BEHAVIORAL INTERACTIONS AND STIMULUS CONTROL DURING CONDITIONAL DISCRIMINATIONS¹

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Two pigeons were exposed to factorial combinations of two values of line tilt and two frequencies of houselight flashes. During each of four baseline stages, key pecking in the presence of all four combinations was reinforced according to a variable-interval schedule. The baseline phases were followed by four different conditional discrimination training procedures in which reinforcement availability for pecking in the presence of the line tilts depended upon the houselight frequency. The subjects acquired each conditional discrimination. Behavioral contrast occurred during the acquisition and abolition of the discriminations. Generalization tests, given after each conditional discrimination, revealed that both the line tilt and houselight frequency dimensions controlled pecking only after conditional discriminations in which reinforcement availability depended upon the value of both dimensions.

The present experiment attempted to establish conditional discriminations in pigeons. The experiment had two main purposes: (1) to determine if some forms of conditional discrimination result in multi-dimensional stimulus control, and (2) to determine if the behavioral interactions (*cf.*, Reynolds, 1961) that often occur during simple discrimination acquisition also occur during the establishment of conditional discriminations.

The term "multi-dimensional stimulus control" is commonly used to denote the fact that several stimulus dimensions or properties control a behavior. A controlling relationship between a stimulus property and a behavior is determined by stimulus variation such as is arranged in stimulus generalization tests. If change in a stimulus property produces systematic change in a response measure such as response rate, that property is said to control the behavior in question. If a response measure varies as a function of change in several stimulus properties, multi-dimensional stimulus control is said to exist. Multi-dimensional stimulus control has been reported in several

experiments. Butter (1963), for example, trained pigeons to key peck in the presence of a monochromatic line. When both the wavelength and angular orientation of the line were varied during a subsequent generalization test, responding varied as a joint function of these two properties.

During a conditional discrimination procedure, the reinforcement contingencies for responding in the presence of values of one stimulus dimension are conditional upon the value of a second stimulus dimension. Several experimenters have successfully established conditional discriminations. Yarczower (1971), for example, presented pigeons with white lines of either 0° (vertical) or 40° orientations on red and green backgrounds. During one stage of his experiment, pecking in the presence of both line tilts on the green background was reinforced and pecking in the presence of only the 0° line was reinforced when the background was red. Under these conditions, the pigeons responded in the presence of both line tilts when the background was green and only in the presence of the vertical line when the background was red.

An interesting feature of the conditional discrimination procedure is the symmetrical relationship between the two stimulus dimensions. Consider the following conditional discrimination. Pecking in the presence of one value from one dimension *sl* is reinforced and pecking in the presence of a second value from

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this dimension s_2 is non-reinforced when a value from a second dimension (S_1) is present. When a second value from the latter dimension (S_2) is present, pecking in the presence of s_1 is non-reinforced and pecking during s_2 is reinforced. If a subject acquired such a discrimination one could say that the S_1 - S_2 dimension determined responding in the presence of s_1 and s_2 . Alternatively, one could say that the s_1 - s_2 dimension determined responding in the presence of S_1 and S_2 . Because of this symmetrical relationship between the dimensions, one might expect responding to vary as a function of changes in both dimensions. If this were the case, one could say that conditional discriminations result in multi-dimensional stimulus control. One purpose of the present investigation was to determine if conditional discrimination training does produce multi-dimensional stimulus control. Pigeons were trained on four conditional discriminations. The first was identical to that described above. The second was as follows. During S_1 , pecking in the presence of s_1 was reinforced and pecking in the presence of s_2 was non-reinforced. During S_2 , pecking in the presence of both s_1 and s_2 was non-reinforced. The third discrimination was similar to that used by Yarczower (1971). During S_1 , pecking in the presence of both s_1 and s_2 was reinforced. During S_2 , pecking in the presence of s_1 was reinforced and pecking in the presence of s_2 was non-reinforced. During the fourth discrimination, pecking in the presence of s_1 and s_2 during S_1 was reinforced and pecking in the presence of s_1 and s_2 during S_2 was extinguished. After each discrimination was established, control by the S_1 - S_2 and s_1 - s_2 dimensions was assessed during a generalization test in which values from both dimensions were presented.

METHOD

Subjects

Two adult White King pigeons were maintained at 80% free-feeding weight by grain obtained during experimental sessions and by post-session supplemental feedings when required. Water and grit were always available in the home cage. One pigeon (P-1) was experimentally naive, the other (P-2) had previously served in a variety of experiments.

Apparatus

A BRS-Foringer Model PS-004 pigeon test chamber containing a response key, stimulus display cell, houselight, and grain feeder served as the experimental space. Operation of the response key required a force of approximately 0.2 N. Mounted directly behind the clear plastic key was an Industrial Electronics Engineers' Series 10 stimulus projector that displayed a 2.54 by 0.32 cm (1 by 0.125 in.) white line in either a vertical, horizontal, or 45-degree orientation. Two 7-W white lamps mounted behind a transparent plastic strip located above the response key served as the houselight. A solenoid-operated grain feeder, which allowed access to mixed grain, was located directly below the response key. During feeder operations, the stimulus on the display cell and the houselight were turned off and a 7-W white lamp illuminated the grain in the feeder tray.

Solid-state circuits were used to schedule events such as feeder operations, stimulus presentations, and to record key pecks, the number of reinforcers obtained, *etc.*

Procedure

Before the experiment proper began, the subjects received approximately 2 hr of preliminary training, during which key pecking in the presence of the four stimulus combinations described below was established. The experiment itself consisted of the eight conditions summarized in Table 1. During each condition the subjects were exposed to four, different, two-stimulus combinations. One stimulus of the combination was either a 0° (vertical) or 90° (horizontal) white line produced by the display cell. The second stimulus was a 50-msec flash of the houselight that occurred either 4 or 0.25 times per sec (Hz). The four combinations were: 4-Hz houselight-0° line; 4-Hz houselight-90° line; 0.25-Hz houselight-0° line; and, 0.25-Hz houselight-90° line. The combinations occurred successively, each lasting for a period of 3 min. Each combination was followed by a 5-sec blackout (display cell off, houselight off, reinforcement unavailable). Once all of the combinations had occurred, the sequence of combinations was repeated until each combination had occurred five times per session. The order of occurrence of the four combinations was constant within

Table 1

Summary of Procedure

S+ indicates that pecking in the presence of a particular stimulus combination was reinforced according to a VI 1-min schedule. S- indicates that pecking in the presence of a particular stimulus combination was non-reinforced. Generalization tests, during which stimulus combinations consisting of various houselight frequencies and line tilts were presented, followed Conditions 2, 4, 6, and 8.

Condition	Stimulus Combination				Number of Sessions	
	Houselight Frequency					
	4 Hz	4 Hz	0.25 Hz	0.25 Hz		
	Line Tilt					
	0°	90°	0°	90°	P-1	P-2
1	S+	S+	S+	S+	24	28
2	S+	S—	S—	S+	20	20
3	S+	S+	S+	S+	12	16
4	S+	S—	S—	S—	12	12
5	S+	S+	S+	S+	12	16
6	S+	S+	S+	S—	24	24
7	S+	S+	S+	S+	20	12
8	S+	S+	S—	S—	20	16

a session but varied between sessions. Four different orders of presentation were used: (1) 4 Hz-0°, 4 Hz-90°, 0.25 Hz-0°, 0.25 Hz-90°, (2) 4 Hz-90°, 4 Hz-0°, 0.25 Hz-90°, 0.25 Hz-0°, (3) 4 Hz-0°, 4 Hz-90°, 0.25 Hz-90°, 0.25 Hz-0°, (4) 4 Hz-90°, 4 Hz-0°, 0.25 Hz-0°, 0.25 Hz-90°. The order for a particular session was randomly chosen with the restriction that each of the four orders had to occur once in each block of four sessions.

Conditions 1, 3, 5, and 7 were baseline conditions in which pecking in the presence of all four combinations was reinforced. Reinforcement consisted of 5-sec access to the grain feeder. Reinforcement availability was arranged according to a variable-interval 1-min (VI 1-min) schedule with a rectangular distribution of inter-reinforcement intervals ranging from 0 to 120 sec.

Conditions 2, 4, 6, and 8 consisted of conditional discrimination training. After each training period, a generalization test was conducted. The tests were conducted during extinction. During each test, nine different stimulus combinations were presented: 4 Hz-0°, 4 Hz-45°, 4 Hz-90°, 1 Hz-0°, 1 Hz-45°, 1 Hz-90°, 0.25 Hz-0°, 0.25 Hz-45°, 0.25 Hz-90°. Each combination was presented five times during a test. The order of presentation of the nine combinations was randomized with the restric-

tion that each combination had to occur once before a combination was repeated. Each combination was presented for a 1-min period and was followed by a 5-sec blackout.

Sessions occurred seven days per week at approximately the same time each day.

RESULTS

Acquisition of the Conditional Discriminations

Figure 1 shows response rate, averaged over blocks of four sessions, in the presence of each of the four stimulus combinations for Conditions 1 to 8. Response rate in the presence of the four combinations was more-or-less equal during the baseline conditions (Conditions 1, 3, 5, and 7). The divergence of response rates in the presence of the combinations associated with reinforcement and non-reinforcement during the conditional discrimination training (Conditions 2, 4, 6, and 8) indicates that the subjects acquired the discriminations. Response rate in the presence of the combinations associated with reinforcement increased over the baseline rate as response rate in the presence of combinations associated with non-reinforcement decreased during the establishment of the conditional discriminations. (The one exception to this was that Subject P-1 during Condition 6 showed a supra-baseline rate during only two of the three combinations associated with reinforcement.) This positive behavioral contrast effect disappeared when the baseline conditions were reinstated. This latter effect (negative behavioral contrast) was clearer for Subject P-2 than for Subject P-1.

Stimulus Control Produced by Conditional Discrimination Training

Figure 2 shows relative responding during the generalization tests as a joint function of line tilt and frequency of houselight flashes. Of primary interest during these tests was the shape of the "generalization surface". When relative response rates in the presence of the different combinations are plotted in isometric-orthographic coordinates, as in Figure 2, the "generalization surface" is the surface formed by connecting the various relative response rates. The shape of the surface indicates the existence and nature of stimulus control. If the surface is a plane parallel to the base, neither stimulus dimension controls

Fig. 1. Response rate during the four stimulus combinations. Response rates are averages of four consecutive sessions. The different panels for each subject correspond to the different conditions summarized in Table 1.

Fig. 2. Gradients showing relative responding as a joint function of line tilt and houselight frequency. The different panels for each subject present the results of the generalization tests given after Condition 2 (Panel A), Condition 4 (Panel B), Condition 6 (Panel C), and Condition 8 (Panel D). The number in the rear right-hand corner of the panels is the number of responses emitted during the stimulus combination having a relative frequency of 1.0. The actual number of responses emitted during any particular stimulus combination can be calculated from these numbers. Note that the houselight frequency axis is distorted.

responding. If the surface is a plane tilted laterally on the line tilt axis the line tilt dimension but not the houselight frequency dimension controls responding. If the surface is a plane tilted laterally on the houselight frequency axis the converse is the case. An irregular surface containing peaks and hollows indicates that both dimensions control responding.

Both the line tilt and houselight frequency dimensions controlled responding after the conditional discrimination training arranged during Conditions 2, 4, and 6. (Panels A, B, and C.) Only houselight frequency controlled responding after the Condition 8 conditional discrimination. (Panel D.)

DISCUSSION

The results show that contrast effects are not limited to discriminations in which the stimuli are uniquely associated with either reinforcement or non-reinforcement. Positive behavioral contrast was observed during stimuli that were, depending upon the value of another stimulus, associated with both reinforcement and non-reinforcement. In this respect, the contrast effects observed in this experiment are similar to those observed during mixed reinforcement schedules in which the same stimulus is associated with both reinforcement availability and nonavailability (e.g., Henke, 1972, Pear and Wilkie, 1970).

In addition to demonstrating that pigeons can readily acquire rather complex condi-

tional discriminations involving visual stimuli, the experiment also provided information on the stimulus control produced by conditional discrimination training. It appears that some, but not all, conditional discrimination training procedures result in control by both stimulus dimensions involved. Conditional discrimination training in which reinforcement availability is predictable from the value of one stimulus dimension does not appear to result in multi-dimensional stimulus control. When reinforcement availability is not predictable from the value of a single stimulus dimension, both dimensions control responding. These results suggest that in conditional discrimination situations, only dimensions necessary to predict reinforcement availability are attended to.

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