GENERALIZATION AND PREFERENCE ON A STIMULUS-INTENSITY CONTINUUM

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The research reported here was suggested by a study of Guttman and Kalish (1956) on wavelength generalization in the pigeon, the first of several important papers on generalization by these authors and their students. Guttman and Kalish pointed out that the stimuli of various wavelengths which they used were not equated in intensity, or, alternatively, in visibility. What contribution might brightness changes have made to their results? The intensity of light from a standard monochromator characteristically increases with wavelength across the visible spectrum. The corresponding visibility, for humans, first increases and then falls with increasing wavelength. Together, these variables make the blues from an uncorrected system look relatively dim to the human observer, the yellows relatively bright. A corresponding change presumably occurs for the pigeon, since the sensitivity of its eye varies in much the same way as that of the human eye over the range of stimuli used by Guttman and Kalish (Blough, 1957).

Stimulus generalization along intensity continua and the problem of response strength as a function of stimulus intensity are topics of considerable interest in their own right. For example, Hull's "stimulus intensity dynamism" (Hull, 1952) suggests that pigeons might tend to peck faster as a stimulus light gets brighter, apart from previous training at any particular intensity. The experiments reported here supply additional data relating response rate to stimulus intensity.

METHOD

Subjects

Ten male domestic pigeons (White Carneaux) were used. The birds were maintained at approximately 65% of their free-feeding weights. None had any prior experimental history.

Apparatus

Experimental chamber. The pigeons worked in a ventilated, light-tight aluminum picnic icebox. The walls of the bird's chamber were painted flat black. The pigeon pecked the surface of a circular metal response key 1 inch in diameter. The stimulus light appeared in the center of this key through a circular aperture 1 millimeter in diameter. A solenoid-operated food magazine was located below the response key. When it operated, this magazine was illuminated by a 6-watt panel lamp shining through a Corning No. 5543 Lantern Blue filter. The walls of the magazine had a luminance of approximately 1 millilambert, as determined by heterochromatic matching with a Macbeth illuminometer. A loud-speaker in the box supplied white masking noise. Each peck on the response key produced a sharp click from a relay in the box.

Stimulus source and control. A strip filament lamp, run on stabilized voltage, supplied light for the stimulus. Light passed from the lamp to the stimulus patch through a lens system, a circular optical wedge, and a red Corning filter (No. 2424) with a 50% cutoff at

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about 610 millimicrons. An image of the lamp filament appeared on a milk-plastic strip that formed the back of the response key. This image illuminated the aperture that formed the stimulus patch.

The neutral-density optical wedge controlled the intensity of the stimulus patch. A silent Bodine motor rotated the wedge to any of 11 predetermined positions. These 11 positions produced 11 stimulus intensities equally spaced over a range of 3.6 log units², so that a series resulted with each stimulus slightly more than twice as intense as the stimulus one step down. Heterochromatic calibration with the Macbeth illuminometer placed the range of stimulus luminance from about 0.14 millilambert at the low extreme to about 820 millilamberts at the high extreme.

Experiment I: Training Procedure

Each of the six birds was trained to peck the response key at a single stimulus intensity. Two birds were trained on the third, two on the sixth, and two on the ninth most intense stimulus. The stimulus was on at all times during the training sessions. The box was open to room light briefly at the beginning of the first training session. Otherwise, the stimulus supplied the only light in the box except that from the food-magazine lamp during reinforcement. The bird was dark-adapted in another box for at least 5 minutes prior to each session after the first. Other work (Blough, 1956) has indicated that this adaptation was sufficient to bring the photopic threshold to a stable level.

For initial training, the bird was placed in the open box and the food magazine was raised within reach. While the bird was eating from the magazine, the room lights were extinguished and the box was partially closed. After magazine training was completed in the darkened box, key training commenced. In several cases the bird gave the lighted stimulus a peck without prompting, was reinforced, and continued to peck the key. In other cases, some approximation training was necessary. *E* worked as best he could by light from the stimulus. After the bird had pecked the key and received food, each of the next 60 pecks produced a 4-second reinforcement.

In subsequent sessions, dark-adapted birds were shut immediately in the experimental box. Over a period of seven sessions, they received reinforcement according to the following schedules: VI 30 seconds (45 minutes); VI 1 minute-VR 5.5 (1 hour); VI 2 minutes-VR 5.5 (2 hours); VI 4 minutes (2 hours); VI 9 minutes (6 hours). During this time, the duration of an individual reinforcement was raised from 4 to 5 seconds, and then from 8 to 12 seconds. At the end of this training period, all the birds were responding at a fairly regular rate on the 9-minute, variable-interval schedule.

Experiment I: Generalization Procedure.

Responses at all 11 stimulus intensities were recorded in repeated generalization sessions. Each session began with a 10-minute exposure of the training stimulus. During this time the bird received four 12-second reinforcements on a variable-interval schedule. Reinforcement then ceased for the remainder of the session. The stimulus changed rapidly to its most intense or least intense extreme (different for each of the two birds with a common training intensity). From this extreme, the intensity moved step by step to the opposite extreme, stopping at each intensity for 30 seconds. Then, the stimulus changed in the reverse direction, stopping at each intensity of 30 seconds. This gradual oscillation between the stimulus

²The intensity values were based on the optical density of the wedge at 600 millimicrons. The calibration of the wedge has been described in a previous paper (Blough, 1957).

extremes continued until each intensity had been presented 12 times. The bird was then removed from the box. At no time did the stimulus disappear entirely. A counter recorded the number of pecks given at each intensity.

Each pigeon received eight generalization sessions.³ Alternating with these sessions were 2-hour reconditioning periods. During reconditioning, the bird was reinforced on a VI 9 minutes at its training stimulus.

Experiment I: Results and Discussion.

Figure 1 shows cumulative-response records from the first generalization sessions of two birds. These records were collected as the stimulus varied periodically between "bright" and "dim" extremes. These extremes are marked by the displacement of the pen recording

Figure 1. Cumulative-response records of two birds during their first generalization sessions. The intensity of the stimulus varied up and down in a step-wise fashion. The high-and-low-intensity extremes are indicated by displacements in the cumulative curves. Arrows indicate the point at which the stimulus intensity had the same value as the intensity used during the bird's training sessions.

the responses. Bird 325 produced the upper curve. It had been trained to peck at a stimulus midway in the intensity range and had never before seen the other intensities. Arrows indicate the point on the curve at which the stimulus assumed the intensity that had previously been reinforced. The S-shaped segments of this record indicate that the bird pecked most rapidly near the training intensity, and progressively less rapidly toward the extreme stimuli. Bird 057 was trained to peck on a stimulus of low intensity, designated by the arrows in the lower curve of Fig. 1. The record shows that in this case the bird pecked most rapidly at the dim stimuli and stopped pecking altogether at the brightest stimuli.

³The effects of drugs—scopolamine, pentobarbital—were recorded on the 4th, 5th, and 7th sessions. Data from these sessions are not reported here.

Generalization curves for all six birds appear in Fig. 2. These curves were derived from raw data such as those shown in Fig. 1 in the following way. For each session, the number of responses made at each intensity was divided by the total number of responses made during the session. The resulting percentages were then averaged over five test sessions for each bird. No systematic differences were noted between data from early and later test sessions, except in Birds 037 and 057. These birds, trained at a low intensity, yielded somewhat flatter functions in the first sessions than on subsequent days. The range of values averaged at each point in Fig. 2 is indicated by the dashed lines.

Figure 2 clearly shows that response rates changed substantially and systematically when the stimulus intensity departed from its original value. The pairs of birds trained at a common intensity showed a high degree of agreement. What generality have the functions? Do they represent "the" intensity generalization curve? Several points deserve comment in this regard.

It is possible that the serial (up-down) order of stimulus presentation affected the form of the curves. Data bearing on this question were collected during each bird's first three test sessions. Responses made when the stimulus was getting brighter ("up" series) were recorded separately from responses made when the stimulus was getting dimmer ("down" series). Mean "up" and "down" curves during these sessions are shown in Fig. 3. The only consistent effect to be seen is that in all six birds, the "down" curve is shifted to the right (brighter) end of the stimulus continuum with respect to the "up" curve. The means and medians of all the pairs of functions show this difference. The shift is very slight in birds trained at low intensities, and it is most evident in the birds trained at high intensities, Bird 338 in particular.

Such a shift may be accounted for in at least two ways. A sensory contrast or adaptation interpretation implies that "down" stimuli look relatively dim because each follows a brighter stimulus, and, similarly, "up" stimuli look relatively bright. A behavioral interpretation rests on the operant equivalent of Pavlov's principle of "induction."⁴ According to this principle, relatively more responses would tend to follow a stimulus correlated with low response rates, and relatively fewer responses following a stimulus correlated with high rates. Both this "behavioral contrast" and the "sensory contrast" just noted would tend to shift the "down" curves to the right and the "up" curves to the left.

A second comment on the curves concerns their continuous, rounded form. Most authors have favored a discontinuous function, one coming to a sharp point at the training stimulus, as the proper expression of the generalization gradient. It might be possible to reconcile the present data with this notion. For example, the rounded curves in Fig. 2 might be said to result from variability around a sharply pointed "underlying" function. However, data from several individual sessions are consistent enough to reveal that the "rounded" curve for the entire session was the sum of 12 small "rounded" curves, one from each series of stimuli presented during the session, and that the total curve did not suffer from an "averaging" effect. It seems more likely that if the rounded shape was in any sense an artifact, it arose from a variation of the effective stimulus luminance during training. A flattened peak would be expected if the bird had been reinforced over a range of stimulus in-

⁴Pavlov, 1927. This is not the same as the "induction" of B. F. Skinner. The latter corresponds to Pavlov's "generalization." For Pavlov, "induction" and "generalization" refer to different phenomena. The distinction is useful, and it is followed in this paper. Instances of induction, in Pavlov's sense, are often seen in operant data. Skinner's "compensatory rate" (Ferster & Skinner, 1957, p. 724) is a closely related concept.

Figure 2. Generalization functions for six individual birds. Means of data from five sessions appear, and the dashed lines indicate the range of the individual sessions. The intensity continuum is the same for all birds. Arrows indicate the intensity on which the bird was trained.

Figure 3. Generalization functions for six individual birds. Means of data from the first three sessions appear. Responses made when the stimulus intensity was increasing step by step contribute to one set of curves (black dots). Responses made when the stimulus intensity was decreasing contribute to the other set (open circles). Arrows indicate the training-stimulus intensity.

tensities, rather than at a single intensity. This might have happened, in effect. To a human observer, a stimulus light at onset looks relatively bright, but fades when steadily fixated. If, as seems likely, an analogous change occurs with the pigeon, the training stimulus might effectively have varied somewhat in luminance, as the bird sometimes fixated the light and sometimes looked away.

A third comment on the shape of the curves has to do with the method of plotting. The form of a generalization gradient can always be changed by changing units along the abscissa. A common transformation applied to generalization data is to change from physical to jnd units.⁵ A transformation based on the human jnd for brightness collapses the curves in Fig. 2 at the left end. This tends to make the middle two curves in Fig. 2 (Birds 325 and 044) more symmetrical, but it cannot correct the shifted peak that appears in each of these curves.

Still other variables should be kept in mind. The birds in this experiment were maintained at about 65% of their free-feeding weights. Thomas and King (1959) found that pigeons under such high deprivation tended to produce rather flat gradients along the wavelength continuum. Unpublished work by the present writer, also on wavelength, suggests further that a small-point stimulus may favor a flatter function than a larger stimulus disc. Such variables could, of course, have corresponding effects on the jnd. These results suggest that a large range of factors may restrict the generality of empirical generalization functions, including the present ones.

The present results bear on generalization data collected over a wavelength continuum, when luminance is not controlled. The luminance of a stimulus system that has been used by the present writer would, if uncorrected, increase 0.8 log unit upon a change of wavelength from 490 to 570 millimicrons. The present results suggest that such a luminance change might in itself cause a considerable variation in response rate.

A final important point remains. Any generalization function may be affected by a stimulus "preference"; that is, the response may vary as the stimulus changes, without regard to the training stimulus that is used. Hull's "stimulus intensity dynamism" (Hull, 1952) implies such a preference. There is no evidence for this "dynamism" in the present data, for there is no indication that higher intensities produce higher rates. This finding agrees with recent results of Pierrel (1958) for auditory intensity. However, other kinds of intensity preference are not ruled out. Experiment II deals with this problem.

Experiment II: Training Procedure

Four birds received equal reinforcement for pecking at each of the 11 stimulus intensities. The procedure on the first day was identical to that described in Experiment I, except that the stimulus intensity continually moved back and forth across its entire range while the bird was in the box, until the bird made its first key-peck. Then, the stimulus moved up and down in a step-wise fashion as in the generalization procedure described above, except that the intensity changed if, and only if, the bird obtained a reinforcement. Including its first reinforced peck, the bird received 77 continuous reinforcements over its first and the initial part of its second sessions. Thus, it was exposed to and reinforced for pecking each stimulus seven times.

⁵This transformation usually implies a theoretical stand on the relationship of discriminability along a stimulus dimension and generalization along that dimension. Data are lacking in the present case, and no particular stand is implied in this discussion. For a treatment of this problem on the wavelength dimension, see Guttman and Kalish, 1956.

Experiment II: Testing Procedure

After the bird had received 77 reinforcements for 77 pecks, 7 at each intensity, the reinforcement schedule was altered. This occurred during the second experimental session. Two birds started at the lowest intensity, and two at the highest. The stimulus remained at a given intensity for 1 minute, during which no reinforcement was given. The next peck after 1 minute brought reinforcement; and, while the bird was eating, the stimulus moved to the next intensity, up or down. This procedure continued for 77 reinforcements. The bird pecked at each intensity a total of 7 minutes, and was reinforced seven times at each on FI 1 minute. Counters recorded the number of pecks at each intensity during this time.

Experiment II: Results and Discussion

Each bird received 7 presentations of each of the 11 test stimuli during its test session. Since response rate is often variable upon first presentation of FI following continuous reinforcement (Ferster & Skinner, 1957), data from the first presentation of each stimulus were omitted, and curves were constructed from the remaining six presentations of each intensity given each bird. The results for each of the four birds are plotted in Fig. 3. The response rates in the lower-middle region of the intensity range are generally higher than elsewhere. For each bird, more responses are given over the lower half of the range than over the upper, and the birds' maximum response rates fall, respectively, at step 3 (two birds), step 4, and step 5 of the 11-step intensity scale.

This preference for the lower-middle intensities may account in some measure for the asymmetry noted in the data of Experiment I. On the other hand, a student of theory might suggest that the preference for lower-middle intensities is a consequence of the asymmetrical form of the generalization gradient. To illustrate this argument, a generalization gradient is erected around each of the reinforced stimuli of Experiment II. This has been done at the bottom of Fig. 5, using the very consistent data of Bird 325 (Fig. 2) as the prototype gradient. The gradient has been extrapolated at either end where necessary. Simple addition of these gradients (Hull, 1943) yields the theoretical preference curve shown at the top of the figure. The theoretical curve has been multiplied by an appropriate constant to fit it to the mean empirical preference data. The two curves correspond well enough to arouse some interest, although whether this sort of theoretical construction has more than parlor-game significance remains to be seen. Kalish and Guttman (1959) have not substantiated Hull's summation hypothesis on the wavelength continuum.

Figure 4. Intensity preference functions for four birds. The data are from a single session with each bird. The birds received equal reinforcement at all intensities.

Figure 5. Observed and theoretical preference curves compared. The empirical curve is the mean of data appearing in Fig. 4. The theoretical curve represents the sum of 11 individual generalization gradients, one at each reinforced stimulus. These gradients (bottom of figure) are all identical with the curve of Bird 325 (Fig. 2).

Other possible sources of a stimulus preference may come to mind. In this connection it may be relevant that the luminances of the food magazine and of the home cages were somewhere within the preferred range. However, perhaps there is some question whether these other stimulus situations would generalize to the pecking of a tiny red point of light.

Appendix on Method

The procedure followed in the present experiment differs in some particulars from that used in wavelength generalization studies with pigeons (e.g., Guttman & Kalish, 1956). The differences arise largely from problems peculiar to the use of intensity as a stimulus dimension. The reasons for some of the differences are touched upon here.

Red Stimulus Patch of Relatively High Intensity. An attempt was made to restrict the stimulus to photopic vision. A homogeneous continuum where difference limens would probably be relatively small seemed a desirable feature. Nonetheless, the lowest stimulus intensities possibly had some scotopic effect. This may have something to do with the shape of the generalization functions at the low end of the intensity scale.

Stimulus Always On, No "Blackout." This feature was designed to give the birds the least possible opportunity to form a discrimination between a dark and a lighted response key. As Logan (1954) and others have pointed out, such a discrimination may be the basis for a spurious "intensity dynamism." Because of the nature of the apparatus, this feature made it necessary to present the stimuli in serial "up-down" fashion.

Dim Blue Magazine Light. This was intended to minimize generalization between the stimulus and the magazine light.

Small-point Stimulus. As well as reducing generalization to other stimuli, this was intended to restrict the effective stimulus to the key. Even so, at its highest intensities the stimulus illuminated the box to some extent.

Use of Long (9-minutes) Variable-interval Schedule. The major reason for this feature was the desirability of collecting enough data from each bird so that significant generalization functions could be plotted for individual birds. A long variable-interval schedule favors the emission of many responses in extinction. It also appears to retard the formation of stimulus discriminations. This may be one reason why so many reconditioning and test sessions could be run with the birds without appreciable changes in the generalization functions.

High level of Deprivation (65% Free-feeding Weight). With stimulus and reinforcement conditions far from ideal (dark box, blue magazine light, long VI), it was thought that difficulty might be encountered unless high deprivation was used. The results of Thomas and King (1959), which showed flatter wavelength generalization functions with high deprivation, should be kept in mind.

Brief Testing in Experiment II. The irregular curves in Fig. 4 indicate that the variability of data from individual birds has not been reduced to a satisfactory level in Experiment II. Why not improve this situation by collecting more preference data from each bird? A difficulty arises here that has not yet been overcome. The "sensory superstition" observed by Morse and Skinner (1957) interferes. When reinforcement is continued in the presence of several stimuli, response-rate differences tend to become superstitiously associated with the different stimuli. Hence, "preference" data can be obtained only during the birds' first exposures to the stimuli.

SUMMARY

Pigeons pecked at a small, red stimulus patch. Six birds (Experiment I) were trained on single stimulus intensities, four birds (Experiment II) were reinforced at all stimulus intensities. Responses of all birds were subsequently recorded at 11 stimulus intensities, spanning a range of 3.6 log units. Generalization functions were based on the number of responses given at each stimulus intensity.

The principal findings were as follows:

1. Birds trained at single intensities produced consistent generalization functions around the training stimulus. These functions were continuous and rounded at their modes. Asymmetry and displacement of the mode from the training stimulus were noted, although there was no evidence of any preference for high intensities.
2. Birds reinforced at all intensities gave a relatively large number of responses in the lower-middle intensity range. This intensity preference may account to some extent for the shape of the generalization curves following training at a single stimulus. It is possible to argue, on the contrary, that the observed preference may derive from a summation of generalization functions around the several stimuli.

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