GENERALIZATION OF EXCITATION AND INHIBITION AFTER DIFFERENT AMOUNTS OF TRAINING OF AN AVOIDANCE BASELINE¹

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After acquisition of a treadle-pressing response maintained by an avoidance contingency, four groups of pigeons received interdimensional discrimination training. For two groups, the positive stimulus was a 1000-Hertz tone correlated with the avoidance schedule and the negative stimulus was noise correlated with extinction. The discriminative stimuli were reversed for the other two groups. For two groups, the test stimuli were presented during extinction without any shocks during the test stimuli, for the other two groups, an unavoidable shock was presented during each test stimulus. Generalization was measured daily during discrimination training by randomly substituting each of six test frequencies for the 1000-Hertz tone. When the 1000-Hertz tone was correlated with the avoidance schedule, the number of responses to it increased and the excitatory gradient became steeper as a function of the amount of training. When the 1000-Hertz tone was associated with extinction, the number of responses to it decreased as a function of days of training and the inhibitory gradient became slightly steeper, provided that responding to the test stimulus was elevated by unavoidable shock. The training effects parallel those obtained with positive reinforcement.

Stimulus control is usually investigated in procedures in which responding in the presence of a particular stimulus is maintained by positive reinforcement. The influence of negative reinforcement on stimulus control has been neglected. An exception is a study by Klein and Rilling (1974), which assessed aversive stimulus control of the treadle-press response of the pigeon. That experiment extended to negative reinforcement an experiment of Honig, Boneau, Burstein, and Pennyacker (1963) in which the pecking response of the pigeon was positively reinforced with food. In the Honig *et al.* study, pecking was positively reinforced in the presence of one stimulus, S+, and was extinguished in the presence of another stimulus, S-, which was selected from an independent or orthogonal dimension. Following training, excitatory or decremental gradients were obtained around S+ and inhibitory or incremental gradients were obtained around S-.

When the S+ and S- dimensions are orthogonal, all of the test stimuli from the S+ dimen-

sion are equally distant psychologically from the stimuli on the S- dimension and conversely. In interdimensional training, S+ is selected from a stimulus dimension that is assumed to be orthogonal to the S- dimension.

Klein and Rilling (1974) maintained the treadle-press response on a baseline of free-operant avoidance. After a minimum of 10 sessions of interdimensional discrimination training, Klein and Rilling obtained an excitatory gradient around S+ when a 1000-Hz tone was correlated with the avoidance schedule. An inhibitory gradient was obtained around S- when a 1000-Hz tone was correlated with extinction. They concluded that excitatory and inhibitory gradients are obtained independently of whether responding is positively or negatively reinforced.

When responding is positively reinforced, the amount of training is one of the most potent variables determining the slope of the gradients of excitation and inhibition. In an independent-groups design, Hearst and Koresko (1968) administered a generalization test following different amounts of training in which responding in the presence of S+ was nondifferentially reinforced. The shallow excitatory gradient obtained on the second day of training became progressively steeper through 14 days of training.

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In another study, Farthing and Hearst (1968) used interdimensional training to examine the effect of the amount of training on the development of inhibitory gradients around S—. Five independent groups received from one to 16 days of discrimination training. After one day of discrimination training, the gradient along the S— dimension was quite shallow, indicating a lack of control by the S— dimension. However, the inhibitory gradients steepened through the first eight days of training.

The present study examined the effect of the amount of training on the development of the excitatory and inhibitory gradients. Following the discrimination procedures developed by Klein and Rilling (1974), the treadle-pressing response of pigeons was maintained on a baseline of free-operant avoidance. The experiments of Hearst and Koresko and Farthing and Hearst on amount of training employed independent group designs that required a large number of subjects. In this experiment, generalization was measured with a maintained procedure in which a generalization gradient for each subject was obtained during each day of discrimination training. For half of the subjects, generalization of excitation was measured by randomly substituting each test stimulus for S+. For the other half, generalization of inhibition was measured by substituting test stimuli for S—.

One of the drawbacks of the maintained procedure is that responding to the test stimuli eventually ceases when the stimuli are presented during extinction. Blough (1972) provided such an example. To solve this problem, a brief unavoidable shock, a probe shock, was presented 5 sec after the onset of each test stimulus from the first day of discrimination training for two groups.

METHOD

Subjects

Twelve experimentally naive White Carneau pigeons served. Each had stainless steel electrodes implanted through the pubic arch (Azrin, 1959) and were attached to an electrical connector mounted on a leather harness worn on the pigeon's back.

Apparatus

A small experimental chamber was employed to maximize the probability of a treadle-press response.

The chamber was a Plexiglas box 29.8 cm high by 21.6 cm wide by 20.5 cm deep. The sides of the chamber were covered by rubber pads 0.64 cm thick. A foot treadle, 6.1 cm long by 8.9 cm wide and extending 6.1 cm into the chamber, was centered on the front wall of the chamber. The treadle was mounted at a 30° angle to the floor, with a front edge 2.4 cm above the floor. A force of 0.6 N with a downward displacement of 1.2 cm was required to operate a microswitch connected to the treadle. The chamber was lighted by a 7.5-W bulb mounted on the ceiling of the chamber.

The experimental chamber was mounted in a sound-attenuating enclosure, serviced by a remote ventilating fan, which also provided a masking noise of 55 dB. Electromechanical equipment, housed in an adjacent room, was used to control stimulus presentations.

The shock source, a 7.8-V ac transformer adjustable from 0 to 7.8 V via a Variac, was connected to the pigeons by a cable attached to a mercury swivel. Internal resistance was measured for each pigeon before each session by a Wheatstone bridge. Implanted electrodes were cleaned when necessary to reduce changes in resistance.

The auditory stimuli were generated by a model LG-18 Heathkit audio generator and a Marietta white-noise generator. A Realistic model AA-18 solid-state amplifier was used to amplify all stimuli to 85 dB, as measured in the chamber with the A scale of a B and K model 2204 sound pressure meter. The speaker was a Realistic 8-ohm speaker mounted in the sound-attenuating enclosure at the pigeon's ear level.

Procedure

Prediscrimination training. The avoidance procedure was that developed by Sidman (1953). Prediscrimination training for all subjects began with sessions of free-operant avoidance training with a shock-shock (SS) interval of 5 sec, a response-shock (RS) interval of 25 sec, and a 4-mA shock of 0.25-sec duration. The SS interval is the time between shocks in the absence of a response and the RS interval is the time that each response postpones the shock. Since the probability of a treadle-press response following a shock was high, shaping of the treadle-press response was not required. Sessions 1 to 4 consisted of 14, 2-min avoidance

components, with no timeout between. In the third and fourth sessions, shock intensity was increased to 7.8 mA. For Sessions 5 to 14, each session was divided into 30, 2-min avoidance components. In the fifteenth through twenty-second session, 44, 2-min avoidance components were presented. No auditory stimuli were presented during prediscrimination training.

Discrimination training. Discrimination training was introduced in the twenty-third session. It consisted of a series of 2-min avoidance components, with a 5-sec timeout between components. During the timeout, no auditory stimuli were presented, the houselight was turned off, and responses on the treadle had no consequences. A discriminative stimulus was presented for the entire 2-min component. The positive stimulus (S+) was associated with the avoidance schedule, and the negative stimulus (S-) was associated with the extinction of avoidance responding. During extinction, no shocks occurred. A total of 22 S+ and 22 S- presentations, arranged in a pseudorandom order, occurred in each discrimination session. The only restriction was that no more than three consecutive presentations of the S+ stimulus or the S- stimulus occurred.

Four groups with three subjects in each group were used. For Groups 1 and 2, S+ was a 1000-Hz tone and S- was white noise. For Groups 3 and 4, S+ was white noise and S- was a 1000-Hz tone.

Generalization testing. Generalization tests started with the first discrimination session (Session 23) and continued for 21 daily sessions. The first 30 min of each session contained no test probes. The generalization-test stimuli were tones spaced at approximately equal intervals along a logarithmic scale employed by Hoffman and Fleshler (1961). The frequencies were 300, 450, 670, 1000, 1500, 2250, and 3400 Hz. These stimuli were presented for 2 min in randomly selected S+ or S- components during the last 60 min of each discrimination session. Each test stimulus was presented once in each discrimination session. The order of assignment of stimuli to the probe components was governed by a 7×7 Latin square. For Groups 1 and 2, the stimuli were presented in S+ components; for Groups 3 and 4, the test stimuli were presented in S- components.

No shock was delivered for Groups 1 and 3 during any probe component in the first 15 discrimination sessions (Sessions 23 to 37). To

increase the response rate to the generalization stimuli for the final six discrimination sessions (Sessions 38 to 43), one unavoidable shock occurred 5 sec after the beginning of the stimulus presentation in each probe component. This produced a total of seven unavoidable shocks in each of the final six discrimination sessions. For Groups 2 and 4, one unavoidable shock occurred 5 sec after the beginning of the stimulus presentation in each probe component for all discrimination sessions (Sessions 23 to 42).

The dependent variable was the number of treadle-press responses to each probe stimulus. For Groups 1 and 2, six different test frequencies were substituted for S+ on randomly selected probe trials; for Groups 3 and 4, the same test stimuli were substituted for S-. For each group, the schedule of free-operant avoidance was not in effect during presentation of a test stimulus.

RESULTS

Figure 1 shows the daily rates of responding for each bird during the last five days of prediscrimination training and the rates of responding to S+ and S- during discrimination training. During the first 22 sessions, auditory stimuli were absent and the avoidance schedule was in effect during the entire session. Discrimination training began in Session 23 with the auditory stimuli specified in Figure 1. During discrimination training, the rate of responding to S- gradually dropped to less than one response per minute for each bird. The introduction of S- produced relatively little change in the rate of responding to S+ throughout the 21 days of discrimination training. During the first few days of discrimination training, seven of the 12 birds (1566, 1143, 962, 388, 66, 665, and 2011) showed a slight decrease in the rate of responding to S+.

The mean percentage of scheduled SS shocks avoided during the last five days of prediscrimination training was 95% and the rate of shocks per minute was 0.57. Eleven of the 12 birds showed an increase in the number of shocks during the first session of discrimination training, which was reflected as a drop to 93% in the mean percentage of shocks avoided. The rate of shocks per minute increased to 0.74 during the first session of discrimination training.

During each of the 21 days of discrimination training, the acquisition data of Figure 1 indi-

Fig. 1. Rate of responding for individual subjects during the last five sessions of prediscrimination training (Sessions 18 to 22) and during the 21 sessions of discrimination training (Sessions 23 to 44). The solid circles show the response rates during S+ and the open circles show the response rates during S-.

cate that generalization testing with the maintained procedures produced little disruption in the rates of responding to S+ and S-.

The gradients in Figure 2 are presented for blocks of three days summed across the three birds in each group. Groups 1 and 2 demonstrate acquisition of excitatory stimulus control; Groups 3 and 4 demonstrate acquisition of inhibitory stimulus control. Notice that the

vertical scale for Groups 1 and 2 is different from that employed for Groups 3 and 4.

For Group 1, the stimuli were presented during extinction without shock for Sessions 1 to 15. During Sessions 16 to 20, one unavoidable shock, a probe shock, was presented 5 sec after the onset of the test stimulus to elevate the rate of responding. For Group 1, the arrow above the 1000-Hz tone shows an increasing number

Fig. 2. Development of gradients of excitation and inhibition. Groups 1 and 2 show the development of the excitatory gradient around S+, while Groups 3 and 4 show the development of the inhibitory gradient around S-. Each gradient was formed by adding the total number of responses to each stimulus across three days of training. Each data point is a sum for the three birds in each group. The closed circles indicate gradients obtained without a probe shock, while the open circles show the gradients obtained with the addition of a probe shock during each test stimulus. For Groups 1 and 3, the probe shock was present during Sessions 16 to 21. For Groups 2 and 4, the probe shock was presented from the beginning of discrimination training. The arrow indicates the 1000-Hz stimulus for each group. Note the different ordinate scales for Groups 1 and 2 and Groups 3 and 4.

gradient was obtained during Days 1 to 3, which became steeper as discrimination training progressed. Relatively few responses were obtained to stimuli other than 1000 Hz during

Days 13 to 15, indicating that the birds acquired a discrimination between the test stimuli, which were always presented during extinction, and the 1000-Hz tone, which was usually associated with the avoidance schedule. The addition of the probe shock in Session 16 flattened the generalization gradient by elevating responding to the test stimuli more than responding to S+.

For Group 2, the unavoidable shock was introduced during the first session of discrimination training. The addition of the unavoidable shocks in Group 2 produced flatter gradients than were obtained from Group 1, particularly during Sessions 7 to 15. The steepening of the excitatory gradients as a function of days of training was much less pronounced than in Group 1.

For Group 3, the arrow above the 1000-Hz tone shows a rapidly decreasing number of responses to S- as a function of the number of days of training. This reflects the acquisition of the low rates of responding to S- indicated by Figure 1. During Sessions 10 to 15, flat gradients with relatively few responses to each test stimulus were obtained. To elevate responding along the S- dimension, an unavoidable shock was employed during Sessions 16 to 21 for Group 3. The introduction of the probe shock produced inhibitory gradients during Sessions 16 to 21: the increase in responding was smallest at S- and greater for the other stimuli as a function of their distance from S-.

For Group 4, in which unavoidable shocks were introduced on the first day of discrimination training, a shallow inhibitory gradient emerged during Days 1 to 3 of training. The gradients steepened slightly through Sessions 4 to 15, as a decreasing number of responses were obtained to S-. The gradients became slightly flatter during Sessions 16 to 21. The addition of the probe shock for Group 4 was more effective in elevating the rates of responding to the test stimuli during Sessions 7 to 15 than was extinction, which was employed for Group 3. A comparison of Groups 3 and 4 during Sessions 16 to 21 shows greater responding to the test stimuli for Group 3 than for Group 4. Thus, the shock is more effective in elevating responding when it is initially introduced than when preceded by 15 sessions of probe shock.

Figures 3 and 4 show the stimulus generalization gradients obtained for the individual birds in each of the four groups. Each gradient

is based upon the total number of responses to a single presentation of each test frequency over blocks of three days.

For Group 1, in which S+ was correlated with 1000 Hz and S- was correlated with white noise, each bird in Figure 3 shows an increase in the number of responses to S+ as a function of the number of days of discrimination training. In Sessions 1 to 15, each test stimulus was presented during extinction without shock. The addition of a single unavoidable shock 5 sec after the onset of each test stimulus in Session 16 flattened the excitatory gradients in each of the remaining sessions for each of the three birds.

For Group 2, in which S+ was also correlated with 1000 Hz and S- was correlated with white noise, Figure 3 shows that, compared with Group 1, the response-independent shock elevated responding to each of the test stimuli other than 1000 Hz during the first 15 days of discrimination training. While more responding was usually obtained to the 1000-Hz tone than to the other test stimuli, little change in the number of responses to 1000 Hz was obtained across sessions.

For Group 3, in which S+ was white noise and S- was a 1000-Hz tone, Figure 4 shows that the number of responses to each test stimulus rapidly dropped toward zero as a function of the number of days of discrimination training. The evidence for inhibitory stimulus control during Sessions 1 to 15 is inconclusive because of the low response output to each test stimulus. During Sessions 16 to 21, when the response output to each test stimulus was elevated by the response-independent shock, an inhibitory gradient with the minimum at S- was obtained from each bird during most sessions. The inhibitory gradients remained stable over the six days of testing with the maintained procedure.

For Group 4, in which S+ was also white noise and S- was a 1000-Hz tone, probe shocks during each test stimulus were present from the first day of discrimination training. Figure 4 shows that stimulus control by the S- dimension was not present during the first six days of discrimination training because the gradients were essentially flat. An inhibitory gradient with the minimum at S- was obtained for each of the three birds during most sessions between Sessions 7 to 15. The assessment of stimulus control during Sessions 16 to 21 was difficult

Fig. 3. Gradients of excitation for the three birds in Groups 1 and 2, summed across blocks of three days of discrimination training. The closed circles indicate gradients obtained without probe shock; the open circles indicate gradients obtained with probe shock. The arrow indicates the 1000-Hz stimulus, S+.

because of the low rates of responding obtained to each of the test stimuli. A comparison of Groups 3 and 4 shows that shock was more effective in producing responding for Group 3 than Group 4. Therefore, the probe shock appears less effective in elevating responding after repeated presentations.

DISCUSSION

Hearst (1969) suggested that differences in stimulus generalization between approach and avoidance behavior are not fundamental, but rather reflect differences in the specific parameters selected by the experimenter. The present

data, and those of Hearst and Koresko (1968) and Farthing and Hearst (1968), support this conclusion with respect to the amount of training. For the S+ and S- dimensions, flat gradients are obtained initially. With further training, the percentage of responses to S+ increases and the gradient becomes steeper. In addition, the percentage of responses to S- decreases as the inhibitory gradient emerges and the gradient becomes slightly steeper. In the present experiment, the excitatory gradient was more sensitive to the amount of discrimination training than was the inhibitory gradient. This account encompasses the present data as well as those obtained on appetitive baselines by

Fig. 4. Gradients of inhibition for the three birds in Groups 3 and 4, summed across blocks of three days of discrimination training. The closed circles indicate gradients obtained without probe shock; the open circles indicate gradients obtained with probe shock. The arrow indicates the 1000-Hz stimulus, S-.

Hearst and Koresko (1968) and Farthing and Hearst (1968).

In the experiments cited above, separate groups were required for each condition. The maintained procedure employed in the present experiment produced reliable gradients day after day, even though each test stimulus was presented only once per session. As Blough (1972) pointed out, one problem with maintained generalization testing is that eventually, the rate of responding to test stimuli drops to zero as the animal acquires a discrimination between the training and the test stimuli. In an attempt to solve this problem, probe shocks were presented 5 sec after the onset of each test

stimulus. The procedure elevated the rate of responding on both the S+ and S- dimensions.

For birds tested on the S+ dimension, presentation of probe shock enhanced the training effect less than it did for birds tested on the S- dimension. For Groups 1 and 2, generalization around the S+ maintained some responding to the test stimuli. For Groups 3 and 4, on the other hand, generalization was around the S-, so there was a low response probability to the test stimuli. The use of probe shocks for Group 4, by counteracting the tendency not to respond, raised the baseline so that training effects were revealed. Therefore, the procedure of presenting probe shocks is an effective tech-

nique for detecting stimulus control by the S— dimension when responding is maintained by an aversive baseline.

Hearst, Besley, and Farthing (1970) argued that a flat stimulus generalization gradient along the S— dimension with few or zero responses to each test stimulus is an equivocal outcome. Both neutral and inhibitory stimuli produce the same result: low rates of responding to the test stimuli. In the present experiment, flat gradients along the S— dimension with few responses to each test stimulus were obtained when generalization was measured for Group III during extinction without shock. However, an inhibitory gradient emerged when responding was elevated by presenting an unavoidable shock during each test stimulus. But the shocks did not elevate the gradient nondifferentially. Rather, fewer responses were produced during S— than during other test stimuli. Clearly, it was the low response outputs in the absence of the probe shock that prevented detection of inhibitory stimulus control for this group. For Group 4, the probe shock eventually failed to elevate responding when presented during S—. The probe shocks produced more responding when presented during the S+ component than during the S— component.

A majority of the birds showed a slight decrease in the response rate during the initial sessions of discrimination training. Similar results were obtained by Klein and Rilling (1973) using a treadle-press response maintained by similar avoidance parameters. Several factors may account for the slight decrease in the response rate that was obtained: (1) novel auditory stimuli were presented on the first day of discrimination training, (2) the increase in the shock rate on the first day of discrimination training may have reduced the rate of treadle pressing, and (3) the decrease in the response rate may have been produced by the differential reinforcement procedure *per se*. The relative importance of these factors remains to be determined. To determine the behavioral interaction, if any, that is produced by the differential reinforcement procedure, the auditory stimuli should be present from the beginning of nondifferential reinforcement to provide a

baseline for comparison with the rate of responding during differential reinforcement. Hemmes (1973) obtained induction, a decrease in the rate of responding to S+ as compared with the baseline, when the treadle-pressing response of the pigeon was maintained by a schedule of food reinforcement. Whether induction is also obtained when the treadle-pressing response of the pigeon is maintained by negative reinforcement with shock must be determined by additional experimental analysis.

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