DISCRIMINATION LEARNING, THE PEAK SHIFT, AND BEHAVIORAL CONTRAST¹

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A discrimination between two successively alternating stimuli was trained under conditions that maintained equal frequencies of reinforcement in the presence of each of the discriminative stimuli (S1 and S2) but that also reduced the rate of responding to S2. These conditions included a multiple variable-interval differential-reinforcement-of-low-rate schedule and a multiple variable-interval variable-interval schedule in which responses to S2 were punished. Whenever the rate of responding to S2 was reduced, rate of responding to S1 (behavioral contrast) increased, and the peak of a subsequently obtained generalization gradient did not occur at the expected location (between S1 and S2) but was displaced away from S2, below S1. Discrimination training in which the frequencies of reinforcement earned in S1 and S2 were *not* equal (variable-interval 1-min variable-interval 5-min training) produced contrast and the peak shift only if the rate of responding to S2 had been reduced, as after non-differential reinforcement in which variable-interval 1-min schedules were correlated with S1 and with S2. It was concluded that a sufficient condition for the occurrence of behavioral contrast and the peak shift was reduction of the rate of responding to one of two alternating discriminative stimuli and that a peak shift will occur only if contrast had occurred during discrimination training.

This study was concerned with delineating the conditions that produce a post-discrimination peak shift and behavioral contrast. These characteristics of discrimination performance have been the focus of interest in recent theoretical and empirical analyses of the acquisition of a discrimination (e.g., Guttman, 1962; Reynolds, 1961a; Terrace, 1966a).

The peak shift was first reported by Hanson (1959) in an experiment in which pigeons were trained to discriminate between two successively alternating monochromatic stimuli, one correlated with reinforcement (S+) and the other with extinction (S-). Hanson showed that the peak of a subsequently obtained generalization gradient of wavelength did not occur at S+ but was instead shifted away from S-. The shift in the location of the peak of a post-discrimination generalization test can be accounted for by classical generalization theory (cf. Spence, 1936; Hull, 1952). The derivation of the peak shift from an algebraic combination of a gradient of excita-

tion, centered at S+, and a gradient of inhibition, centered at S-, is formally analogous to the derivation of transposition offered by Spence (1937).

The phenomenon that has come to be called behavioral contrast was first described by Pavlov (1927, pp. 188 ff), who referred to it as "positive induction". After discrimination training, Pavlov noted that the amount of salivation on an S+ trial that followed an S- trial was greater than the amount of salivation on an S+ trial that followed another S+ trial. Pavlov argued that positive induction was a consequence of inhibition that had been evoked by S-. In a discussion of the same phenomenon, Skinner subsequently referred to positive induction as "contrast" (Skinner, 1938; p. 175) and included in this concept certain changes in the rate of responding to discriminative stimuli during the formation of a discrimination. More recently, Reynolds (1961a) referred to these phenomena as "behavioral contrast".

Behavioral contrast derives its name from the divergence of the rates of responding to S+ and to S- during discrimination learning. According to classical generalization theory (Spence, 1936; Hull, 1952) these rates should converge rather than diverge. Thus, unlike

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the peak shift, classical discrimination theory cannot account for contrast by the algebraic combination of gradients of excitation and inhibition.

The definition of behavioral contrast in the present paper derives from Reynolds' discussion of interactions in a multiple schedule (Reynolds, 1961a, p. 115). Reynolds noted that, after discrimination training on a multiple schedule, the rate of responding to one discriminative stimulus (S1) may change as a result of a change in the schedule associated with another discriminative stimulus (S2). It is important to note that the schedule correlated with S1 remains constant and that the change in the rate of responding to S1 is solely the result of a change in the schedule in a different component of the multiple schedule. If the rate of responding to S1 increases, the interaction is called positive; if the rate of responding to S1 decreases, the interaction is called negative. The interaction is called a *contrast* if the change in rate in the first (constant schedule) component is in a direction away from the rate prevailing in the other (changed schedule) component. If the change in direction in the rate of responding to S1 is toward the rate prevailing in the other component, the interaction is called an *induction*. According to this classificatory scheme, an increase in the rate of responding to S1 that accompanies or follows a decrease in the rate of responding to S2 that results from a change in the schedule associated with S2, would be called a positive contrast.

The general nature of the type of discrimination training which results in the occurrence of a peak shift and contrast was left unclear by experiments performed by Guttman (1959) and by the present author (Terrace, 1963a, b; 1964; 1966a). The Guttman experiment showed that a peak shift could be obtained following discrimination training in which each of two stimuli was correlated with different variable-interval (VI) schedules of reinforcement. S1 was correlated with a schedule in which the mean interval between reinforcement availability was one minute (VI 1-min), while S2 was correlated with a VI 5-min schedule. Thus, on the average, five times as many reinforcements could be produced by responding to S1 than could be produced by responding to S2. This demonstrates that a discriminative stimulus correlated with an

extinction schedule is not a necessary condition for the occurrence of a peak shift. Terrace's 1964 experiment, however, demonstrated that discrimination training in which one stimulus is correlated with an extinction schedule is not sufficient to produce a peak shift. If through the use of a progressive training procedure (Terrace, 1966a) a discrimination is learned without the occurrence of responses to S- (errors), the peak of a subsequently obtained generalization gradient occurs at S+. It has been shown also that contrast does not occur if a discrimination has been learned without errors (Terrace, 1963a, 1963b, 1966a). Thus, discrimination training *per se* will not necessarily produce behavioral contrast or the peak shift.

At first glance, the occurrence of a peak shift following VI 1-min VI 5-min training, and also following S+ - S- training in which errors occur, appears difficult to reconcile. What does responding to S2 in a VI 1-min VI 5-min discrimination have in common with making an error in an S+ - S- discrimination? One possibility was suggested by Guttman (1959), who hypothesized that S2 was rendered "functionally negative" as a result of VI 1-min VI 5-min discrimination training. The "negative" function of S2 was presumed to originate from extinction-like effects that resulted from responding to S2. If this is correct, a peak shift would not occur if the hypothesized extinction-like effects were eliminated.

A pilot experiment (Terrace, 1966a, pp. 331-333) attempted to eliminate extinction-like effects in the presence of S2 during VI 1-min VI 5-min discrimination training as follows: VI 1-min VI 5-min discrimination training was preceded by one of two different types of non-differential reinforcement training. One group received VI 1-min VI 1-min training before VI 1-min VI 5-min training, while a second group initially received VI 5-min VI 5-min training. For the first group, reinforcement density correlated with S2 was reduced. For the second group, however, reinforcement density in the presence of S2 was kept constant. A peak shift was expected only from the group that received VI 1-min VI 1-min training before VI 1-min VI 5-min training, because only under this condition did the change in the schedule of reinforcement correlated with S2 approximate extinction. In four out of four instances, the peaks of the gradi-

ents shifted away from S2 for each of the subjects that underwent the transition from VI 1-min to VI 5-min in the presence of S2. No peak shifts were obtained, again in four out of four instances, from the group that had VI 5-min VI 5-min training before VI 1-min VI 5-min training.

This finding suggested two possible explanations of the peak shift: (1) reduced reinforcement density in the presence of a discriminative stimulus, and (2) reduced response rate in the presence of a discriminative stimulus. Ordinarily, these events occur simultaneously. It is possible, however, to separate these factors by using operations that lower the response rate to S2 and at the same time maintain equal densities of reinforcement in the presence of S1 and S2.

The present study consisted of three experiments: Exp. I sought to determine whether the same conditions that produce a peak shift following VI 1-min VI 5-min training also produce behavioral contrast. This could not be determined in the pilot study cited above because the procedure (a replication of Guttman's 1959 experiment) did not allow sufficient time for the rates of responding to S1 and to S2 during non-differential reinforcement training to stabilize. Since the rates of responding to S1 and to S2 under VI 1-min VI 1-min and under VI 5-min VI 5-min training had not stabilized, there was no baseline against which to assess whether or not contrast had occurred.

Reynolds' relativistic account of contrast (1961a) would predict that contrast should develop in the performance of both groups: "... a change in the relative frequency of reinforcement associated with one of several successive stimuli, changes the rate of responding during that stimulus; an increase in the relative frequency produces an increase in the rate of responding" (Reynolds, 1961a, p. 70). Thus, according to Reynolds, VI 1-min VI 5-min training should result in contrast irrespective of the prior non-differential reinforcement condition, since the relative frequency of reinforcement is greater in S1 than in S2.

A different prediction would follow from this author's observation, that those training conditions that produce contrast also result in a peak shift and that those conditions that do not produce contrast also do not result in a peak shift (Terrace, 1966a). If this generaliza-

tion holds in Exp. I, contrast should occur only following VI 1-min VI 1-min $\rightarrow$ VI 1-min VI 5-min training, since it is only this type of discrimination training that is expected to produce a peak shift.

Experiments II and III attempted to determine whether behavioral contrast and the peak shift result from a reduction in the rate of responding associated with a particular discriminative stimulus or a reduction in the rate of reinforcement associated with a particular discriminative stimulus. In both of these experiments the procedure insured that the reinforcement rates associated with S1 and S2 were equal. The rate of responding to S2, however, was reduced by punishing responding to S2 (Exp. II), or by reinforcing responding to S2 on a differential-reinforcement-of-low-rate schedule of reinforcement (Exp. III).

EXPERIMENT I

METHOD

Subjects

Eight experimentally naive White Carneaux pigeons were maintained at 80% of their free-feeding weights throughout the experiment.

Apparatus

The response key in a standard operant-conditioning chamber (Ferster and Skinner, 1957, pp. 14 ff) could be transilluminated by monochromatic stimuli produced by a monochromator (Terrace, 1966b) which could automatically select a particular stimulus from among 12 different stimuli. Each stimulus had a half-width of less than 15 nm. A force of approximately 15 g was needed to operate the response key. Each response was followed by a brief feedback click produced by a relay. General illumination in the experimental chamber was provided by a 7.5-w bulb situated on the upper right-hand corner of the panel on which the response key and the reinforcement magazine were mounted.

Four inches beneath the response key was a 2- by 2-in. opening that provided access to a hopper filled with mixed grain. The reinforcement was a 4.0-sec access to the grain hopper. During the 4.0-sec reinforcement cycle, the chamber and stimulus lights were turned off, and the grain hopper was illuminated by two 6-w bulbs directly above it. White noise was

continuously present in the chamber to mask extraneous sounds.

Procedure

The subjects were randomly assigned to two groups of three subjects each. During key-peck training, half of the subjects in each group were initially conditioned to peck the response key while it was transilluminated by S1 (573 nm). After five continuous reinforcements, the value of the discriminative stimulus was changed and remained constant until the next five reinforcements were earned. This procedure was repeated until each subject had received 25 continuous reinforcements in the presence of S1 and 25 continuous reinforcements in the presence of S2 (550 nm).

Following the conditioning session, S1 and S2 alternated in an irregular sequence in which a maximum of three successive repetitions of S1 or S2 was allowed. The duration of each S1 and each S2 presentation was 1 min. At the end of each minute, a shutter interrupted the beam of monochromatic light for 2 sec. During the 2-sec timeout (TO) periods, the chamber light remained on. The TO periods were used during the non-differential and differential reinforcement sessions to change the value of the discriminative stimuli and during the generalization test to change the value of the test stimuli. Responses to the dark key were never reinforced.

Non-differential reinforcement. VI 5-min VI 5-min $\rightarrow$ VI 1-min VI 5-min group: After the conditioning session, the subjects of this group (B-27, B-26, B-24) were given one VI 30-sec VI 30-sec session, one VI 1-min VI 1-min session, two VI 3-min VI 3-min sessions, and 10 VI 5-min VI 5-min sessions.

VI 1-min VI 1-min $\rightarrow$ VI 1-min VI 5-min group: After the conditioning session, the subjects of this group (B-32, B-30, B-28) were given one VI 30-sec VI 30-sec session and 10 VI 1-min VI 1-min sessions.

Differential reinforcement. Following non-differential training, both groups were given 12 sessions of discrimination training in which S1 was correlated with a VI 1-min schedule, and S2 was correlated with a VI 5-min schedule. Aside from the change in the schedules of reinforcement, the discrimination sessions were identical to the non-differential reinforcement sessions.

Generalization test. After VI 1-min VI 5-min discrimination training was completed, each subject was given a generalization test of wavelength. The test, conducted in extinction, consisted of 15 stimuli (470, 482, 494, 507, 517, 528, 541, 550, 561, 573, 586, 595, 608, 622, and 634 nm) presented in four different random sequences. Each wavelength was presented for 1 min.

In all instances, each of the above procedures was carried out on successive days of daily experimentation.

RESULTS

The rates of responding to S1 and S2 during the non-differential and differential reinforcement sessions and the generalization gradients of wavelength for each subject are shown in Fig. 1 and 2. Figure 1 shows the rates of responding to S1 and to S2 (left-hand panel) and the generalization gradients (right-hand panel) of the VI 1-min VI 1-min $\rightarrow$ VI 1-min VI 5-min group. Figure 2 shows the same functions for the VI 5-min VI 5-min $\rightarrow$ VI 1-min VI 5-min group. The horizontal lines drawn through the S1 and S2 rate functions of each subject represent the mean rate of responding to S1 and to S2 during the last three sessions of VI 1-min VI 1-min training.

Each subject of the VI 1-min VI 1-min $\rightarrow$ VI 1-min VI 5-min group showed a clear positive contrast effect. After the start of VI 1-min VI 5-min training, the rate of responding to S1 continued to increase while the rate of responding to S2 decreased. The peak of each subject's gradient of wavelength generalization was shifted away from S2 and in each instance occurred at 586 nm, the first test stimulus above S1. These results confirm the finding obtained by the pilot experiment (Terrace, 1966a) that VI 1-min VI 1-min $\rightarrow$ VI 1-min VI 5-min training results in a peak shift, and also helps to extend the domain of the generalization that those conditions that result in contrast will also produce a peak shift.

The data obtained from the VI 5-min VI 5-min $\rightarrow$ VI 1-min VI 5-min group also are consistent with the principle that contrast and the peak shift covary as a function of the same variables. Figure 2 shows that two subjects, B-24 and B-27, did not show any contrast effects and that the peaks of both subjects' gradients were between S1 and S2. It should be

VI 1' VI 1' → VI 1' VI 5'

Fig. 1. Rates of responding to S1 and to S2, before and after discrimination training, and generalization gradients of VI 1-min VI 1-min → VI 1-min VI 5-min group.

noted that the increase in the rate of responding to S1 can be accounted for in terms of the five-fold increase in reinforcement density. This is not the case for the VI 1-min VI 1-min → VI 1-min VI 5-min subjects where the

schedule of reinforcement correlated with S1 was always VI 1-min.

The rate function of the third subject, B-26, did show a clear contrast effect. According to Reynolds' classificatory scheme discussed

Fig. 2. Rates of responding to S1 and to S2, before and after discrimination training, and generalization gradients of VI 5-min VI 5-min → VI 1-min VI 5-min group.

above, B-26's rate function would be categorized as a negative contrast effect, since the schedule of reinforcement in the S2 component was held constant and the rate increase in S1, resulting from the change from a VI 5-min to a VI 1-min schedule, was accompanied by a decrease in the rate of responding to S2.

The peak of B-26's gradient was shifted away from S2. Thus, while one subject was an exception to the rule that VI 5-min VI 5-min → VI 1-min VI 5-min training does not result in a peak shift, a rule which held for six of seven subjects trained under this condition in the present experiment and in the pilot experiment, its data support the principle that contrast is characteristic of the discrimination performance of those subjects from which a peak shift is obtained.

EXPERIMENT II

Experiment I showed that a peak shift is obtained during a generalization test only if there was a prior reduction in the reinforcement density associated with one of two successively alternating stimuli during discrimination training. At first glance this suggests that reduction in reinforcement density may be a necessary condition for the occurrence of the peak shift. The exception to this rule, however, provided by B-26 of Exp. I, suggests an alternative interpretation: a peak shift will result when the rate of responding is reduced in the presence of one member of a group of alternating discriminative stimuli. The rate of responding in one component of a multiple schedule is ordinarily reduced by reducing the

rate of reinforcement in that component. It is possible, however, to lower response rate and, at the same time, to maintain a high density of reinforcement. This can, for example, be accomplished by punishing responses to S2 with a brief, mild electric shock or by reinforcing responding to S2 on a DRL schedule of reinforcement. Experiment II sought to determine whether the suppression of the rate of responding in the presence of one of two alternating stimuli, which was not the result of a lowering of the S2 reinforcement density, would result in contrast and the peak shift. In Exp. II, the rate of responding to S2 was reduced by electric shock punishment.

METHOD

Subjects

Three experimentally naive White Carneau pigeons were maintained at 80% of their free-feeding weight throughout the experiment.

Apparatus

The apparatus was identical to that used in Exp. I.

Procedure

Two subjects (B-49 and B-67) were initially conditioned to peck a key transilluminated by S1 (586 nm) while one subject (B-82) was initially conditioned to peck at a key transilluminated by S2 (561 nm). After receiving five continuous reinforcements in the presence of S1 and S2, the value of the stimulus was changed. S1 and S2 were alternated successively, after each five reinforcements throughout the first session, until each subject received 25 continuous reinforcements in the presence of S1 and 25 continuous reinforcements in the presence of S2. During the next two sessions, identical but independent VI 30-sec schedules of reinforcement were correlated with S1 and S2. Beginning with the fourth session, identical but independent VI 1-min schedules of reinforcement were correlated with S1 and S2. During all of the sessions following the conditioning session, S1 and S2 were alternated randomly, with the restriction that there be no more than three successive presentations of each stimulus. Each presentation of S1 and S2 lasted for 1 min and was followed by a

2-sec TO, during which the value of the next stimulus was selected from an irregular sequence. Each experimental session terminated after a total of 50 reinforcements. Thus, during the VI 1-min sessions, S1 and S2 each appeared for a total duration of approximately 25 min.

After 14 sessions of VI 1-min VI 1-min training, an electric shock of approximately 70-msec duration followed each response to S2. The shock was internally administered by a method previously developed by Azrin (1959). Shock level was adjusted on a day-to-day basis so that the rate of responding to S2 declined to a greater than zero rate that was sufficient to produce all of the scheduled reinforcements. The range of shock values was 1 to 8 v. During each of the 14 VI 1-min VI 1-min plus shock sessions, each subject produced at least as many reinforcements in S2 as in S1. In many instances, more reinforcements occurred in the presence of S2 than occurred in the presence of S1. After 14 VI 1-min VI 1-min plus shock sessions, each subject was given a generalization test that used the same sequence of test stimuli followed in Exp. I. No responses were reinforced during the generalization test. All responses to S2 were, however, punished in order to avoid the typical sharp rise in rate of responding following the abrupt removal of a punishment contingency (*cf.* Azrin, 1960, 1966).

RESULTS

The functions showing the rate of responding to S1 and to S2 during the VI 1-min VI 1-min and the VI 1-min VI 1-min plus shock sessions (left-hand panel) and the generalization gradients of wavelength (right-hand panel) of each subject are shown in Fig. 3. During the VI 1-min VI 1-min sessions, the rates of responding to S1 and to S2 reached asymptotic values ranging from 40 to 60 responses/min. These were similar to the S1 and the S2 rates observed at the end of VI 1-min VI 1-min training in Exp. II. After shock was introduced, the rate of responding to S2 decreased, and the rate of responding to S1 increased (contrast).

It should be recalled that the densities of reinforcement associated with S1 and S2 were equal, if not slightly higher in S2. This demonstrates that contrast can occur without a

Fig. 3. Rates of responding to S1 and to S2, before and after discrimination training in which responses to S2 were punished, and subsequent generalization gradients.

reduction in the relative density of reinforcement correlated with a discriminative stimulus. These results suggest also that contrast is the result of a reduction in the rate of responding to one member of a pair of alternating discriminative stimuli.

The peak of each of the gradients of wavelength generalization was shifted away from S2, the stimulus associated with punishment. This confirms the previously noted principle that a peak shift results whenever contrast occurs during discrimination training.

One noteworthy feature of the gradients obtained after VI 1-min VI 1-min plus shock training that distinguishes them from gradients obtained after VI EXT training or VI 1-min VI 5-min is the secondary peaks that occurred in two instances (B-67, B-82) at 550 nm, the first stimulus below S2. These secondary peaks, confirmed in observations in more recent experiments, can probably be attributed to the punishment of responses to S2 during the generalization test.

EXPERIMENT III

Experiment III asked the same question raised in Exp. II: is the reduction of the rate of responding to one of two alternating discriminative stimuli, independent of a reduction in reinforcement density, a sufficient condition for the occurrence of contrast and the peak shift? In Exp. III, rate of responding to S2 was reduced by a DRL schedule, rather than by punishment.

METHOD

Subjects

Six experimentally naive White Carneaux pigeons were maintained at 80% of their free-feeding weights throughout the experiment.

Apparatus

The apparatus was the same as that used in Exp. I and II, except that the monochromatic stimuli were produced by sending col-

limited white light through Bausch & Lomb interference filters (half-widths less than 15 nm in each case), rather than through a monochromator.

Procedure

Each subject was conditioned to respond to a key transilluminated by 580 nm. After conditioning, each subject received two sessions of VI 30-sec training and 14 sessions of VI 1-min training. Each session was terminated after 25 reinforcements. Discrimination training began after the fourteenth VI 1-min session. S1 was correlated with the same VI 1-min schedule that was in effect during the nondifferential reinforcement sessions. S2 (550 nm) was correlated with a DRL schedule that required a period of at least t sec between responses for reinforcement to occur. Thus, on a 6-sec DRL, the first response that occurred more than 6 sec after the last response occurred was reinforced. An interresponse time of less than 6 sec established a reference point for a new 6-sec interval. If that next response occurred more than 6 sec later, it was reinforced. Otherwise, a new cycle was started, and so on. The value of the DRL schedule ranged from 6 to 8 sec and was modified for each subject on a day-to-day basis in an attempt to keep the number of reinforcements produced in S2 at least as high as the number produced in S1. Other experiments, *e.g.*, Catania, Gill, and Fry (1965), Staddon (1965), along with pilot studies conducted by the author, have shown that a high proportion of responses are reinforced when pigeons are trained on DRL schedules whose values range between 6 and 8 sec.

The S1 and the S2 components, each of 1-min duration, alternated randomly according to the sequence followed in Exp. I and II. Each of the discrimination sessions was terminated after 50 reinforcements. During both the non-differential and the discrimination sessions, a 2-sec timeout period occurred at the end of each component.

After 14 sessions of VI DRL training, each subject was tested, in extinction, for wavelength generalization. The generalization test consisted of four random sequences of 15 test stimuli (490, 510, 520, 530, 540, 550, 560, 570, 580, 590, 600, 610, 630, 650, and 670 nm). Each test stimulus was presented for 1 min and was followed by a 2-sec TO.

RESULTS

The performance of three of the six subjects (G-464, B-50, and G-401) showed both contrast and a peak shift. Neither phenomenon was observed in the performances of the remaining subjects (G-470, B-51, and G-465). Thus, the correlation between the occurrence of contrast and the peak shift observed in the earlier experiments was confirmed in Exp. III.

The data from subjects that showed both contrast and the peak shift are shown in Fig. 4. The left-hand panel shows the rate of responding to S1 and S2 during the 14 discrimination sessions. The horizontal line drawn through the S1 rate function in the left-hand panel represents the average rate of responding of each subject over the last five pre-discrimination sessions and was used as a baseline for assessing the increase in the S1 rate during VI DRL training.

In each case the rate of responding to S1 increased as the rate of responding to S2 decreased. The initial rate of responding to S2 was approximately the same as the rate of responding that prevailed at the end of VI training.

The points on the S2 rate function of Fig. 4 enclosed by squares represent those sessions in which less than 50% of the total reinforcements for that session occurred in S2. In none of these instances did the percent of reinforcements earned in S2 fall below 46%. In all remaining sessions, at least 52% of the total number of reinforcements occurred in S2.

The shape of the generalization gradients differed from subject to subject, but in each case a peak shift was obtained. Another characteristic feature of these gradients is the relatively high level of responding between S1 and S2. Kalish and Guttman (1957) showed that after VI VI training in which S1 and S2 were separated by 30 nm, the level of responding to test stimuli in the interval between S1 and S2 tended to be uniformly high with a slight peak occurring between S1 and S2. Thus, VI DRL training appears to have produced a dip in what might otherwise have been a flatter gradient. B-50 provides an especially striking and somewhat atypical example of the control exerted by the DRL contingency. At S2 and below, B-50 responded at a uniformly low rate. Above S2, B-50 responded at a uniformly high rate.

Fig. 4. Rates of responding to S1 and to S2, before and after VI DRL training, and generalization gradients of wavelength of those subjects that showed contrast. See text for further details.

The rate functions and generalization gradients of the remaining subjects are shown in Fig. 5. The pre-discrimination rates of responding of these subjects (G-470, B-51, and G-465) fall within the range of values of the pre-discrimination rates of responding encompassed by G-464, B-50, and G-401, the subjects that did show contrast and a peak shift. After the start of discrimination training, the rate of responding to S1 remained the same (G-470, B-51) or decreased (G-465). G-465, it might be noted, showed what Skinner (1938, pp. 174 ff) and Reynolds (1961a) have referred to as induction. This is the opposite of contrast and refers to a change in the rate of responding to S1 that is in the same direction as the change in the rate of responding to S2. In all three instances, the rate of re-

sponding to S2 remained unchanged throughout discrimination training. The rate of responding to S1 for subjects that did not show contrast was significantly lower than the rate of responding to S1 of those subjects that did show contrast.

The points surrounded by squares in Fig. 5 represent those sessions in which less than 50% of the total number of reinforcements occurred in the presence of S2. In no instance did fewer than 44% of the total number of reinforcements occur in the presence of S2, and in all of the remaining sessions at least 53% of the total number of reinforcements occurred in the presence of S2.

The peak of the gradients of G-470, B-51, and G-465 each occurred at S1. The gradients obtained from these subjects also tended to

Fig. 5. Rates of responding to S1 and to S2, before and after VI DRL training, and generalization gradients of wavelength of those subjects that did not show contrast. See text for further details.

be more symmetrical than gradients obtained from subjects that showed a peak shift. However, the same elevation between S2 and S1 noted in the gradients of those subjects that did show a peak shift can also be seen in the gradients of those subjects that did not show a peak shift.

DISCUSSION

These experiments demonstrated that a post-discrimination peak shift will occur only if contrast occurred during discrimination training and that a sufficient condition for the occurrence of both phenomena is a reduction in the rate of responding to one of two alternating discriminative stimuli. Another implication of these results, taken in combination with the results of earlier experiments (Terrace, 1966a), is that reducing the rate of responding to a discriminative stimulus by extinction, by changing from a VI 1-min to a VI 5-min schedule of reinforcement, by a DRL schedule, or by electric shock punishment are functionally equivalent in that in each case, contrast and the peak shift result. The discussion that follows will seek to: (1)

review the relationship between contrast and the peak shift and the implications that these relationships have for discrimination learning theory; (2) specify the sufficient conditions for the occurrence of contrast and the peak shift; (3) apply these conditions to distinguish between two types of discrimination learning; and, (4) explore the relationship between extinction and punishment.

Contrast and the Peak Shift

The relationship between contrast and the peak shift, two widely observed characteristics of discrimination performance, makes it necessary to revise classical discrimination theory. The relevant issues, which have been extensively discussed elsewhere (Terrace, 1966a) can be summarized as follows. The peak shift can be derived from a simple algebraic combination of a gradient of excitation and inhibition. It is assumed that (1) reinforcement establishes a gradient of excitation centered around S1, (2) non-reinforced responding, a low-density schedule of reinforcement, or punishment establishes a gradient of inhibition centered around S2, and (3) the gradient of excitation is both higher and wider than

the gradient of inhibition. The same combination of gradients, on the other hand, would predict an induction rather than a contrast between the rates of responding to S1 and S2 (cf. Gynther, 1957; Kimble, 1961, pp. 364-369). While induction does occur in certain instances (e.g., when S2 is correlated with a DRL schedule or when a strong negative reinforcer is used) the typical finding is a contrast between the rates of responding to S1 and S2.

One way of resolving these inconsistencies is to assume an excitatory as well as an inhibitory effect of response suppression. The excitatory effect is assumed to be non-stimulus specific in the sense that it uniformly elevates the gradient of excitation. Thus, two factors contribute to a post-discrimination excitatory gradient. One is the stimulus value. This is responsible for the typical gradient of excitation with a peak at S+. The second is a non-stimulus specific increment of excitation that results from response suppression. A uniform increment of excitation along the stimulus continuum would, of course, still retain the peak at S+. This position, which is similar to those elaborated by Pavlov (1928, pp. 188 ff), by Amsel (1962) and by Lawson (1965), appears to be the most parsimonious way of integrating the results of the present experiments and earlier experiments concerned with differences in performance following discrimination learning without errors (Terrace, 1963a, b; 1966a).

Aside from contrast, other performance characteristics that are absent from discrimination performance following learning without errors are gross emotional responses (Terrace, 1966a), drug-induced responding to S- (Terrace, 1963c), and the peak shift (Terrace, 1964). It should also be noted that contrast can be observed immediately after the first period of non-reinforcement at the start of discrimination training (Terrace, 1963a, p. 20) and will occur even when the discriminative stimuli are from different continua, e.g., wavelength and line orientation (Terrace, 1966c).

*Behavioral Contrast and the Peak Shift:
The Result of Reinforcement-Density
Reduction or of Response-
Rate Reduction?*

The results of each of the three experiments constituting the present study also bear on Reynolds' "relativity of reinforcement" ac-

count of behavioral contrast. While Reynolds' analysis of behavioral contrast did not consider the relationship between contrast and the peak shift, the evidence described above, regarding the extent to which these phenomena co-varied as a function of the same variables, makes it desirable to determine if a general principle can be found that states the sufficient conditions for each phenomenon.

As noted in the introduction, Reynolds stated that the relative rate of responding to one of two alternating discriminative stimuli is a function of the relative frequency of reinforcement correlated with that stimulus (Reynolds, 1961a, p. 70). In another study, Reynolds argued that the "... relative rate of responding on a constant schedule ... turns out to be a linear function of the relative frequency of reinforcement. . . ." (Reynolds, 1961b, p. 179).

The overall absence of a contrast effect in the VI 5-min VI 5-min $\rightarrow$ VI 1-min VI 5-min group of Exp. I and the occurrence of contrast in Exp. II and III in the present study, under conditions in which the reinforcement density in S2 was equal to the reinforcement density in S1, stand out as exceptions to Reynolds' generalization. One might argue that in Exp. II, the punishment of responding to S2 reduced the effect of positive reinforcement, but this argument cannot be made in Exp. III in which the rate of responding to S2 was reduced by employing a DRL schedule.

The evidence described above suggests that Reynolds' assertion that the relative rate of responding is proportional to the relative rate of reinforcement is a special case of the principle that a sufficient condition for the occurrence of contrast is a reduction in the rate of responding to one member of a group of alternating discriminative stimuli.

Reynolds generally obtained a reduction in the rate of responding to S2 by reducing the density of reinforcement correlated with S2 (e.g., Reynolds, 1961a, b). Thus, in these studies the rate of responding was confounded with a reduction in the rate of reinforcement. The one major exception comes from a study by Reynolds (1961a) in which pigeons were trained on a multiple schedule of reinforcement in which responding to S1 was reinforced on a VI 3-min schedule of reinforcement and responding to S2 was reinforced on a differential-reinforcement-of-other-behavior

schedule (DRO). In Reynolds' study, the DRO schedule provided a reinforcement every 50 sec so long as a response to S2 had not occurred during the 50 sec. Reynolds observed that while the rate of responding to S2 was reduced to an essentially zero value, contrast did not occur during VI DRO training. Reynolds attributed the absence of contrast to the equal densities of reinforcement in S1 and S2.

Certain features of Reynolds' procedure and results, however, raise doubts concerning the validity of his conclusion that contrast does not occur as a result of VI DRO training. Each of the subjects trained on the VI DRO schedule had been previously trained on a VI EXT schedule in which S1 and S2 were the same stimuli as during VI DRO training. Between VI EXT and VI DRO training, these subjects received VI VI training in which S1 and S2 were again the same stimuli. Reynolds' data show that responding to S2 declined shortly after VI DRO training commenced following VI VI training. It appears, therefore, that the development of not responding to S2 during VI EXT training may have facilitated the cessation of responding to S2 following the onset of VI DRO training. Reynolds' assertion that VI DRO training does not result in contrast was also based on the difference between the values of the rate of responding to S1 at the start and at the end of VI DRO training. The rate of responding to S1 had, however, increased during some of the VI DRO sessions even though the reinforcement frequencies associated with S1 and S2 were essentially equal. These problems indicate that in order to determine whether VI DRO training produces contrast, it will be necessary to repeat the VI DRO procedure under conditions where VI DRO training is not preceded by VI EXT training. Until this is done it is unclear whether Reynolds' (1961) VI DRO study is an exception to the principle that a reduction of the rate of responding to one of the two alternating discriminative stimuli is sufficient to produce contrast.

The present results indicate also that a sufficient condition for the occurrence of the peak shift is a reduction in the rate of responding to one of two alternating discriminative stimuli. The shift in the peak is, of course, away from the stimulus in the presence of which the rate of responding was reduced. The results from an experiment by Yarczower, *et al*

(1966) also confirm the findings of Exp. II and III that a peak shift can be obtained following discrimination training which reduces the rate of responding to a discriminative stimulus, even when the densities of reinforcement associated with each discriminative stimulus are equal. In the Yarczower experiment, pigeons were trained on a multiple VI tandem DRL VI tandem DRL schedule which decreased the rate of responding to S2 under conditions where the frequencies of reinforcement earned in S1 and S2 were equal. The peaks of subsequently obtained generalization gradients were shifted away from S2. Yarczower *et al.* also showed that, so long as the response rates to the discriminative stimuli were equal, a peak shift did not occur even when the frequencies of reinforcement associated with the two discriminative stimuli were unequal. These authors stated that their "... data imply that response rates at the end of training, rather than reinforcement *per se*, determine the characteristics of the generalization gradient." (Yarczower *et al.*, 1966, p. 631).

Two Types of Discrimination Learning

(a) *Respond to S1 and not to S2.* The present results, and those of earlier experiments on errorless discrimination learning, suggest two basically different types of discrimination learning (*cf.* Jenkins, 1965). The first is exemplified by discrimination learning with errors, by discrimination learning resulting from VI 1-min VI 5-min training preceded by VI 1-min VI 1-min training, and also by discrimination learning in which responding to one member of a pair of alternating discriminative stimuli is reduced by punishment or by a DRL contingency. Common to all these examples is the reduction of the rate of responding to S2. In this type of discrimination learning, two types of stimulus control are established. The organism learns to respond to S1 and not to respond to S2. When S1 and S2 are from orthogonal continua this can be shown by obtaining an excitatory gradient peaked at S1 and an inhibitory gradient centered at S2 following VI EXT training (*cf.* Terrace, 1966c). Contrast is presumed to be a consequence of the subjects' learning not to respond to S2.

(b) *Respond to S1 and not to its absence.* In the second type of discrimination learning, exemplified by discrimination learning with-

out errors, by discrimination learning resulting from VI 1-min VI 5-min training preceded by VI 5-min VI 5-min training, and by VI DRL training in which the rate of responding to S2 remains at a constant low value, there is clearly no reduction in the S2 rate of responding, no emotional response to S2, and no contrast. This type of discrimination learning is presumed to establish stimulus control only with respect to S1. The subject learns to respond to S1 and not to its absence, but it does not specifically learn not to respond to S2. When S1 and S2 are from orthogonal continua, this can be shown by an excitatory gradient peaked at S1 and a flat gradient along the S2 continuum following VI EXT training (*cf.* Terrace, 1966c).

Equivalent Effects of Extinction and Punishment

It is important to note that contrast and the peak shift occurred both when the rate of responding to S2 was reduced as a result of punishing responding to S2 and when the rate of responding to S2 was reduced as a consequence of non-reinforcement, as in the case of discrimination learning with errors (*cf.* Terrace, 1963a; 1964). This functional equivalence between the presentation of a negative reinforcer and the removal of a positive reinforcer has also been observed in a number of other experiments. Herrnstein (1955), for example, (described in Sidman, 1960, pp. 154-157) reported that, under certain conditions, the superimposition of the conditioned emotional response (CER) paradigm on a multiple schedule reduces the rate of responding to S+ when the warning stimulus that signaled the onset of S- was presented.

Two other experiments, one concerned with behavioral contrast and the other with the peak shift, have also reported equivalent effects of punishment and extinction. Brethower and Reynolds (1962) showed that contrast could be obtained following VI VI plus shock training even in those instances when the densities of reinforcement associated with S1 and S2 were the same. This is the same as the result reported in the present Exp. II. Discrimination training on a VI EXT schedule, in which errors occur, also produces contrast (Reynolds, 1961a; Terrace, 1963a). Brethower and Reynolds conclude that "... either punishment or a decrease in the frequency

of reinforcement correlated with one stimulus is sufficient to produce contrast in the presence of a different stimulus." (Brethower and Reynolds, 1962, p. 198, italics added). They also suggest that "... punishment is functionally similar to a decrease in the frequency of positive reinforcement." (Brethower and Reynolds, 1962, p. 198). It should be noted that the Brethower and Reynolds study provided another exception to Reynolds' relativity principle which holds that the relative rate of responding to a discriminative stimulus is a linear function of the relative frequency of reinforcement associated with that stimulus.

Grusec (1968) demonstrated that a peak shift can be obtained following discrimination learning without errors if non-contingent electric shock is presented in the presence of S2. In this experiment, a generalization test was first obtained following discrimination training between two monochromatic stimuli (S+ = 550 nm; S- = 570 nm). This discrimination was trained without errors by a fading procedure. The peak of the initial generalization gradient occurred at S+, thus confirming this author's earlier observation (Terrace, 1964) that a peak shift does not occur following discrimination learning without errors. After the first generalization test, non-contingent shock was introduced in the presence of S2. The peak of a second generalization test occurred at 540 nm, a shift away from the stimulus correlated with non-contingent electric shock. A peak shift away from S- would also occur following discrimination training with errors (Hanson, 1959; Terrace, 1964; Grusec, 1968). Thus, we again see that negative reinforcement produced the same effect as non-reinforced responding.

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