Stimulus generalization gradients for auditory intensity in rats and guinea pigs*

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Eight hooded rats and eight albino guinea pigs were given successive discrimination training involving variable-interval reinforcement (for barpressing in the presence of one intensity of a 1,000-Hz tone) randomly alternated with extinction (for pressing during another intensity). For half of the animals in each group, the S+ was 75 dB and the S- was 65 dB; for the other half, the S+ was 85 dB and the S- was 95 dB. All Ss were then tested in extinction for generalization along the intensity dimension with values of 65, 70, 75, 80, 85, 90, and 95 dB. The discrimination performance of the rats and guinea pigs was comparable, but the latter species showed less resistance to extinction during generalization testing. For both species, the discrimination employing the more intense training stimuli was mastered faster than that using the less intense ones. A peaked generalization gradient was obtained from most of the Ss, with maximal responding emitted to a stimulus displaced from S+ in the direction opposite S-, and reduced responding to stimuli still farther removed from S-. The group average function contained a significant quadratic component for each species, although occasional deviations from this pattern were observed.

Most experimental studies of stimulus generalization following successive intradimensional discrimination training report peaked gradients with maximal responding displaced from the positive stimulus (S+) in the direction away from the negative stimulus (S-) and a reduction in the level of responding to stimuli still farther removed from S-. Three examples are studies by Hanson (1959), who employed the wavelength dimension, Bloomfield (1967), who used line tilt, and Riccio, Urda, & Thomas (1966), who used floor tilt. On the other hand, Heinemann & Chase (1970) reported two separate experiments demonstrating that generalization gradients for intensity of white noise, obtained after training pigeons to discriminate between two intensities, have the (monotonic) sigmoidal form of psychometric functions. Experiment 1 employed a two-key choice situation and Experiment 2 used the standard single-key free-operant method, yet the results were entirely comparable. This study replicated an earlier one reported by Heinemann, Avin, Sullivan, & Chase (1969). Heinemann and his colleagues have speculated that differences in stimulus continua account for the observed discrepancy in the form of generalization gradients, and they implied that the monotonic form may be typical of intensity dimensions. A subsequent study by

Ernst, Engberg, & Thomas (1971) disputes this suggestion, however. These investigators trained 12 pigeons to discriminate between two intensities of monochromatic light, one associated with variable-interval (VI) reinforcement and one signifying extinction. For six of the pigeons, for which the test included only three values beyond the positive stimulus, four showed peaked gradients but two did not, showing monotonic gradients with maximal responding to the most extreme test value. For another six pigeons tested over a wider range, all showed peaked gradients, however. Thus, when a sufficiently wide range of test values was employed, generalization gradients for visual intensity had the same peaked form as do gradients for qualitative visual dimensions such as wavelength or line angle.

On the basis of the Ernst, Engberg, & Thomas (1971) study, the possibility that monotonic gradients are typical of all intensity dimensions must be rejected. The question of whether they are typical of auditory intensity is, of course, another matter. In addition to the work of Heinemann and his colleagues, two unpublished studies have been reported with pigeon Ss and auditory intensity. Using white noise stimuli, Lawrence (1970) reported peaked (i.e., nonmonotonic) gradients in all eight of his Ss, and Malott and Malott (1967) reported peaked intensity gradients for all three of their pigeons following an intensity discrimination involving pure tones. These findings contradict those of Heinemann and his colleagues with the same species and stimulus dimension that they employed. In view of the

controversy over the form of auditory intensity generalization gradients in pigeons, we endeavored, in the present study, to obtain auditory intensity gradients from two other species, rats and guinea pigs.

SUBJECTS

The Ss were eight male 90-120-day-old Long-Evans hooded rats obtained from the Redwood Game Farm, Salt Lake City, Utah, and eight male 120-150-day-old Hartley albino guinea pigs, bred and raised in our laboratory from stock obtained from the same supplier. The animals were individually housed, each species in a separate room, and they had free access to water in their home cages throughout the study. The rats were run at 85% of their free-feeding weights. The guinea pigs were run at 90%-95% of their free-feeding weights, since pilot work had yielded response rates comparable to those of rats at a higher deprivation level and since it proved difficult to train and maintain guinea pigs in good health under more severe deprivation conditions.

APPARATUS

Eight operant conditioning apparatuses (Davis Scientific Instrument Co., Model DB 103, equipped with a Model PD 109 food pellet dispenser) were modified by the addition of a houselight mounted 2 in. above the food dish. A 4-in. speaker (Quam Model 4A-15) was suspended 10 in. above the floor of the apparatus, directly above the response lever. Each chamber was placed in an insulated chest equipped with a "noiseless" blower (Pamotor Model 4800) which provided adequate ventilation. A custom-made square-wave tone generator was used to produce the training stimuli. The houselight was on throughout the study. Stimulus presentations and reinforcement contingencies were programmed and responses were recorded on electromechanical equipment located in an adjoining room.

PROCEDURE

Four of the apparatuses were set aside for rats and four for guinea pigs. Reinforcement consisted of 45-mg Noyes rat pellets for the rats and 45-mg Noyes alfalfa pellets for the guinea pigs. Otherwise, identical procedures were employed with the two species. Throughout the entire experiment, a tone of 1,000-Hz was continuously present in each experimental chamber.

Daily sessions were typically 1 h in duration. On the first day, all Ss were adapted to the experimental chamber, magazine trained, and shaped to emit a barpress response. As soon as each animal had made 100 continuously reinforced responses, it was removed

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Fig. 1. Relative generalization gradients of the eight rats. The number in parentheses indicates sessions to criterion.

from the apparatus and supplementally fed, if necessary, to maintain its designated weight. On the next 3 days, training was carried out with VI 10-, 15-, and 20-sec schedules, respectively. During all of this training, the 1,000-Hz tone was set at 70 dB for half of the Ss of each species and at 90 dB for the others. Ss which performed poorly under a given schedule were given another session under the same condition before being moved on to the next.

Discrimination training began on the next day and consisted of a quasirandom order of S+ presentations (signifying a VI 20-sec schedule) and S- presentations (signifying extinction). For the Ss for which the training stimulus had been 70 dB, the S+ was 75 dB and the S- was 65 dB, for the other Ss, the S+ was 85 dB and the S- was 95 dB. On the first day of discrimination training, the duration

of each stimulus presentation was 30 sec. On the next day, that duration was increased to 45 sec, and on the third day of discrimination training and thereafter (including during generalization testing), 60-sec stimulus periods were used. The S+ and S- values were presented randomly, with the restriction that neither stimulus could occur more than twice in a row, and each block of 10 presentations included 5 of S+ and 5 of S-. In training and in subsequent generalization testing, the stimuli were presented sequentially, with no intervening periods of silence.

The Ss were trained 1 h daily until a criterion ratio of five S+ responses to one S- response was obtained within a single session. On the next day, following a 20-min reinforced warm-up including 10 S+ and 10 S- periods, a generalization test in extinction was administered. Seven

stimuli, 65, 70, 75, 80, 85, 90, and 95 dB, were randomized within a series, and 12 different random series comprised the test.

RESULTS AND DISCUSSION

The rats required a mean of 40.0 days to achieve criterion, compared to 44.1 for the guinea pigs ($F < 1$). Averaged over species, the 85-dB S+ problem required a mean of 26.3 sessions to criterion, while the 75-dB S+ problem required a mean of 57.9 sessions [$F(1,12) = 20.17$, $p < .01$].

Intensity of the training stimuli did not significantly affect response levels either during training or during the generalization test. A mean of 1,976.1 responses was made to the 85-dB S+ on the terminal training session, compared to 2,142.5 responses to the 75-dB S+ ($F < 1$). In generalization testing, the 85-dB S+ group emitted a mean of 799.5 responses, compared to 1,008.8 for the 75-dB S+ animals ($F < 1$). A species difference was revealed in response levels during testing, however. Guinea pigs emitted a mean of 490.3 responses, compared to 1,318.1 for the rats [$F(1,12) = 7.48$, $p < .025$]. This difference is particularly notable in view of the fact that the guinea pigs were responding at a (nonsignificantly) higher rate on the last day of training. Since the guinea pigs were trained for a comparable length of time and were performing the discrimination at a comparable level, their lower resistance to extinction in generalization testing would appear to be a genuine species difference.

The data of major interest in this study are the generalization gradients. The relative generalization gradients obtained for the rats are presented in Fig. 1 and those for the guinea pigs in Fig. 2. Relative gradients are plotted rather than absolute ones in order to facilitate comparison of gradients involving vastly different numbers of responses. As the figures indicate, all Ss showed very little responding in the vicinity of S- and a displacement of maximal responding from S+ in the direction opposite S-. The gradients of the guinea pigs are somewhat more variable than those of the rats (i.e., they show more inversions), but their form seems to be the same. Most of the gradients are peaked, with responding systematically decreasing to stimuli farther removed from S+ than the peak value. Occasionally the reduction in responding beyond the peak is slight or unsystematic, and in the case of one S (Rat 2), the gradient is clearly monotonic.

To test the form of the gradients statistically, all gradients were plotted on a comparable abscissa, i.e., in terms of distance from S-, independent of direction, and an analysis of variance

trend test was performed. The result indicated a significant quadratic component in the gradients of the rats [$F(1,42) = 4.43, p < .05$] and in those of the guinea pigs [$F(1,42) = 9.14, p < .01$]. Thus, the group average gradient is reliably nonmonotonic (i.e., "peaked") for both species.

It is very difficult to reconcile these results with those of Heinemann and his associates. Nonmonotonic gradients have now been shown with several different species on many different stimulus continua, including both quantitative (intensity) and qualitative ones. A variety of different experimental conditions, e.g., reinforcement schedules, reward amounts, specific training, and testing values, etc., have been used with basically comparable results. One remaining possibility concerns the difficulty of the discrimination problem. Both Hanson (1959) and Thomas (1962) have shown with pigeons that the more difficult the discrimination problem, as manipulated by changes in S+S-distance, the greater the resulting peak shift. Data obtained by Ernst, Engberg, & Thomas (1971), also with pigeons, suggests that those Ss which required the most training to achieve criterion also showed the greatest peak shift. In the present study, the data obtained with rats indicates that those Ss for which the discrimination was most difficult, Rats 2 and 4 (see days to criterion in Fig. 1) showed the greatest shift in their gradients. (No such relationship appears to exist with the guinea pigs.) Presumably, the gradient of Rat 2 would have peaked at 95 dB or at a value still greater if test stimuli of greater intensity had been available. In the study most comparable in procedures to the rest of the literature (Heinemann & Chase, 1970, Experiment II), over 80 days of training were used, suggesting that the discrimination was a difficult one indeed. Ernst, Engberg, & Thomas (1971) have speculated that Heinemann and Chase would have obtained nonmonotonic gradients had they used an easier discrimination or a wider range of test stimuli.

If the problem was not a very difficult one for Heinemann and Chase's Ss, then they were substantially overtrained. Little is known about the effects of overtraining on postdiscrimination generalization gradients, and perhaps this factor contributes to the form of the gradients that Heinemann and Chase obtained. It remains to be discovered what procedural manipulation or combination of

Fig. 2. Relative generalization gradients of the eight guinea pigs. The number in parentheses indicates sessions to criterion.

manipulations leads to the production of monotonic postdiscrimination gradients. It is clear, however, that such gradients are the exception rather than the rule for any stimulus dimension yet investigated.

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