CONTRAST AND STIMULUS GENERALIZATION FOLLOWING PROLONGED DISCRIMINATION TRAINING¹

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Different groups of pigeons received discrimination training in which the reinforcement-associated and extinction-associated stimuli were respectively either (a) a line tilt *vs* a blank key, (b) a blank key *vs* a line tilt, or (c) two different line tilts. The high response rates that developed to the positive stimulus in all groups during discrimination learning were maintained over 64 sessions of training. After these sessions, all subjects were tested for stimulus generalization along the line-tilt dimension. Gradients of relative (per cent) generalization around the stimulus associated with reinforcement (so-called excitatory gradients) and around the stimulus associated with extinction (so-called inhibitory gradients) were as steep as they typically are after much briefer training periods. These results do not support several of Terrace's predictions on the basis of the hypothesis that emotional responses develop to the stimulus associated with extinction during discrimination learning with errors, but eventually dissipate after extended training.

The effects of amount of training on the rate and generalization of responding to reinforcement-associated (S+) and extinction-associated (S-) stimuli have been investigated for training periods up to two or three weeks (14 to 16 sessions: Farthing and Hearst, 1968; Hearst and Koresko, 1968). Over this period of time, increases were found in response rate to S+ and in the slope of separate generalization gradients around S+ and S-. However, the question still remains as to whether response rate to S+ and gradient slope would increase, decrease, or stay the same if training were continued for a much longer period.

These questions are relevant to Terrace's proposal (1966a, b, c) that S- becomes an aversive stimulus during the learning of a discrimination in which errors occur to S-. Such aversiveness is assumed to be a relatively transitory emotional effect, which disappears with extended training. Terrace further argued that three phenomena, (a) behavioral contrast (the increase in S+ rate that occurs while S- responses are being eliminated), (b) shifts in the distribution of responding along the generalization dimension, such that rela-

tively more responding occurs to values on the side of S+ opposite to that on which S- lies, and (c) clear incremental (inhibitory) gradients around S-, probably involve an aversive S-. Therefore, all three of these phenomena should be most prominent while a discrimination is being mastered, but should gradually disappear during overtraining, as S- loses its aversive properties. In support of this argument, Terrace (1966a) reported that behavioral contrast and peak shift (*i.e.*, gradients in which maximum responding is not to S+, but is shifted to a value even further away from S-) are absent after 60 sessions of differential wavelength training. However, Terrace has not obtained measures of (c), the shape and slope of gradients around S-, after prolonged training.

The present study investigated the effects of overtraining in different groups of pigeons when responding was either reinforced at one line-tilt value (*i.e.*, S+ = vertical line, S- = a blank key), extinguished at one line-tilt value (*i.e.*, S+ = a blank key, S- = a vertical line or, for other birds, a line tilted 30° clockwise from the vertical), or reinforced at one line-tilt value and extinguished at another (*i.e.*, S+ = vertical line, S- = a line tilted 30° clockwise) for 64 consecutive daily sessions. Then, a standard generalization test along the line-tilt dimension was administered. The birds tested for generalization around S- provided infor-

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mation concerning effects not investigated in Terrace's studies of extended training. Furthermore, data from those subjects and from other groups in the present experiment (plus related findings from Farthing and Hearst [1968], Hearst and Koresko [1968], and Hearst [1969] for shorter amounts of training) ought to permit a fairly complete evaluation of Terrace's general prediction that measures of contrast, shifts in the gradient distribution, and slope of gradients around S— will closely covary throughout the course of discrimination learning.

METHOD

Subjects

Fifteen experimentally naive female White Carneaux pigeons (5 to 7 yr old) were maintained at 75% of their free-feeding weights throughout the study. Water was available in their individual home cages at all times.

Apparatus

A Lehigh Valley Electronics pigeon test chamber without a houselight was used. Details of this chamber, of the method for varying the tilt of a black line projected on the otherwise white response key, and of the controlling and recording equipment, have been reported in Farthing and Hearst (1968). A 5-sec presentation of grain served as the reinforcer.

Procedure

All subjects were run seven days a week. On the first three days of work with a subject, it was trained to approach and eat from the grain magazine, and the key peck was shaped, followed by 60 continuous reinforcements (CRF). During shaping and CRF, the stimulus to be used as S+ in all the subsequent sessions appeared on the response key.

The treatment of the four different groups corresponded to that for birds in the preliminary phase and first two main phases of standard procedures used in previous experiments (Hearst, 1968, 1969), except for the prolonged discrimination training given all present subjects. Three birds were placed in a group that received reinforcement at one value along the line-tilt dimension and extinction at an orthogonal stimulus (S+ = a vertical line, 0°; S— = a blank white field), six in a group that re-

ceived extinction at one line-tilt value and reinforcement at an orthogonal stimulus (S+ = blank; S— = 0°), three in another group given extinction at a different line-tilt value (S+ = blank; S— = +30°), and three in a group that received reinforcement at one line tilt and extinction at another (S+ = 0°; S— = +30°). After CRF training, all the birds received seven sessions of reinforcement on a 1-min variable interval (VI 1-min) schedule. These sessions consisted of sixty 30-sec presentations of S+, alternated with 10-sec blackouts. This preliminary phase was included to permit time for initial establishment of key pecking under intermittent reinforcement and to provide a VI baseline from which to evaluate behavioral contrast in later sessions.

After the VI phase, subjects were trained on their respective S+ *vs* S— discriminations for 64 consecutive sessions. The 40-min daily sessions consisted of 30 S+ (1-min VI) and 30 S— (extinction) presentations, with each 30-sec presentation separated by a 10-sec blackout. Trials with S+ and S— were scheduled in a mixed order, with the restriction that neither stimulus could occur on more than three successive trials.

On the day after the sixty-fourth discrimination session, birds were given a brief warmup of additional discrimination training (eight S+ and eight S— trials) followed by a generalization test in extinction. Six different line tilts (30° apart), and the blank key, were presented in each of 12 randomized blocks, and the total number of responses to each stimulus value was recorded. Different sequences of stimulus presentations were used for each subject in a group. Stimulus presentations lasted 30 sec and were separated by 10-sec blackouts, as during training.

RESULTS

Group mean measures of (a) response rate to S+ over successive blocks of training, and (b) relative (per cent) line-tilt generalization after 64 days of training, are shown in Fig. 1 to 3 for the four different experimental conditions. The vertical line is designated as 0° on the generalization gradients and other line tilts are indicated as clockwise (+) or counterclockwise (—) deviations from 0°. In the interests of symmetry the same data point is plotted at +90° and -90°. Measures of re-

Fig. 1. Behavioral contrast and relative generalization for the group trained with a line tilt as S^+ and a blank key as S^- . On the left, mean response rate to S^+ is plotted as a function of successive stages of training. The VI-baseline value is the mean of the individual median rates obtained over the last three days of the VI phase; subsequently, from Days 1 through 64 subjects received discrimination training with S^+ and S^- and the means of the individual median rates to S^+ are shown for successive eight-day blocks. On the right, mean relative generalization (per cent of total responses to line tilts) on the test given after Day 64 is plotted for different values along the line-tilt dimension.

Fig. 2. Behavioral contrast and relative generalization for the two groups trained with a line tilt as S^- and a blank key as S^+ . The generalization gradient on the upper right is based on $N=5$, since one bird made no response to any of the line tilts during the generalization test.

Fig. 3. Behavioral contrast and relative generalization for the group trained with an S+ and S- that both lie on the line-tilt dimension.

sponding to the blank stimulus during generalization tests are not shown in these figures (but see Fig. 4 and 5 for this information).

The development and permanence of behavioral contrast will be considered first. Among the four groups, mean response rates to S+ ranged between 23 and 34 responses per minute (rpm) on the last three days of preliminary VI (baseline) training and between 35 and 40 rpm on Day 1 of discrimination training. However, response rates increased markedly in all groups as training continued for eight days; mean rates for discrimination Days 1 through 8 were appreciably higher than for either the VI baseline or Day 1 of discrimination training in every group. These changes provide an example of the phenomenon of behavioral contrast according to Reynolds' definition (1961), since rate to S+ increased as rate to S- was decreasing (S- rates are not shown in the figures). This effect did not disappear over the course of 64 days of training, *i.e.*, response rates in S+ never returned to their level during the initial VI sessions. In fact, in three of the four groups response rates did not even decline during prolonged training; mean response rate to S+ was actually higher on Days 49 to 64 than on Days 1 to 16.

Analysis of the individual data strongly supports the conclusions about the permanence of contrast that were reached from the group data of Fig. 1 to 3. For example, 11 of the 15

birds in the experiment displayed an increase in mean S+ response rate between Days 1 to 16 and Days 49 to 64. Of the four birds (one in each of the experimental groups) that showed a decline in rate over this period, only one exhibited a decrease of more than 7 rpm. Even this latter bird (the middle subject in the top row of Fig. 5) still responded on Days 49 to 64 at a rate more than 70% higher than its VI baseline rate.

All the group gradients of relative generalization in Fig. 1 to 3 demonstrate clear control by the appropriate training stimulus values. The gradient around S+ in Fig. 1 was, if anything, slightly steeper than the comparable group gradients reported in Hearst (1968, 1969), which were obtained from birds trained with the identical S+ and S- in the same experimental chamber, but for much shorter training periods (a mean of 4.7 days). Likewise, the two gradients around S- in Fig. 2 were similar in shape and slope to those obtained for S-s of 0° or +30° after training periods of approximately 4 to 16 days (Farthing and Hearst, 1968; Hearst, 1969). Despite the small number of birds contributing to the (S- = 0°) gradient in Fig. 2, the main effect of Stimuli still proved significant at well beyond the 0.01 level in that group ($F = 5.49$, $df = 5/20$). Therefore, control along a dimension of S- remains strong even after 64 days of training. As will be seen in Fig. 5, individual

data from the S- groups also support this conclusion, since almost every bird emitting enough responses to permit inferences about dimensional effects showed incremental gradients around S-.

The gradient in Fig. 3, obtained after discrimination training between two line tilts, 0° and $+30^\circ$, was much steeper and displayed less distribution shift away from S- than has been observed in previous experiments in this laboratory, all of which employed much shorter training periods (a mean of 15 sessions in Hearst, 1969). In fact, two of the three birds in that group (see Fig. 5) produced the steepest gradients around 0° we have ever obtained, from a total of more than 50 subjects trained in the same experimental chamber with $S+ = 0^\circ$ and various S- values, including $+30^\circ$. However, discussion of the individual data in Fig. 5 will point out a complication that seems to prevent any strong conclusions from the group gradient in Fig. 3.

Gradients of absolute (actual response output) generalization for the four different groups are presented in Fig. 4. As has been observed many times previously (e.g., Hearst, 1969), response output to S+ was appreciably higher in the group that had another dimensional value as S- (i.e., $+30^\circ$) than in the group with the blank S-. In the present ex-

periment, birds in these two groups did not differ very much in mean S+ response rate immediately before generalization testing, i.e., on Days 49 to 64 in Fig. 1 and 3. Thus, the differences in S+ responding that appeared during the generalization test cannot be explained as a mere carryover of unequal response levels reached by the two groups at the end of the 64 days of acquisition; the differences presumably arose within the context of the test session itself (see Donahoe, McCroskery, and Richardson, 1970).

Both of the gradients around S- in Fig. 4 look extremely flat in comparison to the other two gradients plotted on the same absolute scale. However, it will be recalled that when the gradients around S- were scaled on a relative basis in Fig. 2, differential control by values along the line-tilt dimension was clearly revealed.

All individual gradients for the birds (15 of the 16 subjects) that emitted responses to line-tilt values during the generalization test are shown in Fig. 5. Almost every gradient evidenced clear control by the appropriate S+ or S- values. It ought to be noted that the bird on the right in the bottom row, whose gradient was much less steep than the other two subjects in its group, made far more responses to S- throughout the 64 days of training than did the other two subjects (a total of 14,482 responses to S- as compared to 523 and 1433 responses to S- for the others) and made more responses to S- during the generalization test (98 responses to the $+30^\circ$ value, as compared to 9 and 0 responses for the others). As mentioned above, the latter two birds produced the steepest gradients around 0° we have ever obtained.

Unfortunately for clear interpretation, however, these two subjects also happened to master the relatively difficult 0° vs $+30^\circ$ discrimination much faster than any of our previous subjects; they took two and four days to achieve a discrimination index of 10% (S- responses/S+ responses), whereas past subjects required a mean of 15 days, with the fastest one reaching this level in nine days. The bird on the right in the bottom row of Fig. 5 took 17 days to reach the 10% level. Therefore, it would be unwarranted to conclude that the exceptional steepness of the group gradient in Fig. 3 is a result of the extended training that subjects in this group received compared to

Fig. 4. Gradients of absolute generalization for the four different experimental groups. The mean total responses to the blank stimulus are given on the extreme right for each group.

Fig. 5. Individual gradients of relative generalization for all birds responding to line tilts during the generalization test. Identification of the different groups is supplied at the extreme right of each row, in terms of the S+ and S- values for that group during the 64 days of prior training. The numbers in parentheses on each gradient refer (a) on the left, to the total number of responses made to the six line tilts during generalization testing, and (b) on the right, to the total number of responses made to the blank stimulus during generalization testing.

prior birds. The steepness of the gradient could also be related to the fact that two of the three birds learned the original discrimination unusually rapidly.

DISCUSSION

This experiment produced no evidence that prolonged discrimination training leads either to a disappearance of behavioral contrast or to a loss of control by dimensions of S—. In fact, these two effects seem to change very little as the number of training sessions is increased from 8 or 16 sessions (Farthing and Hearst, 1968) up to the 64 sessions employed here. Therefore, the results do not support Terrace's (1966*b*) prediction (see also Biederman, 1970) that behavioral contrast and inhibitory control will disappear or greatly decrease in magnitude during extended training on a discrimination learned with errors. However, there are several specific aspects of Terrace's procedures and definitions that seem to require further discussion in any evaluation of the relevance of the present results for his hypothesis.

With regard to behavioral contrast, Terrace (1966*a*, p. 616, footnote 2) suggested that the permanence of rate increases to S+ following the introduction of S— trials may depend on whether or not a correction procedure is in force during S—. In his studies, the length of S— was contingent on the subject's behavior; each S— period could end only after a bird had failed to respond for 30 sec. In his 1966*a* experiment, S+ rates did decline appreciably after 60 sessions on this procedure. On the other hand, results from studies in which S— always lasted a fixed time (noncorrection), as in Rilling, Askew, Ahlskog, and Kramer (1969) and the present experiment, have shown little or no decline in S+ rates over 60 to 64 training sessions. But if this procedural detail is so crucial, then Terrace's assumptions and predictions about the relation of contrast to the temporal development and dissipation of emotional responses to S— seem to require serious revision; both the correction and noncorrection procedures involve discrimination learning "with errors", which he hypothesizes to produce an aversive S—.

Some recent results of Selekman (1970) cast further doubt on Terrace's analysis. Selekman found no consistent decrease in the level of

contrast even after 70 sessions of wavelength training with a *correction* procedure analogous to Terrace's. This result is thus in line with the findings of Rilling *et al.* (1969) and those reported in the present experiment with a non-correction procedure.

A problem with the present study, as well as with many prior experiments on the topic of behavioral contrast, involves the question of whether a stable VI baseline had been achieved before the introduction of S— trials. Typically, no more than two weeks of exposure to VI baseline sessions are arranged before the start of discrimination training. Since responding on a simple VI schedule may continue to increase gradually for as many as 20 or 30 sessions (*e.g.*, Sadowsky, 1970), there is no way of determining how much of the increase in S+ rate depicted in Fig. 1 to 3 is due specifically to the introduction of S— trials. Only the use of a strict stability criterion for VI responding in individual birds before discrimination training is begun, or the inclusion of appropriate control groups maintained on a VI schedule while the other subjects receive discrimination training, would presumably permit separation of these two effects. In our past experience, however, increases in VI rate with more than seven days of mere exposure to the schedule are smaller than the two- or three-fold increments obtained here after the introduction of S—s. Moreover, even in studies (Rilling *et al.*, 1969; Selekman, 1970) in which a relatively stable VI baseline had been established before discrimination training, there was still no consistent decline in S+ rate over 60 to 70 sessions.

A final decision about whether generalization gradients around S— remain as steep after 64 days of training as after, say, two or three weeks of training, seems to depend to a large degree on one's general definition and method of measuring so-called "inhibitory stimulus control". Hearst, Besley, and Farthing (1970) reviewed several definitions and detection techniques used in studying effects of this kind. They suggested that the term "inhibitory control" has been applied most frequently either to (a) the response suppression produced by the presentation of a specific stimulus (*e.g.*, S—), or (b) a dimensional effect, in which an incremental generalization gradient occurs along some dimension of that specific stimulus. An example of the latter definition is the one

employed by Terrace (1966c, p. 1678) who wrote that "a U-shaped gradient, with a minimum at S—, would indicate that S— was an inhibitory stimulus, while a flat gradient would indicate the absence of any inhibitory function." By this definition, the incremental relative gradients of Fig. 2 and 5 would seem to qualify as a clear example of inhibitory control.

On the other hand, the S— gradients based on absolute response output in Fig. 4 were extremely flat in comparison with the other two gradients in the same figure. If one adopts this type of criterion for the flatness of gradients around S—, *i.e.*, in comparison with absolute gradients around S+ at the same stage of training, or with absolute gradients around S— at much earlier stages of training (*e.g.*, in Farthing and Hearst, 1968, Fig. 1, where the mean number of responses per stimulus value along the line-tilt dimension ranged from 5 to 100 responses after 8 to 16 training days; here the range was from 1 to 11 responses), then some support can be generated for Terrace's prediction that differential control along a dimension of S— declines with prolonged training. Terrace (1966c, 1967) apparently based his conclusions about differences between S— gradients, obtained after discrimination learning either with or without errors, on comparisons of gradients based on absolute numbers of responses; relative gradients for his errorless group would have been indeterminate since virtually no responses occurred along the S— dimension in errorless birds. However, as Hearst *et al.* (1970) argued, near-zero responding in absolute gradients makes differential control along a dimension almost impossible to detect because of a floor effect. Moreover, gradients based on an extremely small number of responses are probably not very reliable.²

Therefore, future experimenters and theorists ought to be more precise and analytical than past researchers about whether they are referring to absolute *vs* relative generalization,

amount of generalization *vs* slope of gradients, response suppression by S— itself, *vs* differential suppression along some dimension of S—, *etc.* (Hearst and Koresko, 1968; Hearst *et al.*, 1970). Absolute and relative effects may both have to be taken into account in some way in making predictions or numerical manipulations of the kind offered by Terrace (1966b) and Hearst (1969, see pp. 33-34).

Besides the predictions concerning the permanence of behavioral contrast and control along a dimension of S—, Terrace has also argued that shifts in gradient distribution away from S— should disappear or be greatly reduced after extended training with S+ and S— at different points on the same dimension. His 1966a experiment confirmed this hypothesis in pigeons trained and tested with stimulus values along a wavelength continuum. Although the steep gradient around S+ in Fig. 3 after 64 days of training with two line tilts is consistent with Terrace's general finding, in that it exhibits appreciably less distribution shift than do gradients for birds trained on this same discrimination for much shorter periods (Hearst, 1969, Fig. 4), we pointed out earlier that the two birds responsible for this effect were unusually rapid learners. On the basis of the present experiment, therefore, conclusions about the effect of extended training on shifts in the gradient distribution ought to remain tentative.

In summary, results from this study clearly revealed that rate increases to S+ and steep (incremental) gradients of relative generalization around S— are not eliminated or even greatly changed by prolonged training on a discrimination learned with errors. In a sense, therefore, the two phenomena are positively related—the presence of one implies the presence of the other. However, Terrace's prediction of a high positive correlation between the two phenomena involved the additional statement that both should disappear or at least greatly decrease with extended training. The results seriously question the generality of this aspect of Terrace's analysis.

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²Although most of the gradients around S— in Fig. 5 were based on considerably greater-than-zero responding, a "resistance to reinforcement" procedure—in which uniform intermittent reinforcement is supplied for responses at all values along the generalization dimension during testing (Hearst *et al.*, 1970)—would probably have been a more sensitive and reliable way of detecting dimensional control in the present experiment.

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