DIMENSIONAL STIMULUS CONTROL FOLLOWING BRIEF WAVELENGTH TRAINING¹

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Pigeons with extensive training pecking a key illuminated by a white line then had brief training with the key illuminated by 555 nanometers. This was immediately followed by a wavelength generalization test in extinction. Dimensional stimulus control about the training wavelength increased with the duration and number of reinforcements given on variable-interval 30-sec and variable-interval 10-sec schedules in Experiment I. In Experiment II, dimensional stimulus control was obtained after only 4 min of wavelength training from birds with prior and independent discrimination training. Experiment III provided groups equated in number of reinforcers with groups in Experiment I and two 8-min duration groups. Analyses, which included results from both Experiments I and III, showed that dimensional stimulus control increased: (a) more rapidly as a function of the duration of variable-interval 10-sec than variable-interval 30-sec reinforcement; (b) at the same rate across variable-interval reinforcement schedules, as a function of the number of reinforcers available during brief wavelength training.

Key words: dimensional stimulus control, attention, number of reinforcements, duration of training, pigeons

The development of dimensional stimulus control as a function of the parameters of operant training has been the topic of considerable discussion (Kimble, 1961; Terrace, 1966). Hearst, Koresko, and Poppen (1964) examined stimulus control across the line orientation dimension after two to 14, 50-min sessions of variable-interval 1-min (VI 1-min) reinforcement. The gradient of dimensional stimulus control steepened with increased training. Schadler and Thomas (1972) noted that acquisition of response strength and the acquisition of stimulus control by line orientation occurred simultaneously in the Hearst *et al.* study. Thus, reinforcement histories of a few minutes or hours might have failed to yield sufficient responding in extinction to observe dimensional stimulus control.

In their study of the development of dimensional stimulus control, Schadler and Thomas preceded brief training to a line orientation with extensive training to overall white il-

lumination of the response key. Steep gradients of dimensional stimulus control were obtained after only 20 min of line-orientation training. In fact, these gradients were virtually as steep as those obtained by Hearst *et al.* after over 11 hr of line-orientation training. The present experiments used procedures similar to those of Schadler and Thomas to provide further analysis of dimensional stimulus control following brief training. The roles of the duration of training, the number of reinforcers, and prior discrimination training were examined in three experiments.

EXPERIMENT I

In Experiment I, as in the Schadler and Thomas work, extensive training with one stimulus preceded various durations of brief training with another stimulus. In the present work, brief training was in the wavelength dimension, while in the Schadler and Thomas work, brief training was in line-orientation dimension. Also, Experiment I provided comparisons between gradients obtained following equivalent training durations with different numbers of reinforcers. This was accomplished by replicating each duration of training in two separate groups trained with either a VI 10-sec or a VI 30-sec reinforcement schedule.

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METHOD

Subjects

Thirty-four experimentally naive adult male Silver King pigeons were maintained at about 80% of their free-feeding weights.

Apparatus

A standard operant-conditioning chamber (Ferster and Skinner, 1957) was used. An Industrial Electronics Engineers in-line display cell transilluminated the key. The display cell was fitted with Kodak Wratten filters No. 65, 74, 99, 73, and 72B, which projected peak wavelengths at 501, 538, 555, 576, and 606 nm respectively. The display cell also provided a white vertical line 0.3 cm wide by 2.2 cm high on an unlighted background.

The reinforcer was 2-sec access to mixed grain illuminated by a 3-W bulb while the hopper was raised. The lamp over the hopper and stimuli projected on the response key provided the only illumination in the pigeon chamber. White noise and noise from an exhaust fan masked extraneous sound. Recording and scheduling equipment were located in a separate room.

Procedure

Key-peck training was followed by sessions in which the requirement for reinforcement was raised to 45 responses. This initial training was complete in three to four sessions. Each of 19 birds then had nine sessions with a VI 30-sec reinforcement schedule. Throughout this training, a white vertical line on an unlighted background appeared on the key during a 30-sec trial and the key was darkened during a 5-sec timeout. Training sessions ended after 60 trials.

During the tenth session, after two trials with the white line, the stimulus on the key was shifted to 555 nm for 16 birds. Groups of four birds each had 2, 12, 20, or 50, 30-sec trials, that is 1, 6, 10, or 25 min training with the wavelength stimulus correlated with VI 30-sec reinforcement. Timing of the duration of wavelength training began with the first key peck to 555 nm to ensure that the number of reinforcements obtained would be essentially the same as the number available. A control group of three birds had no trials (0 min) with 555 nm before the generalization test.

Immediately following the final training session, each bird had a stimulus generalization test in extinction (Guttman and Kalish, 1956). During the generalization test five stimuli: 501, 538, 555, 576, and 606 nm were presented 10 times each in randomized blocks of five 30-sec trials separated by 5-sec timeouts.

A systematic replication of these procedures, for 15 birds, was identical to that already described with the following important exceptions: (a) a VI 10-sec reinforcement schedule was used during training; (b) prewavelength training sessions lasted 10 min rather than 30 min; (c) a 25-min wavelength training group was omitted because of possible satiation effects in a session of that duration. Approximately 150 reinforcements could be obtained in a 25-min session on a VI 10-sec schedule.

RESULTS

Responding to each stimulus presented during the generalization test is shown for the groups trained with the VI 30-sec reinforcement schedule in Figure 1 and for the groups trained with the VI 10-sec reinforcement schedule in Figure 2. Birds with little (1 min) or no (0 min) wavelength training did not respond equally to all of the stimuli. Instead, responding tended to be more frequent to 606 nm and 576 nm than to other wavelengths. However, as the duration of wavelength training increased, responding to 555 nm and adjacent wavelengths increased considerably. After 10 min of VI 10-sec, or 25 min of VI 30-sec, a relatively steep convex gradient of stimulus control was obtained from each bird. A comparison of the VI 30-sec and VI 10-sec groups at 6 min and 10 min of wavelength training suggested that steeper gradients were obtained with the latter schedule.

EXPERIMENT II

Experiment I showed that if wavelength training is preceded by an extensive experimental history of responding to other stimuli, then dimensional stimulus control can be observed after only several minutes of wavelength training. Experiment II examined the possibility that if the experimental history also included operant discrimination in a dimension other than wavelength, then dimensional stimulus control might be observed following briefer wavelength training.

Fig. 1. Generalization gradients following 0-, 1-, 6-, 10-, or 25-min wavelength training with the VI 30-sec reinforcement schedule.

METHOD

Subjects

Eight adult male Silver King pigeons were maintained at about 80% of their free-feeding weights. Four of the birds: 65, 01, 46, and 71 were without prior training. Four of the birds:

Fig. 2. Generalization gradients following 0-, 1-, 6-, or 10-min wavelength training with the VI 10-sec reinforcement schedule.

57, 11, 20, and 37 had previous discrimination training described below.

Procedure

The training and testing procedure was identical to that of the VI 10-sec groups of Experiment I with two exceptions: (a) four birds had 10 multiple-schedule discrimination training sessions in which a black vertical line on a white surround was correlated with VI 1-min and the white surround alone was correlated with extinction before the procedures of Experiment I. Trial and session durations during this prior discrimination training were as in VI 30-sec groups of Experiment I. (b) Each bird had 4-min wavelength training just before the stimulus generalization test.

RESULTS

The results for birds without prior discrimination training are shown in the upper panel

Fig. 3. Generalization gradients following 4-min wavelength training with the VI 10-sec reinforcement schedule. The upper panel (A) shows gradients for previously experimentally naive birds. The lower panel (B) shows gradients with previous independent (extra-dimensional) discrimination training.

(A) of Figure 3. As might be expected from an extrapolation of Experiment I, 4 min of wavelength training was not by itself sufficient to generate stimulus control in the wavelength dimension. The results for birds with prior discrimination training are shown in the lower panel (B) of Figure 3. Contrary to any simple extrapolation of the results of Experiment I, all four birds showed gradients peaking at 555 nm. These gradients of stimulus control were at least as orderly as those obtained in Experiment I and steeper than any gradient obtained after less than 10 min of wavelength training.

EXPERIMENT III

The number of reinforcements correlated with responding in the presence of a stimulus has been cast as an important determinant of steepening gradients of dimensional stimulus control (Hull, 1947; Millenson, 1967; Spence, 1937). Hearst, Taus, and Koresko (1971) studied dimensional stimulus control following reinforcement histories of 60, 120, or 300 reinforcements. The resulting gradients varied little, if at all, with the number of reinforcements. Hearst *et al.* suggested that with fewer than 60 reinforcements, increases in either the duration of brief training or the number of reinforcements might contribute to development of dimensional stimulus control. Experiment I of the present study provided groups on VI 30-sec and VI 10-sec reinforcement

schedules matched in the duration of wavelength training, but receiving different numbers of reinforcers per duration. When the gradients for these groups are compared (see Figures 1 and 2), it seems that dimensional stimulus control developed more rapidly with the VI 10-sec schedule, which made a greater number of reinforcers available at each duration of training. Experiment III provided groups matched with selected VI 10-sec and VI 30-sec groups of Experiment I in the number of reinforcers available and two additional groups matched in the duration of training. Thus, the results of Experiment III, together with those for the previous experiments, permitted a more complete analysis of the effects of both the number of reinforcers and the duration of brief wavelength training on dimensional stimulus control.

METHOD

Subjects

Twenty experimentally naive Silver King pigeons were maintained at about 80% of their free-feeding weights.

Procedure

The procedure was identical to that of the VI 30-sec groups of Experiment I for 12 birds, except that three groups of four birds each had 8, 18, or 30 min, respectively, of wavelength training. The procedure was identical to that of the VI 10-sec groups of Experiment I for the remaining eight birds, except that two groups of four birds each had 2 or 8 min, respectively, of wavelength training.

Table 1 shows how groups were equated, in pairs, in the number of reinforcers, or separately, in the duration of training, across the present experiments through the procedures of Experiment III. Groups with the same training duration (D) were paired in one analysis; groups with the same, or in the case of the 48- and 50-reinforcer groups highly similar, numbers of reinforcers (R) were paired in a second analysis. With the additional groups provided by Experiment III, in the first analysis comparisons were available at 0, 1, 6, 8, and 10 min of wavelength training; in the second analysis, comparisons were available at 0, 12, 36, 50(48), and 60 reinforcers. Excluded from Table 1, and further comparisons, were results, obtained in Experiment II, for the group with prior discrimination training.

Table 1

A summary of matching by the number of reinforcers (R) and the duration of training (D) across pairs of groups drawn from Experiments I and III.

<i>Schedule of Reinforcement</i>	<i>Duration of Training (min)</i>	<i>Number of Reinforcers</i>	<i>Equated by Duration or Reinforcers</i>
EXPERIMENT I			
VI 30-sec	0	0	D, R
	1	2	D, -
	6	12	D, R
	10	20	D, -
	25	50	-, R
VI 10-sec	0	0	D, R
	1	6	D, -
	6	36	D, R
	10	60	D, R
EXPERIMENT II			
VI 10-sec	4	24	-, -
EXPERIMENT III			
VI 10-sec	2	12	-, R
	8	48	D, R
VI 30-sec	8	16	D, -
	18	36	-, R
	30	60	-, R

RESULTS

Responding to each stimulus presented during the generalization test is shown in Figure 4. These gradients increased in steepness with increased duration of wavelength training, but dimensional stimulus control after 8-min of wavelength training was greater in the VI 10-sec, 48-reinforcer group than in the VI 30-sec, 16-reinforcer group.

A point estimate of the steepness of the generalization gradient was utilized to simplify further presentation and comparison between the 15 groups of Experiments I, II, and III, listed in Table 1. This relative transformation, the proportion of total responses emitted to the training stimulus, useful when the maxima of the gradient is sought at the training stimulus, is seen as effective in reducing individual variation, while revealing systematic shifts in dimensional stimulus control with training (Lyons and Thomas, 1967). In the present work, this proportion was obtained for each bird by dividing the number of responses emitted to 555 nm by the total number of responses emitted to all five wavelength stimuli during the generalization test. The proportion of total responses to 555 nm varied directly with visual evidence of increased dimensional

Fig. 4. Generalization gradients following 2- and 8-min wavelength training with the VI 10-sec, and 8-, 18-, and 30-min wavelength training with the VI 30-sec reinforcement schedule.

stimulus control (in Figure 2, the proportion was 0.38 for Bird 40 and 0.77 for Bird 46), but varied relatively independently across individ-

ual birds from total responding during the test ($r = 0.09$; $df = 48$; n.s.).

Figure 5 presents the mean proportion of responses to 555 nm for the groups listed in Table 1, in the left-hand panel as a function of the duration of wavelength training, and in the right-hand panel as a function of the number of reinforcers available during wavelength training. The mean proportion of responses to 555 nm increased more rapidly with the duration of training in the VI 10-sec groups than in the VI 30-sec groups ($F = 3.783$; $df = 4/28$, $p < 0.025$ for the interaction term of an analysis of variance for the matched duration groups in Table 1). The mean proportion of responses to 555 nm increased at the same rate as a function of the number of reinforcers ($F = 14.009$; $df = 4/28$; $p < 0.001$ for the effect of number of reinforcers in an analysis of variance for the matched reinforcer groups in Table 1) but was hardly affected, either visually or statistically, by differences in the duration of training between VI 10-sec and VI 30-sec groups.

GENERAL DISCUSSION

The present results for brief training in the wavelength dimension are generally in line with those of Schadler and Thomas for brief

training in the line-orientation dimension: (a) following little or no training, responding showed measurable pre-experimental biases across stimuli in the wavelength dimension during the test; (b) following a few minutes of training, responding was approximately equal to all stimuli presented in the test; (c) following more than a few minutes of training, responding at the training stimulus and adjacent generalization stimuli increased, producing a steepening gradient of dimensional stimulus control. In the present analyses, however, steepening of the gradient of dimensional stimulus control with increases in the duration of training, seen by Schadler and Thomas and in the present work, was shown to be a product of concomitant increases in the number of reinforcers available during longer-duration training.

Our conclusions and those of Schadler and Thomas differ somewhat concerning the effect of brief training on the amount of responding during the generalization test in extinction. A review of Figures 1 and 2 of the present report shows that overall responding increased with the duration of prior brief wavelength training ($F = 6.63$; $df = 3/22$; $p < 0.005$ for an analysis of variance across 0-, 1-, 6-, and 10-min groups of Experiment I), Schadler and Thomas also obtained increased responding with prior

Fig. 5. The mean proportion of total responses emitted to 555 nm during the generalization test shown as a function, in the left-hand panel, of the duration of brief training and, in the right-hand panel, of the number of reinforcers available during brief training. The standard error for these means was 0.05, approximately.

dimensional training, approximately half again as many responses during the generalization test from 10-min groups as against 0-min groups, but the result was not judged statistically reliable. Taken together, the two reports provide some evidence that an extensive prior reinforcement history was not wholly effective in eliminating differences in response strength in extinction attributable to brief training.

Experiment II demonstrated that the prior experimental history of the bird can be a critical determinant of dimensional stimulus control following brief wavelength training. Prior visual discrimination training in a dimension other than wavelength, the presence *versus* absence of a line on the key, had a striking effect on later dimensional control by wavelength: dimensional stimulus control was observed after only 4 min (24 reinforcements) of training with 555 nm. This finding may be viewed as an extension of work reported by Thomas (1969) and by Honig (1969). These authors also found steeper gradients when single-stimulus training was preceded by separate visual discrimination training, but used much more extensive single-stimulus training. The results of Experiment III suggest that the effect of prior discrimination training is observable from nearly the onset of single-stimulus training.

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