STIMULUS DURATION AS A MEASURE OF STIMULUS GENERALIZATION¹

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Four pigeons in the line-positive group were trained with a vertical line on a green background that signalled intermittent reinforcement while a plain green field signalled extinction. Four pigeons in the line-negative group were trained with the opposite discrimination. Response to a control key terminated any trial and initiated the next trial. The birds also used the control key during generalization tests to control the durations of trials in which various line orientations were presented. These durations were summed to provide generalization gradients of stimulus duration that were positive or negative in accordance with the trained discriminations. In Experiment 2, birds from the line-positive group were tested with a procedure in which the control key was not available on some trials. This provided an independent assessment of response rates to the test stimuli. These rates were used to predict the stimulus durations obtained when the control key was available. The findings supported a general model for the prediction of response distributions among concurrent stimuli from rates observed with single stimuli.

Key words: generalization, gradients, stimulus duration, choice behavior, key peck, pigeons

Rate and probability of response have been the most common measures of stimulus control in studies of instrumental learning. In recent years, stimulus duration has also become useful as a dependent variable, by permitting the subject some control over this aspect of the procedure. Findley (1958) provided the pigeon with a changeover key (or "switching key", as he called it) with which the subject could alternate at will between components of a concurrent schedule. Since then, the changeover technique has been applied to multiple as well as concurrent schedules (e.g., Findley, 1962; Honig, Beale, Seraganian, Lander, and Muir, 1967; Leyland and Honig, 1975). This method results in more rapid discrimination learning than the conventional one where stimulus durations are fixed. The distribution of time between concurrent alternatives is also thought to reflect

the relative "values" of conditions differentially associated with reinforcement (Baum and Rachlin, 1969).

A control key (as we will call it) can also be used together with a set of stimuli presented on the food key in a generalization test. Beale and Winton (1970) obtained incremental, or negative gradients of stimulus duration on the dimension of line orientation, after training pigeons with a plain blue key as S+ and a blue key with a vertical line on it as S-. This gradient was in fact steeper than that based on response rates to the test stimuli, both when the control key was available and when it was not. Gradients of stimulus duration have also been obtained following a discrimination between two line orientations (Winton and Beale, 1971) or two orientations of a grating (Seraganian, 1973). Positive and negative peak shifts were generally observed; the pigeon spent more time in the presence of test stimuli further along the continuum than S+ in a direction away from S-, and less time in the presence of test stimuli further along the continuum than S- in a direction away from S+. All of these data suggest that many of the phenomena in the area of stimulus control can be obtained with stimulus duration as the measure.

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The present study sought to compare positive and negative gradients of stimulus duration obtained on the same dimension following comparable training procedures. The strategy was similar to that used by Honig, Boneau, Burstein, and Pennypacker (1963). We were particularly interested in comparing response rate as a dependent measure with the distribution of time spent in the different test stimuli; these two measures appear to be closely related, and perhaps reflect a fundamental process underlying stimulus control.

EXPERIMENT I: POSITIVE AND NEGATIVE GRADIENTS

Subjects

Eight experimentally naive White Carneaux pigeons were maintained at about 80% of their free-feeding weights.

Apparatus

A standard Grason-Stadler three-key pigeon apparatus was enclosed in a ventilated, sound-attenuating chamber. The food key, 2.5 cm in diameter, was centered 13 cm directly above the opening for the food magazine. The control key was located 10 cm to the left of the food key. The third key was not used. Scheduling and recording equipment was in a separate room. The control key, when it was illuminated and in operation, was always white. The food key was illuminated by an in-line IEE digital display projector mounted directly behind the key. Green was provided by a Wratten filter in the projector with a nominal dominant wavelength of 555 nm. A single white line, about 3 mm wide, could be combined with this color. The orientation of the white line assumed any of six orientations: 0° (vertical); +30° and +60° (tilts clockwise from vertical); -30° and -60° (tilts counterclockwise); and 90° (horizontal).

Procedure

Preliminary training. All subjects were magazine trained with a cycle of 4 sec and then shaped to peck the food key through successive approximations. The food key was illuminated with the stimulus designated as S+ for each bird. After shaping, and the delivery of about 50 reinforcements, variable-interval schedules were introduced. These provided

reinforcement at irregular intervals, dependent on pecking the food key. The mean inter-reinforcement interval was extended over the course of several sessions until the final training schedule of VI 1-min was attained. This schedule was in effect for about six sessions, each of which lasted 30 min.

Discrimination training. For the line-positive group (Birds 8, 10, 12, and 14) S+ was the green key with a vertical white line superimposed on it, and S- was the green key with no line. The same stimuli were S- and S+, respectively, for the line-negative group (Birds 7, 9, 11, and 13). Each session began with S+, and the stimuli alternated every 60 sec in the absence of a control-key response. The VI 1-min reinforcement schedule was associated with S+. Reinforcement was not available in S-. A training session terminated after 1800 sec in the presence of S+. When discrimination training began, the control key was illuminated. A response to it terminated the current stimulus and produced the other stimulus and the appropriate condition of reinforcement. A stimulus presentation lasted for 60 sec unless terminated by a control-key response. At the beginning of each stimulus period, the control key was dark and inoperative for 2 sec. Control-key responses also prevented the delivery of food for 2 sec.

Generalization tests. Two tests were carried out, with several discrimination training sessions between them. After a warm-up period of five S+ and five S- trials, further reinforcement was discontinued, and the test sequence was initiated. In the first test, this sequence consisted of four blocks of six trials each. The test stimuli were the six line orientations. Each orientation was presented once in each block, in a randomized order. The no-line stimulus was not included in this test. A response to the control key terminated the test trial and initiated the next trial in the sequence. In the absence of a control-key response, the next trial began after 60 sec. The sequence of six-trial blocks was repeated as often as required until the end of the test, when the subject came to the end of the first six-trial block after 1800 sec of testing. The total number of blocks varied, of course, with the pace at which the subject progressed through the sequence by pecking the control key.

The second test was like the first, except that the green no-line stimulus was included

in the test sequence, and the blocks therefore contained seven stimuli each. The test was terminated after completion of the first seven-trial block following 2400 sec of testing.

RESULTS

Three measures of discriminative control were available: the total number of responses to each stimulus during a session, the time spent in the presence of each stimulus, and the rate of responding to each. Each of these measures was converted to a proportion of the total responses, time, or rate, respectively, during a session to provide discrimination ratios (DRs) for training sessions, and relative gradients of generalization based upon test data.

After nine days of discrimination training, the mean DR based on rate was 0.925 (range: 0.89 to 0.98) for the line-positive group, and 0.940 (range: 0.92 to 0.97) for the line-negative group. All but one bird used the control key to reduce time spent in S-. The three birds that used it in the line-positive group had a mean DR based on time of 0.930 on the last day of training (range: 0.92 to 0.94) while the four birds in the line-negative group had a

mean DR of 0.923 (range: 0.91 to 0.93). Generally, these birds made control-key responses in all of the negative periods that they encountered during a training session, while they made only a few control-key responses in S+ periods. The one bird (#8) that had not started to use the control key by this time was not given the first generalization test. In subsequent sessions, #8 started to use the key, and rapidly reached the level maintained by the other birds in the line-positive group.

The two generalization tests given to the line-positive group will be called P1 and P2. The stimulus duration data are presented in Figure 1. Of the three individual gradients obtained on test P1, one was quite orderly, with a clear peak at 0° (S+), one was relatively high at S+ and 30°, and one was irregular and flat. In Test 2, where S- was presented, each bird provided a sloping, symmetrical gradient of stimulus duration, with a peak at S+.

The two tests given to the line-negative group are called N1 and N2, and the stimulus duration data are presented in Figure 2. All birds provided orderly gradients on test N1. For three of four, the minimum value was at

Fig. 1. Positive gradients of stimulus duration obtained from individual subjects in tests P1 and P2. Subject 8 did not receive test P1. The values for $\pm 90^\circ$ are duplicated to provide symmetry.

Fig. 2. Negative gradients of stimulus duration obtained from individual subjects in tests N1 and N2. The values on the right ordinate apply only to the data obtained under the no-line condition.

Fig. 3. Mean positive gradients based upon absolute rate to the test stimuli, and upon relative rate and relative time. The right ordinate indicates responses per second, and it applies to the absolute rate data from both test P1 and test P2.

S—; for Bird 9, the minimum was at -30° . When S+ was included in the stimulus series in test N2, the gradients of stimulus duration became low and flat for three birds. These spent upwards of 65% of the test time in S+. The one subject that spent less time in S+ (about 650 sec) also provided an orderly, steep negative gradient.

Mean gradients of response rate, and mean relative gradients of stimulus duration and of response rate, are presented in Figures 3 and 4 for these four tests. The relative gradients were first calculated for individual subjects and then averaged. The flattening effect of including S+ in the test of inhibitory control is evident in Figure 4. This flatness is not an artifact of including the time spent in S+ in the calculation. The relative gradient of duration from test N2 was recalculated with the time in S+ omitted, which makes it more com-

parable to the gradient obtained in test N1. The N2 gradient is clearly still flatter and less orderly than the N1 gradient. The lack of stimulus control observed in the former is largely due to the fact that the subjects reduced the time spent in all the line-present stimuli when S+ was introduced to the test series. The mean duration of all line-present stimuli, averaged across orientations and subjects, was 12.2 sec in test N2, as against 21.6 sec in test N1.

The gradients based on relative rate and relative duration were similar both for test P1 and for test N1. The birds appeared to distribute the time spent in different test stimuli in the same proportion as they distributed response rates among them. Tests P2 and N2 showed a similar correspondence, but there was greater dispersion among the values based on rate than among the values based on duration.

Fig. 4. Mean negative gradients based upon absolute rate to the test stimuli, and upon relative rate and relative time. The right ordinate indicates responses per second, and it applies to the absolute rate data from both test N1 and test N2. The open squares for relative time were calculated on the basis of the duration gradient omitting the time spent in the no-line stimulus.

DISCUSSION

The generation of positive gradients of stimulus duration is important theoretically. We have argued (Honig *et al.*, 1972) that negative gradients of stimulus duration manifest inhibitory characteristics of stimuli associated with extinction. Yet, such gradients may be positive or excitatory gradients in disguise because they are generated by differential latencies of the control-key response. This latency is shortest in the presence of S— and increases as the difference between the test stimulus and S— increases. If this alone is responsible for the production of gradients, then one should obtain flat gradients of stimulus duration around the vertical line when it serves as S+. During training, the pigeons withheld control-key responses in the presence of that stimulus. If line orientation is orthogonal to line absence, there is no reason for the pigeon to make control-key responses more quickly as the test stimuli differ increasingly from S+, as none of them will be more similar to S— than any of the others. We did obtain an orderly relationship between the latencies of control-key responding and the orientation dimension when the vertical key was S+. Furthermore, if the positive gradient is interpreted as a gradient of response latencies, then it would have to be classed as an *inhibitory* gradient.

The negative gradients were flatter than the positive ones, both in terms of rate and of stimulus duration, particularly when the no-line stimulus was included in the test series. The difference cannot be accounted for by poorer original acquisition of the line-negative problem, since the DRs were very similar at the end of training. Nor can it be ascribed to a difference in the maintenance of the discriminations in the tests. The mean discrimination ratio based on vertical line *versus* no line in test P2 was 0.85; in test N2 it was 0.89. While Honig *et al.* (1963) obtained positive and negative gradients with similar slopes on the line-orientation dimension, other related research indicates that negative gradients tend to be relatively flat. (Jenkins and Harrison, 1962; Terrace, 1966; Weisman, 1969. See Hearst, Besley, and Farthing, 1970, for a more extended discussion of this problem.)

Inclusion of S+ in test N2 markedly reduced the time spent in the presence of the other test stimuli, and increased the overall

rate of responding to the control key. A possible explanation for this is that the occasional production of S+ reinforces the control-key response and thus increases its rate. Leyland and Honig (1975) found that the response-contingent production of S+ was the single most important factor that maintained control-key responding. This explanation cannot account for the enhancement of the slopes of positive gradients in test P2. The reason for this effect is obscure; it may be due to repeated testing, since the inclusion of S— in the test series was not counterbalanced across test repetition. On the other hand, the inclusion of S— in the test may have a "real" effect in sharpening the gradient; this question has not, as far as we know, been studied experimentally.

EXPERIMENT II: PREDICTION OF DURATION GRADIENTS

The close correspondence observed in Experiment I between gradients based on rate and on duration permits prediction of one gradient from the other. The observations were not, however, independently obtained. Rate and duration were assessed within the same set of trials. The bird's control of the duration of a trial may constrain the rate of responding, or rate of pecking the food key may constrain responses to the control key. This problem can be overcome by obtaining independent measures of stimulus control. In this study, response rates obtained when the control key was not available were used to predict stimulus durations and total responses for positive generalization gradients obtained with the use of the control key. The assumptions were (1) that the pigeon would distribute durations among stimuli in the control-key test in the same proportions as response rates in the absence of the control key, and (2) that it would respond to the stimuli at the same rate under both types of testing conditions.

METHOD

After further retraining on the original problem, the four pigeons of the line-positive group were given a third test, P3. This test was composed of two different kinds of trials, and can in effect be separated into two tests, the *fixed-trials test* and the *control-key test*. In

the former, trials were 30 sec long, with the control key dark and ineffective. In each trial block, the six line orientations and the no-line green background were presented once in a randomized order. Ten such blocks comprised the fixed-trials test, which thus lasted for 2100 sec in all. These blocks alternated in a test session with similar blocks of trials from the control-key test, in which the control key was turned on, but the maximum duration of any trial was limited to 60 sec. The blocks were presented so that the running total durations of each test were kept approximately equal during the test session. Since the subjects generally spent less than 30 sec (on the average) in a trial that they could terminate, two or even more blocks of control-key trials were often presented in succession in order to equalize the running total durations. Occasionally, if a pigeon failed to use the control key over a series of trials, the reverse was necessary, since such control-key trials would each last 60 sec, or twice as long as the fixed trials.

RESULTS

To predict time and total responses for the control-key tests: (1) Relative response rates to the seven test stimuli were calculated from the fixed-trials test. (2) Total duration of the control-key test was multiplied by each of these proportions to obtain the predicted time for each stimulus. (3) These predicted durations were in turn multiplied by the response rates to the corresponding stimuli in the fixed-trials test, to obtain the predicted total responses to each value in the control-key test. These calculations were done for each subject and then averaged.² The same set of predictions was also carried out on the basis of the response rates obtained in the control-key test. If the opportunity to make a control-key response did not affect rate of responding to the food key, and food-key rates were the same for both tests, the predicted values based on them should be substantially the same.

²The control key was not illuminated for the first 2 sec of any control-key test trial. This limited, to a slight degree, the bird's opportunity to make control-key responses with very short latencies. The predictions were therefore carried out a second time to correct for this, based on the actual time that the control key was available during each trial. The resulting correction produced only a small deviation from the original predicted values.

Predicted and obtained values are compared in Figure 5. A number of points should be noted. The procedure captured the general form of the gradients obtained under the control-key procedure. Systematic discrepancies corresponded to differences observed in Experiment 1. The relative time spent in the stimulus farthest removed from S+ on the continuum ($\pm 90^\circ$), and in S-, was greater than predicted on the basis of relative response rates. On the other hand, the time spent in $\pm 30^\circ$ was overpredicted on the basis of response rates. The predictive errors observed for stimulus duration were reduced when these durations were multiplied by response rates to provide predicted total responses. The main reason for this is that the response rates to $\pm 60^\circ$, to $\pm 90^\circ$, and to S- were very low, and the product of rate and time was therefore also quite low. Finally, the predictions based on rates from the control-key test agreed substantially with those from the fixed-trials test. This attests to the fact that food-key rates were quite similar for both tests, and the opportunity to make the control-key response did not seem to bias them. The predicted gradient of duration based on the control-key test was somewhat steeper than the obtained gradient. This difference was similar to that observed for gradients of relative rate and relative duration obtained from test P1 (Figure 3).

The proportion of the variance of the obtained values attributable to the predicted values was calculated by squaring the correlation coefficient between the values predicted from the fixed-trials test and the obtained values. This proportion is 88% for the duration data and 95% for the total responses. Mean predicted and obtained values were used. When values determined for individual subjects are used, these percentages are not as high because of considerable scatter, which is greatly reduced through averaging.

DISCUSSION

The prediction of stimulus durations is relevant to the prediction of response output to two (or more) available stimuli on the basis of response rates to single stimuli. Honig (1962) compared simultaneous presentation with successive presentation of pairs of stimuli from a spectral generalization gradient. To account for the obtained choice behavior in the simul-

Fig. 5. Total time (left) and total responses (right) predicted and obtained from the test in Experiment 2. The connected squares indicate the values predicted from the fixed-trials test, when the control key was inoperative; the triangles indicate the values predicted from those trials in which the control key was available.

taneous situation, he assumed (1) that the pigeons peck at each member of a stimulus pair at the same rates as they do to the same stimuli presented alone, and (2) that they distribute the time spent pecking at the two keys in the same proportion as those rates. The same principles were successfully used by Eckerman, McGourty, and Shonfeld (1972) to predict response distributions in similar but more extensive tests carried out on the dimension of line orientation.

In neither set of studies was the duration of responding to each of the simultaneously presented stimuli observed directly. A first step toward such an observation is provided by the control-key procedure, which at least provides an accurate account of the amount of time that the subject spends in the presence of each stimulus, even though the time spent *responding* to it may be different. The close correspondence between relative response rates and

the distribution of time among stimuli, observed in both present experiments, supports Honig's second assumption. The similarity of absolute response rates in fixed-duration and in control-key trials confirms the first. The main discrepancy was that the pigeons spent too much time in the presence of stimuli controlling low rates of response. An evaluation of the time spent responding to such stimuli, as against the time spent in their presence, might resolve this discrepancy.

Previous work on the study of response distributions has dealt largely with choices between two simultaneously presented stimuli. The model regarding distribution of times is a general one, and in the present work it was applied to seven test stimuli that were concurrently available but not simultaneously presented. Support for the original model on the basis of this generalized instance is particularly promising, and further research will

certainly be facilitated by the method in which the subject has explicit control over the duration of the concurrent choices.

Stimulus duration provides a sensitive indicator of stimulus control, as reflected in orderly generalization gradients sensitive both to conditions of training and conditions of testing. This measure may be particularly useful in situations where response rate is not a suitable indicator as, for example, when there is no instrumental contingency for receiving reinforcement. There is a very close relationship between rate of instrumental responding for food and the duration of stimuli controlling that behavior. While the latter can be predicted from the former, it is too early to determine a causal relationship between the two. Indeed, these dependent variables probably reflect some more fundamental psychological characteristic of the stimulus, such as its "value" to the subject within the group of available stimuli.

REFERENCES

- Baum, W. M. and Rachlin, H. C. Choice as time allocation. *Journal of the Experimental Analysis of Behavior*, 1969, 12, 861-874.
- Beale, I. L. and Winton, J. S. W. Inhibitory control in concurrent schedules. *Journal of the Experimental Analysis of Behavior*, 1970, 14, 133-137.
- Eckerman, D. A., McGourty, D. P., and Shonfeld, R. E. A comparison of models relating successive to simultaneous measures of stimulus control. *Learning and Motivation*, 1972, 3, 223-236.
- Findley, J. D. Preference and switching under concurrent scheduling. *Journal of the Experimental Analysis of Behavior*, 1958, 1, 123-144.
- Findley, J. D. An experimental outline for building and exploring multi-operant repertoires. *Journal of the Experimental Analysis of Behavior*, 1962, 5, 113-166.
- Hearst, E., Besley, S., and Farthing, G. W. Inhibition and the stimulus control of operant behavior. *Journal of the Experimental Analysis of Behavior*, 1970, 14, 373-409.
- Honig, W. K. Prediction of preference, transposition and transposition-reversal from the generalization gradient. *Journal of Experimental Psychology*, 1962, 64, 239-248.
- Honig, W. K., Boneau, C. A., Burstein, K. R., and Pennypacker, H. S. Positive and negative generalization gradients obtained after equivalent training conditions. *Journal of Comparative and Physiological Psychology*, 1963, 56, 111-116.
- Honig, W. K., Beale, I. L., Seraganian, P., Lander, D. G., and Muir, D. Stimulus and response reduction: two aspects of inhibitory control in learning. In R. A. Boakes and M. S. Halliday (Eds.), *Inhibition and learning*. London: Academic Press, 1972. Pp. 41-71.
- Jenkins, H. M. and Harrison, R. H. Generalization gradients of inhibition following auditory discrimination learning. *Journal of the Experimental Analysis of Behavior*, 1962, 5, 435-441.
- Leyland, C. M. and Honig, W. K. Maintenance of behavior controlling the duration of discriminative stimuli. *Journal of the Experimental Analysis of Behavior*, 1975, 24, 207-214.
- Seraganian, P. *The transfer of discriminative control*. Unpublished doctoral dissertation. Dalhousie University, 1973.
- Terrace, H. S. Discrimination learning and inhibition. *Science*, 1966, 154, 1677-1680.
- Weisman, R. G. Some determinants of inhibitory stimulus control. *Journal of the Experimental Analysis of Behavior*, 1969, 12, 443-450.
- Winton, J. S. W. and Beale, I. L. Peak shift in concurrent schedules. *Journal of the Experimental Analysis of Behavior*, 1971, 15, 73-81.

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