GENERALIZATION GRADIENTS OF INHIBITION FOLLOWING AUDITORY DISCRIMINATION LEARNING¹

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A more direct method than the usual ones for obtaining inhibitory gradients requires that the dimension of the nonreinforced stimulus selected for testing be orthogonal to the dimensions of the reinforced stimulus. In that case, the test points along the inhibitory gradient are equally distant from the reinforced stimulus. An attempt was made to realize this condition by obtaining inhibitory gradients along the frequency dimension of a pure tone after discrimination training in which the nonreinforced stimulus was a pure tone (or tones), and the reinforced stimulus was either white noise or the absence of a tone. The results showed that some degree of specific inhibitory control was exerted by the frequency of the tone, although the gradients were broad and shallow in slope.

A further experiment was conducted to see whether the modification of an excitatory gradient resulting from training to discriminate neighboring tones could arise from a simple interaction of inhibitory and excitatory gradients. The results indicated that it could not, since discrimination training produced a concentration of responding in the vicinity of the reinforced stimulus which cannot be derived from any plausible gradient of inhibition.

The construct of an inhibitory gradient resulting from nonreinforcement in the presence of a particular stimulus has played a prominent role in the theoretical accounts of discrimination learning developed by Hull (1952) and by Spence (1937). Less attention has been given to the problem of obtaining inhibitory gradients by direct experimental method. The present experiments are addressed to this problem.

Previous methods of obtaining inhibitory gradients have been of two sorts. One method is to compare a simple excitatory gradient obtained after reinforcement of a response in the presence of one stimulus with the gradient obtained after discrimination training (Hanson, 1959). In discrimination training, reinforcement occurs at one stimulus value and nonreinforcement at another; therefore, the postdiscrimination gradient may be regarded as the result of a combination of excitatory and inhibitory gradients. The inhibitory component is then isolated by subtracting the complex gradient of extinction and inhibition from the simple excitatory gradient. In the second method, reinforcement for a broad range of stimulus values is followed by non-

reinforcement on a particular stimulus value (Honig, 1961). The resulting depression in the excitatory gradient centered at the nonreinforced stimulus value may be regarded as the result of inhibitory control. Both of these methods are indirect because the empirical gradient must be considered as a joint function of excitatory and inhibitory processes. This is so because the reinforced and nonreinforced stimuli lie along the same dimension. As the distance between the test stimulus and the nonreinforced stimulus is changed, the distance between the test stimulus and the reinforced stimulus is also changed.

The required condition for a more direct evaluation of an inhibitory gradient is one in which the stimulus dimension on which the inhibitory gradient is obtained is orthogonal to the dimensions of the reinforced stimulus. Thus, test stimuli at different distances along a dimension of the nonreinforced stimulus are at equal distances from any dimension of the reinforced stimulus. In that case, the inhibitory gradient would be an analog to the simple excitatory gradient because in testing for the excitatory gradient we do not move toward or away from a previously nonreinforced stimulus value as we move toward or away from the reinforced stimulus value.

In the present experiments, we attempted to meet this condition by choosing a nonrein-

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forced stimulus (or stimuli) that could be varied along a dimension which is not shared by the reinforced stimulus. We conducted three experiments. In the first, the nonreinforced stimulus (S^-) was a tone at 1000 cps while the reinforced stimulus (S^+) was no tone. In the second experiment, two tones of widely different frequencies were nonreinforced (S^-_1 , S^-_2), and, again, the S^+ was no tone. In a third experiment, S^- was a tone at 1000 cps while S^+ was white noise. In each experiment we tested for an inhibitory gradient by observing responses in extinction to tones of different frequency. The gradients are purely inhibitory to the extent that tones of different frequencies are equally similar or dissimilar to no tone or to white noise.

A fourth experiment is reported in which an excitatory gradient is modified by discrimination training. The hypothetical inhibitory gradient needed to account for the changes in the excitatory gradient resulting from discrimination training is then compared qualitatively with gradients of inhibition obtained in the first three experiments.

EXPERIMENTS I, II, AND III

Subjects

The subjects were adult, male, White Carneaux pigeons without prior experimental history. They were maintained by restricted feeding at approximately 80% of their free-feeding body weight.

Apparatus

An apparatus of Skinner design identical to that previously described (Jenkins & Harrison, 1960) was used. Reinforcement for the key peck was access to mixed grain for a 4-sec period. The auditory stimuli were sounded by a 5-in. speaker suspended directly behind the response key. The stimuli were interrupted for 0.25 sec in each second in order to reduce possible adaptation to a steady sound. The amplification of tones or white noise was adjusted to a sound-pressure level of 70 db *re* 0.0002 dyne/cm², as measured with the aid of a calibrated microphone.

Procedure

Preliminary training consisted of four sessions in which subjects were trained to eat

from the grain tray, and to strike the response key on a variable-interval (VI) schedule of reinforcement. Successive approximation was used to establish the key peck. In the second session, the VI schedule was introduced. Beginning with the third session, sessions were divided into 33-sec working periods by 7-sec intervals for which the compartment was totally dark, the sound stimuli were off, and the response-reinforcement circuit was disconnected. The VI schedule programmed at least 1, at most 3, and on the average 1.7 reinforcements in each 33-sec working period. In every session beginning with the third, 25 working periods of this type were used. For experiments in which a sound stimulus was used as S^+ , the sound was introduced in the first session of preliminary training as soon as the key peck was established.

The discriminative stimuli in training were as follows:

<i>Experiment</i>	S^+	$S^-(cps)$
I	no tone	1000
II	no tone	300, 3500
III	white noise	1000

Three subjects were trained in each experiment. A training session consisted of 25 working periods with S^+ reinforced on the VI schedule, and a number of unreinforced working periods with S^- , which was increased from 25 in the first training session to 125 (Experiments I and III) or 200 (Experiment II) in later sessions.

The S^+ and S^- periods were programmed in a random order. Training continued until the rate of response in S^+ was at least four times that for S^- in two successive sessions. In Experiment II, this criterion was met for each S^- stimulus taken separately. The number of training sessions ranged from 8 to 18.

The stimuli for the generalization tests were as follows: tones at 300, 450, 670, 1000, 1500, 2250, and 3500 cps, and the stimulus which served as S^+ in training. These eight stimuli were presented in eight blocks (a block consists of one presentation of each stimulus), making a total of 64 presentations. The order of presentation within blocks was governed by 8×8 latin squares so that each stimulus appeared once in every ordinal position in the block.

A stimulus presentation was 33 sec, separated by 7-sec dark periods as in training. In Experiments I and III, a single reinforcement was given in one-half of the test presentations of the S^+ stimulus in training. Data for these periods were excluded from the results. With this exception, the generalization tests were run without reinforcement.

Results and Discussion

Inhibitory gradients based on the relative frequency of response for individual subjects are shown for Experiments I, II, and III in the top-left, lower-left, and top-right panels of Fig. 1, respectively. The gradients are plotted in terms of the per cent of the total responses. The average rate of response at each test stimulus can be readily obtained from the following response totals for individuals: (Experiment I) S_{65} -536, S_{64} -503, S_{69} -943; (Experiment II) S_{74} -969, S_{73} -687, S_{75} -1301; (Experiment III) S_{61} -462, S_{51} -1440, S_{57} -1118. The first feature of the results to be noted is that

in each of the three experiments, responding at any tonal stimulus was less than to the stimulus which served as S^+ in training. Several considerations indicate that the difference was not the result of a spontaneous generalization decrement resulting from the introduction of novel tones, but was rather the result of explicit discrimination training. In the early sessions of training, the rate of response in the presence of tones could not be distinguished from the rate in S^+ periods (no tone or white noise). Further evidence on this point was obtained by training one subject simply to respond in the absence of a tone as S^+ , and then by performing the generalization test. The result was a flat gradient of generalization which showed no decrement in responding in the presence of tones when compared with S^+ in training and no preference for any part of the tonal range. These results, together with more extensive data from a previous experiment (Jenkins & Harrison, 1960), indicate that auditory stimuli of this variety

Fig 1. Gradients of inhibition for individual subjects: Experiments I, II, and III; top-left, lower-left, and top-right panels, respectively.

had no discernible effect on responding in pigeons until the stimuli are involved in explicit discrimination training.

The shallow gradients in Experiment I, considered alone, show little evidence for a sloping gradient of inhibitory control. The slight rise in responding toward the higher tonal frequencies might be explained away on the assumption that tones of higher frequencies were less loud to the pigeon and hence more similar to the reinforced stimulus condition of no tone.

In Experiment II, the S^- values were at the extremes of the tonal range. If discrimination training produces a sloping gradient of inhibition, the least inhibitory effect, and, therefore, the maximum responding, would be expected in the vicinity of 1000 cps, which, on a logarithmic scale, is midway between the S^- values. Since increased responding at this portion of the frequency range could not be attributed to a loss of loudness, one of the difficulties in the interpretation of Experiment I is avoided.

The gradients in Experiment II (lower-left panel of Fig. 1) do show a local maximum in responding at 1000 cps for each subject. The systematic departure of these gradients from those in Experiment I provides evidence that the S^- stimuli have some specific inhibitory effect, since the form of the gradient depends on the location of the S^- stimuli along the frequency dimension. Although we have not able to devise a satisfactory overall test of the significance of the difference between the gradients in Experiments I and II, it is instructive to consider the relative level of responding at 1000 cps. In Experiment I, the difference between the per cent of responses at 1000 cps and the average per cent of responses for all other test tones was as follows for each subject: -4.4, -2.1, and -6.4. The comparable scores for Experiment II were +7.4, +15.4, and +6.4. A t test of the mean difference between these sets of scores yielded a value of 4.51 (4 df), which is significant at the .025 level.

The shallowness of the gradients in Experiments I and II might be attributed to the gross difference in sound level between tone and no tone. Perhaps the discrimination was formed on the basis of the presence or absence of sound, so that the frequency of the tone was of little consequence. In order to explore this

question and to provide additional evidence on the possible role of differential loudness of the test tones, Experiment III was run in which S^+ was a broadband noise equated in sound-pressure level to S^- , which was a tone at 1000 cps. The resulting gradients (top-right panel of Fig. 1) were still shallow, although they appear somewhat better formed than those in Experiment I. It is of interest to see that the form of the inhibitory gradient was not markedly affected by the radical change of S^+ from no tone (Experiment I) to noise (Experiment III).

Considered as a whole, the results support the conclusion that a shallow gradient of inhibitory control is obtained in these experiments, and that it cannot be explained away in terms of different degrees of similarity between the test stimuli and the reinforced stimulus.

EXPERIMENT IV

Procedure

Two subjects were trained to discriminate an S^+ of 1000 cps from an S^- of no tone on a procedure similar to the one previously described. Three generalization tests with interpolated retraining were made in order to obtain excitatory gradients along the dimension of tonal frequency. Results for these subjects have been previously reported (Jenkins & Harrison, 1960). For the purpose of the present experiment, further discrimination training was given with S^+ at 1000 cps and S^- at 950 cps. In each session 25 periods of S^+ were programmed and 200 periods of S^- . The criterion of a 4:1 ratio of the rate of response in S^+ to that in S^- was reached in 14 sessions for one subject, and in 12 sessions for the other.

Generalization tests were run as previously described with the following eight tones: 250, 900, 950, 1000, 1050, 1110, 1170, and 5000 cps. No reinforcement was delivered during the test.

Results and Discussion

For each subject, the top panels of Fig. 2 show the excitatory generalization gradient in the last of a series of three tests following training to discriminate an S^+ of 1000 cps from an S^- of no tone, as well as gradients following additional training to discriminate

Fig. 2. Gradients following discrimination between presence and absence of a tone ($S^+ = 1000$ cps; $S^- = \text{no tone}$) and after subsequent training to discriminate between tones ($S^+ = 1000$ cps; $S^- = 950$ cps) are shown for individual subjects in the top panel. Note that for the latter gradient, points at the extreme frequencies are not connected. Lower panels show difference gradients obtained by subtraction (see text). Dotted lines indicate regions of greater uncertainty about the shape of the gradient.

an S^+ at 1000 cps from an S^- of 950 cps. The gradients are plotted in terms of rate of response. The latter gradient is referred to as the fine-discrimination gradient. The fine-discrimination gradients show a lower overall level of responding, which may simply be the result of the repeated conditioning and extinction involved in the several tests. Of more interest than the level of responding is the considerable sharpening of the generaliza-

tion gradient. This was clearly the result of training to discriminate neighboring frequencies. Although some sharpening occurred over the first three tests of generalization before training on the fine discrimination, it was very slight compared with that obtained after the fine discrimination was introduced. One subject (No. 60) showed a shift in the peak of responding from 1000 to 1050 cps. A shift of this type has been reported previously

for visual generalization gradients (Hanson, 1959; Honig, Thomas, & Guttman, 1959). The other subject did not show the shift.

Difference gradients were obtained by subtracting the response rates at test points on the fine-discrimination gradient from the excitatory gradient. Because corresponding test points were not generally available for the two gradients, the values on the excitatory gradient at points corresponding to the test stimuli on the fine-discrimination gradient were estimated by linear interpolation. Consequently, the difference gradients are inexact.

If the effect of the fine-discrimination training on the gradient is to be accounted for by a counter gradient of inhibition, the difference gradients should bear some resemblance to the inhibitory gradients obtained by the more direct method used in the prior experiment. It is apparent, however, that no monotonic transformation of the difference gradients would match them with the obtained gradients of inhibition. The principal discrepancy lies in a local minimum in the inhibitory effect which appears in the difference gradient in the vicinity of the S^+ stimulus value. It is of interest at this point to compare the present results with those of Honig, Thomas, and Guttman (1959) for visual generalization along the dimension of wavelength. They obtained a gradient after single stimulus training (S^+

$= 550 \text{ m}\mu$) and another after discrimination training ($S^+ = 550 \text{ m}\mu$; $S^- = 570 \text{ m}\mu$). Figure 3 shows a difference gradient obtained by subtracting corresponding values on the two gradients. This difference gradient also shows a sharp decrease in inhibitory effect in the vicinity of S^+ but displaced in a direction away from S^- , a shift similar to that obtained with one of the two subjects in the present experiment.

Therefore, the major effect of training to discriminate neighboring values, aside from the peak shift, appears to be to sharpen the gradient by increasing the relative concentration of responding in the vicinity of the reinforced stimulus. This effect, which may be likened to tuning, cannot be reconstructed by any simple rational method of combining excitatory and inhibitory gradients.

It may be proper to consider the effect of training to discriminate between tones of different frequencies as a refinement or extension of the effect of training to discriminate the presence from the absence of a tone, a procedure which also greatly sharpens the gradient of generalization on the frequency dimension (Jenkins & Harrison, 1960). A counter gradient of inhibition on the dimension of frequency is clearly not involved in the sharpening produced by such training. It has been proposed (Jenkins & Harrison, 1960) that the sharpening occurs through a reduction in the influence of incidental stimuli (e.g., constant features of the apparatus), because these stimuli are present during periods of both nonreinforced and reinforced responding. The argument can be extended to the case of discrimination between neighboring values by noting that the tonal stimulus itself has features which are incidental to the experimentally relevant dimension of frequency, e.g., intensity, and in this experiment, periodic interruption. These incidental features which are correlated with reinforcement under training on presence versus absence lose their correlation with reinforcement when training is given to discriminate a tone at one frequency from a tone at a different frequency.

Fig. 3. Difference gradient based on results of Honig, Thomas, and Guttman (1959). The curve plots the difference between rates of response for the excitatory gradient and the postdiscrimination gradient obtained in their Experiment II and shown in Figure 3, p. 149, in which the excitatory gradient is labeled "control group" and the postdiscrimination gradient is labeled "20 min extinction."

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