PEAK SHIFT AS A FUNCTION OF MULTIPLE SCHEDULES OF REINFORCEMENT¹

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Pigeons were trained to respond to two stimuli on the wavelength continuum, 550 nm and 570 nm, each correlated with an independent schedule of reinforcement. The multiple schedule component in effect during 550 nm (S1) was always a variable-interval 1-min. During the 570-nm stimulus (S2) the second component of the schedule was either variable-interval 30-sec, 1-min, 2-min, 5-min, or extinction for different groups of birds. Generalization gradients were obtained after this training, with the following results: (1) response rate to S1 during training was related to the reinforcement frequency associated with S2; the distribution of responding during generalization testing was a function of the schedules of reinforcement used during training and the response rates they produced. Decreases in the relative frequency of reinforcement correlated with S2 resulted in increases in the distribution shift of responses away from S2 during generalization testing.

The present experiment sought to extend Guttman's (1959) conclusion that an ordinarily positive stimulus can take on negative qualities when a frame of reference is provided by another stimulus and reinforcement schedule. In Guttman's (1959) experiment, pigeons were trained on a multiple variable-interval 1-min variable-interval 5-min (*mult VI 1-min VI 5-min*) schedule of reinforcement to 550-nm and 570-nm stimuli respectively. During generalization testing, the stimulus to which the maximum responding occurred shifted away from both 550 and 570 nm (peak shift). These results are interpreted as indicating that the stimulus associated with the lower frequency of reinforcement (570 nm) is negative relative to the stimulus with the higher frequency of reinforcement (550 nm). Since 570 nm becomes negative relative to 550 nm, maximum responding during generalization testing shifts away (peak shift) from 570 nm.

If a stimulus associated with a low reinforcement frequency does become functionally negative relative to a stimulus associated with a higher frequency of reinforcement,

then the degree to which this former stimulus takes on these negative qualities should be a function of the relative difference between the reinforcement schedules associated with the two stimuli, or, as Terrace (1968) suggested, the change in response rates maintained by the two schedules relative to the baseline rates of response. Amount of peak shift should be a measure of the degree of these assumed negative qualities. Thus, for example, subjects trained on a *mult VI 1-min VI 5-min* schedule should show peak shift in their postdiscrimination gradients but not as much shift as subjects trained on a *mult VI 1-min EXT* schedule. This study was designed to determine if amount of peak shift is a function of the relative differences between the reinforcement schedules in effect during discrimination training.

METHOD

Subjects

Thirty experimentally naive male White Carneaux pigeons, six months to 2 yr of age, were maintained at 80% of their free-feeding weights.

Apparatus

The apparatus consisted of a 30.5 by 30.5 by 38.1 cm experimental chamber with a 5.1-cm square grain magazine located on one wall 9.5 cm above the floor. The chamber was lo-

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cated within a ventilated refrigerator shell and illuminated during stimulus presentations by a white houselight located overhead and by the colored light projected onto the key. The key, 2.5 cm in diameter, was located 7.6 cm above the food magazine, and could be illuminated by nine different wavelengths with nominal values ranging from 510 to 590 nm in 10-nm steps. The actual values of these filters were 514, 519, 529, 538, 549, 558, 574, 584, and 595 nm. Peak transmittance varied from 35 to 47%, and half widths were either 8 or 10 nm. For ease of presentation, filters will be referred to by their nominal values.

The light source was a Bausch and Lomb Nicholas microscope illuminator. Second-order interference filters in the path of the light determined the wavelength projected onto the key. The light also passed through a collimating lens and a Corning K-2 auxiliary filter that removed the side bands in the ultraviolet region. Intensities of the nine different stimuli were not equated. Stimulus presentations, timeouts, and reinforcement were automatically scheduled with switching devices commonly employed in operant conditioning studies.

Pretraining procedure. All subjects were magazine trained, trained to key peck by successive approximations, and given 40 continuous reinforcements on the first day. The wavelength projected onto the key during this training was 550 nm.

Discrimination training procedure. Discrimination training began on the second day and continued for 15 days. Two stimuli (550 nm and 570 nm) were employed and each was correlated with an independent schedule of reinforcement. The 550-nm stimulus (S1) was always correlated with a VI 1-min schedule of reinforcement. The schedule correlated with the 570-nm stimulus (S2) was either VI 30-sec, VI 1-min, VI 2-min, VI 5-min, or extinction for different groups of subjects. Thus, the following five multiple schedules were employed, with six subjects trained on each: *mult* VI 1-min VI 30-sec, *mult* VI 1-min VI 1-min, *mult* VI 1-min VI 2-min, *mult* VI 1-min VI 5-min, and *mult* VI 1-min EXT.

Each training session consisted of five 3-min presentations of 550 nm and five 3-min presentations of 570 nm presented in a mixed order each day, with the restriction that neither stimulus appear more than three times

in succession. Each 3-min period was followed by a 10-sec timeout, during which the key was not lighted, no responses were recorded, and the VI programmers were inoperative. The houselight remained on during timeout. Reinforcement consisted of 4-sec access to mixed grain. Total session responses to each stimulus were recorded.

Testing procedure. On the day following the last day of discrimination training, all subjects were given a brief warmup period and a generalization test. The warmup consisted of two 3-min presentations of each of the two training stimuli in the following order: 550 nm, 570 nm, 570 nm, 550 nm. The reinforcement schedules were the same as in training. Immediately after warmup, extinction was begun and a generalization test was administered that consisted of the presentation of the nine different wavelengths (510, 520, 530, 540, 550, 560, 570, 580, and 590 nm for 30-sec periods with a 10-sec timeout between each presentation. There were nine presentations of each of the stimuli for a total of 81 presentations during generalization testing. Stimuli were presented in nine successive blocks such that each block included each of the nine stimuli in a different order. The use of two orders, each given to half of the subjects, enabled balancing for sequence effects. Orders were determined by orthogonal Latin Squares. The number of responses to each stimulus presentation was recorded.

RESULTS

Discrimination training. Figure 1 summarizes the course of discrimination training for the five different multiple schedules. Each panel presents the average response rates, corrected for reinforcement time, in the presence of 550 nm and 570 nm for the six subjects trained on each schedule. An analysis of variance was computed on the mean response rate to 550 nm (VI 1-min) for the last five days of discrimination training, with days and schedule as the variables. There was a significant schedule difference in response rate ($F = 4.44$, $df = 4/25$, $p < 0.01$) and a significant difference in response rate over days ($F = 7.17$, $df = 4/100$, $p < 0.01$). The test for interaction between schedules and days was not significant ($F = 1.11$, $df = 16/100$). Although a significant overall difference in

Fig. 1. Mean responses per minute during each component of the multiple schedule for the 15 days of discrimination training. The values plotted for each multiple schedule are the averages for the six birds on each schedule.

response rate in the presence of 550 nm occurred among schedules, with response rate increasing as the relative frequency of reinforcement correlated with 550 nm increased,

the mean rates were not significantly different between *mult* VI 1-min VI 1-min and *mult* VI 1-min VI 2-min or between *mult* VI 1-min VI 5-min and *mult* VI 1-min EXT.

The significant days factor indicates that the subjects had not reached asymptotic performance, in the presence of 550 nm over the last five days, if this measure were to be used as the criterion. However, evidence of stabilization is shown by the mean percentage of the total responding to 550 nm during the last five days of training. An analysis of variance of these data found a significant schedules difference ($F = 119.20$, $df = 4/25$, $p < 0.01$) but no difference over days and no significant interaction ($F < 1.00$ for both effects).

Figure 2 summarizes the final average rates of responding to 550 nm and 570 nm in relation to the frequency of reinforcement correlated with 550 nm relative to 570 nm.

Fig. 2. Mean response rate for the last five days of discrimination training plotted as a function of the relative frequency of reinforcement correlated with S1 (550 nm).

Results indicate that as relative reinforcement to 550 nm increased, absolute response rate increased to 550 nm and decreased to 570 nm. This is indirect evidence for behavioral contrast, defined as a change in the rate of responding in the presence of one stimulus (S1) resulting from a change in the schedule associated with another stimulus (S2).

In the usual behavioral-contrast experiment, a baseline of responding to S1 and S2 is established with nondifferential reinforcement. Contrast is then assessed by changes in the rate of response to S1 when the schedule associ-

ated with S2 is changed. Since the schedule in effect during S1 remains constant, changes in response to S1 are a result of the change in the component of the multiple schedule associated with S2. In the present study, subjects did not receive a baseline period of nondifferential reinforcement during S1 and S2, therefore contrast cannot be assessed against a baseline obtained for each subject. However, the subjects that received *mult VI 1-min VI 1-min* throughout discrimination training can serve as a baseline control group, for nondifferential reinforcement, against which contrast can be indirectly assessed. Contrast is indicated for all multiple schedules except that responses to S1 did not differ between *mult VI 1-min VI 5-min* and *mult VI 1-min EXT*. The present data differ from previous studies (Lander and Irwin, 1968; Nevin, 1968; Reynolds, 1963) in that independent groups of birds were exposed to only one schedule. These typical studies of contrast and multiple schedules employ single subjects exposed to many combinations of schedule values.

The relative number of responses emitted during the first component (always VI 1-min

Fig. 3. Relative frequency of response during the S1 component (always VI 1-min at 550 nm) of the multiple schedule plotted as a function of the relative frequency of reinforcement during that component. The solid S-shaped curve is a plot of Herrnstein's (1970) hypothetical function. Matching of relative frequency of response and relative frequency of reinforcement would result in the function plotted on the dashed diagonal line. See text for further discussion.

at 550 nm) of each schedule is plotted in Figure 3 as a function of the relative number of reinforcements obtained during that component. Each point represents the mean for the six birds averaged for the last five days of discrimination training. Matching of the relative number of responses and reinforcements would be indicated if the points were on the diagonal line. The solid reverse S-shaped curve is a plot of Herrnstein's (1970) equation 21:

$$\frac{P_1}{P_1 + P_2} = \frac{1}{1 + \frac{R_2(R_1 + mR_2 + R_0)}{R_1(R_2 + mR_1 + R_0)}}$$

where $\frac{P_1}{P_1 + P_2}$ is the relative frequency of responding during the first component, and R_1 and R_2 are the number of reinforcements obtained during the first and second components respectively. Interaction between com-

ponents (m) is absent when $m = 0$ and maximal when $m = 1.0$; R_0 is the extra-experimental reinforcement. The curve in Figure 3 is plotted with $m = 0.3$ and $R_0 = 0$.

The fit of the present data to the theoretical function, using independent groups of subjects for each schedule, extends and supports Herrnstein's equation, which was formulated to account for data obtained from single subjects exposed to several schedule values over long periods of time (*e.g.*, Lander and Irwin, 1986; Nevin, 1968; Reynolds, 1963).

Generalization testing. Generalization gradients were obtained for each subject. The mean gradient for the six birds on each schedule is presented in Figure 4. The change in the shape of the gradient as a result of the training schedules is clear. An analysis of variance was performed on each side of the gradient separately (excluding the 550-nm point). For

Fig. 4. Average generalization gradients obtained following discrimination training to the five multiple schedules. Each gradient is the average for the group of six birds exposed to one of the multiple schedules.

the low-wavelength side of the gradient, both stimuli and schedules x stimuli were significant at $p < 0.01$ ($F = 145.42$, $df = 4/100$, and $F = 2.50$, $df = 16/100$, respectively). For the high-wavelength side of the gradient, schedules, stimuli, and the schedules x stimuli interaction were all significant at $p < 0.01$ ($F = 5.12$, $df = 4/25$; $F = 87.87$, $df = 4/100$; and $F = 9.8$, $df = 16/100$, respectively).

A look at the individual peaks yields several additional points of interest. All subjects on *mult* VI 1-min VI 30-sec showed peak responding at 570 nm. However, subjects on other schedules were not as consistent. Table 1 lists the point at which maximum responding occurred for each subject in the study.

Contrary to the results of Kalish and Guttman (1957), which showed a bimodal gradient after equally reinforced training to two stimuli on the wavelength continuum, the mean gradient for *mult* VI 1-min VI 1-min suggests some type of summation at 560 nm. As Table 1 shows, three of the six subjects on *mult* VI 1-min VI 1-min showed such summation, rather than a bimodal curve. One subject showed a peak at 550 nm and a second peaked at 570 nm. The final subject (#7706) on this schedule responded almost equally to 540, 550, 560, and 570 nm, with peaks at 540 nm and 560 nm.

The number of subjects that showed maximum responding at 540 nm is of interest in birds with VI 2-min, VI 5-min, or EXT as the second component of the multiple schedule. On *mult* VI 1-min VI 2-min, two subjects peaked at 540 nm and the rest at 550 nm. Three of the six subjects on *mult* VI 1-min VI 5-min peaked at 540 nm or had equal responding at 540 and 550 nm. Two additional

subjects on this schedule showed peak responding at 550 nm, and the final subject peaked at 560 nm. On *mult* VI 1-min EXT, four subjects showed peak responding at 540 nm, with one peaking at 550 nm and the last at 560 nm. Thus, there was an increase in the number of subjects that demonstrated maximum responding at a shorter wavelength than 550 nm as the second component of the multiple schedule increased from VI 2-min to VI 5-min to extinction.

In addition to shift in the actual peak of the gradient, some measure of the shift of the distribution is needed in order to evaluate the effects of the different schedules of reinforcement used in discrimination training. Since a mere reduction in responding on the high-wavelength side would affect the total number of responses made, and thereby cause an extra increase in the relative responding on the low-wavelength side of the gradient, the use of relative response could be misleading. Data are therefore plotted from both absolute (Figure 4) and relative generalization gradients. The relative gradient (per cent response to each stimulus) for each group was determined by dividing the response to each stimulus by the total response to all stimuli. Further to eliminate effects of response reduction on the high-wavelength side of the gradient, an independent estimate of the shift of the distribution was made for the low-wavelength side of the gradient. Since the points along the continuum were too far separated to show consistent peak shift, a measure was computed for the area under the curve to the left of 550 nm for each schedule. This measure was a simple count of the number of squares on the graph paper under each curve. Figure 5 presents this area measure

Table 1

Point of maximum responding (peak) during generalization test according to the second component of the multiple schedule.

VI 30-sec		VI 1-min		VI 2-min		VI 5-min		EXT	
Bird #	Peak (nm)	Bird #	Peak (nm)	Bird #	Peak (nm)	Bird #	Peak (nm)	Bird #	Peak (nm)
7445	570	7638	560	1859	550	7549	540	7996	560
1424	570	7706	540	NT*	540	83	540	7632	540
1482	570	1444	560	886	540	1484	540, 550	1421	540
1974	570	1272	550	2279	550	1174	550	1996	540
7213	570	1950	570	1955	550	2423	550	1907	550
1903	570	358	560	2308	550	7918	550	1990	540

* No tag number.

as a function of the relative frequency of reinforcement correlated with 550 nm. Absolute areas were determined from the absolute gradients (Figure 4) and relative areas were determined from relative gradients (per cent response to each stimulus). All area measures were determined from group gradients.

With the exception of *mult VI 1-min EXT*, decreases in relative reinforcement to 570 nm (increases to 550 nm) resulted in increasing relative and absolute distribution shift toward the low-wavelength side. The failure of *mult VI 1-min EXT* to shift the distribution more than *mult VI 1-min VI 5-min* may have occurred because the two multiple schedules did not result in differential absolute response rates to 550 nm (Figure 2). However, the actual peak shift was to 540 nm for *mult VI 1-min EXT* and at 550 nm for *mult VI 1-min VI 5-min*, although the low-wavelength

distribution shift from the absolute generalization gradients did not increase further with *VI 5-min* or *EXT* as the second component of the multiple schedule. This inconsistency may be a result of values of the test stimuli being too far to the left of 550 nm. In consideration of both peak shift and low-wavelength side distribution shift, the general conclusion can be drawn that decreasing relative reinforcement to 570 nm resulted in increasing shift away from 570 nm towards the low-wavelength side of the gradient.

DISCUSSION

The primary purpose of this study was to determine the relationship between generalization gradients, with special reference to peak shift, and the schedules of reinforcement used in the discrimination training. The differences that occurred on the low-wavelength side of the generalization gradient among schedules were used to define and measure peak shift and distribution shift. The demonstration of peak shift in generalization gradients following discrimination training has usually involved a change in the point of maximum responding. The distance from this point to S1 has been considered a measure of the amount of peak shift. In this design, the points of the continuum that were tested were not close enough for a difference in modal value to be a good measure of peak shift. Only a few of the subjects peaked at the 540-nm stimulus. In order to measure just a change in the responding on the left side of the gradient, the area under the relative response gradients on the low-wavelength side (550 nm) of the gradient was used.

A baseline value of this distribution measure had to be ascertained such that any change from the baseline could be considered a shift in the distribution. For this reason, *mult VI 1-min VI 1-min* was included in the present study. Subjects on this schedule did not receive differential reinforcement with respect to S1 and S2. These subjects served to provide a control for responding at two points along the wavelength continuum and to provide generalization gradients to which the gradients from the other schedules could be compared. Thus, a schedule discrimination that results in a distribution shift different from the shift observed with *mult VI 1-min*

Fig. 5. Distribution shift, as measured by the area on the left side (≤ 549 nm) of the relative and absolute generalization gradients, plotted as functions of the relative frequency of reinforcement correlated with 550 nm. The area measure is a count of the number of squares on the graph paper under the curves. This area measure is only for the low-wavelength side (≤ 549 nm) of the generalization gradients.

distribution shift was the same. The failure of *mult VI 1-min EXT* to increase the response rate to S1 (550 nm) over the rate produced by *mult VI 1-min VI 5-min* may be the result of an asymptotic limit on response rate under these conditions. Response rate to S2 (570 nm) did decrease further with *mult VI 1-min EXT*, indicating that the schedule did change response but that the upper limit may have been reached in S1. The left-side area of the

VI 1-min can be said to produce distribution shift in the postdiscrimination gradient.

The difference between the area measure of *mult* VI 1-min VI 1-min and the area measures of the other schedules should be an indication of the amount and the direction of distribution shift. With this area measure of the responding to the left side of the gradient, all the schedules resulted in a shift of the generalization gradient when compared with *mult* VI 1-min VI 1-min.

Hanson's (1959) study demonstrated that responding on a multiple schedule with one stimulus correlated with reinforcement (S1) and the other stimulus correlated with extinction (S2) resulted in a shift of the postdiscrimination generalization gradient. This shift in the peak of the generalization gradient was in the direction away from S2 below S1. Guttman (1959) found that extinction was not necessary at S2 in order for peak shift to occur. Peak shift was obtained after discrimination training on a *mult* VI 1-min VI 5-min schedule.

Terrace (1968) related peak shift to changes in response rate to S2 and the correlated change in response rate to S1 relative to baseline response. This change in response rate, defined as behavioral contrast, was found to be a sufficient condition for the occurrence of peak shift. In the present study, increases in relative reinforcement during S1 resulted in increases in response rates to S1 and decreases in response rates to S2 when compared with a group of birds that did not have differential reinforcement to S1 and S2. Thus, indirect evidence for behavioral contrast was obtained using independent groups of birds exposed to single multiple schedules.

If behavioral contrast is a sufficient condition for the peak shift, then we may expect that increases in peak shift will occur along with increases in contrast. To the extent that the degree of contrast can be said reflect the relative "negativity" of S2, the increase in relative "negativity" will result in an increase in peak shift. This notion of "negativity" receives some independent support from a study using shock during the S2 component of the multiple schedule (Grusec, 1968). Shock dur-

ing S2 (shock and extinction) was found to enhance peak shift over that obtained with only extinction during S2.

The present study indicates that the distribution shifts were correlated with behavioral contrast and that contrast (as measured by response rate to S1 with reference to the *mult* VI 1-min VI 1-min group) was a function of the schedule during S2. If the relative schedule "value" at S2 is assumed to be on a continuum from positive to negative, then the more negative the value is at S2 the greater is the contrast and the associated distribution shift. No statement can be made as to whether relative reinforcement or relative response is the more important determinant of contrast and peak shift, because of the high correlation (+0.972) between relative reinforcement and relative response.

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