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SOME DETERMINANTS OF INHIBITORY STIMULUS CONTROL[1]

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Interspersed reinforcement and extinction during discrimination learning generate a U-shaped gradient of inhibition about the stimulus correlated with extinction. The present work showed that extinction is not a necessary determinant of inhibitory stimulus control. In Exp. I, a reduction in the rate of reinforcement, through a shift from a multiple variable-interval 1-min variable-interval 1-min schedule to a multiple variable-interval 1-min variable-interval 5-min schedule, resulted in a post-discrimination line orientation gradient of inhibition about the stimulus correlated with the variable-interval 5-min schedule. In Exp. II, the rates of reinforcement, correlated with a pair of stimuli, were held constant during a shift from a multiple variable-interval 1-min variable-interval 1-min schedule to a multiple variable-interval 1-min differential-reinforcement-of-low-rate schedule. Inhibitory stimulus control about the stimulus correlated with the differential reinforcement of low rate was obtained. In both experiments, a reduction in the rate of responding during one stimulus and behavioral contrast during the other stimulus preceded the observation of inhibitory stimulus control.

The post-discrimination stimulus control function is an important result of discrimination learning (Jenkins, 1965; Terrace, 1966*a*). When discrimination training was between two stimuli from the dimension on which the test stimuli of the post-discrimination generalization test were varied, the peak of the gradient shifted from the discriminative stimulus correlated with reinforcement (S+) in the direction away from the discriminative stimulus correlated with extinction (S−) (Hanson, 1959; Bloomfield, 1967). It has been suggested that the peak shift is the result of the formation of an underlying U-shaped gradient of inhibition about S− (Thomas and Williams, 1963; Terrace, 1966*a*). In support of the hypothesis, inhibitory stimulus control has been observed when S−, but not S+, was in the dimension examined during the post-discrimination test (Jenkins and Harrison, 1962; Honig, Boneau, Burstein, and Pennypacker, 1963). A second, perhaps related, characteristic of discrimination learning is the occurrence of behavioral contrast. Behavioral contrast has been defined as an increase in the rate of responding to S+ that accompanies a reduction in the rate of responding to S−; it has been observed during the acquisition of multiple-schedule discriminations (*mult* VI EXT) employing a variety of training procedures (Reynolds, 1961; Terrace, 1963; Bloomfield, 1966).

Although the peak shift was first investigated using *mult* VI EXT schedules, the phenomenon does not appear to be dependent on the alternation of reinforcement and extinction. The alternation of a discriminative stimulus (S_1) correlated with VI 1-min and a discriminative stimulus (S_2) correlated with VI 5-min (*mult* VI 1-min VI 5-min) has been shown to generate the peak shift (Guttman, 1959). Indeed, Terrace (1968) showed that no reduction in the rate of reinforcement correlated with S_2 is necessary to produce a peak shift away from S_2. He obtained a peak shift with *mult* VI 1-min DRL and *mult* VI 1-min VI 1-min + shock discriminations that did not reduce the rate of reinforcement correlated with S_2. Terrace further observed that behavioral contrast in S_1 was a regular feature of discrimination performance which was also followed by a peak shift.

Is the peak shift a "symptom of inhibitory stimulus control" (Jenkins, 1965), when positive reinforcement schedules were correlated with both S_1 and S_2? The hypothesis explored in the present work was that a stimulus (S_2)

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correlated with a reduced rate of responding becomes a "functional S−", while S_2 is neutral following discrimination learning that leaves the rate of responding to S_2 unchanged (Terrace, 1968). Thus, inhibitory stimulus control was predicted with multiple schedules already reported to yield post-discrimination peak shift.

EXPERIMENT I

In Exp. I, inhibitory stimulus control following *mult* VI 1-min VI 5-min was investigated directly, rather than inferred from the peak shift. The experiment was similar to Terrace's (1968) work with the same multiple schedule except that the post-discrimination gradient was in a dimension (line orientation) that included only the discriminative stimulus for VI 5-min reinforcement.

METHOD

Subjects

Eight experimentally naive, male, Silver King pigeons, 6 to 8 yr old, were maintained at about 75% of their free-feeding weight during the experiment.

Apparatus

The side keys in a Lehigh Valley Model 1519 three-key pigeon chamber were covered with metal shields. A houselight, which was used only during early training, was mounted above the center key. An Industrial Electronics Engineers in-line display cell transilluminated the center key. Six orientations of a 0.125-in. wide by 0.875-in. high white line (±90°, −60°, −30°, 0°, +30°, and +60°, of departure from a vertical line orientation) and a green surround were projected by the display cell.

Reinforcement was 3-sec access to mixed grain, illuminated during the reinforcement cycle by a lamp above the hopper. An opening 2 in. by 2 in. high and 4 in. below the response key provided access to the hopper during the reinforcement cycle. The lamp over the hopper and stimuli projected on the face of the display cell provided the only illumination in the pigeon chamber. White noise and noise from an exhaust fan masked extraneous sound. Recording and scheduling equipment were located in a separate room.

Procedure

Key-peck training was followed by sessions in which the requirement for reinforcement was increased to 45 responses (FR 45). Key-peck and FR 45 training were complete in 3 to 4 sessions, the visual stimuli on the key during this preliminary training were those presented during the first phase of the experiment proper.

Throughout the experiment, a visual stimulus appeared on the key during 60-sec trials and the key was darkened during alternated 10-sec timeout for 28 trials per session. A white vertical (0°) line on a green surround and the (blank) green surround alone appeared on the key in an irregular sequence (several independent randomized orders were used) of approximately 14 presentations of each stimulus during each session.

During the non-differential reinforcement phase of the experiment, identical but independent variable-interval (VI) schedules of reinforcement were correlated with the 0° line and the blank green key. The *mult* VI 1-min VI 1-min → *mult* VI 1-min VI 5-min Group (Birds 1176, 1497, 2439, and 2624) had two sessions with *mult* VI 30-sec VI 30-sec followed by 20 sessions with *mult* VI 1-min VI 1-min during non-differential training. The *mult* VI 5-min VI 5-min → VI 1-min VI 5-min Group (Birds 1233, 1246, 1428, and 2533) had two sessions with *mult* VI 30-sec VI 30-sec, three sessions with *mult* VI 1-min VI 1-min, three sessions with *mult* VI 3-min VI 3-min, followed by 20 sessions with *mult* VI 5-min VI 5-min during non-differential reinforcement.

After non-differential reinforcement, both groups had 14 sessions of discrimination training with a *mult* VI 1-min VI 5-min schedule. During this training, the VI 5-min schedule was correlated with the 0° line on the green surround. Thus, during discrimination training, the rate of reinforcement correlated with the 0° line decreased in the *mult* VI 1-min VI 1-min → *mult* VI 1-min VI 5-min Group, and the rate of reinforcement correlated with the blank key increased in the *mult* VI 5-min VI 5-min → *mult* VI 1-min VI 5-min Group. Discrimination training was identical to prior non-differential reinforcement, except for the change in reinforcement schedules.

Each bird had a generalization test in extinction after discrimination training. The session in which the test was conducted began with four reinforced (VI 1-min) presentations of the blank green key; the 0° line was not presented during this "warm-up". During the generalization test, the stimuli were six orientations of the white line: ±90°, −60°, −30°, 0°, +30°, and +60° departures from vertical, each on a green surround, and the green surround (blank key) alone. These stimuli were each presented 10 times in randomized blocks of seven 30-sec trials separated by 5-sec blackouts.

RESULTS

Line orientation gradients obtained from the *mult* VI 1-min VI 1-min → *mult* VI 1-min VI 5-min Group are shown in Fig. 1. Response strength in the line orientation dimension increased slowly in a shallow U-shaped function about the 0° line. The minima of individual gradients ranged from 53 to 155 responses and were generally at the vertical (0°) line orientation. Figure 2 presents the post-discrimination gradients of the *mult* VI 5-min VI 5-min → *mult* VI 1-min VI 5-min Group. The stimulus functions obtained from three of these birds, 1233, 1428, and 2533, were nearly flat, but a shallow inverted gradient was obtained from one bird (1246).

The number of responses to the blank green key is plotted to the right of each gradient in Fig. 1 and 2. Note that the left ordinate of each figure is for responses in the line orientation dimension, while the right ordinate is for responses to the blank green key. Fewer responses were emitted to the line orientation dimension than to the blank green key during the generalization tests obtained from each bird. That is, response strength in the line orientation dimension was lower than response strength to the blank key, regardless of whether the results of the generalization test indicated inhibitory stimulus control or only a flat gradient.

Rates of responding to the 0° line and blank green key, during the last 10 sessions of non-differential reinforcement and 14 sessions of discrimination training, are shown in Fig. 3. The response rate functions for each bird in the *mult* VI 1-min VI 1-min → *mult* VI 1-min VI 5-min Group (the left-hand panels of Fig. 3) showed evidence of behavioral contrast during discrimination training. The rate of responding to the blank green key increased as the rate of responding to the 0° line declined, relative to the response rates generated during prior non-differential reinforcement.

As might be expected with a five-fold increase in reinforcement frequency, during discrimination training the rate of responding to the blank green key in the *mult* VI 5-min VI 5-min *mult* VI 1-min VI 5-min Group (the right panels of Fig. 3) increased relative to the rate observed during prior non-differential reinforcement. The rate of responding to the 0° line was unchanged, or increased slightly, for three of these birds (1233, 1428, and 2533). Only Bird 1246 showed a reduced rate of responding to the 0° line after the schedule correlated with the blank key was shifted from VI 5-min to VI 1-min. Thus, only one bird of four in the group showed negative behavioral con-

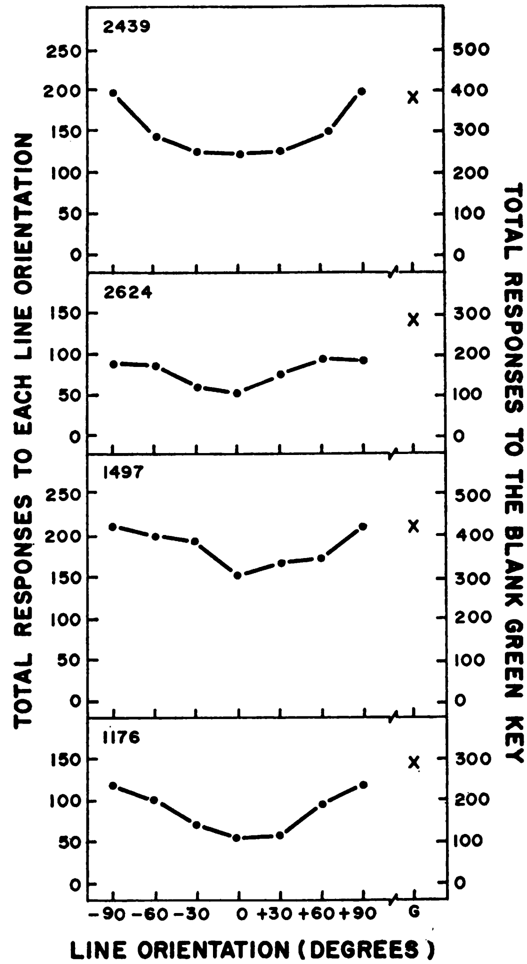

Fig. 1. Post-discrimination line orientation gradients for the stimulus correlated with VI 1-min in the *mult* VI 1-min VI 1-min *mult* VI 1-min VI 5-min Group.

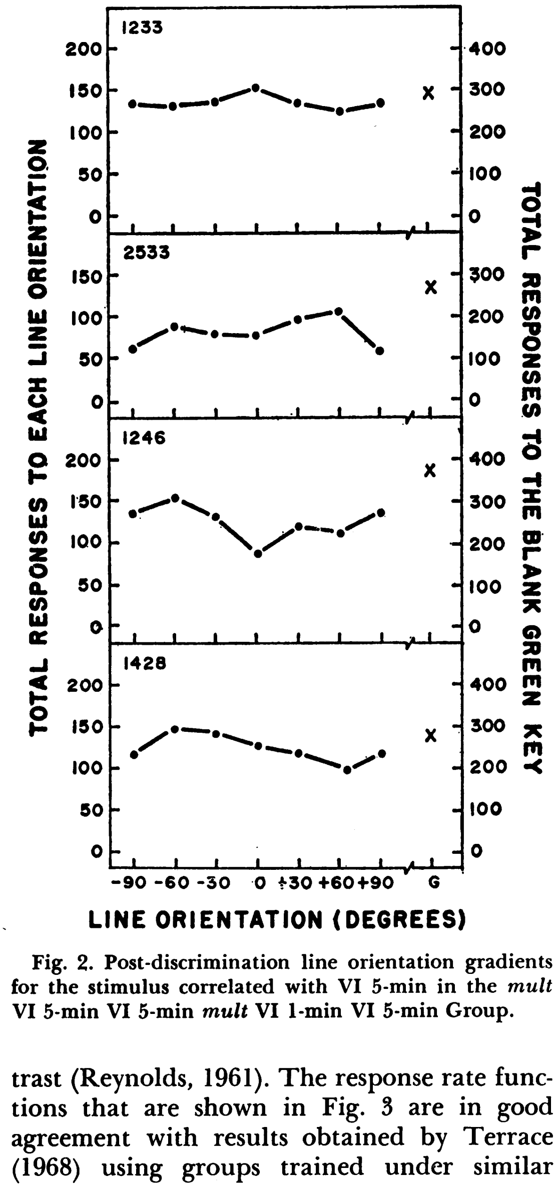

Fig. 2. Post-discrimination line orientation gradients for the stimulus correlated with VI 5-min in the *mult* VI 5-min VI 5-min *mult* VI 1-min VI 5-min Group.

trast (Reynolds, 1961). The response rate functions that are shown in Fig. 3 are in good agreement with results obtained by Terrace (1968) using groups trained under similar conditions.

The results of Exp. I prompt the following tentative conclusions: (a) Interspersed reinforcement and extinction during discrimination training is not necessary to obtain inhibitory stimulus control, as shown by the post-discrimination gradients obtained from the *mult* VI 1-min VI 1-min → *mult* VI 1-min VI 5-min Group (see Fig. 1). (b) Inhibitory stimulus control, like behavioral contrast and the peak shift, may depend more upon a reduction in the rate of responding than on the density of reinforcement (see Fig. 2, Bird 1246). (c) The occurrence of inhibitory stimulus control may be predicted by the prior occurrence of behavioral contrast in the same bird. (d) The hypothesis that a gradient of inhibitory stimulus control underlies the peak shift observed following *mult* VI 1-min VI 5-min discrimination training by other investigators received some support.

EXPERIMENT II

Experiment I found behavioral contrast and inhibitory stimulus control correlated, when responding was based on differential reinforcement density during discrimination training. Is a change in the rate of reinforcement correlated with S_2 a necessary antecedent for these two phenomena? Terrace (1968) has observed behavioral contrast and the peak shift when the rate of responding to S_2 was reduced by differential reinforcement of low rate without a corresponding reduction in relative reinforcement density. A schedule on which only interresponse times longer than some specified duration are reinforced, and non-reinforced responses serve only to reset a clock timing reinforced interresponse times is termed differential reinforcement of low rate (DRL).

In Exp. II, inhibitory stimulus control was sought following a shift from *mult* VI 1-min VI 1-min → *mult* VI 1-min DRL. During *mult* VI 1-min DRL discrimination training, the rate of reinforcement during DRL was equated with the rate of reinforcement that prevailed during VI 1-min.

METHOD

Subjects

Four experimentally naive adult, male, Silver King pigeons were maintained at about 75% of their free-feeding weight during the experiment.

Procedure

The procedure was identical to that used in Exp. I with the *mult* VI 1-min VI 1-min *mult* VI 1-min VI 5-min Group, except that DRL, rather than VI 5-min, was correlated with the vertical (0°) line on a green surround. The discrimination training administered in Exp. II has been termed *mult* VI 1-min DRL. Timing of the DRL requirement commenced with the onset of a 0° line trial, but during the trial began with the last response. To maintain

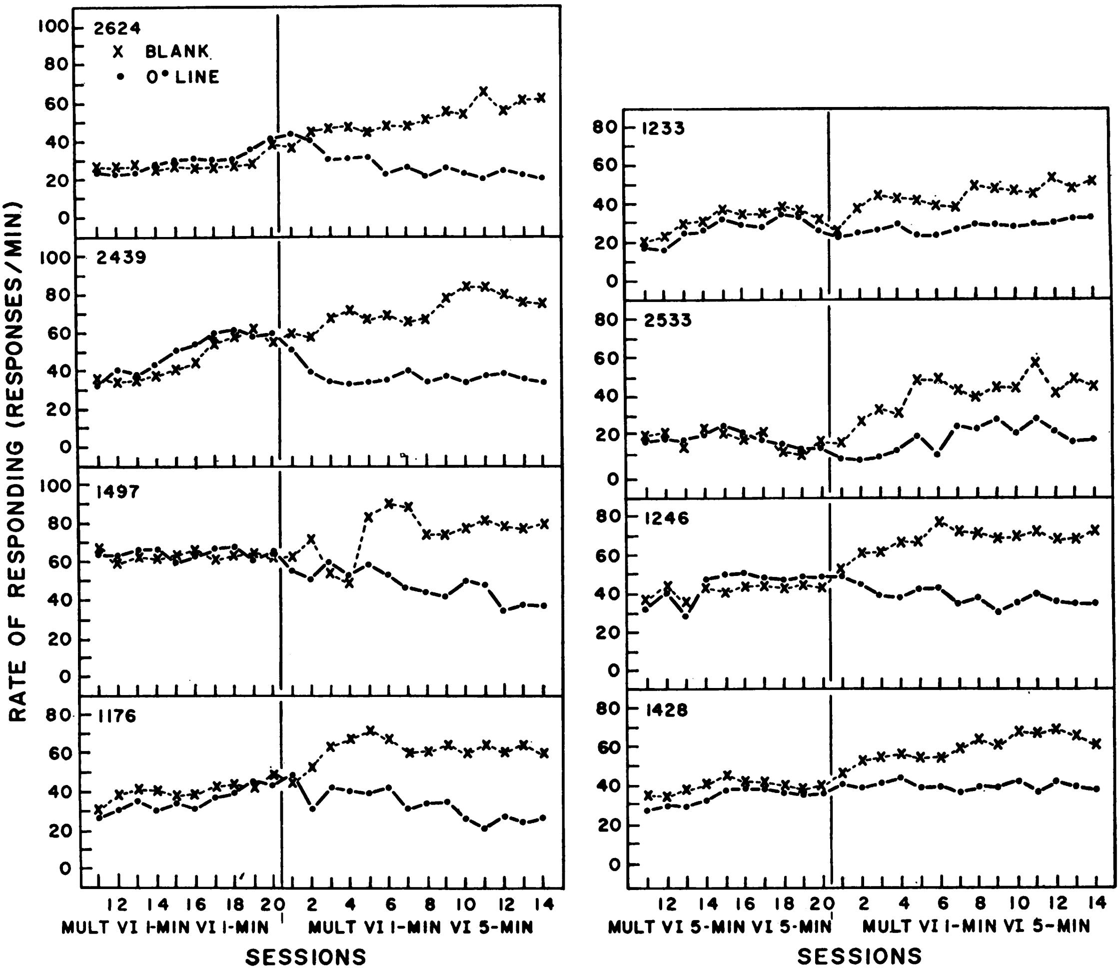

Fig. 3. The rates of responding to the 0° line and blank green key during the last 10 sessions of non-differential reinforcement and 14 sessions of discrimination training in Exp. I.

equality between the rates of reinforcement prevailing during VI 1-min, correlated with the blank green key, and DRL, correlated with the 0° line, it was necessary to adjust the minimum duration of an interresponse time reinforced by the DRL schedule during each session of discrimination training. The DRL requirement was gradually increased within and between sessions from DRL 4-sec to DRL 16-sec or DRL 20-sec.

RESULTS

Only if reinforcement density was nearly equal for the two stimuli presented during *mult* VI 1-min DRL can the effect of a reduction in the rate of responding to the 0° line be assessed. Figure 4 shows the rates of reinforcement, either reinforcements per minute (the left ordinate) or average interreinforcement interval (the right ordinate) for 14 sessions of *mult* VI 1-min DRL discrimination training. In order to avoid overlap, reinforcement rates for the 0° line are shown just to the left, and reinforcement rates for the blank green key just to the right of the point at which both would usually be plotted. Adjustment of the reinforced DRL interresponse time appears to have been successful, since reinforcements occurred at nearly the same rate during DRL as during VI 1-min.

The results of a post-discrimination generalization test administered to each bird are shown in Fig. 5. The line orientation stimulus functions of Birds 1406, 1275, and 2950 had their minima at the 0° line; the minimum for one bird, 1558, was at +30° but only seven more responses were emitted to the 0° line. The minima of these functions ranged from 102 to 230 responses. Each function was a U-shaped gradient of inhibitory stimulus control. Response strength to the blank green key, plotted to the right of each function in Fig. 5, was considerably greater than in the line orientation dimension, just as in Exp. I.

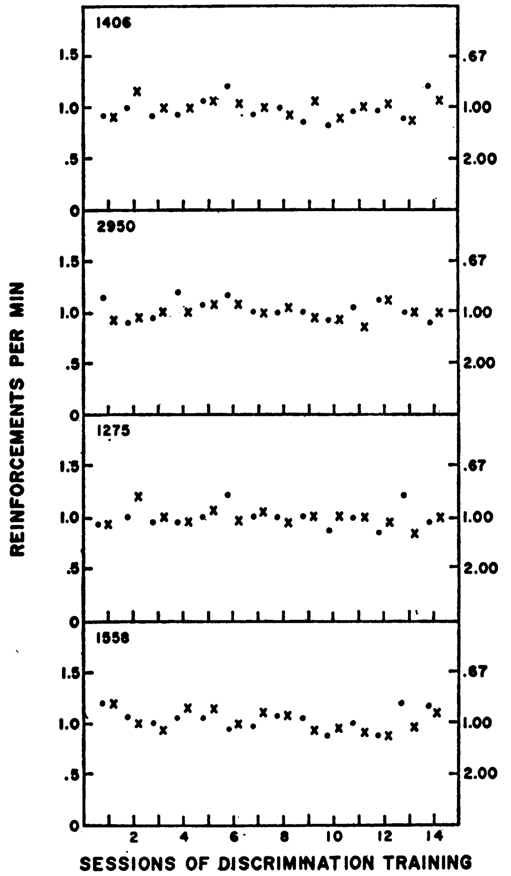

Fig. 4. The rates of reinforcement correlated with the 0° line and blank green key during *mult* VI 1-min DRL. The rates were displaced laterally in plotting to avoid overlap.

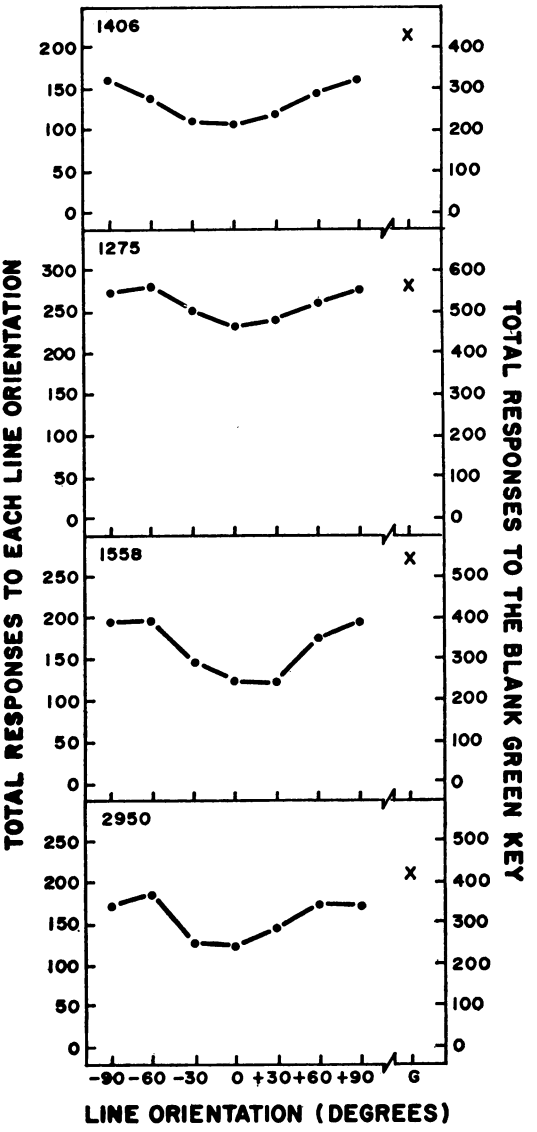

Fig. 5. Post-discrimination line orientation gradients for the stimulus correlated with DRL during prior *mult* VI 1-min DRL.

Response rate functions for the last 10 sessions of non-differential reinforcement (*mult* VI 1-min VI 1-min) and 14 sessions of discrimination training (*mult* VI 1-min DRL) are presented in Fig. 6. Each bird showed a reduced rate of responding to the 0° line after the switch from VI 1-min to DRL reinforcement. Behavioral contrast was observed in each case: the rate of responding to the blank green key increased as the rate of responding to the 0° line decreased. Behavioral contrast was an expected result on the basis of prior research (Terrace, 1968) already discussed.

These results indicate that a reduction in the relative rate of reinforcement, correlated with a discriminative stimulus, is not a necessary antecedent of inhibitory stimulus control or behavioral contrast. Instead, the findings of Exp. II are in line with Terrace's (1968) conclusion that both phenomena may be the result of a reduction in the rate of responding to a discriminative stimulus.

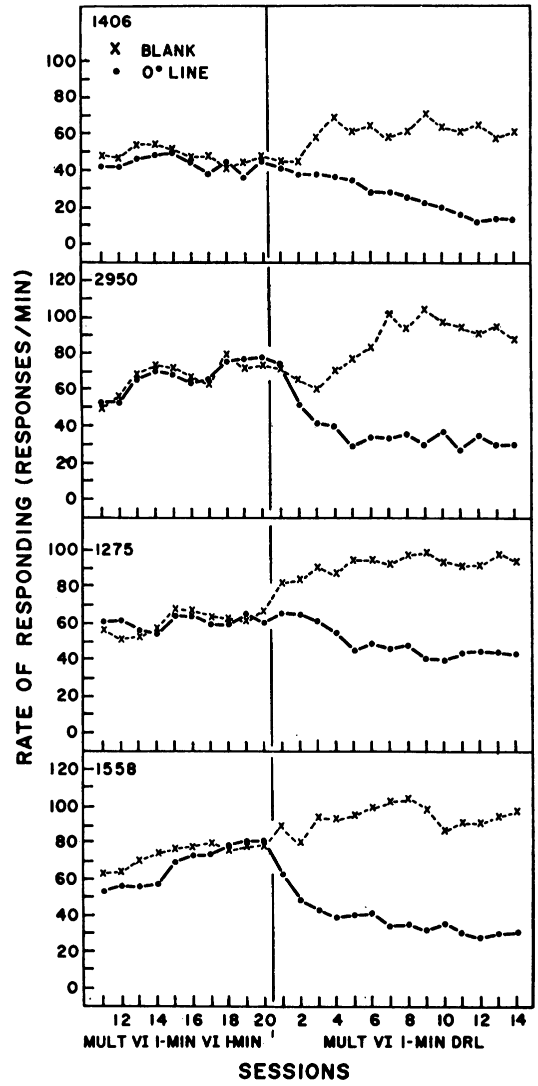

Fig. 6. The rates of responding to the 0° line and blank green key during the last 10 sessions of non-differential reinforcement and 14 sessions of discrimination training in Exp. II.

DISCUSSION

The present results can be incorporated into a broader analysis of discrimination learning. It has been suggested that the many procedures for obtaining differential response probabilities to two alternating stimuli may be classified into a few categories, or types, on the basis of the presence or absence of post-discrimination inhibitory stimulus control (Jenkins, 1965; Terrace, 1968). One type of discrimination learning would establish stimulus control only for S_1. The organism learns to respond to S_1, but does not learn not to respond in its absence; if the organism were already responding to S_1, then the rate of responding to S_1 may increase. In any case, no inhibitory stimulus control for S_2 should result. Terrace's (1963, 1966*b*) errorless discrimination and *mult* VI 5-min VI 5-min → *mult* VI 1-min VI 5-min appear to be examples of this type of discrimination learning.

A second type of discrimination learning would be necessary to establish both excitatory and inhibitory stimulus control. During this second type of discrimination, an organism learns to respond to S_1 and learns not to respond to S_2. If responses are already occurring to S_1 and S_2, the organism may learn to increase responding to S_1 and learn to reduce responding to S_2. The alternation of reinforcement correlated with S_1 and extinction correlated with S_2 has been shown to generate post-discrimination inhibitory stimulus control (Jenkins and Harrison, 1962; Honig *et al.*, 1963; Terrace, 1966*b*). However, inhibitory stimulus control does not depend on the reduction to zero, or any other reduction, in the rate of reinforcement correlated with S_2. Inhibitory stimulus control was obtained when the rates of reinforcement correlated with S_1 and S_2 were equated throughout Exp. II. The results of Exp. I and II point to a reduction in the rate of responding to S_2 as the determinant of discrimination learning resulting in inhibitory stimulus control.

A comparison of the present results with those of other investigators (Guttman, 1959; Terrace, 1968) demonstrates that post-discrimination gradients showing peak shift and those showing direct evidence of inhibitory stimulus control are complementary findings. This is in line with the suggestion that the combination of an augmented gradient of excitation, and a gradient of inhibition, account for the peak shift (Thomas and Williams, 1963; Terrace, 1966*a*). This analysis would appear to support the general use of the peak shift as an indicant of inhibitory stimulus control. Unfortunately, too few discriminative paradigms have been compared thus far to justify the general use of this otherwise parsimonious rule.

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