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GENERALIZATION GRADIENTS OF INHIBITION AFTER DIFFERENT AMOUNTS OF TRAINING[1]

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Five groups of pigeons received seven sessions of variable-interval reinforcement for pecking a blank white key, followed by either 1, 2, 4, 8, or 16 sessions of training on a successive discrimination in which the positive stimulus was the blank white key and the negative stimulus was a black vertical line on the white key. After training, a generalization test was administered along the line-tilt continuum. Relative gradients of inhibition became steeper with increased amounts of training, and reliably nonhorizontal absolute gradients were obtained only from groups of subjects with at least four days of training. Therefore, inhibitory stimulus control improves with added training. Several problems with the concept of "inhibition" are examined and some implications of the results for theoretical analyses of operant discrimination learning are discussed.

On successive-discrimination procedures two stimuli are usually presented in a random order and responses in the presence of S+ are reinforced, while responses in the presence of S— are not. As training progresses, responding during S— extinguishes and responding during S+ usually increases. Do excitatory and inhibitory control of behavior become more and more specific to S+ and S—, respectively, as discrimination training proceeds?

Jenkins and Harrison (1962); Honig, Boneau, Burstein, and Pennypacker (1963); and Jenkins (1965) have described a method for obtaining generalization gradients of inhibition which is analogus to conventional methods for obtaining gradients of excitation (*e.g.*, Guttman and Kalish, 1956). This new method employs an S+ which is orthogonal to the dimension of the generalization test. For example, Honig *et al.* (1963) obtained inhibitory gradients on a line-tilt continuum after training pigeons on a successive discrimination between S+ (blank white key) and S— (a white key bisected by a black vertical line). Since the blank (no line) stimulus is presumably equidistant from all stimuli on the line-tilt continuum, generalized response strength from the blank stimulus can be assumed to be equal to all line stimuli. The line-tilt gradient in the study of Honig *et al.* was U-shaped, with the fewest responses at S—. This result demonstrated that S— has a specific inhibitory influence on responding.

Excitatory gradients centered around S+ and inhibitory gradients centered around S— are important constructs in the theoretical accounts of discrimination learning presented by Hull (1943, 1952) and Spence (1937). In order to further understanding of the process of discrimination learning and associated phenomena such as transposition, peak shift, behavioral contrast, and the overlearning discrimination-reversal effect [see, *e.g.*, the discussions of these problems in Mackintosh (1965) and Terrace (1966*a*)], it would be valuable to have extensive parametric data on the training variables which influence generalization gradients of excitation and inhibition.

Hearst and Koresko (1968) have shown that absolute and relative generalization gradients of excitation along a line-tilt continuum become steeper with increased nondifferential training (up to 14 days) on variable-interval

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(VI) reinforcement. Steepening of the excitatory gradient with increased training implies a more precise excitatory control of behavior by S+. If discrimination learning involves learning not to respond to S−, as well as learning to respond to S+, then one would predict that increased prior training will steepen the inhibitory gradient. In other words, stimulus control of not responding should become more specific to S− with increased training. The purpose of the present study was to determine the effect of amount of prior training on the slope of the generalization gradient of inhibition.

METHOD

Subjects

Thirty experimentally naive female White Carneaux pigeons (5 to 8 yr old) were maintained at 75% of free-feeding weight. Three other subjects were eliminated and replaced, one due to failure to meet a preset criterion of responding to at least 80% of the S+ presentations on the first day of discrimination training, and two because of procedural errors.

Apparatus

A Lehigh Valley Electronics pigeon test chamber without a house light was used. A transparent plastic response key (1-in. diameter) was located 10 in. above the floor and approximately 5 in. above the feeder opening. Stimulus variation was produced by a projector-type miniature display unit mounted behind the response key. This unit could transilluminate the key with any of seven different stimuli: a plain white field (blank), or a white field bisected by a ⅛ in.-wide black line at one of six angles of orientation [0° (vertical), 30°, 60°, 90°, 120°, and 150°]. These stimuli were initially adjusted as closely as possible for equal brightness and were rechecked weekly with a photometer to ensure that the brightnesses remained approximately equal. Subjects received 5-sec opportunities to eat from the lighted grain magazine as reinforcement.

The relay circuitry and recording equipment were located in an adjoining room. External sounds were masked by a continuous white noise in the experimental room and by an air blower in the test chamber.

Procedure

Experimental sessions were scheduled seven days a week. On the first three days of the experiment, subjects were trained to approach and eat from the grain magazine, shaped to peck the response key, and given 30 continuous reinforcements (CRF) per day for two consecutive days. During shaping and CRF the key was constantly illuminated by the blank stimulus.

After CRF training, all subjects received seven sessions of reinforcement on a VI 1-min schedule. VI sessions consisted of sixty 30-sec presentations of S+ (blank), alternated with 10-sec blackouts during which the chamber was completely dark and reinforcement was not possible. The blackouts were employed to keep the procedure as close as possible to that during the forthcoming generalization test, in which a 10-sec period between trials enabled the experimenter to record data and change stimuli.

After the VI sessions, all subjects were trained on the successive discrimination, S+ (blank key: VI 1-min) *vs.* S− (vertical line on key: extinction). On the basis of performance on the first day of this discrimination training, subjects were assigned to five groups of six pigeons each, in such a manner that the groups were approximately equated for mean and variance of a discrimination index (100 × Number of Responses to S+/Total Responses to S+ and S−), expressed as a percentage. The five groups were given discrimination training for a total of 1, 2, 4, 8, or 16 sessions. The 40-min daily sessions consisted of 30 S+ and 30 S− presentations, with successive 30-sec stimulus presentations separated by 10-sec blackouts. Presentations of S+ and S− were scheduled in a mixed order, with the restriction that neither stimulus could occur on more than three consecutive trials.

On the day after the last discrimination session, subjects were given a brief warmup of additional discrimination training (eight S+ and eight S− presentations) followed by a generalization test in extinction. All seven stimuli (six line orientations and the blank key) were presented in each of 12 randomized blocks for a total of 84 stimulus-on presentations, separated by 10-sec blackouts. Six test stimulus sequences were used, with a different sequence for each subject in each group. The number of key-pecks during each 30-sec stimulus presentation was recorded.

RESULTS

The groups did not differ significantly in response rate to S+ on the last day of VI training, nor were there significant differences between groups in response rate to either S+ or S− on the first day of discrimination training. Therefore, since the five groups were well equated on the first day of discrimination training, any later differences between them can be attributed to the effects of additional discrimination sessions. Mean discrimination indices for the final discrimination session before generalization testing were 61.0, 81.9, 89.8, 96.2, and 99.4% for the 1-, 2-, 4-, 8-, and 16-day groups respectively (see also Fig. 4).

Absolute generalization gradients of inhibition, which plot the mean number of responses to each test stimulus for each group, are shown in Fig. 1. The vertical line (S−) is designated as 0° and other line orientations are indicated as clockwise (+) or counterclockwise (−) deviations from 0° (*e.g.*, the line 60° from S− in a counterclockwise direction is designated −60°). In the interests of symmetry

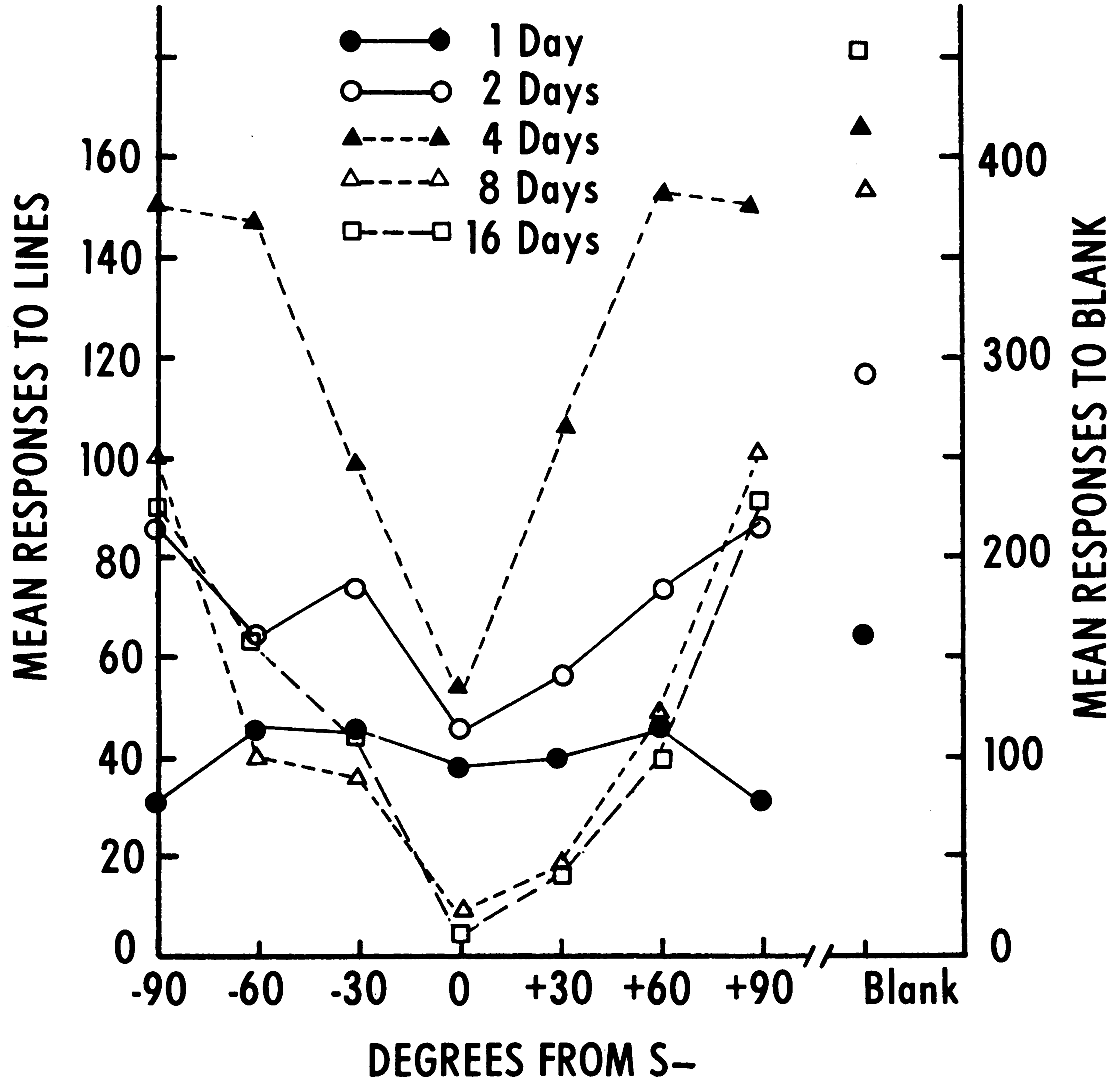

Fig. 1. Absolute generalization gradients of inhibition for different groups of birds. The mean number of responses in the presence of each stimulus is plotted against the angular deviation of the stimulus from S− (vertical line). Responses in the presence of S+ (blank) are plotted on a different scale.

the same data point is plotted at +90° and −90°.

Statistical analysis of the absolute number of test responses (omitting S+, blank) revealed that the simple main effects for stimuli were significant only for the 4-, 8-, and 16-day groups (*F*'s > 3.48, $df = 5/125$, $p < 0.01$ in each of these three groups). By this criterion, reliably nonhorizontal gradients were obtained only in the three groups with the largest amounts of prior training; however, inspection of Fig. 3 reveals that three of the six subjects in the two-day group also produced U-shaped inhibitory gradients, with minima at S−. The five groups did not differ significantly in total generalization test responses to all the line stimuli. Another analysis showed that the groups did differ significantly in response out-

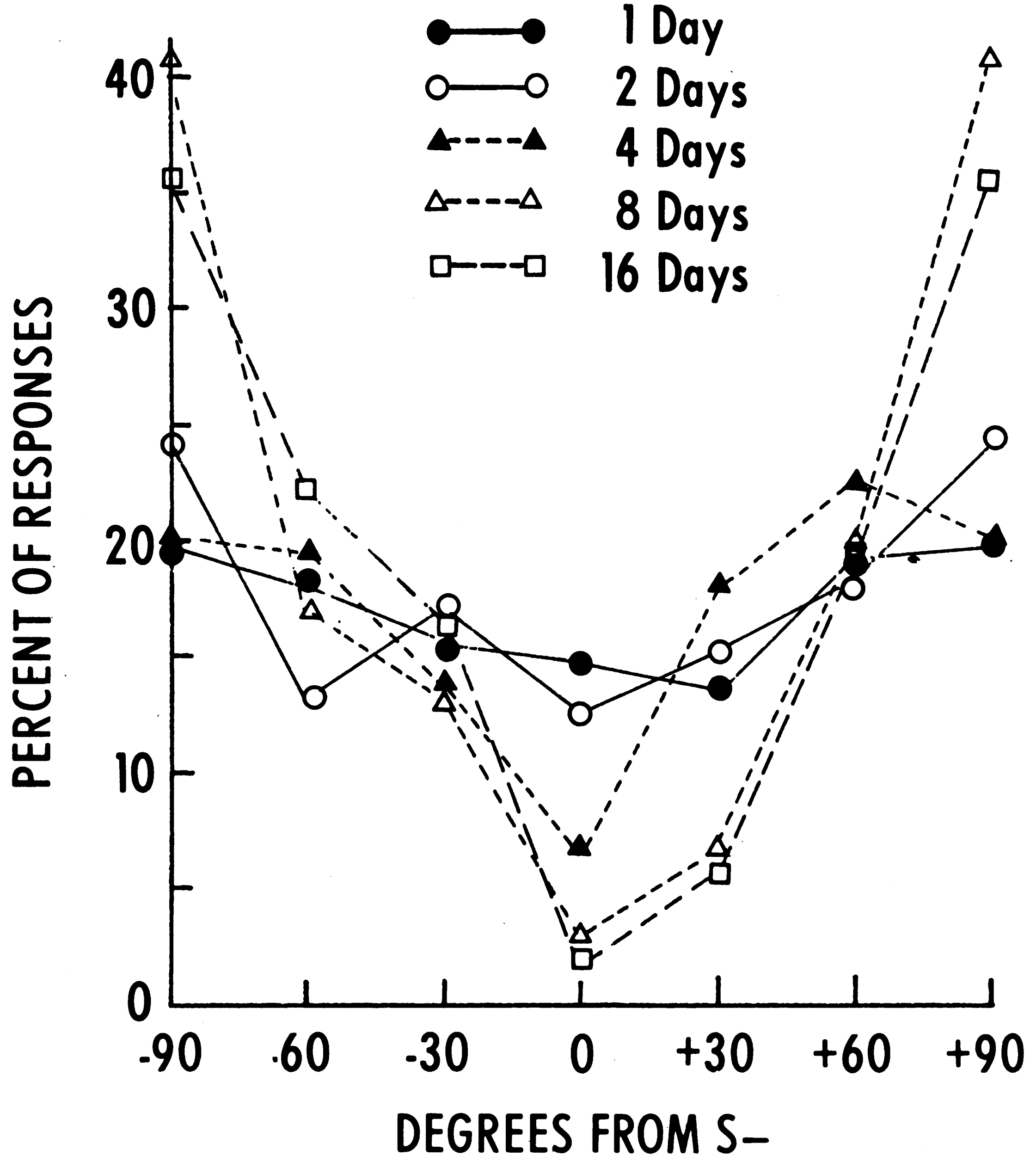

Fig. 2. Relative gradients of inhibition for different groups of birds. The mean percent of total test responses to lines is plotted for each line stimulus.

put to S+ (blank) during testing ($F = 3.51$, $\text{df} = 4/25$, $p < 0.05$), with response rate to S+ generally increasing as amount of training increased.

Relative gradients of inhibition are displayed in Fig. 2. Within each group the mean percent of total test responses to lines (omitting S+, blank) was calculated for each line orientation. The rationale for plotting relative gradients is to weight equally the gradients of subjects which differ markedly in total response output. Figure 2 shows that the relative gradients were rather shallow for the 1- and 2-day groups, the 4-day group was intermediate, and the 8- and 16-day groups produced relatively steep inhibitory gradients. Therefore, inhibitory control of responding became more specific to S− with increased discrimination training. This is clearly shown in Fig. 2 by the decreasing percent of total responses emitted to S−.

Relative gradients for all individual subjects are shown in Fig. 3. The group gradients presented in Fig. 2 seem fairly representative of the majority of subjects in each group. Three birds whose gradients differ appreciably from others in their groups should be pointed out: the fifth bird from the left in the one-day group performed markedly better (in terms if its discrimination index on the one day of training) than the other birds in that group, whereas the fifth bird from the left in the two-day group and the fourth bird from the left in the four-day group performed the worst of all subjects in their respective groups on the last day of discrimination training before generalization testing.

These data indicate clearly that as the number of days of prior training increased, inhibitory gradients became steeper around S−. All individual subjects in the 8- and 16-day groups exhibited minima at S− and maxima relatively far from S−. In the 2- and 4-day groups only half the birds did so, and in the 1-day group birds rarely produced clearcut gradients.

Honig *et al.* (1963) found that relative gradients of inhibition became uniformly flatter as generalization testing in extinction progressed. Present results failed to confirm this finding. Relative gradients during successive thirds of the generalization test (Blocks 1-4,

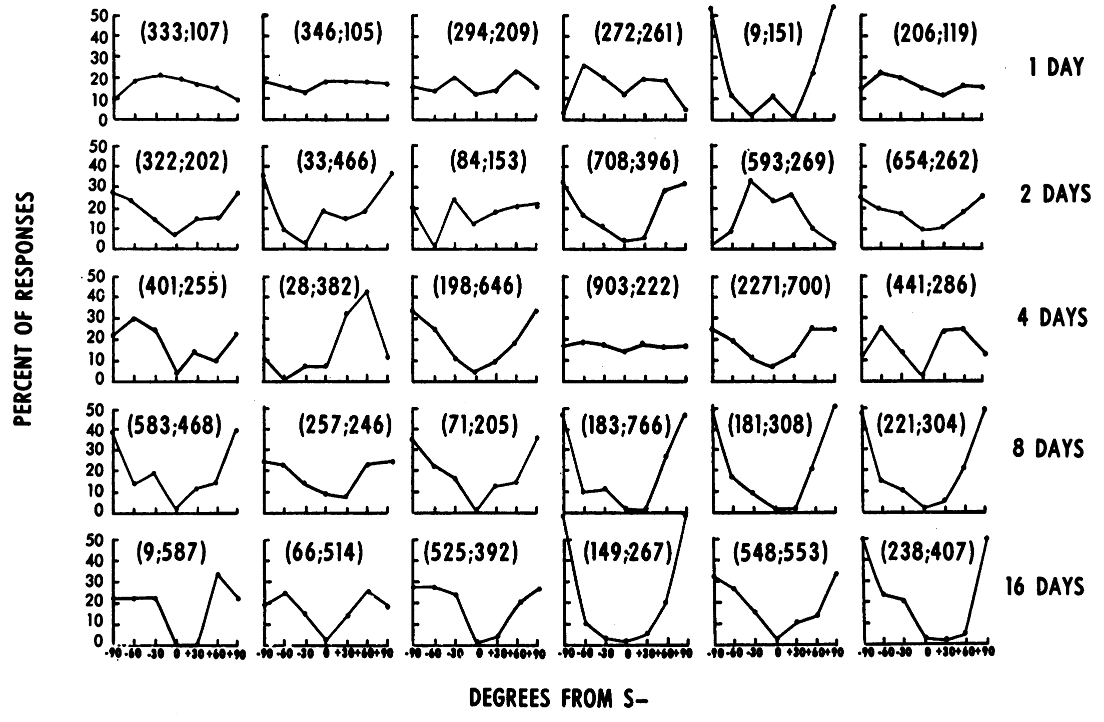

Fig. 3. Relative gradients of inhibition for all individual birds. The numbers in parentheses for each bird represent, on the left, the total responses to the six-line test stimuli, and, on the right, the number of test responses to S+ (blank).

5-8, and 9-12) were calculated for the 8- and 16- day groups combined, but these data revealed no statistically significant differences in gradient slope between the three blocks. One important difference between the procedure of Honig *et al.* and that used in the present experiment is that birds in the earlier study were tested on the day after meeting a discrimination criterion. Since subjects in our 8- and 16-day groups met this 90% criterion in only 3.7 days on the average, the birds were in effect overtrained for about 4 to 12 days before testing. However, relative gradients for the groups that were trained for only a short time (1, 2, or 4 days) in the present experiment also showed no consistent changes during generalization testing. Furthermore, when we trained a naive group of nine birds in a new study (Hearst, 1968) following the present one, according to the same procedure except that (a) S— was a horizontal line instead of a vertical one, and (b) birds were tested on the day after meeting the 90% criterion, no consistent changes in the slopes of relative gradients occurred over the course of testing, even though the U-shaped inhibitory gradients for the entire generalization test were similar to those reported by Honig *et al.* Apparently the overall flattening effect which Honig *et al.* observed is not an easy phenomenon to replicate; in several experiments we have obtained no reliable changes in relative inhibitory gradients as generalization testing progressed.

DISCUSSION

The present study shows that both relative and absolute generalization gradients of inhibition steepen around S— with increased training up to 16 sessions on a successive go/no-go type of discrimination. Therefore, inhibitory control of responding becomes more specific to S— with extended training.

Before some implications of these results can be examined, it seems necessary to discuss a few problems in the definition and measurement of "inhibition" and "inhibitory control". Along the line of reasoning suggested by Jenkins (1965), Terrace (1966*c*, 1967) proposed that an inhibitory function be attributed to a stimulus only when response strength on the S— dimension increases as stimulus values more and more different from S— are presented. Thus, contrary to definitions implicitly or explicitly employed by Hull or Pavlov in their use of the term "inhibition", Terrace did not include a reduction-in-responding compared to some original baseline in his definition of an inhibitory stimulus; for him "inhibition" can be measured only through evidence of selective stimulus control. On the other hand, Hull wrote that "inhibitory potential can be observed only indirectly through the failure of some positive reactions which the antecedent conditions would otherwise produce (1943, p. 289)", and Rescorla, in discussing Pavlovian control procedures, stated that "inhibitory effects can be measured only when there is some level of excitation to be reduced (1967, p. 78)"; in these statements no mention of specific stimulus control is involved.

The frequent use of these two different types of definition of "inhibition" has confused the interpretation of recent experiments on this topic. Deutsch (1967) and Terrace (1967) reached virtually opposite conclusions from Terrace's (1966*c*) empirical finding that generalization gradients on the S— continuum following errorless discrimination learning are extremely flat and involve near-zero responding, as opposed to the clear stimulus control and appreciable responding to values far from S— that were displayed by subjects which learned the discrimination with errors. Employing a definition based on the specificity of stimulus control, Terrace concluded that S— does not acquire an inhibitory function during errorless learning. Employing a definition based on the absolute amount of responding to stimuli on the S— continuum, Deutsch concluded that greater inhibition is exhibited along the S— dimension following errorless learning.

In our opinion, the words "inhibition" and "inhibitory control" should be used, if at all, in comparable fashion to the words "excitation" and "excitatory stimulus control". Just as there can be excitation without experimental evidence of specific excitatory stimulus control [see, for example, the flat auditory frequency gradients of Jenkins and Harrison (1960) following nondifferential (excitatory) training to peck in the presence of one tonal frequency], it seems reasonable that inhibition may occur without experimental evidence of specific inhibitory stimulus control.

"Excitation" would here loosely refer to an increase in response strength over some initial level, whereas "inhibition" would refer to certain types of decrease in response output from a stable high level of responding. Skinner (1938) has pointed out that in many cases of response decrement the concept of "inhibition" is really unparsimonious, since these effects could be more simply labelled as decreases in excitation. However, Brown and Jenkins (1967) have convincingly argued that such phenomena as Pavlovian "conditioned inhibition" and perhaps "external inhibition", in which the addition of some new stimulus to a stable behavioral baseline produces a decremental effect, cannot easily be described as mere decreases in excitation. Brown and Jenkins are here using a definition of inhibition which is mainly based on a reduction-in-behavior, rather than the definition employed in Jenkins (1965) and Terrace (1967) which emphasizes specific control along some dimension of S−.

Therefore, less confusion among different experimenters might be achieved in the use of the term "inhibitory control" if both a reduction in behavior and specific stimulus control were considered as part of the definition, not merely specific stimulus control. The critical problem would then seem to be the determination of proper empirical baselines from which to measure the inhibitory (reductive) effects of a stimulus. We have attempted to establish such a baseline from which to measure response reductions in the present experiment. Our colleagues, Minnie Koresko and Dennis Hilker, trained nine pigeons on VI reinforcement to the blank stimulus for seven sessions and then gave the birds a standard "generalization" test which included the blank and six line stimuli; in this study the birds had never seen a line on the key before the generalization test. In all other major details this experiment was exactly the same as the one reported above. This generalization baseline provides a measure of the strength of responding along the line-tilt dimension after reinforcement during the blank stimulus but without prior exposure or extinction to S−.

Although some individual subjects responded more frequently to certain line orientations than to others, the group average line-tilt gradient was approximately flat, supporting our original presumption that the line-tilt dimension was "orthogonal" to the blank stimulus. Total test responses to each of the line stimuli (the group mean was approximately 80 responses per line) was about 40% of the total responses to the blank (the group mean was approximately 200 responses).

There are several problems in using this baseline to estimate response decrements along the line-tilt dimension that were produced by the different amounts of discrimination training. These difficulties arise principally because of two response-elevating effects of our discrimination procedure: (a) compared to the baseline procedure, the birds in Fig. 1 had received more than seven sessions of S+ training, if one includes S+ presentations during the discrimination-learning sessions; possibly, equivalent additional training with S+ alone would have led to higher S+ rates, and a greater number of generalized responses to non-S+ values, as it did in Hearst and Koresko (1968); and (b) "behavioral contrast" (Reynolds, 1961), an increase in S+ rates during discrimination learning as compared to response rates at the end of S+-only training, was observed in all our groups with at least two days of training (see Fig. 4).

Both these factors would presumably lead to a greater absolute amount of generalization from S+ to all values along the line-tilt dimension, as compared to the values obtained from the Koresko-Hilker procedure. Despite the possibility of such response-enhancing effects, all groups in Fig. 1 averaged many fewer than 80 responses to S− (the level in the Koresko-Hilker study). As amount of training increased, response output to S− eventually declined to an extremely low level (Fig. 1). On this basis, one could conclude that "inhibition" (reduction) is strongest at S− after 8 to 16 sessions of training, and that the greatest amount of "inhibitory control" (steepness of gradient) occurs after these same amounts of training.

This general method for establishing a baseline of responding on the orthogonal dimension before first introducing S− seems to offer an empirical means for estimating a relatively pure measure of generalized excitation from the blank stimulus to the line-tilt dimension. Thus, the method may enable later determination of the inhibitory (reductive) effects that

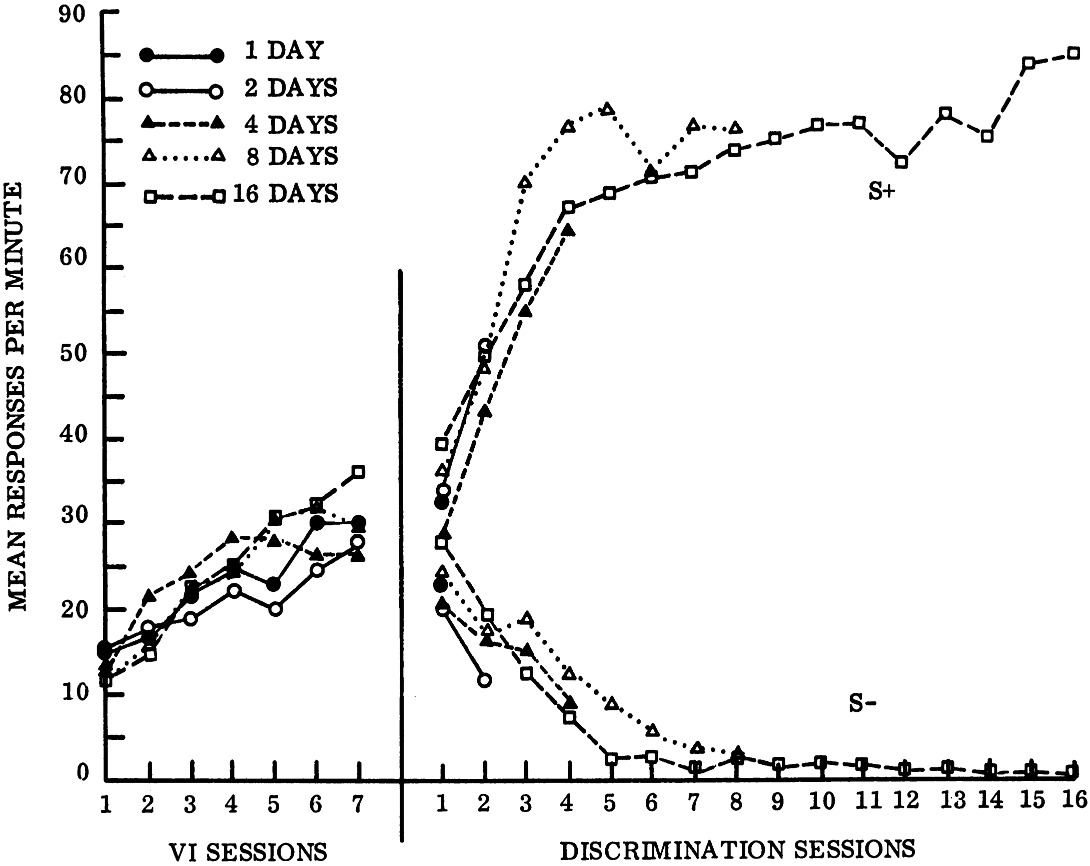

Fig. 4. Group mean response rate to S+ (blank) during seven days of VI training, and to S+ (blank), and S− (vertical line) during 1, 2, 4, 8, or 16 days of discrimination training.

are produced by continued extinction to one particular line tilt. We have not actually computed the amount of "inhibition" based on the Koresko-Hilker baseline for our experiment, because we would like to wait until work is completed which may enable us to take (a) and (b) above into account by equating the number of S+ trials and the amount of behavioral contrast with the values achieved by the respective groups in Fig. 4. Despite the rough application of the method here, the Koresko-Hilker values showed that absolute responding to S− had been "inhibited" by extinction in every one of our experimental groups (Fig. 1).

What are the implications of such an analysis for the controversy between Terrace and Deutsch? Terrace did not employ a "fading" technique for training a discrimination without errors (S+ was a white line on a black background; S− a 580-nm light) following 14 sessions of VI training to S+ alone; he merely placed subjects that learned the discrimination with very few errors into the "errorless" category. However, because of this selection procedure, "errorless learning" simply refers to the fact that these subjects showed almost no initial generalization from S+ to S−. In other words, the baseline of responding all along the presumably orthogonal hue dimension was probably close to zero before any alternations of S+ and S− began. Thus, Terrace's method would not permit the measurement of an inhibitory (reductive) effect of the discrimination procedure itself, since in the absence of any generalized excitation [or "inductive conditioning", as Skinner (1938) calls it] from S+ to the hue dimension, there is nothing to inhibit. Of course Terrace's definition of "inhibition" does not involve a reduction from some original baseline, but his results seem uninterpretable even insofar as stimulus control is concerned; since values far from S− proved to produce zero responding, there was no way in this situation to measure less responding at S−. Although Terrace may well be correct that discrimination learning without errors leads to flat inhibitory gradients and a "neutral" S−, it does not seem to us that this particular experiment permits any strong conclusions to be drawn about such a possibility.

Likewise, Deutsch's conclusion that extreme inhibition (response reduction) is produced during errorless discrimination learning appears to be misleading. The reductive effects of the discrimination procedure in the errorless group would have to be measured as decrements from the initial response strengths to the different hues, before the first introduction of a particular hue as S− in the discrimination procedure. As noted above, however, responding all along the hue dimension was probably close to zero (errorless) in these subjects after 14 sessions of S+-only training, and therefore a reductive effect could not possibly have been observed. The analogous initial baseline in the "with errors" group was above zero, and therefore this group was the only group of the two which could conceivably have shown "inhibition" by the response-reduction definition. Deutsch's procedure of examining only the absolute number of responses in the inhibitory gradients, without taking into account the pre-discrimination level of responding to the S− dimension, seems dubious to us.

According to Spence's (1937) model for intradimensional discrimination learning, moderately sloped excitatory and inhibitory gradients, produced by reinforcement at S+ and extinction at S−, can be combined to predict such phenomena as peak shift and transposition. Moreover, if relative gradients of excitation and inhibition become steeper with increased training [as Hearst and Koresko (1968) and the present study respectively suggest], then a simple application of Spence's model predicts a reduction and eventual disappearance of peak shift following relatively large amounts of discrimination training; with increasing control by the specific S+ and the specific S−, gradient interaction would be reduced. This is exactly the result obtained by Terrace (1966*b*), who trained pigeons on an intradimensional hue discrimination for 60 sessions and found that peak shift eventually disappeared.

Although Terrace attributed the disappearance of peak shift to a loss in the "emotional effects" of S− with increased training, the results seem to be more parsimoniously explained by the increasing specificity of excitatory control by S+ and inhibitory control by S−. Eventually little or no interaction remains between the two gradients and peak shift would therefore be expected to disappear. Additional concepts like "aversiveness" or "emotionality" seem unnecessary to account for peak shift, but may play an important explanatory role in analyzing other phenomena like "behavioral contrast".

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