REINFORCEMENT OF PROBE RESPONSES AND ACQUISITION OF STIMULUS CONTROL IN FADING PROCEDURES

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Stimulus control of pigeons' key pecking was transferred from colors to lines by the method of stimulus fading. Fading was conducted with the addition of probes consisting of the line stimuli presented alone at each fading level. Probe responding was used to measure stimulus-control acquisition by the lines. Effects of reinforcement and nonreinforcement of probe responding upon acquisition of stimulus control were assessed using a single-organism repeated-acquisition design in which three fades were conducted serially. Probe responding was not reinforced in the first and third fade but was in the second. Reinforcement of probe responding substantially reduced the number of fading levels needed to complete fading. The outcome of a control experiment ruled out the possibility of accounting for these results in terms of the specific stimuli used in each fade or in terms of the sequential exposure to the three discriminations. Although probes permitted measurement of stimulus-control acquisition in fading, a measurement/acquisition interaction was also present.

Key words: stimulus fading, probe stimuli, measurement/acquisition interaction, repeated acquisition procedure, reinforcement of probe responding, discrimination learning, stimulus control transfer, key pecking, pigeons

Stimulus fading refers to a group of procedures for establishing stimulus control through use of two sets of stimuli: originals that control responding at the beginning of fading and new stimuli that do not. The new stimuli gain control of responding by being presented concurrently with the originals while the originals are gradually attenuated. During this process, the new stimuli frequently gain control of responding without the occurrence of errors. Under these conditions, the course of acquisition cannot be measured because error reduction, the typical means of assessing acquisition of stimulus control, does not occur (Sidman, 1977). To measure that acquisition, fading procedures have been modified by presenting the new stimuli alone at various points

in fading. These stimuli have been referred to as probes. Thus, responding to the probes has been used to assess the control acquired by the new stimuli (Doran & Holland, 1979; Fields, 1978, 1979; Fields, Bruno, & Keller, 1976; Lazar, 1977; Moore & Goldiamond, 1964; Schusterman, 1967; Sidman & Stoddard, 1967; Touchette, 1971).

Although probes have been introduced to measure stimulus control, their presentation could also influence acquisition itself. Indeed, this possibility was confirmed when Fields (1979, 1980) demonstrated that earlier introduction of probes reduced the number of fading levels needed for new stimuli to acquire control of responding. Another aspect of probe stimuli that might influence acquisition is the contingency of reinforcement that prevails when probes are presented. In some experiments, S+ and S- probe responding have been differentially reinforced (Doran & Holland, 1979; Fields, 1980, 1981; Moore & Goldiamond, 1964; Sidman & Stoddard, 1967; Touchette, 1971). Alternatively, S+ and S- probe responding have been unreinforced (Fields, 1978, 1979; Fields et al., 1976; Lazar,

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1979). Finally, S+ and S- probe responding have been reinforced nondifferentially (Huguenin & Touchette, 1980; Schusterman, 1967). Although different sets of probe contingencies have been used, none of the studies mentioned compared the effects of those contingencies. The present experiment was designed to assess the effects of different probe reinforcement contingencies upon acquisition of stimulus control in fading. This was done using a within-subjects repeated-acquisition technique within the context of a mixed experimental design (Boren & Devine, 1968).

METHOD

Subjects

Sixteen pigeons, naive at the beginning of the experiment, were used as subjects. They were maintained throughout the experiment at 80% of their free-feeding weights.

Apparatus

Subjects were studied in single-key Scientific Prototype chambers. The operant was defined as depression of the 25-mm diameter response key with a force of at least 0.2 N. Reinforcement consisted of 2.5-s access to mixed grain. Stimuli transilluminating the response key were generated from an IEE in-line projector, and consisted of red and green fields as well as white lines having 0, 45, 90, or 135-degree angular orientations. The intensities of the colors and lines were controlled by changing the value of precision resistors wired in series with the projector bulbs. Thus, 0 ohms corresponded to full intensity, and higher resistance was inversely related to stimulus intensity (Fields, 1978, 1979; Fields et al., 1976; Karpicke & Hearst, 1975; Terrace, 1963). A D.E.C. PDP-8/L minicomputer and Super-SKED software were used to control all experimental contingencies and data recording.

Procedure

Subjects were trained to discriminate between successively presented full intensity (0-ohm) red S+ and green S- stimuli by means of differential autoshaping (Brown & Jenkins, 1968). The two stimuli were presented

in pseudorandom order. Once responding occurred on red and not on green, pecking at the red key (S+) was maintained on a variable-interval (VI) 15-s schedule of reinforcement, in which S+ trials lasted from 5 to 30 s and each terminated upon the presentation of the first reinforcer, while S- occasioned extinction for 20-s periods. All stimuli were followed by 10-s intertrial intervals (ITIs) during which the response key was darkened. The experiment was continued until all presentations of S+ terminated with food delivery, and no pecks at S- occurred. Thereafter, full intensity 0-degree and 90-degree lines were introduced, presented against dark backgrounds. On every third trial, one of the two line probes was presented with a probability of .5 after any color trial in which appropriate responding or nonresponding occurred. If inappropriate responding occurred on a color trial, presentation of the next probe was postponed until the color-trial criterion was satisfied. Each of the lines was presented for an average of 20 s under extinction conditions. Once no responding occurred in the presence of either line for five consecutive presentations, their intensity was reduced to 60 ohms, and each was superimposed on red or green, respectively, forming compound stimuli. The intensity of the lines was then increased in 4-ohm steps until full intensity (0 ohms) was reached. Each increment occurred following the completion of at least four reinforcer-terminated S+ trials and two successive S- trials with no responses. Once lines reached full intensity, colors in both compounds were attenuated in small steps following every fourth S+ presentation, on the average, in which at least two reinforcer-terminated S+ trials and at least two consecutive response-free S- trials occurred. Attenuation in 2-ohm steps followed, until responding occurred in the presence of either probe. Thereafter, attenuation progressed in 1-ohm steps. Prior to each attenuation, the S+ line element and the S- line element were presented alone, once each, as probes. Pecking at the probe stimuli was used to assess degree of control acquired by the lines. The procedure stopped once S+ probe responding exceeded 90% of the prevailing compound S+ rate, and no

Table 1

Experimental Conditions and Stimuli Used				
Fade	Line Tilt (degrees)		Groups	
	S+	S-	Experimental	Control
1	90	0	N	N
2	45	135	R	N
3	90	45	N	N

S- probe responding occurred in two consecutive fading levels.

After completion of the first fade, the procedure was repeated by reexposing each subject to the original red-green discrimination for one or two sessions. Thereafter, new lines (45 degrees and 135 degrees) were presented as described above until no responding occurred in their presence. They were then superimposed on the red and green stimuli, respectively. Finally, fading was conducted as described above. Once completed, the procedure was repeated a third time but with 90-degree and 45-degree lines superimposed on the red and green stimuli. Thus, three fades (F1, F2, and F3) were conducted. The stimuli used in each fade and their functions are indicated in Columns 2 and 3 of Table 1.

To assess the effects of probe reinforcement contingencies, an experimental group of 8 pigeons was studied in which S+ probe responding was not reinforced in Fades 1 and 3, but was reinforced in Fade 2. Responding during each S+ probe was reinforced using the same contingencies that prevailed in the presence of a compound S+. The effect of reinforcement and nonreinforcement of S+ probe responding was assessed by comparing acquisition of stimulus control across adjacent fades within subjects. Using this procedure, reinforcement and nonreinforcement of S+ probe responding was also correlated with line orientations that were unique to each discrimination. Additionally, the three fades were conducted serially. Because both factors covaried with the reinforcement and nonreinforcement of probe responding, either or both might be responsible for any differences observed across fades in the experimental group. To determine whether they were, the remaining 8 subjects were assigned to a control group for which three fades were conducted;

the stimuli used in each were the same as those used in the corresponding fade in the experimental group. In addition, all three fades were conducted with nonreinforcement of probe responding. The reinforcement contingencies that prevailed for S+ probe responding for each fade in each group are summarized in Columns 4 and 5 of Table 1.

RESULTS AND DISCUSSION

The differential effects of nonreinforcement and reinforcement of probe responding can be manifested only after probe responding begins to occur at a level that would produce reinforcers. To assess the effects of reinforcement and nonreinforcement of probe responding, the first fading level at which S+ probe responding would have qualified for reinforcement was identified in each of the three fades. This was accomplished by determining if at least one response occurred after the reinforcer would have become available, whether or not S+ probe responding was slated for reinforcement. The number of fading levels from that point to the completion of a fade was determined and will be referred to as the "corrected number of fading levels." The effects of reinforcement and nonreinforcement of probe responding upon stimulus control acquisition then were assessed by comparing the number of corrected fading levels needed to complete adjacent fades for each subject in the experimental group.

Figure 1 illustrates the number of corrected fading levels needed to complete each discrimination for each subject. Data for subjects in the experimental group are displayed on the left side of the figure. When the first and second fades were compared, fewer corrected fading levels were needed for stimuli to acquire control in the second discrimination than in the first, for 7 of 8 subjects. Likewise, when the second and third fades were compared, 7 of 8 subjects learned the second discrimination in fewer corrected fading levels than the third. The likelihood of at least 7 of 8 subjects learning the second fade faster than the first and third by chance was .035, based upon a binomial test. Using number of trials as a

Fig. 1. Number of corrected fading levels (CFL 1) needed to complete the learning of each discrimination for each subject. Data for subjects in the Experimental group are plotted on the left; those for Control group subjects are plotted on the right. N = nonreinforced S+ probe responding; R = reinforced S+ probe responding.

dependent variable yields equivalent results.

In addition, although the average difference between number of corrected levels needed to learn adjacent discriminations was statistically significant for Fades 1 and 2, and 3, there was no significant difference when the first and third discriminations were compared. The significance of these differences, determined at $p < .05$ using Welsch's (1977) test for pairwise comparisons, is summarized in Table 2.

The statistical analyses of the within-subject comparisons just presented show that reinforcement of S+ probe responding accelerated stimulus-control acquisition in fading when compared to nonreinforcement of S+ probe responding. Such statistical analyses, however, do not specify the magnitude of the effect. That was assessed by determining the number of corrected fading levels needed to complete the second fade relative to adjacent fades. To compare the first two fades, the corrected number of levels needed to complete the first fade (CFL 1) was subtracted from the corrected number of levels to complete the second fade (CFL 2), and the difference was divided by the number of corrected levels to complete the first fade (CFL 1): $(CFL\ 2 - CFL\ 1)/CFL\ 1$. To compare the second and third fade, the corrected number of fading levels to complete the third fade (CFL 3) was subtracted from the corrected number of fading levels needed to complete the second (CFL 2), and the difference was divided by the corrected number of fading levels needed to complete the third fade (CFL 3): $(CFL\ 2 - CFL\ 3)/CFL\ 3$. Both proportions had the same characteristics. When the same number of corrected fading levels were needed to complete adjacent fades, the proportions equaled zero. When fewer corrected fading levels were needed in the second fade than in adjacent fades, the proportions were negative. When more corrected fading levels occurred in the second fade than in the adjacent fades, the proportions were positive. As the relative difference in number of levels needed to complete adjacent fades increased, the absolute value of the proportions increased. Figure 2 shows how reinforcement of probe responding enhanced learning for each subject in the experimental group. Reinforce-

Table 2

Statistical analysis of the differences in the average number of corrected fading levels for pairs of fades, using Welsch's test for pairwise comparisons.

		<i>Experimental Group</i>			<i>Critical Value</i>	<i>P <</i>
		<i>CFL 2 =</i> 15.875	<i>CFL 1 =</i> 33.000	<i>CFL 3 =</i> 34.875		
CFL 2 =	15.875	_____	17.125*	19.000*	16.543	.05
CFL 1 =	33.000	_____	_____	1.875	12.438	.05
		<i>Control Group</i>			<i>Critical Value</i>	<i>P <</i>
		<i>CFL 2 =</i> 38.875	<i>CFL 1 =</i> 40.375	<i>CFL 3 =</i> 48.625		
CFL 2 =	38.875	_____	1.500	9.750	38.955	.05
CFL 1 =	40.375	_____	_____	8.250	29.289	.05

* = statistically significant differences; CFL *i* = average number of corrected fading levels for the *i*-th fade.

ment of probe responding reduced the corrected number of fading levels by an average of 52% when comparing the first and second discriminations, and by an average of 46% when comparing the second and third fades.

Subjects in the control group were studied to determine how stimulus-control acquisition would vary across three fades in which S+ probe responding was never reinforced. Results obtained from these subjects were presented in the right hand column of Figure 1. A comparison of the second discrimination and the first revealed that 3 of 8 subjects learned the second in fewer corrected fading levels than the first. The likelihood of at least 3 of 8 subjects learning the second discrimination faster than the first by chance, was equal to .86 using a binomial test. When the second and third discriminations were compared, 5 of 8 subjects learned the second in fewer corrected fading levels than the third. The likelihood of at least 5 of 8 subjects learning the second discrimination faster than the third by chance, was equal to .36 using the binomial test. In addition, the differences in the number of corrected fading levels needed to learn the discriminations in Fades 1 and 2, Fades 2 and 3, and Fades 1 and 3 were not statistically significant, using Welsch's test for pairwise comparisons (see Table 2). To summarize, when fading was conducted with no reinforcement of S+ probe responding, there were no systematic differences in the number of corrected fading levels needed by the new stimuli to acquire control in each of the three discrim-

inations, learned serially. Finally, when viewed in terms of the overall rate of stimulus-control acquisition, the results were entirely comparable to the acquisition relationships characterized above.

Fields (1978, 1979, 1981) demonstrated that some temporal parameters of probe stimuli influenced acquisition of stimulus control in fading procedures. The present experiment demonstrated that the parameter of reinforcement present during the probe stimuli also influenced acquisition. Thus, the probes used to measure stimulus-control acquisition in fading also influenced the process they were used to measure. To conclude that their use represents a critical shortcoming, however, is neither ineluctable nor appropriate. If stimulus-control acquisition is to be measured in fading, inclusion of probes would appear to be a necessity because other measurement alternatives are not now available. Since various parameters of probe stimuli that produce systematic changes in acquisition of stimulus control in fading have been identified, the influence of probes upon acquisition is measurable and controllable. Rather than viewing probes as being problematic, then, it would be more appropriate to acknowledge the apparently inevitable role they play in the measurement process, and to conceptualize the parameters of the probe stimuli as determinants of acquisition of stimulus control. Indeed, the routine inclusion of probes would provide far more information about such acquisition than is currently available (Rilling, 1977), and might also

Fig. 2. Relative difference in the number of corrected fading levels (CFL 1) needed to learn adjacent discriminations in the Experimental group. The upper graph shows a comparison of Fades 1 and 2, computed with (CFL 2 - CFL 1)/CFL 2. The lower graph shows a comparison of Fades 2 and 3, computed with (CFL 2 - CFL 3)/CFL 3.

permit a systematic integration of the effects of traditional discrimination training and stimulus-fading procedures upon discrimination learning.

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