CONTRAST, GENERALIZATION, AND THE PROCESS OF DISCRIMINATION[1]

GEORGE S. REYNOLDS

HARVARD UNIVERSITY

A combination of generalization gradients for reinforcement and extinction fails to predict the generalization gradient produced by training a discrimination between two stimuli (Honig, Thomas, & Guttman, 1959; Hanson, 1959). One reason for this failure is that the usual generalization gradient for extinction reflects only an inhibitory effect of extinction, whereas extinction has not only an inhibitory effect but also an excitatory one. The inhibitory effect is an over-all decrease in responding over the stimulus continuum. The excitatory effect appears during the formation of a discrimination as an increase in responding in the presence of the stimulus correlated with reinforcement. This increase is called behavioral contrast (Reynolds, 1961). Moreover, an adequate description of the process of discrimination must take into account both the inhibitory and the excitatory effects of extinction.

The primary purpose of this research is to compare generalization gradients for extinction and reinforcement obtained by a procedure that allows both effects of extinction to be measured. A second purpose is to examine the contribution of contrast to postdiscrimination generalization gradients. In this method, a pigeon's key pecking is first reinforced in the presence of ten values of a stimulus continuum. To obtain the reinforcement gradient, responding is then reinforced in only two of the values and extinguished in the remaining eight; or to obtain the extinction gradient, responding is extinguished in two of the values and reinforced in eight. With this method of maintained generalization gradients (cf. Pierrel, 1958), the effect of extinction on reinforced responding can be measured as increases in the rate of responding over the base-line rate maintained by reinforcement in all ten stimuli.

METHOD

Apparatus

A modified picnic icebox contained the experimental chamber (Ferster & Skinner, 1957). A transparent, but otherwise standard, response key, 0.75 inch in diameter and faced with cover glass to minimize scratching, was mounted on one wall, which was painted a uniform flat black. An effective force of about 15 grams operated the key. The pigeon occasionally had access to grain for 3 seconds (reinforcement) through a 2-by 2-inch opening beneath the key.

Two 6-watt white lamps mounted behind the panel, one on each side of the key, were the only illumination in the chamber. A white masking noise was always present.

The stimulus continuum was the spatial orientation of the apex of a triangle. A black isosceles triangle, 0.5 inch high and 0.25 inch along the base, was mounted on a white background 0.5 inch behind the transparent key. This triangle and the background were attached to a synchronous motor that slowly but continually rotated clockwise at a speed of slightly less than 0.19 degree per second (about twice the speed of the minute hand of a clock). The rotation of the triangle was in a plane perpendicular to the pigeon's line of sight and around an axis through the geometrical center of the triangle. The motor also drove a circular commutator that completed a circuit with a stationary brush after every 36 degrees of rotation. This circuit controlled automatic programming equipment that provided for reinforcing in the presence of appropriate orientations of the triangle and for counting key pecks separately for each 36 degrees of the triangle's rotation.
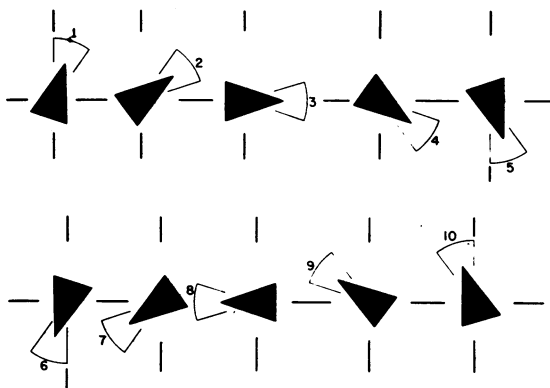

Fig. 1. The triangle in the middle of each of the 10 decants of rotation and the reference number assigned to each decant.

Each 36 degrees of rotation was called a decant, and the decants were numbered for reference. The first decant of clockwise rotation from the apex pointing up was called 1, and successive numbers were given to successive rotations of 36 degrees. Figure 1 shows the numbers and the various orientations that the triangle assumed together with horizontal and vertical reference lines. The apex of the triangle is oriented in the middle of each decant in the figure. In fact, it rotated continually and clockwise through each decant.

Subjects

Four adult, male White Carneaux pigeons, previously trained to peck a response key, were maintained at 80% of their free-feeding weights throughout the experiments.

Procedure

A daily session consisted of two complete rotations of the triangle (64.2 minutes). First, responding was reinforced for several sessions on a variable-interval (VI) schedule regardless of the orientation of the triangle. The VI schedule had a minimum average inter-reinforcement time of 90 seconds. Then, the procedure was changed so that for 42 sessions, responding was reinforced on VI 90 seconds when the apex of the triangle was located in the upper two decants (10 and 1 in Fig. 1). When the apex lay elsewhere (decants 2 through 9), responding was extinguished. The apex of the triangle was situated at the start of a different decant in an irregular order before the start of each day's session.

In order to change daily the order of the decants appearing during a session, the procedure was modified by introducing periods of total darkness and no reinforcement (time outs) at irregular intervals during each session. A time out always began at the boundary between two decants. During a time out, the triangle continued to rotate, and the lights came on again after the triangle had moved through 1, 2, or 3 decants from its position when they had gone off. There were still two *lighted* revolutions of the triangle during each session, but now a total of one revolution without illumination was interspersed among the two lighted ones. Responding was reinforced in the presence of decants 10 and 1 for an additional 14 sessions.

In the next procedure, responding was extinguished when the apex was in decants 10 and 1 and reinforced on VI 90 seconds when the apex lay elsewhere. The interspersed time outs still occurred. After 43 sessions of this procedure, the rate of responding in each decant appeared stable.

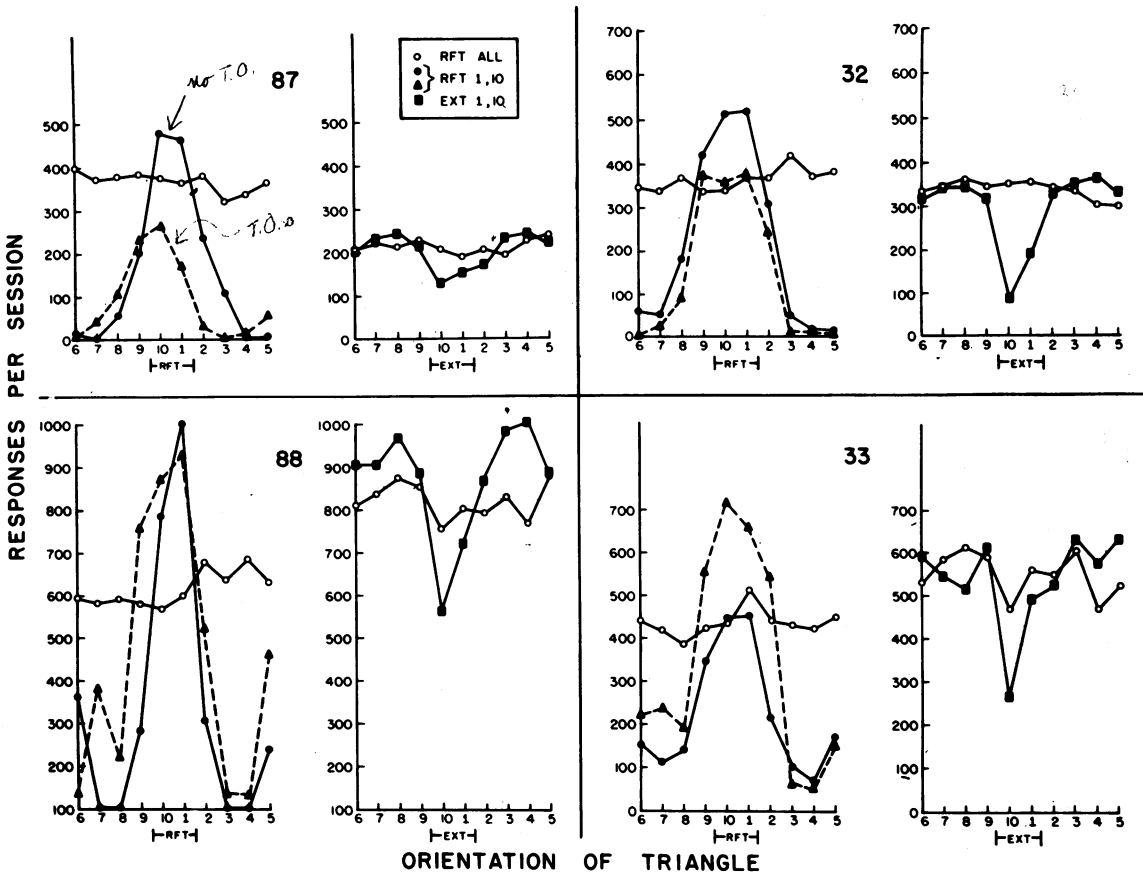Finally, responding was reinforced in *all* decants for 16 sessions, still with interspersed time outs.

Fig. 2. The number of responses per session as a function of decants of rotation for each pigeon on each procedure. The left-hand graph of each pair gives the data for reinforcement in only decants 10 and 1; the right-hand graph, the data for extinction in only decants 10 and 1.

RESULTS

Figure 2 shows the median number of responses in each decant in the last five sessions of each procedure. There are two graphs for each of the four pigeons. In the left-hand graph of each pair, the open circles show the effects of reinforcing in every decant; the filled circles, the effects of reinforcing in only decants 10 and 1; and the filled triangles, the effects of reinforcing in decants 10 and 1 with interspersed time outs. In the right-hand graphs, the filled squares show the effects of extinguishing in decants 10 and 1 and reinforcing elsewhere; and the open circles show the effects of reinforcing in every decant at the end of the experiment.

When the same VI 90-second schedule of reinforcement was correlated with each decant, the rate of responding was reasonably constant across decants (open circles). For each bird, extinction during decants 2 through 9 produced an increase in the rate of responding maintained by VI 90 seconds and a decrease in responding in the other decants. The rate of responding in extinction generally declined as the triangle rotated away from the decants correlated with reinforcement (cf. Pierrel, 1958).

The introduction of time outs after the establishment of the gradients shown by the filled circles produced different effects for each bird (filled triangles). The effects are of two sorts: a broadening of the gradient (to the left for Pigeons 87 and 88, or in both directions for Pigeon 33) and a change in the over-all rate of responding. The same changes in the over-all level of responding are found in the subsequent base-line rate supported by the VI schedule. For each pigeon, the second base line produced by reinforcement in all decants with interspersed time outs (open circles in right-hand graphs) is shifted away from the original base line (open circles in left-hand graphs) in the same direction as the shift in rate produced by the introduction of the time outs. This change in the base line suggests that the effects of reinforcing in only two decants with time outs should be assessed relative to the second base line, and that the effects without the time outs (filled circles) should be assessed relative to the initial base line. In these comparisons, the effects with and without time out turn out to be similar.

Despite the irregular changes in level and some broadening in one or both directions, the gradients after the introduction of time outs still show less responding in extinction the farther the decant is from decants 10 and 1. However, there was often more responding in decants 6 and 5 than in decants 7 and 4. Reference to Fig. 1 shows that the position of the triangle in decants 6 and 5 is simply inverted from its position in decants 10 and 1.

A cumulative record (for Pigeon 88) from one session in which responding was reinforced in only decants 10 and 1 shows the high rates of responding maintained in decants 10 and 1 and the steadily de-

clining rate of responding as the triangle rotated into and through decants 2, 3, and 4 (Fig. 3A). The increase in responding as the triangle rotated through decants 7, 8, and 9 occurred more suddenly a short distance into decant 9. The order of decants in the cumulative record has been rearranged, since the pigeon never saw them in numerical order during a session with time outs.
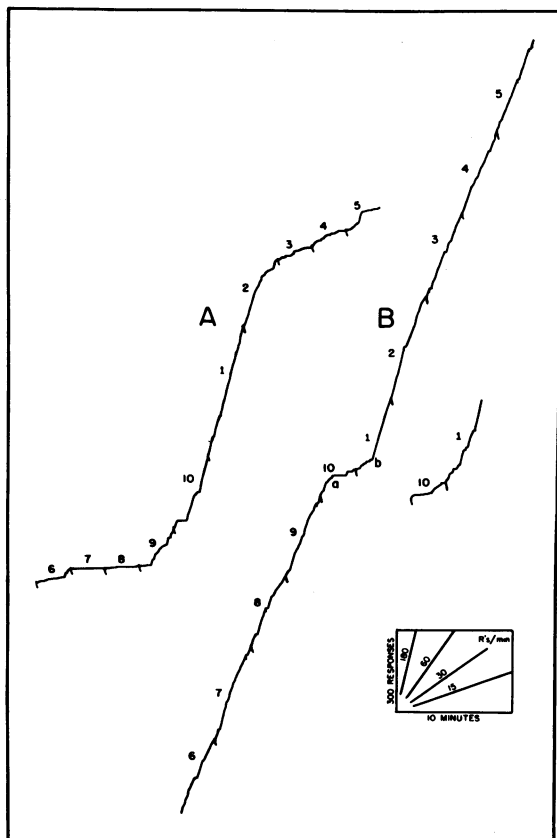

Fig. 3. Composite cumulative records showing the responding of Pigeon 88 in each decant (numbers on the record) when responding was reinforced in only decants 10 and 1 (A), and the responding of Pigeon 33 in each decant when responding was extinguished in only decants 10 and 1 (B).

Extinguishing in decants 10 and 1 and reinforcing elsewhere produced a decrease in the rate of responding in decants 10 and 1 and, generally, an increase in responding in the other decants (right-hand graphs of Fig. 2). The increases and decreases are assessed relative to the rate of responding subsequently maintained by reinforcement in each decant (open circles).

A rearranged cumulative record (Pigeon 33, Fig. 3B) shows the decline in rate in extinction in decant 10 and the early part of decant 1. An asymmetry appears in the effects of extinction (Fig. 2) because the

rate of responding always increased toward the end of decant 1. Smaller class intervals in Fig. 2 would have correctly represented the acceleration of responding in decant 1; but since the increase in responding typically occurred earlier in decant 1 (*b* in Fig. 3B) than the decrease due to extinction occurred in decant
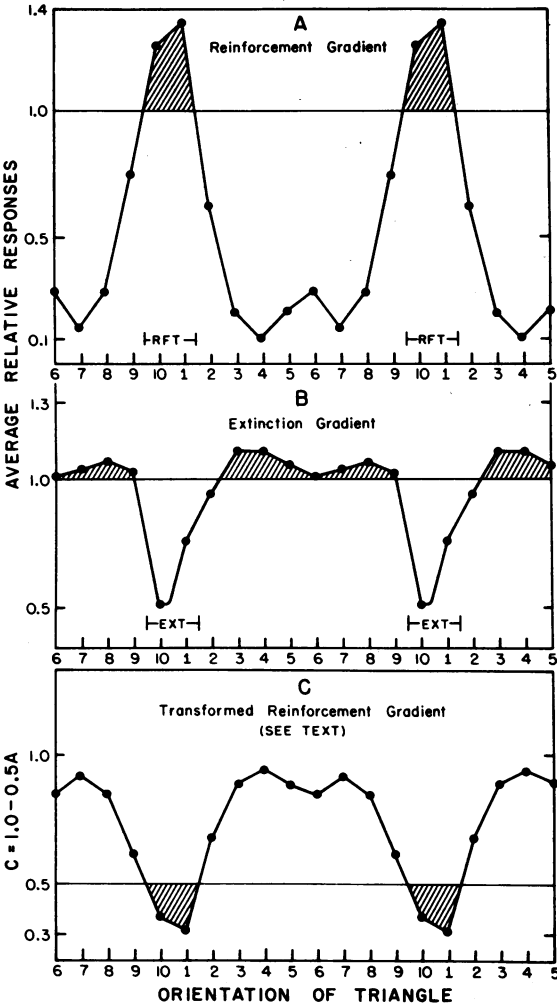

Fig. 4. The average (for four pigeons) relative responses in each decant for reinforcement (A) or extinction (B) in only decants 10 and 1. The ordinates are ratios relative to the median responding when all 10 decants were correlated with reinforcement. The crosshatched areas emphasize the increases over the control rates of responding. The function in C is a transformation of the function in A. (See text.)

10 (*a* in Fig. 3B), the effect of extinction is nevertheless asymmetrical.

The rate of responding is higher the farther the decant is from 10 and 1, except that the rate is often lower in decants 5 and 6 than in decants 4 and 7. These reversals may be compared with the increases

in responding in decants 5 and 6 when responding is reinforced in decants 10 and 1.

The results have been summarized by averaging across birds the frequency of responding in each decant relative to the median number of responses during the base lines (open circles in Fig. 2). These base lines appear in Fig. 4A and 4B as the horizontal lines at 1.0. The data from reinforcement in decants 10 and 1 after the introduction of time outs have not been summarized because, as indicated, their appropriate base line is in doubt. Figure 4A shows the average relative frequency of responding in each decant when responding was extinguished in all decants except 10 and 1. Figure 4B shows the effects of extinguishing responding only in decants 10 and 1. On the basis of the cumulative record of responding in Fig. 3B, a smooth curve connects the points of decants 10 and 1 in Fig. 4B. Each graph shows the same data plotted twice so that the changes in responding in decants 5 and 6 as well as those in decants 10 and 1 can be examined more easily. The crosshatched areas in each graph emphasize the location of the increases in the rate of responding over the rate supported by reinforcement in all decants.

DISCUSSION

The generalization gradient produced by reinforcement during the presentation of two of the ten decants may be compared with the gradient produced by extinction during only two decants (or, equivalently, reinforcement during eight decants). In each gradient, the rate of responding increases during the presentation of the two or eight decants correlated with reinforcement and decreases during the eight or two decants correlated with extinction (Fig. 4A and 4B, respectively). The magnitude of the increases and decreases in each gradient can be measured against their respective base lines and compared. This comparison shows that the increase in rate per decant of reinforced responding is greater when responding is reinforced in only two decants (Fig. 4A) than when it is reinforced in eight decants (Fig. 4B). Also, the decrease in responding during extinction is greater when responding is extinguished in eight rather than in two decants. The *rate* of decline of responding as the triangle rotates through the decants correlated with extinction, however, shows no consistent difference between the two procedures (Fig. 2).

In order to compare directly the shapes of the two gradients, the reinforcement gradient (Fig. 4A) has been halved and inverted in Fig. 4C. Each ordinate in Fig. 4C is equal to 1.0 minus one-half the corresponding ordinate in Fig. 4A. The factor one-half was chosen because the maximum rate difference produced by extinction in two decants (Fig. 2B) is almost exactly one-half the maximum difference with reinforcement in two decants (Fig. 2A). The close congruence of the ranges of the functions in 4B and 4C reinforces this choice.

Comparing the extinction gradient (Fig. 4B) with the transformed reinforcement gradient (Fig. 4C) shows directly that the reinforcement gradient is broader. The broadness is mainly produced by the increase in responding in decant 9 of the reinforcement gradient (a decrease in Fig. 4C), which is relatively greater than the decrease in responding in decant 9 of the extinction gradient. Also, with reinforcement, the rate in decant 1 remains high (or low in 4C), whereas with extinction the rate increases in decant 1. Both the increase in decant 9 of the reinforcement gradient and the increase in decant 1 of the extinction gradient may be partly maintained by reinforcement in the next decant as in a chained schedule of reinforcement.

The comparison also reveals a remarkably close inverse relation between the effects of these two procedures on responding in decants 5 and 6.

In summary, the effects of reinforcing in two decants appear to be about twice as great in magnitude as the effects of extinguishing in two decants. The generalization gradient for reinforcement is broader than the gradient for extinction, and an inverse relation holds between the effects of these two procedures on responding in decants 5 and 6. (These conclusions also apply to the reinforcement gradients with interspersed time outs, shown by the triangles in Fig. 2.)

In the steady state, there is more generalization to decants 5 and 6—the triangle inverted from its position during reinforcement—than to decants 4 and 7. Since the procedure does not differentially reinforce responding in decants 5 and 6, the increase in rate there presumably indicates one characteristic of the pigeon's perception of isosceles triangles.

After about 80 hours of extinction in only decants 10 and 1, the rate of reinforced responding is generally below the base line in decant 2; it increases in decants 3 and 4, and starts to decline in decant 9. There is also less responding in decants 5 and 6 than in decants 4 and 7 (Fig. 4B). I have called the decreases in responding in decants 2, 5, 6, and 9 generalization on the basis of an analogy to the generalized increases in reinforced responding, which occur in the same decants. It is important to notice, however, that the generalized decreases in rate in decants 5, 6, and 9 are also increases relative to the base line (hatched area in Fig. 4B). This latter fact illustrates that the effects of extinction during discrimination are not exclusively inhibitory.

The hatched areas (Fig. 4) are examples of behavioral contrast, which is a second, excitatory effect of extinction. Some recent experiments (Reynolds, 1961) suggest that the magnitude of behavioral contrast is an increasing function of the relative frequency of reinforcement correlated with that stimulus. This notion is not contradicted by the present data. The relative frequency of reinforcement in each decant (stimulus) is 0.10 when responding is reinforced in all ten decants. When responding is reinforced in two decants, the relative frequency of reinforcement is 0.50 in each reinforced decant. When responding is reinforced in eight decants, the relative frequency of reinforcement is 0.125 in each reinforced decant. The corresponding average relative increases in responding per decant are on the order of 0.30 and 0.10, respectively (Fig. 4B). A greater relative frequency of reinforcement per decant produces a greater increase in responding relative to the base line. Once again, a simple notion of inhibitory generalization is inadequate since the increase in responding is greater the greater the percentage of the continuum over which responding is extinguished.

A combination of the two effects of extinction—inhibition in decants 2 and 9 (rate decreases) and contrast in decants 3 and 8 (rate increases) —determines the position of the modes of the distribution of responding in the maintained generalization gradient for extinction (Fig. 4B). The modes fall in decants 3 and 8 rather than at the ends of the range correlated with reinforcement. Hanson's (1959) postdiscrimination "peak-shift" may also be brought about by the combined effect of inhibition and contrast.

The preceding facts mean, of course, that a gradient of extinction containing only inhibitory response decrements is not an adequate description of the effects of extinction during discrimination. A more complete account includes contrast. Historically, contrast was recognized by Pavlov (who called it "positive induction," Lecture XI, 1927); but it disappeared from theoretical consideration after Spence (1936) postulated that the generalized effects of extinction were exclusively negative. This error of omission might have been rectified early. In his classical study of frequency generalization, Hovland (1937) showed that discrimination training produces an over-all increase in the magnitude of responding (GSR) in the generalization gradient, relative to the gradient after reinforcing only one stimulus. But, failing to realize the significance of the change in *absolute* level or attributing it to additional training, he recognized only the increased steepness of the postdiscrimination gradient.

It now seems clear that contrast occurs during discrimination, but it is still moot whether discrimination is its necessary condition. Perhaps continuous extinction in one, isolated stimulus also produces contrast, but it has not been detected in subsequent generalization gradients because these have been obtained in extinction. This is plausible, since the base line against which the effects of extinction in one stimulus should be measured is the rate produced when reinforcement is correlated with each stimulus of the continuum, and the magnitude of this base line would also decline in extinction during the generalization test. As a result, what have been called decrements due to extinction might actually be increments relative to this decreased base line. If this were true, then the gradient for extinction would have negative values centered around the extinguished stimulus and positive values some distance from it (somewhat like Fig. 4B here). This type of extinction gradient would

combine with the usual generalization gradient for reinforcement to produce the typical postdiscrimination gradient. But, on the other hand, since the magnitude of contrast is related to the relative frequency of reinforcement in one of two stimuli (see above), it now appears more likely that a necessary condition for contrast is differential reinforcement or discrimination, although not necessarily extinction (Guttman, 1959; Reynolds, 1961). Once generated, contrast combines with gradients of reinforcement and extinction to determine the postdiscrimination gradient.

SUMMARY

A pigeon pecked at a transparent response key behind which an isosceles triangle slowly rotated in a plane perpendicular to the pigeon's line of sight. When pecking was reinforced on a VI 90-second schedule regardless of the orientation of the triangle, the rate of responding was reasonably constant during all orientations. When responding was reinforced only when the apex of the triangle pointed in the uppermost 72 degrees, and was extinguished when the apex lay elsewhere, the rate of responding increased during the presentation of the orientations still correlated with reinforcement and decreased when the apex rotated away from the uppermost 72 degrees. When responding was extinguished in only the uppermost 72 degrees and reinforced elsewhere, the changes in responding were nearly the inverse except that they were about one-half as great in magnitude.

REFERENCES

Ferster, C. B., and Skinner, B. F. *Schedules of reinforcement.* New York: Appleton-Century-Crofts, 1957.

Hanson, H. M. Effects of discrimination training on stimulus generalization. *J. exp. Psychol.,* 1959, **58,** 321-334.

Guttman, N. Generalization gradients around stimuli associated with different reinforcement schedules. *J. exp. Psychol.,* 1959, **58,** 335-340.

Honig, W. K., Thomas, D. R., and Guttman, N. Differential effects of continuous extinction and discrimination training on the generalization gradient. *J. exp. Psychol.,* 1959, **58,** 145-152.

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.

Pavlov, I. P. *Conditioned reflexes.* Trans. Anrep, Oxford, 1927.

Pierrel, R. A generalization gradient for auditory intensity in the rat. *J. exp. Anal. Behav.,* 1958, **1,** 303-315.

Reynolds, G. S. Behavioral contrast. *J. exp. Anal. Behav.,* 1961, **4,** 57-71.

Reynolds, G. S. Relativity of response rate and reinforcement frequency in a multiple schedule. *J. exp. Anal. Behav.,* 1961, **4,** 179-184.

Spence, K. The nature of discrimination training in animals. *Psychol. Rev.,* 1936, **43,** 427-449.