

*A GENERALIZATION GRADIENT
FOR AUDITORY INTENSITY IN THE RAT¹*

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In the natural (nonlaboratory) environment, the organism responds in a fairly stable and consistent manner to stimulation which is similar to, but not identical with, prior stimulation. This phenomenon of "generalization" ranks as an important problem in the field of learning and is considered relevant to such questions as those of concept formation and transfer of training.

Pavlov (13) developed an empirical approach to this problem using his conditioned-reflex technique. The typical procedure consisted in establishing a conditioned response (CR) to a given stimulus, say a 1000 cycle tone. Then, the animal's response to other tones was tested. He noted that a gradation in magnitude of the CR was produced by the presentation of stimuli along the same continuum, but varying in remoteness from the training stimulus. Further experiments in Pavlov's laboratory demonstrated the existence of a generalization gradient of extinction effects as well. Salivary CR's of equal magnitude were elicited through a training procedure in which stimulation was applied at five spatially disparate points on the dog's hind leg. When the CR was extinguished to stimulation at a single point, a CR decrement was observed to stimulation at the other points. This decrement was systematically related to the distance from the stimulus location used in extinction.

A number of later investigators have dealt with stimulus generalization in the Pavlovian situation. Hovland (8, 9), for example, has presented some concave generalization gradients for respondent conditioning and extinction. These were obtained using auditory stimuli. A large number of respondent generalization studies have been reviewed by Hull (10).

In the operant experiment the stimulus features of the situation which are present just antecedant to, or concomitant with, the reinforced response may be considered the analogue of the CS in the Pavlovian experiment. Such stimulus features are frequently termed S^D 's, whereas training stimuli present only during nonreinforcement are known as S^A 's. Relatively little work has been published on stimulus generalization in which operants are involved. Gibson (4) has derived a gradient for the percentage frequency of verbal responses to spacially separated vibratory stimuli which is comparable in form to Hovland's classical gradients.

The generalization of reinforcement effects as measured by rate of responding in extinction has been examined by Guttman and Kalish (5) as well as Hanson (6). The phenomena observed are extremely transient in nature since there is a progressive decrement in the response values with time. A discrimination arrangement has the virtue of allowing the experimenter to maintain responding to the S^D while examining the S^A rate over an extended period of time. One, of course, examines generalization of extinction effects simultaneously with those of conditioning. Both Frick (3) and Raben (14) trained several groups of animals on a discrimination in which the intensity difference between S^D and S^A differed for each group. A general-

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ization gradient was plotted in the case of each study, indicating that response values obtained in S^{Δ} were systematically related to the S^D - S^{Δ} intensity difference.

Our interest, in the present study, was threefold:

- (1) to obtain an auditory intensity gradient in the rat, using a special form of a discrimination situation;
- (2) to examine changes in gradient form for an individual animal as discrimination training continued; and
- (3) to investigate changes in gradient form under extinction.

METHOD

Apparatus

Two identically constructed operant spaces were used. A diagram of these is shown in Fig. 1. The outer shell of each box was a refrigerator with the internal furnishings removed. Two-inch Fiberglas board, covered with glass cloth, was ap-

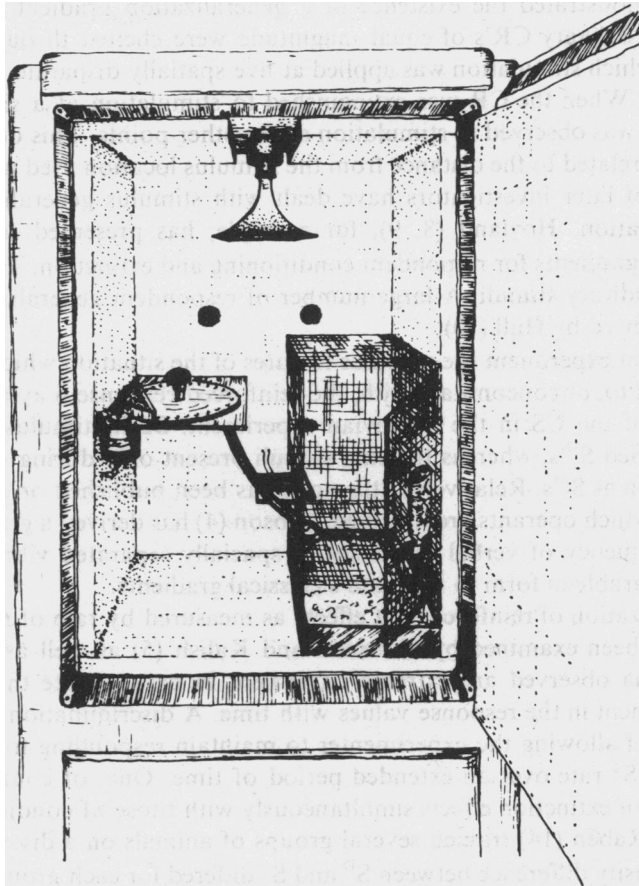


Figure 1. Drawing of the operant space within a sound-deadened enclosure. The tweeter is suspended above the mesh animal cage and the pellet dispenser is shown at the left. The two holes indicated in the rear of the enclosure represent the inlet and outlet apertures of the ventilating unit.

plied on all of the inside surfaces, resulting in a box with the dimensions, 21 inches high by 12 inches wide by 9 inches deep. An animal enclosure, constructed of 1/2-inch galvanized mesh, measuring 10 inches high by 7 inches wide by 8 inches deep was placed within this box. This was equipped with a Gerbrands lever and a food tray. The floor of the enclosure was suspended 5 inches from the floor of the box. A masonite feces tray containing 2 inches of shavings slid in on the floor of the box, directly beneath the wire mesh of the animal enclosure. A Williams-Anger pellet dispenser for Noyes 4-millimeter, 45-milligram pellets was mounted alongside the enclosure and connected to it by a tube. A model 4401 University tweeter was suspended 4 inches above the enclosure.

The equipment used for ventilation, programming, presenting stimuli, and recording responses was housed in an adjacent room. The sound stimuli were recorded on magnetic tape from a Heathkit signal generator. They were presented to the organism by a Viking ff75 stereophonic tape recorded through a Heathkit A-9B amplifier and the tweeter. Sound levels were monitored with a Ballantine Model 643 voltmeter. Different sound levels were recorded on the two tape channels. Selection of the appropriate channel was made through the use of relay circuits, programmed by a Gerbrands punched-tape interval programmer. Reinforcements were scheduled by a second punched-tape programmer. Responses and reinforcements were registered on Gerbrands cumulative-response recorders and also on electric counters. When a number of different intensities were presented within a session, a separate counter registered as each intensity was presented. The counters were scheduled by use of a punched-tape programmer and a stepping relay which selected a new "hot" counter to register whenever the sound level changed. A specially constructed sound-proofed ventilating unit was connected to the box through the two vent holes shown in the center back of Fig. 1. This unit completely changed the air in the box every 3 minutes.

Subjects

Four male albino rats, bred in the Barnard colony from Wistar stock, were used as *S*'s. They were 110-120 days old at the start of experimentation. They were maintained on a deprivation schedule for approximately 2 weeks prior to experimentation, until their body weights had stabilized at 80% of their free feeding weights. Throughout the course of the experiment the animals were maintained close to an 80% criterion value. The criterion weight was increased by 4 grams per week in an effort to parallel the weight increase noted in animals of comparable ages on free feeding. The animals were weighed, returned to their living cages, and fed, following each experimental session.

PROCEDURE

The experiment may be conveniently divided into three phases, including two different sets of discrimination training operations, and a final extinction operation.

Discrimination Training I

Two animals were run simultaneously under identical conditions. They were placed in the boxes in the dark and given 2 hours of training, at the same hour each day. On the first day of training they were placed in the boxes with the S^D intensity

(reinforcing contingency) constantly present. Reinforcements were programmed on a 10-second, fixed-interval schedule. Thereafter, with bar-pressing well established, the 2-hour session was evenly divided into S^D and S^A (nonreinforcing contingency) conditions. The order of succession of interval lengths for S^D and S^A was taken from the Gellerman series designed to avoid simple alternation sequences. Each R (right turn) in his series was assigned a value of 1 minute of S^D , and each L a value of 1 minute of S^A . This produced a series of S^D and S^A intervals which ranged between 1 and 3 minutes. During S^D the organism was now reinforced on a geometric schedule which had a mean interval length of 59 seconds. The nature of the schedule made it possible that an occasional S^D interval would occur and no reinforcement would be programmed. This type of schedule presumably generates fairly high, stable rates and considerable resistance to extinction.

Sound Stimuli

The frequency used was a 4000 cycle tone, presented at a low intensity (0.01 volts at speaker) and at a high intensity (1.0 volts at speaker). Thus, there was a difference of 40 decibels between the high and the low intensities. For two S 's the low intensity served as the S^D and the high intensity for S^A . For the other two S 's the high intensity was S^D and the low intensity S^A . The animals were run for 6 weeks until a stable difference in S^D and S^A was obtained ($S^A/S^D < 0.10$). One animal in the high intensity S^D group was dropped at this point since his S^A/S^D ratios never decreased below 0.33 and his behavior was highly variable. Aside from this animal, no important differences in performance were noted between the two groups of animals in the development of the discrimination.

Discrimination Training II

With a stable discrimination between two intensities, 40 decibels apart, established, the second phase of training was begun. The animals were now presented with the same S^D intensity as that used previously and the geometric reinforcement schedule was continued as before. However, the half of the session previously devoted to S^A was divided in such a way that each of four intensities was presented for an equal total interval. These intensities were the same S^A as previously used, and intensities 10, 20, and 30 decibels removed from it in the direction of S^D . These four intensities were all presented under a nonreinforcement contingency. The sequence of intensity presentation was randomized and then counterbalanced. An S^A intensity was as often followed by another S^A intensity as it was by the S^D intensity. The range of both S^D and S^A interval lengths was 2-6 minutes. The experimental sessions in this phase of the experiment were 1 hour in length.

Extinction

After 18 days of running under Discrimination Training II conditions, a fairly stable level of performance had been obtained. The animals were then run under extinction conditions for 12 days. The same tape program of intensities was presented as in Discrimination II. Daily sessions were 1 hour long. The only difference in procedure here, from Discrimination II, was that no reinforcement was presented with any intensity.

RESULTS

For all of the data-processing, the total number of responses in S^D was divided by a constant. The purpose of this was to make the response values under one intensity comparable with those obtained under other intensities, since the S^D intensity was presented a total of 50% of the session, whereas each other intensity was presented a total of 12.5% of the session. This pro-rating of S^D response values means that rates are read from the ordinate in terms of responses per 7.5 minute period in all figures which follow.

Figure 2 presents the mean data of all three rats. For two rats the intensity decreased by 10 decibel steps between S^D and S^A , whereas for one rat the intensity increased from S^D to S^A . These curves were fitted by least squares to an hyperbolic equation. The equations for the curves are:

$$\begin{array}{ll} \text{Days 1-6,} & y = 234x^{-1.3077} + 7.0886 \\ \text{Days 7-12,} & y = 247x^{-1.8456} + 0.2481 \\ \text{Days 13-18,} & y = 228x^{-2.5053} + 0.7780 \end{array}$$

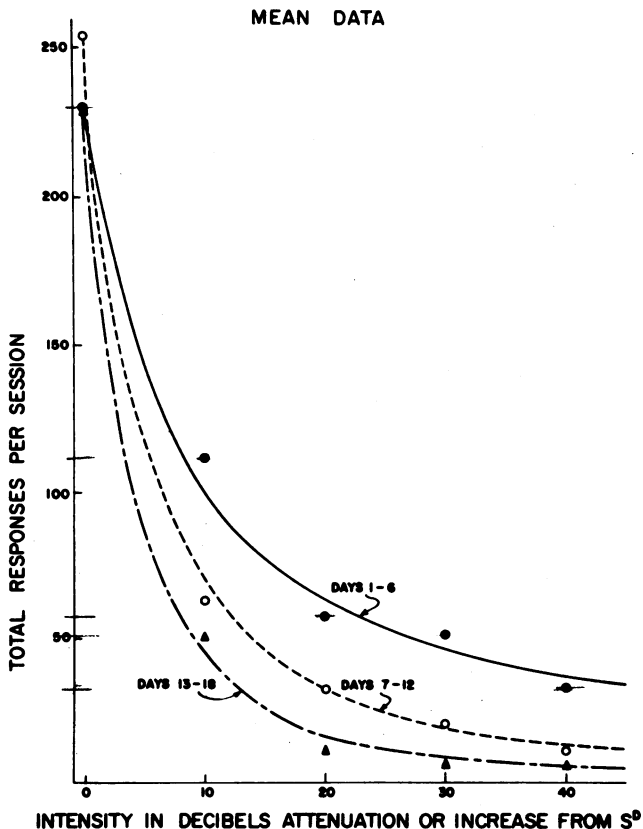


Figure 2. Total responses per session as a function of intensity level. Each point represents the mean of the three animals taken over a block of 6 consecutive days.

Hoel (7) outlines a method for determining whether the difference between the slopes of two curves might be attributed to sampling variation rather than to experimental operations. This consists in establishing confidence limits for a regression coefficient using Student's t distribution. This analysis was applied to the data yielding the curves shown in Fig. 2. The results are given in Table 1.

TABLE 1
CONFIDENCE LIMITS FOR SLOPE OF A REGRESSION LINE:
MEANS FOR THREE RATS TAKEN IN BLOCKS
OF SIX CONSECUTIVE DAYS

Comparison	t	Confidence Level
Days 1- 6 vs. days 13-18	3.073	0.005
Days 1- 6 vs. days 7-12	0.232	0.450
Days 7-12 vs. days 13-18	1.192	0.200

In each comparison given in Table 1, $N = 15$ and t was calculated with 13 degrees of freedom.

The only significant difference to be found in these comparisons is the difference in slope between the curve representing the first block of 6 days and the curve for the last 6 days of discrimination training with 4 S^A 's. This suggests that these gradients show progressive changes in slope throughout the training period, although these slope changes are not marked when adjacent days (or blocks of days) of running are considered. The curve-fitting data indicates, however, that despite changes in slope the gradients do retain a hyperbolic form throughout.

At each intensity (excepting S^D), t -tests were run between each of the three possible pairings of rate values. The results of these t -tests are shown in Table 2.

TABLE 2
 t -RATIOS AND CONFIDENCE LEVELS WHEN RATES ARE COMPARED
AT EACH INTENSITY AT THREE STAGES OF
DISCRIMINATION TRAINING:
MEAN OF THREE RATS

	<i>Days 1-6 vs. days 7-12</i>			
Intensity	10	20	30	40
t -ratio	1.97	1.86	2.96	1.94
Confidence level	0.050	0.050	0.005	0.050
	<i>Days 1-6 vs. days 13-18</i>			
Intensity	10	20	30	40
t -ratio	2.39	3.28	5.15	2.56
Confidence level	0.025	0.005	0.001	0.010
	<i>Days 7-12 vs. days 13-18</i>			
Intensity	10	20	30	40
t -ratio	0.82	2.03	5.55	2.05
Confidence level	0.250	0.050	0.001	0.050

With the exception of the rates at intensity 10 in the last two stages of discrimination training, significant differences were found between the corresponding points at each intensity on the three curves. All of these differences are significant at better than the 0.05 level for a one-tailed t with 17 degrees of freedom.

The generalization curves for the individual animals over each of the three 6-day blocks of Phase II are presented in Fig. 3. The individual curves for any given block

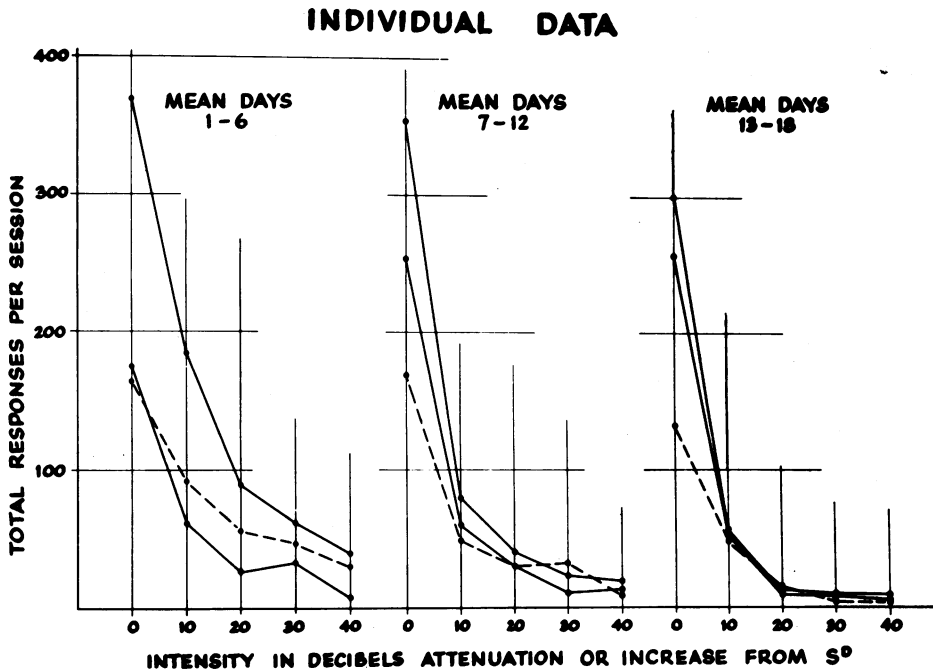


Figure 3. Total responses per session as a function of intensity level. Each point represents the mean for a single animal taken over a block of 6 consecutive days of discrimination training with four S^D 's. Rat No. 3 is indicated by the dashed curves. Rat No. 1 is the highest-rate S^D animal in each set of curves.

of 6 days show considerable similarity in form, although in the case of Rat No. 3 intensity *decreased* between S^D and S^A . In order to indicate the comparability between the curves for separate animals in a single session, the total response data for each rat at each intensity is presented in Fig. 4. This figure includes data for the first and last days of discrimination with four S^D 's. Although the individual animals show differences in their S^D rates, there is a remarkable similarity in the general form of the individual curves and in the progressive changes with training.

Figure 5 shows the mean data for all rats for each of the two 6-day blocks of extinction sessions. The rates for all intensities drop markedly and progressively with continued extinction training. However, graded responding along the former S^D - S^A continuum is evident as long as response rate remains above zero. On the last day or two of extinction training the animals responded at an extremely low rate, and generally only in the presence of the former S^D intensity.

INDIVIDUAL DATA

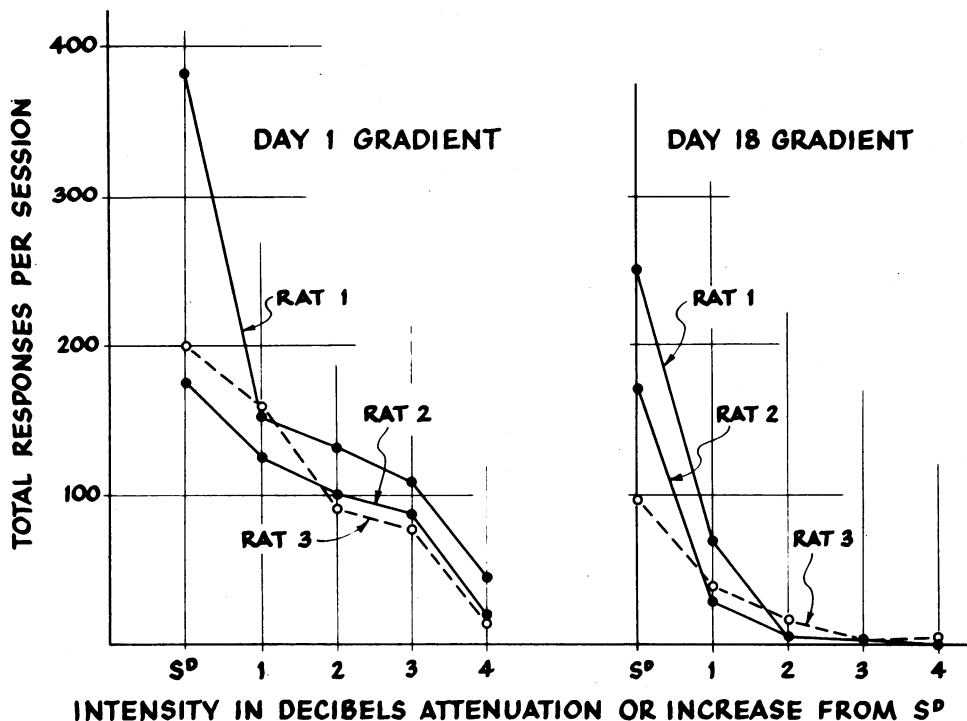


Figure 4. Total responses per session as a function of intensity level. Each point represents the total number of responses made by a single animal in a single 1-hour session.

DISCUSSION

Testing for generalization in a discrimination situation may be viewed as a psychophysical scaling technique. Here, the animal's rate might be considered as a kind of rating scale measure—as a rating made along a continuum which provides anchors (S^D and S^A) at each extreme. These animals rate the intensities close to S^D independently of their direction of change in physical magnitude. Hull (10, 11) has proposed that the magnitude of the stimulus intensity (V) is related to the evocation of response, particularly in the generalization experiment. We might then expect that the course of development of a stable discrimination would differ in the case of the two groups of animals, predicting that the animals with the high-intensity S^A would be slower to exhibit low rates under S^D . This did not seem to be the case, as both groups of animals developed differential responding at about the same rate. This can be shown by taking an index of the number of responses in S^D divided by the number of responses in S^A as a criterion for the development of the discrimination. When such values are computed, all three animals show similar ratios throughout the period of training as well as similar day-to-day variability in these ratios. Neither effects of stimulus-intensity dynamism nor response suppression resulting from high-intensity presentation appear to be significantly present in the generalization gradients derived in this experiment. When the data are plotted

with decibels' attenuation or increase from S^D on the abscissa, the high-intensity S^A animal gradients do not show greater generalization effects, but exhibit similar form and slope to gradients of the animal presented with the low-intensity S^A .

Schlosberg and Solomon (15) have suggested that the generalization gradient should approach linearity when reinforcement is presented at only one extreme of the continuum and the abscissa is plotted in equal-appearing interval steps. They have shown that Hovland's concave j.n.d. gradients do not depart significantly from a straight line when replotted in equal-appearing interval units. Since we did not have intensity j.n.d. data available on the rat, a series of intensities separated by log steps was used. Reasoning by analogy to the transformation of the Hovland data, it is possible that our data might approach linearity if a plot of equal-appearing intervals were possible.

The gradients obtained at the three stages of training show progressive changes in slope as training with the generalization stimuli is continued and a new discrimination between the original S^D and the four S^A 's developed. This finding is in agreement with that of Raben, who demonstrated a progressive decrement in generalization with increased discrimination training in a runway apparatus. Both Guttman and Margolius (12) have pointed out that generalization of reinforcement effects is directly related to variation in response strength as obtained by differences in amount of training or amount of extinction. Within limits, the gradients become flatter as an increasing number of reinforcements is presented or as extinction conditions are continued. However, such effects are apparently overridden during discrimination training by generalization of extinction effects resulting from the presence of S^A . We find that discrimination between S^D and the other four intensities

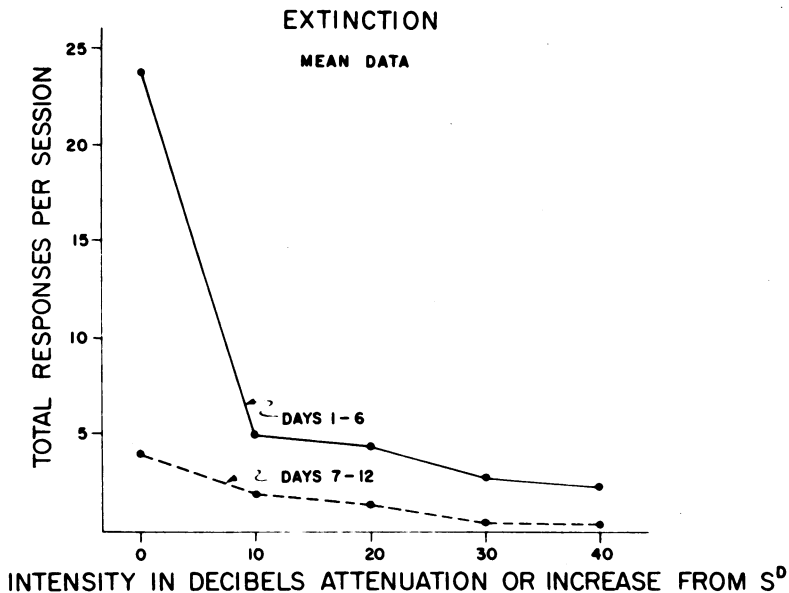


Figure 5. Total responses per session as a function of intensity level. Data obtained under extinction conditions. Each point represents the mean for the three animals taken over a block of 6 consecutive days.

(S^A 's) progressively sharpens throughout Phase II although S^D rate is relatively invariable. Both Frick and Raben report a similar finding. An increase in relative generalization, however, is observed in the flattened gradients obtained under extinction conditions in this study. It might be noted, though, that the rates under all intensities have dropped markedly as compared with Phase II, so that rate differences are now evident over a very restricted range of values.

At all stages of Phases II and III a decelerated gradient which appears to be approaching an asymptote is obtained. This roughly resembles the respondent generalization gradients of Hovland for pitch and auditory intensity as well as those for operants given by Gibson, Frick, Raben, Guttman and Kalish, and Hanson. This represents a surprising degree of generality when one considers the range of organisms and methods used to yield these gradients. The gradients obtained in this investigation under both discrimination and extinction conditions indicate that discrimination between adjacent intensities progressively worsens as S^A is approached. Perhaps this might be better stated as a decrement in discrimination as we depart from S^D , since Guttman's gradients obtained with no S^A condition show comparable form. Hanson's gradients with the maximum displaced from S^D in a direction away from S^A suggest that generalization of extinction effectively operates along the continuum, at least as far away as S^D .

The following conclusions may be drawn from this study:

1. Concave gradients are obtained when animals who have previously attained a stable discrimination between two intensities are subsequently presented with a number of S^A intensities lying between the original S^D and S^A .
2. These graded responses to stimuli intermediate between S^D and S^A show progressively greater generalization of extinction effects with continued training.
3. The discrimination between generalization stimuli progressively worsens as S^A is approached.
4. The response rate is independent of direction of change in physical magnitude of the stimulus, but is related to distance from S^D .
5. Gradients obtained under extinction conditions are much flatter than those obtained when an intensity at one extreme of the continuum was reinforced. Graded responding is evident under extinction conditions as long as response rate remains above zero.

SUMMARY

Rats were trained on an auditory intensity discrimination, using bar-press rate as the response measure. Training was carried out over a period of 6 weeks until stable differential responding occurred to two 4000 cps tones which were separated by an intensity difference of 40 decibels. Then, three new intensities, intermediate between the original training stimuli, were introduced along with the original stimuli. This presented the organism with five stimuli separated by 10 decibel steps along an auditory intensity continuum. Response rates to the original positive training stimulus, located at one extreme of the continuum, were maintained at a high level through a variable-interval schedule of reinforcement. This phase of training was continued for 18 days. Three generalization gradients, one for each successive block of 6 days of training, were obtained relating mean response rate to the five inten-

sities. The curves are similar in form, decelerated gradients well fitted by an hyperbolic equation. The curves show progressive changes in slope with continued training. With the exception of the reinforced intensity rate value, statistically significant differences can be shown between corresponding points on each of these three curves at different training stages. Gradients obtained under extinction conditions are considerably flatter but show graded responding, relative to intensity, as long as response rate remains above zero.

All animals were run on the same intensities though the positive stimulus for one group was the negative stimulus for the other, and vice versa. No differences were noted between the two groups in the development of differential responding. A comparison of these two groups suggests that response rate is independent of the direction of change in intensity (increase or attenuation), but rather is related to the distance away from the positive stimulus.

REFERENCES

1. Estes, W. K. Discriminative conditioning I. A Discriminative property of conditioned anticipation: *J. exp. Psychol.*, 1943, **32**, 150-155.
2. ———. Discriminative conditioning II. Effects of a Pavlovian conditioned stimulus upon a subsequently established operant response. *J. exp. Psychol.*, 1948, **38**, 173-177.
3. Frick, F. C. An analysis of an operant discrimination. *J. Psychol.*, 1948, **26**, 93-123.
4. Gibson, E. J. Sensory generalization with voluntary reactions. *J. exp. Psychol.*, 1939, **24**, 237-253.
5. Guttman, N., and Kalish, H. I. Discriminability and stimulus generalization. *J. exp. Psychol.*, 1956, **51**, 79-88.
6. Hanson, H. M. Discrimination training effect on stimulus generalization gradient for spectrum stimuli. *Science*, 1957, **125**, 888-889.
7. Hoel, P. G. *Introduction to mathematical statistics*. New York: Wiley, 1954.
8. Hovland, C. I. The generalization of conditioned responses: I, the sensory generalization of conditioned responses with varying frequencies of tone. *J. gen. Psychol.*, 1937, **17**, 125-148.
9. ———. The generalization of conditioned responses: II, the sensory generalization of conditioned responses with varying frequencies of tone. *J. genet. Psychol.*, 1937, **51**, 279-291.
10. Hull, C. L. The problem of primary stimulus generalization. *Psychol. Rev.*, 1947, **54**, 120-134.
11. ———. *Essentials of behavior*. New Haven, Yale University Press, 1951.
12. Margolius, G. Stimulus generalization of an instrumental response as a function of number of reinforced trials. *J. exp. Psychol.*, 1955, **49**, 105-111.
13. Pavlov, I. P. *Conditioned reflexes* (Trans G. V. Anrep). London: Oxford University Press, 1927.
14. Raben, M. W. The white rat's discrimination of differences in intensity of illumination as measured by a running response. *J. comp. physiol. Psychol.*, 1949, **42**, 254-272.
15. Schlosberg, H. and Solomon, R. L. Latency of response in a choice discrimination. *J. exp. Psychol.*, 1943, **33**, 22-39.