting his individual data points as a function of relative reinforcement frequency, fitting linear functions by eye to the data of each subject, and averaging the slopes and intercepts of the functions. The two methods agreed almost perfectly.

Bloomfield's (1967) multiple VI FR experiment does not lend itself to comparable treatment, since the FR component duration varied contingent upon behavior, and always ended with reinforcement. Instead, data have been taken from an experiment by Reynolds (1961*b*), using a multiple schedule with a constant VI 3-min schedule in one component (S_1) and an FR schedule in the alternated component (S_2). The components were constant and equal in duration. In Reynolds' procedure, the S_2 schedule took on values of FR 75, FR 150, or extinction. The average rate of responding in the VI component was determined from the data given in Reynolds' Fig. 1, and is plotted in Fig. 8 as a function of the average relative frequency of reinforcement obtained in the VI component. The agreement among these three functions, despite the enormous differences in level or direction of change in response rate in the alternated component, suggests the following generalization: the average rate of responding in a constant VI component of a multiple schedule is systematically related to the relative frequency of reinforcement obtained in its presence, regardless of the scheduled reinforcement contingencies or the resulting performance in the alternated component. Rate changes within a constant VI schedule component following exposure to more frequent reinforcement are also consistent with this generalization (Nevin and Shettleworth, 1966). After exposure to a stimulus correlated with VI 1-min reinforcement, responding in the presence of a stimulus correlated with VI 5-min reinforcement was initially low, and increased with the passage of time in the VI 5-min stimulus. This pattern of responding was observed both when the VI 1-min stimulus controlled high rates with a conventional VI reinforcement contingency, and when it controlled near-zero rates through the use of a DRO contingency.

The foregoing generalization for multiple schedules has an exact parallel in the case of concurrent schedules. Catania (1963) trained pigeons with two VI schedules of reinforce-

ment available concurrently in the presence of different stimuli, in a procedure requiring a switching response to change from one stimulus and schedule to the other. In one part of his study, the VI schedule in one stimulus was held constant, while the other was varied systematically. The average rate of responding on the constant schedule decreased as the frequency of reinforcement provided by the varied schedule increased, leading to increases in the rate of responding on the varied schedule. The same function was obtained when reinforcement on the varied schedule was signaled by illumination of the switching key. Under this procedure, the pigeons spent very little time in the presence of the stimulus correlated with the varied schedule, and average rates on the varied schedule remained low at all reinforcement frequencies.

The relation between response rate maintained by one schedule of reinforcement and the frequency of reinforcement in the presence of stimuli correlated with other component schedules is of general interest in the analysis of behavior. The usual contrast effect during multiple VI extinction training after non-differential reinforcement is a special case of this relation. Other factors also contribute to contrast effects. "Correction" procedures during multiple VI extinction training enhance contrast (Bloomfield, 1966), while errorless training prevents its occurrence even under equivalent shifts in reinforcement scheduling (Terrace, 1966a, p. 318).

It could be argued that there is only a superficial resemblance between the reduction in response rate in S_1 produced by frequent DRO reinforcement in S_2 in the present experiments, and the absence of positive contrast in Terrace's work, despite the equivalent findings with respect to inhibitory stimulus control by S_2. Support for such an argument might come from a demonstration of differences in other aspects of the situation, for instance, in the degree of stimulus control exerted over responding by S_1. Until further comparisons of this sort are available, however, the present findings suggest that variables affecting positive contrast and gradients of inhibition may be functionally equivalent in the determination of discriminated operant behavior.

REFERENCES

Bloomfield, T. M. Two types of behavioral contrast in discrimination learning. *Journal of the Experimental Analysis of Behavior*, 1966, **9**, 155-161.

Bloomfield, T. M. Behavioral contrast and relative reinforcement frequency in two multiple schedules. *Journal of the Experimental Analysis of Behavior*, 1967, **10**, 151-158.

Catania, A. C. Behavioral contrast in a multiple and concurrent schedule of reinforcement. *Journal of the Experimental Analysis of Behavior*, 1961, **4**, 335-342.

Catania, A. C. Concurrent performances: Reinforcement interaction and response independence. *Journal of the Experimental Analysis of Behavior*, 1963, **6**, 253-263.

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

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

Honig, W. K., Boneau, C. A., Burstein, K. R., and Pennypacker, H. S. Positive and negative generalization gradients obtained after equivalent training conditions. *Journal of Comparative and Physiological Psychology*, 1963, **56**, 111-116.

Jenkins, H. M. Generalization gradients and the concept of inhibition. In D. I. Mostofsky (Ed.), *Stimulus generalization*. Stanford: Stanford University Press, 1965. Pp. 55-61.

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

Reynolds, G. S. *An analysis of interactions in a multiple schedule*. Doctoral dissertation, Harvard, University, 1960.

Reynolds, G. S. Behavioral contrast. *Journal of the Experimental Analysis of Behavior*, 1961, **4**, 57-71. (a)

Reynolds, G. S. Relativity of response rate and reinforcement frequency in a multiple schedule. *Journal of the Experimental Analysis of Behavior*, 1961, **4**, 179-184. (b)

Terrace, H. S. Wavelength generalization after discrimination learning with and without errors. *Science*, 1964, **144**, 78-80.

Terrace, H. S. Stimulus control. In W. K. Honig (Ed.), *Operant behavior: areas of research and application*, New York: Appleton-Century-Crofts, 1966. Pp. 271-344. (a)

Terrace, H. S. Discrimination learning and inhibition. *Science*, 1966, **154**, 1677-1680. (b)

Yarczower, M., Dickson, J. F., and Gollub, L. R. Some effects on generalization gradients of tandem schedules. *Journal of the Experimental Analysis of Behavior*, 1966, **9**, 631-639.

Yarczower, M., Gollub, L. R., and Dickson, J. F. Some effects of discrimination training with equated frequency of reinforcement. *Journal of the Experimental Analysis of Behavior*, 1968, **11**, 415-423.