CONDITIONED REINFORCEMENT BY CONDITIONAL DISCRIMINATIVE STIMULI

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A concurrent-chains schedule was used to examine how a delay to conditional discriminative stimuli affects conditioned reinforcement strength. Pigeons' key-peck responses in the initial link produced either of two terminal links according to independent variable-interval 30-s schedules. Each terminal link involved an identical successive conditional discrimination and was segmented into three links: a delay interval (green), a color conditional discriminative stimulus (blue or red), and a line conditional discriminative stimulus (vertical or horizontal lines). Food delivery occurred 45 s after entering the terminal link with a probability of .5, but its conditional probability (1.0 or 0) depended on the combination of the color and the line stimuli. One of the color stimuli occurred independently of further responding, 5 s after entry into the right terminal link, but it occurred 35 s after entry into the left terminal link. One of the line stimuli occurred independently of responding 40 s after entry into either terminal link, synchronized with the offset of the color stimulus. The initial-link relative response rate for the right was consistently higher in comparison with a control condition in which the color stimuli occurred 20 s after entry into either terminal link. The preference for the short delay to the color conditional discriminative stimuli suggests the possibility of conditioned reinforcement by information about the relation between the line conditional discriminative stimuli and the outcomes.

Key words: concurrent-chains schedules, conditioned reinforcement, conditional discrimination, delay-reduction hypothesis, information hypothesis, pigeons

A stimulus can function as a conditioned reinforcer by correlation with another reinforcing stimulus, and the circumstances under which conditioned reinforcement develops have been studied extensively (e.g., Fantino, 1977; Kelleher, 1966). Lieberman (1972) found that rhesus monkeys observed more frequently when an observing response produced both positive discriminative stimuli (S^+ or S^D) and negative discriminative stimuli (S^- or S^A) as opposed to when it produced only S^- (but see Mueller & Dinsmoor, 1984, 1986). Schrier, Thompson, and Spector (1980) showed that stump-tailed monkeys made observing responses when those responses produced S^- as frequently as S^+ . These observations and related findings have been taken as supporting the suggestion that uncertainty reduction about an outcome, or information about an outcome, is necessary for a stimulus to function as a conditioned reinforcer (Berlyne, 1957, 1960; Bloomfield, 1972; Hendry, 1969), an interpretation implying that S^- as well as S^+ should be an effective conditioned reinforcer.

Dinsmoor, Browne, and Lawrence (1972) showed that pigeons' observing behavior was eliminated when observing produced only S^- , and several other experiments have supported the finding that S^- presentation alone does not reinforce observing behavior (e.g., Blanchard, 1975; Dinsmoor, Browne, Lawrence, & Wasserman, 1971; Dinsmoor, Flint, Smith, & Viemeister, 1969; Jenkins & Boakes, 1973; Kendall, 1973; Mulvaney, Dinsmoor, Jwaideh, & Hughes, 1974; Preston, 1985). Producing S^+ increases reinforcement frequency relative to its absence, but producing S^- decreases it. Thus, frequency of primary reinforcement in the presence of different stimuli is important in establishing conditioned reinforcers. This account has been called the *reinforcement-density hypothesis* (Fantino, 1977). Producing S^+ also constitutes transition into a situation in which the delay to primary reinforcement is reduced relative to that in the absence of S^+ . Fantino (1977) labeled this interpretation the *delay-reduction hypothesis*. Both the reinforcement-density hypothesis and the delay-reduction hypothesis assert that only S^+ should be an effective conditioned reinforcer.

To distinguish the information hypothesis from the delay-reduction and reinforcement-density hypotheses, previous experiments have

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examined whether S- can function as a conditioned reinforcer using an observing-response procedure or a concurrent-chains schedule (Dinsmoor, 1983; Fantino, 1977). Whether only S+ or both S+ and S- function as conditioned reinforcers, these two procedures are based on an implicit assumption that the discriminative stimuli were *directly* correlated with the outcomes. Other procedures for studying conditioned reinforcement are possible, however, and may be valuable in extending the necessary conditions for its occurrence and in assessing whether S- can maintain conditioned reinforcement. For example, a stimulus can be *indirectly* correlated with the outcomes and may function as a conditioned reinforcer. An attempt was made in the present experiment to study the conditioned reinforcing properties of stimuli in a conditional discrimination procedure in which those stimuli were conditionally correlated with the presence or absence of reinforcement.

In a typical conditional discrimination, the outcomes depend on the combination of two sets of stimuli (e.g., S_A/S_B and S_X/S_Y); for example, S_A/S_X and S_B/S_Y are positive, whereas S_A/S_Y and S_B/S_X are negative. The probability of reinforcement in the presence of each individual stimulus is .5. When a response produces S_A or S_B , probability of reinforcement does not increase relative to its absence but information concerning the relation between S_X or S_Y and the outcomes is provided such that the discriminative function of S_X and S_Y is conditional on S_A and S_B .

The present experiment employed a concurrent-chains schedule in which pigeons' key pecks in the initial concurrent schedule occasionally produced either terminal link containing an identical conditional discrimination. Conditioned reinforcing properties of the conditional discriminative stimuli were evaluated by delaying onset of S_A and S_B to different degrees in the two terminal links (5 s vs. 35 s). If these stimuli serve as conditioned reinforcers because they reduce uncertainty about the relation between S_X or S_Y and outcomes, the terminal link with the shorter delay to S_A and S_B should be preferred.

METHOD

Subjects

Two adult experimentally naive pigeons (S1 and S2) were used. Each was maintained at

approximately 80% of its free-feeding weight and after each experimental session was fed measured amounts of grain to maintain its weight. Water and grit were freely available in the home cages.

Apparatus

One hand-manufactured soundproof operant conditioning chamber (37 cm long, 30 cm wide and 30 cm high) was used. Three translucent response keys were mounted 8 cm apart and 23 cm above the floor. The center key was not used. Each key required a minimum force of about 0.15 N to be activated. The operation of a microswitch provided auditory feedback for key pecks. Keys could be illuminated by in-line projectors (I.E.E. 10-0052) with white, green, blue, red, three vertical white lines, or three horizontal white lines.

A solenoid-operated grain hopper, located below the center key, provided 5-s access to grain. No general chamber illumination was used. White noise was present continuously. A UNITEC UP8® microcomputer, located in an adjacent room, controlled the experiment and collected data.

Procedure

Autoshaping was used to train pecking of the two response keys illuminated white. Once reliable responding was established preliminary schedules were introduced, in which Bird S1 was trained only on either the left or right key during alternate sessions, and Bird S2 was trained on both keys concurrently. Following reinforcement of each response, the schedules correlated with white keys were shifted gradually to a variable-interval (VI) 30-s schedule. Terminal links then were added in the following way: First, only the positive stimuli, of compounded colors and lines, were introduced and pecking was reinforced on a fixed-interval (FI) 5-s schedule; second, half of the positive compound stimuli were replaced gradually with negative compounds; third, fixed-time (FT) schedules, correlated with blue or red key lights, were introduced between the initial link and FI 5 s, and the chain schedule was increased to FT 20 s FI 5 s; fourth, green was inserted after the initial link, extending the chain to FT 20 s FT 20 s FI 5 s. The final concurrent-chains schedules are illustrated in Figure 1. S1 was trained on both keys for the first time at this point. The line stimuli were separated from the color stimuli and followed

Fig. 1. The concurrent-chain procedure. The right panel depicts the experimental condition and the left panel depicts the control condition. B = blue, R = red, V = vertical lines, H = horizontal lines.

the offset of the color stimuli. The two conditions are shown in the left and right panels of Figure 1 and are described below.

Control condition. In the initial link, both keys were transilluminated with white lights. Entrance to the terminal links was controlled by two independent VI 30-s schedules (concurrent VI 30 s VI 30 s). When terminal link entrance was made available by either VI schedule, the timer controlling that VI schedule stopped but the timer controlling the other VI schedule continued to operate. The next response on the appropriate key produced the second-link stimulus (green), both timers stopped, and the other key was darkened.

Twenty seconds later (FT 20 s), green changed to blue or red independently of any response. Another 20 s later (FT 20 s), vertical or horizontal lines followed the offset of blue or red. The stimulus-reinforcement condition in the last link for Bird S1 was as follows: If the horizontal lines followed blue or the vertical lines followed red, an FI 5-s schedule was followed by 5-s food delivery and the trial ended; if the horizontal lines followed red or the vertical lines followed blue, a 5-s blackout occurred independently of responding after 5 s, with the following qualifications. A reset contingency during a negative discriminative stim-

ulus ensured that any peck postponed the offset of the line stimulus until 5 s passed without a peck. The stimulus-reinforcement condition for Bird S2 was the reverse: If the horizontal lines followed red or the vertical lines followed blue, the food delivery resulted at the end of the trial; if the horizontal lines followed blue or the vertical lines followed red, the trial ended in blackout.

Experimental condition. The initial-link schedules were the same as in the control condition. Because both subjects showed a positional bias to the left side during the control condition, the earlier onset of blue or red was scheduled on the right side. When a peck produced the second link on the right side, the key turned green and the left side key was darkened. After 5 s, green changed to blue or red. Thirty-five seconds later, either the vertical or horizontal lines followed the offset of blue or red. When the pecking produced the second link on the left side, the left key turned green and the right key was darkened. After 35 s, green changed to blue or red. Five seconds later, either the vertical or horizontal lines followed the offset of blue or red. The last link schedule was the same as during the control condition whether the terminal entry was on the left side or on the right side: If the line

Table 1

Initial link response rate, initial link entry proportion for right, and last link response rate during the last five sessions of each condition for each subject. B = blue, R = red, H = horizontal lines, V = vertical lines.

Subject	Condition	Session	Initial link response rate (per second)		Terminal link entry proportion for right
			Left	Right	
S1	Control 1	1	.65	.12	.40
		2	.72	.11	.40
		3	.67	.11	.42
		4	.62	.12	.40
		5	.61	.09	.44
	Experimental	1	.39	.22	.46
		2	.36	.20	.50
		3	.34	.22	.50
		4	.37	.25	.54
		5	.34	.23	.54
	Control 2	1	.35	.16	.54
		2	.31	.15	.52
		3	.45	.18	.46
		4	.40	.18	.48
		5	.39	.18	.46
S2	Control 1	1	.13	.11	.50
		2	.16	.14	.42
		3	.19	.15	.44
		4	.14	.12	.44
		5	.10	.09	.46
	Experimental	1	.05	.08	.62
		2	.07	.10	.54
		3	.07	.11	.48
		4	.14	.21	.52
		5	.11	.16	.48
	Control 2	1	.07	.08	.48
		2	.06	.06	.50
		3	.06	.06	.50
		4	.05	.05	.46
		5	.06	.06	.50

was positive, the first key peck after 5 s was reinforced. If negative, the trial ended in blackout independently of responding with the qualifying reset contingency described under the control condition.

In both conditions, a 5-s blackout occurred between each trial. If the trial ended in no reinforcement, a total of 10 s of blackout occurred. Daily sessions were conducted 6 or 7 days per week until either 50 trials were completed or 90 min passed, whichever came first. The order of the conditions was as follows: Control 1, Experimental, Control 2. Control 1 and Control 2 were identical.

Each condition remained in effect until the following criteria for stability were met: (a) at least 14 sessions occurred; (b) throughout the last five sessions, the difference between the highest and the lowest values of the five choice

proportions could not span a range greater than .05; (c) an overall discrimination ratio (the sum of response rates in two types of S—stimuli was divided by the sum of rates in the S+ and S—stimuli) of .20 was attained on each side during these five sessions, with the further stipulation that the ratios for those calculated separately for trials ending with vertical lines or horizontal lines should not be more than .25 on each side during every session in which the overall ratio reached .20 (see Honig & Wasserman, 1981). The number of sessions for Control 1, Experimental, and Control 2 were 24, 27, and 29 for S1, and 20, 33, and 71 for S2.

RESULTS

The results are summarized in Table 1 and Figure 2. Based on the relative response rate,

Table 1 (Continued)

Last Link (FI 5-s) Response Rate (per second)							
Left				Right			
(B-H)	(R-V)	(B-V)	(R-H)	(B-H)	(R-V)	(B-V)	(R-H)
0.952	0.424	0	0	0.679	0.290	0.065	0
0.814	0.390	0.096	0.195	0.453	0.553	0	0.040
1.278	0.582	0	0.082	0.796	0.657	0	0.106
1.286	0.631	0.016	0.082	0.692	0.677	0	0.034
1.213	0.803	0	0.229	0.618	0.459	0	0
1.379	0.294	0	0.089	0.541	0.432	0.104	0.065
1.584	0.438	0	0.111	0.574	0.494	0	0.028
1.275	0.405	0.122	0.034	0.636	0.518	0.024	0
1.371	0.319	0.027	0.022	0.505	0.603	0.044	0
1.018	0.157	0.041	0.128	0.591	0.395	0	0
1.949	0.300	0	0	0.631	0.627	0.153	0
2.329	0.355	0.027	0	0.955	0.512	0.018	0.047
2.531	0.313	0	0	0.508	0.334	0	0
2.470	0.218	0	0.028	0.728	0.349	0.098	0
2.392	0.128	0	0	0.712	0.640	0	0.061
0	0	1.530	1.563	0	0.240	1.786	0.890
0	0.245	1.956	1.371	0	0	1.814	0.506
0	0	1.635	2.037	0	0	1.706	0.939
0.268	0	1.414	1.552	0	0	1.543	0.697
0	0.018	2.245	2.067	0	0	2.294	0.837
0	0	1.186	1.396	0.220	0.084	2.072	1.217
0	0	0.884	0.654	0.097	0.200	1.877	1.068
0	0	0.722	0.916	0	0	2.070	1.080
0.165	0	0.890	0.736	0.132	0	1.858	0.456
0	0	1.365	0.253	0.125	0	1.964	1.064
0	0	0.267	0.402	0	0	1.612	0.556
0	0	0.540	0.629	0	0	1.700	0.778
0	0	0.352	0.452	0	0	1.857	0.644
0	0	0.772	0.836	0.053	0	1.202	0.756
0	0	0.446	1.355	0	0.155	1.488	0.841

both subjects showed consistent changes in preferences as a function of delay to the onset of the red or blue lights, with shorter delays preferred relative to the control condition. During the initial control condition, S1 had a strong positional bias toward the left key, whereas S2 had only a slight bias. When changed to the experimental condition, median relative response rate on the right key increased from .15 to .40 for S1 and from .46 to .61 for S2. When the control condition was reinstated, median relative response rate decreased from .40 to .32 for S1 and from .61 to .53 for S2.

Proportions of right-key entry are shown in the third column of Table 1. Both subjects entered the left terminal link during the first control condition more frequently than during any other condition. The preference change

from the initial control condition to the experimental condition may have resulted from the entry difference and the unequal obtained reinforcement frequency in each condition. The proportions of right-key entry were comparable between the experimental condition and the second control condition. The preference did change, however, from the experimental condition to the second control condition even though reinforcement frequency was unchanged. This excluded the possibility that the preference change between the experimental condition and the control condition was controlled exclusively by unequal reinforcement frequencies between the two conditions.

S1's bias for the left side remained throughout the experiment and relative response rates did not exceed .5 in the experimental condition. Although S2 showed a slight positional bias in

Fig. 2. The median relative response rate on each condition for the side with earlier onset of the blue or red stimulus in the experimental condition. The left panel shows the performance of Bird S1 and the right that of Bird S2. The center bar of each panel indicates the experimental (Exp.) condition and the side bars the control (Cont.) conditions. The line on each bar represents the range during the last five sessions of each condition.

each condition, its relative response rates on the experimental condition were above .5, and there was a preference for earlier presentation of blue or red. Regardless of the positional bias, however, manipulating the delay to the color conditional discriminative stimuli had systematic effects on choice.

The response rates in the last link are shown in Columns 4 through 11 of Table 1. The proportion of S- trials without any response was high, raising the possibility that subjects responded differentially not according to the conditional discrimination contingency but according to temporal variables. In the present procedure, if 5 s passed without any response, negative trials ended automatically but positive trials did not. Because the FI 5-s schedule was in effect on the positive trials, the subjects could wait for 5 s without any response, and when the line stimulus did not go out, this indicated that a response would be reinforced. If this contingency controlled behavior, the subjects

would have responded only once after about 5 s; that is, the response rate on the positive trials would have been about .2 or less. In all except three instances, response rates were sufficiently high to make unlikely differential responding according to such temporal control. High response rates on the positive trials and low response rates on the negative trials ensured that the conditional discrimination contingency differentially controlled responding.

DISCUSSION

For both subjects, reducing the delay to blue or red increased the reinforcing value of the conditional discrimination task in the terminal link of the concurrent-chains schedule, as measured by the relative response rates. In spite of arranging the earlier presentation of blue or red on the right side opposite to the biased side on the first control condition, the relative response rates increased as a function of the delay to blue or red but not as a function of the differential frequency of the terminal-link entrance.

The degree to which preference shifted was greater from the first control condition to the experimental condition than from the experimental condition to the second control condition. This asymmetry may be due either to the difference of the terminal entrance frequency between the first shift and the second shift or to hysteresis (Baum, 1974) whereby the preference in the experimental condition was carried over to the second control condition, whether or not such an effect was due to a lack of sensitivity to concurrent reinforcement conditions (Davison & Hunter, 1979; Keller & Gollub, 1977) or bias produced by exposure to the experimental condition (de Villiers, 1977). The present experiment does not provide decisive evidence on this point.

The side with the shorter delay to the blue or red stimulus onset may be viewed as providing information sooner. It also may enable earlier entry into the second FT link of the terminal chain FT FT FI schedule or earlier onset of the blue or red stimulus itself. This suggests two possible explanations. First, Fantino (personal communication, March 21, 1984) noted "Since . . . the later links are more reinforcing, independent of their temporal association to primary reinforcement, it could be that this more immediate conditioned rein-

forcement is maintaining preference." Second, following Kish's (1966) review of sensory reinforcement, presentation of blue or red may have increased the sensory reinforcing power of mere stimulus change by making it more contiguous with the initial-link response. To evaluate these explanations, it is useful to examine the effect of earlier presentation of later link stimuli without any conditional discriminative function.

Duncan and Fantino (1972) and Fantino (1983) showed that, if the length of the terminal links are equal, a simple FI 2x-s schedule is preferred over chain FI x s FI x s, and chain FI 3x s FI 3x s is preferred over chain FI 2x s FI 2x s FI 2x s. Leung and Winton (1986) also showed the preference for tandem FI x s FT 5 s over chain FI x s FT 5 s. The preference for the terminal link with fewer segments suggests the effectiveness of earlier presentation of the later link, because the later link is a more effective signal in terms of proximity to primary reinforcement (Fantino, 1977). Schneider (1972, Experiment 3) did not, however, show a preference for chain FI 20 s FI 20 s over chain FI 38 s FI 2 s. Although the terminal links were composed of chain FI FI schedules, that experiment suggests that the earlier onset of the third link as well as sensory reinforcement may not be a sufficient condition for preference when the length of the terminal link and its number of segments are identical. If the length of the terminal link is equal, the critical variable may be instead the ordinal number of segmented links with different stimuli in the terminal link.

The terminal-link schedule (FT) of the present experiment is different from that (FI) of Schneider's (1972) Experiment 3, so his findings may not be directly relevant. Wallace (1973, reported in Fantino & Logan, 1979, pp. 235-237), however, showed that the segmentation effect was far smaller if the terminal links are composed of FT schedules rather than of FI schedules. Wallace's findings may suggest that, because the present terminal links were of equal length (45 s) and were segmented into an identical number of chains (three) which included two FT schedules, the earlier onset of the second FT schedule link signaled by blue or red cannot determine preference without considering the conditional discriminative stimulus functions of blue or red.

Furthermore, the earlier onset of blue or red without regard to the conditional discriminative stimulus function does not seem to be preferred, also making a sensory reinforcement account implausible.

If one attempts to explain the preference for earlier onset of the later link in terms of the delay-reduction hypothesis, two possibilities must be considered: (a) the long-delayed blue or red stimulus signals a greater reduction in the time to reinforcement than does the short-delayed blue or red stimulus and (b) the short-delayed blue or red stimulus is a stronger conditioned reinforcer of the responses in the initial concurrent VI VI schedule than is the long-delayed blue or red stimulus. In the experimental condition, there is a trade-off between conditioned reinforcing value due to delay reduction and delay of conditioned reinforcement, and it is not clear which way preference should go (although the preference can be explained in an *a posteriori* manner). The delay-reduction hypothesis (and perhaps similarly the reinforcement-density hypothesis) can account for the present findings as an earlier onset of the later link with some elaborations. For example, one may suppose that conditioned reinforcement due to the greater delay reduction accompanied by the blue or red stimulus was weakened by the long delay to its onset still more than was conditioned reinforcement due to the smaller delay reduction by the short delay in the present schedule parameters of the experimental condition. On the other hand, the information hypothesis does predict, in an *a priori* manner, the preference for a shorter delay to the color conditional discriminative stimuli due to an earlier reduction of uncertainty about the relation between the line stimuli and the outcomes. In this respect, the information hypothesis may have the advantage of greater utility over the delay-reduction hypothesis in the present paradigm.

Previous experiments that have studied the necessary and sufficient conditions for conditioned reinforcement have asked whether S-functions as a conditioned reinforcer in simple discrimination tasks (see Dinsmoor, 1983; Fantino, 1977). The results of such experiments suggest that the possibility is unlikely, at least in pigeons. At present, the delay-reduction hypothesis or the reinforcement-density hypothesis is more viable in conditioned reinforcement studied by the simple discrim-

ination procedures. The information hypothesis does not provide a straightforward account and needs some revisions. For example, Schaub (1969, p. 355) presented an additive model of associative and informative sources, and Killeen (1982, p. 225) proposed a multiplicative model including an informational factor. Indeed, negative discriminative stimuli have been shown to function as negative reinforcers and punishers (Blanchard, 1975; Mulvaney et al., 1974; Terrace, 1971). If one accepts the validity of the information hypothesis, the aversive properties of S- appear to overshadow the informational value of S-. The aversive property derives from the fact that the discriminative stimuli are directly correlated with the absence of reinforcement. Conditional discriminative stimuli, such as blue or red in the present experiment, are neither negative nor positive but neutral, because they are neither positively nor negatively correlated with the outcomes. They are, however, informative about the relation between another set of conditional discriminative stimuli (e.g., vertical or horizontal) and the outcomes. The conditional discrimination procedure seems useful in assessing an uncertainty-reduction interpretation of conditioned reinforcement in the absence of possible aversive properties. Such a procedure also extends the necessary conditions for conditioned reinforcement from the direct relation between discriminative stimuli and reinforcers or their absence to more complex relations among discriminative stimuli and the outcomes.

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