*DEVALUATION OF STIMULI CONTINGENT ON CHOICE:
EVIDENCE FOR CONDITIONED REINFORCEMENT*

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Pigeons were presented a concurrent-chains schedule of reinforcement that had terminal links of equal duration. The initial links of the schedule were periodically interrupted by 15-s periods during which an extinction schedule was in effect. The extinction periods were presented on either a response-contingent or a noncontingent basis. Relative response rate for the left alternative decreased when the extinction periods were accompanied by the left terminal-link stimulus. Relative response rate for the right alternative decreased when the extinction periods were accompanied by the right terminal-link stimulus. Relative response rate varied inversely with the frequency of presentation of the extinction periods but was unaffected by presence versus absence of the response contingency in the schedule of extinction-period presentation. Furthermore, relative response rate was unaffected by presentation of extinction periods accompanied by a novel stimulus. When the extinction periods were presented after reinforcement in the left terminal link instead of as interruptions of the initial links, relative response rate for the left alternative was reduced if the postreinforcement extinction period was accompanied by the terminal-link stimulus for the left chain and reduced less if the extinction period was accompanied by the terminal-link stimulus for the right chain. The results demonstrate that the correlation between the terminal-link stimulus and extinction influenced the relative response rate in the initial link.

Key words: conditioned reinforcement, stimulus value, extinction, concurrent chains, choice, pigeons

The concept of a conditioned reinforcer entails an initially neutral stimulus acquiring properties of a reinforcer via a history of correlation with a primary reinforcer. One of the most common procedures to study the properties of conditioned reinforcers uses chain schedules in which the initial links are concurrently available (concurrent chains), and the terminal-link stimuli are correlated with different parameters of primary reinforcement. The critical measure is the relative rate of responding ("preference") in the concurrent initial links of the chains (see Fantino, 1977, for a review). The procedure is seen as useful in the study of conditioned reinforcement if one assumes that choice during the initial links reflects the relative conditioned reinforcement strength of the two terminal-link stimuli. The determinants of conditioned reinforcement

strength can then be assessed by the effects of various parameters of the terminal-link schedules of primary reinforcement on preference.

Early research with the concurrent-chains procedure suggested that preference was determined by the rate of reinforcement during the terminal links. For example, Herrnstein (1964b) demonstrated that the relative rate of responding in initial links matched the relative rate of reinforcement on a variable-ratio schedule in one terminal link and a variable-interval (VI) schedule in the other despite the differing response requirements. But subsequent research demonstrated that a simple arithmetic average of the reinforcement rates in the two terminal links did not predict preference. Herrnstein (1964a), Fantino (1967), and Killeen (1968) compared fixed versus variable terminal-link schedules, and all reported higher rates in the initial link leading to the variable schedules. Killeen also investigated the effects of different distributions of interreinforcement intervals constituting different pairs of VI schedules and demonstrated that preference was determined primarily by the shorter intervals in the VI distribution. Based on these data, Killeen suggested that the appropriate measure of reinforcement rate was the harmonic mean, rather than the arithmetic mean,

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of the interreinforcement intervals. That is, the effective reinforcement rate in the presence of a terminal-link stimulus is given by the mean of the reciprocals of the interreinforcement intervals.

In each of the above studies a single reinforcer was presented during each terminal-link presentation. With that arrangement, the harmonic mean of the terminal-link interreinforcement intervals is equivalent to the average of the inverses of the individual delays between initial-link response that produces the terminal link and the eventual primary reinforcer. Consequently, relative response rates in the initial links might depend simply on the response-reinforcer delays. That is, the response that produces the terminal link may be reinforced directly by the primary reinforcer that follows at the end of the terminal link rather than by the terminal-link stimulus. When terminal links are unequal, the difference between response-reinforcer delays should determine the relative rate of responding in the initial links. Thus, the concurrent-chains procedure may not be relevant to the study of conditioned reinforcement because the notion that the terminal-link stimuli possess conditioned strength becomes superfluous if response-reinforcer delay alone is sufficient to predict preference.

Several lines of evidence are consistent with an interpretation in terms of response-reinforcer delays. For example, Chung and Herrnstein (1967) found that relative response rates matched the relative immediacy of reinforcement (see Williams & Fantino, 1978, for qualifications). In a series of experiments Mazur (1984, 1985, 1986) has shown that choice between stimuli correlated with a fixed delay versus various collections of different delays could be described accurately by the following equation:

$$\text{Value} = \sum_{j=1}^n p_j [A / (1 + KD_j)], \quad (1)$$

where A corresponds to the amount of the reinforcer (on some arbitrary scale), D_j to each delay involved in the comparison, K to a constant representing the delay-discount function for individual subjects, and p_j to the probability of occurrence of each delay. While this equation described data from a large number of experiments involving discrete-trial choice,

Mazur noted that it was not directly applicable to the concurrent-chains procedure because it does not incorporate the effects of the relative durations of the initial and terminal links of the schedules (e.g., Dunn & Fantino, 1982). However, similar descriptions have been applied successfully to a limited range of concurrent-chains schedules and comparable procedures (McDiarmid & Rilling, 1965; Shull, Spear, & Bryson, 1981). For the present purposes, the accurate fit of Equation 1 to a substantial body of data suggests that the delay of reinforcement from the onset of the terminal link is a major controlling variable.

Although relative response rate may be predicted by the cumulative effects of each individual response-reinforcer delay interval, the separate stimuli correlated with the terminal links of concurrent chains seem to play an important role. When the same stimulus is correlated with both terminal-link delay values, preference for the shorter delay is substantially reduced (Williams & Fantino, 1978), sometimes to indifference (Navarick & Fantino, 1976). Such effects suggest that the different stimuli correlated with the terminal-link schedules mediate the effects of the different delays of reinforcement. The issue posed is whether the function of the different stimuli should be interpreted in terms of conditioned reinforcement or in terms of some discriminative function that awaits definition (for a comparable distinction in classical conditioning procedures, see Rescorla, 1982).

One approach to reconciling the concept of conditioned reinforcement with the finding that preference is predicted by the cumulative effects of the individual delay intervals is to assume that the conditioned reinforcement properties of the terminal-link stimuli are defined by the different delays to reinforcement predicted by stimulus onset. Such a view seems implicit in theories of conditioned reinforcement such as delay-reduction theory (Fantino, 1977) and has been explicitly adopted by Shull and Spear (1987). The distinction between this description and description in terms of response-reinforcer delay is that the stimulus-reinforcer delays, rather than the response-reinforcer delays, are said to determine preference. Thus, the two descriptions differ in terms of the events that might be expected to influence preference. The "stimulus-onset" view of conditioned reinforcement suggests that

any method of changing the average delay to reinforcement from stimulus onset should affect behavior, regardless of whether the stimulus onset occurs contingent on a choice response.

An important challenge to both the delayed-reinforcement account and the stimulus-onset conception of conditioned reinforcement is the effect of additional exposures to the terminal-link stimuli during periods of extinction. For example, when a terminal-link stimulus is continued after the last reinforcer has occurred during a terminal-link presentation, preference for that stimulus decreases (Logan, 1965; Poniewaz, 1984). In these studies, the "devalued" stimulus was correlated with a reduction in the overall rate of reinforcement in the absence of any change in the response-reinforcer or stimulus-reinforcer delays during the terminal link. The size of the effect varied directly with the absolute terminal-link durations. These results suggest that the overall rate of reinforcement in the presence of the stimulus may play a significant role independent of the delays of primary reinforcement. However, Shull and Spear (1987) have suggested that the effects of the delays after the last reinforcer in a terminal link are best understood in terms of the increases in the delays to the next reinforcer. That is, the delay to reinforcement from stimulus onset includes not only the time to the first reinforcer but also the time to subsequent reinforcers obtained after the intervening return to the initial links. The increase in overall stimulus-reinforcer delay would therefore devalue the onset of the terminal-link stimulus as a conditioned reinforcer. This account could of course be phrased in terms of the response-reinforcer delays without reference to a conditioned reinforcement function of stimulus onset (e.g., Mazur, Snyderman, & Coe, 1985).

The present study investigated the role of terminal-link stimuli as determinants of the relative rate of responding in the initial links of a concurrent-chains procedure. At issue is whether relative response rates can be predicted by response-reinforcer delays without provision for the value of the terminal-link stimulus as a conditioned reinforcer. The method for making the dissociation was to present occasionally the terminal-link stimuli during the initial-link period, but without reinforcement and without changing the delays

between reinforced initial-link responses and primary reinforcement. Pigeons were presented two response alternatives both on independent VI schedules of entry into equal fixed-interval (FI) terminal links. The critical feature of the procedure is that the initial links of the concurrent chains were occasionally interrupted by 15-s periods of extinction, accompanied by presentations of one of the terminal-link stimuli. The extent to which the addition of extinction periods affects relative response rates should thus provide evidence of the role of the relationship between the stimulus and reinforcement.

A critical comparison was made between conditions in which the extinction periods were presented independently of initial-link responding (i.e., on variable-time (VT) schedules) and conditions in which the extinction periods were contingent on one of the initial-link responses (i.e., on a VI schedule). To the extent that the value of the stimulus as a conditioned reinforcer is decreased by correlation with the periods of extinction, both manipulations should reduce the relative rate of the response that produces the terminal link correlated with the devalued stimulus. But because the terminal-link stimulus should continue to possess some conditioned reinforcing properties (although lessened by the correlation with extinction), the more frequent presentation of that stimulus contingent on the initial-link response might be expected to offset some of the effect of the extinction training. The resulting relative response rate in the initial link leading to the devalued stimulus should then be greater in the condition with extinction periods presented on a response-contingent, VI schedule, than in the VT condition, where their presentation is independent of responding.

Quite a different prediction may be derived from an account based solely on response-reinforcer delays. To the extent that response-contingent delays to subsequent reinforcers contribute to the response rates in the initial links, the occurrence of extinction periods contingent on one of the two alternatives should differentially decrease the response rate to that alternative. In contrast, when the extinction periods are presented independently (on the VT schedule) of initial-link responding, any increase in the delays to the reinforcers obtained upon the next completion of the terminal links should be nondifferential in its effects. Thus,

a view based on response-reinforcer delays should require that relative response rates for the alternative leading to the devalued stimulus be lower when the schedule of presentations of the extinction periods was VI than when it was VT—a prediction in the opposite direction of that suggested by a conditioned reinforcement account.

A second critical comparison in the present study was made between the effects of extinction periods that were correlated with one of the terminal-link stimuli and the effects of extinction periods correlated with a stimulus presented at no other time. To the extent that the response-reinforcer delay is critical, similar outcomes should occur in both cases because the correlation between particular stimuli and extinction periods in no way affects the obtained delays between initial-link responding and reinforcers. However, to the extent that initial-link responding is maintained by the conditioned reinforcement value of the terminal-link stimuli, a greater reduction in preference should occur when the stimulus correlated with extinction was the same as one of the terminal-link stimuli.

The remaining conditions included a comparison between two conditions in which the extinction periods were presented after reinforcement in the terminal link of one of the chains. This manipulation is similar to the postreinforcement "detention time" investigated by Poniewaz (1984). In the first condition extinction was accompanied by the terminal-link stimulus, presented again after reinforcement. In the second condition extinction was accompanied by the stimulus correlated with the terminal link of the alternative chain. Together with the conditions in which extinction periods were presented during the initial links, these two conditions provide an index of the comparability of the various ways of reducing the correlation between the terminal-link stimulus and reinforcement.

METHOD

Subjects

Four male White King pigeons with previous experience in concurrent-chains procedures were maintained at 80% of their free-feeding weights with supplemental feedings after the experimental sessions. Water and grit were freely available in the home cages.

Apparatus

The experimental chambers for Birds S-8, S-10, and S-11 were rectangular and consisted of opaque black plastic side walls, sheet aluminum front and back walls, plywood ceilings, and wire-mesh floors. Each chamber measured 32 cm high, 35 cm wide, and 36 cm deep. There were three response keys, each 2.5 cm in diameter, mounted 23 cm from the floor and 7.25 cm apart, center to center. Access to a solenoid-operated grain hopper, when activated, was available through a rectangular opening 5 cm high and 6 cm wide, located 10 cm below the center key. The chambers were housed within double-walled wooden enclosures.

The chamber for Bird R-5 was constructed of PVC pipe and was cylindrical in shape. The chamber measured 36 cm high, 35 cm in diameter, and had three response keys, each 2 cm in diameter, mounted 24 cm above the floor and 7 cm apart. The opening to the solenoid-operated hopper was 5 cm high, 6 cm wide, and 10 cm below the center key.

In all chambers the response keys could be transilluminated from the rear and required a minimum force of approximately 0.15 N to operate. Feedback for each effective peck on a lighted key was provided by darkening the key for 50 ms. Reinforcers consisted of 3-s access to milo. When operated, the hopper was illuminated by a white light and the keylights were extinguished. General chamber illumination was provided by a houselight mounted above the keys. Ventilation fans and white noise masked extraneous sounds. Scheduling of experimental events and data recording were accomplished with a PDP-8E® computer (Digital Equipment Corporation) located in an adjacent room.

Procedure

All 4 birds had previous exposure to concurrent-chains procedures, and no preliminary training was needed. The concurrent-chains procedure common to all conditions consisted of two equal, independent VI 90-s schedules of entry to FI 15-s terminal links. The initial links (the VI schedules) were programmed on the two side keys and the terminal links were both programmed on the center key. During the initial links, the two side keys were transilluminated with white light, and the first response on a key after a terminal-link entry had been scheduled for that key produced two

events: (a) both side keys became dark and inoperative, and (b) the center key was trans-illuminated with blue light for the terminal link produced by initial-link responses on the left key or by red light for the terminal link of the right alternative. Responding on the terminal-link key resulted in food delivery according to the FI 15-s schedule. Following this reinforcement, the initial links were reinstated.

Throughout all phases of the experiment, the basic manipulation consisted of interrupting the concurrent-chains schedule with 15-s extinction periods. The phases differed according to the stimulus conditions during extinction, the frequency of presentation of the extinction periods, the temporal location in the concurrent-chains schedule at which the extinction periods were presented, and whether the extinction periods were presented on a response-contingent or noncontingent basis. In all cases, responses during an extinction period had no effect other than the 50-ms keylight feedback flash.

Subjects were successively exposed to five series of conditions. Within each series, the order of conditions varied somewhat from subject to subject. The sequence of conditions for each subject is shown in Table 1.

In the first series of conditions, the extinction periods were presented as interruptions of the initial links on either a response-contingent VI 90-s schedule in some conditions, or on a noncontingent VT 90-s schedule in alternate conditions. During VI conditions, the extinction periods were contingent on left-key responses. In the VT conditions the extinction periods could follow a response on either side or a period of nonresponding. The extinction periods were scheduled concurrent with, but independent of, the initial-link schedules. During extinction periods, however, the initial-link schedules were suspended and the side keys were dark and inoperative. In this first series of conditions, extinction was accompanied by the left terminal-link stimulus, a blue center keylight. Baseline conditions in which extinction periods were not added to the basic concurrent-chains paradigm were interspersed with the above manipulations during this series.

The contingencies during the second series of conditions were identical to those during the first series except that the extinction periods were accompanied by a stimulus that was presented at no other time: a black cross on a

white background on the center key. As in the first series, alternate conditions in the second series differed with respect to the response-contingent or noncontingent presentation of the extinction periods.

In the third series of conditions, the extinction periods were again accompanied by the blue center keylight as in the first series, but the frequency of presentation of the extinction periods (VI 90-s in the first two series) was varied. Extinction periods were first presented on a VI 30-s and then on a VI 180-s schedule. One subject, S-8, was also exposed to a VT 30-s schedule of extinction periods.

In the fourth series of conditions, the periods of extinction were presented immediately after each food delivery in the left terminal link and first accompanied by the blue center keylight and later by a red center keylight, the stimulus correlated with the right terminal link.

The final series of conditions varied the frequency of extinction presentations accompanied by the red center keylight and presented on a VT schedule during the initial links of the concurrent chains. Thus, these conditions were similar to those in the first and third series except that the stimulus correlated with extinction was the terminal-link stimulus for the right, rather than the left, alternative.

The daily sessions were terminated after 50 reinforcers or 1 hr, whichever occurred first. Each condition was maintained for either a maximum of 30 sessions or until stability criteria had been satisfied. After 15 sessions the choice proportions for the previous nine sessions were divided into blocks of three. Performance was considered stable when the means of the three blocks differed by no more than ± 0.05 and did not exhibit a trend, that is, neither $M_1 > M_2 > M_3$ nor $M_1 < M_2 < M_3$.

RESULTS

The data for each subject were averaged over the final nine sessions of each condition. Choice proportions for the left alternative (which led to the blue terminal link) were calculated by dividing the number of initial-link responses on the left key by the total number of initial-link responses. Figure 1 shows the results from those conditions in which the added extinction periods were accompanied by the blue keylight. The data from replications of a condition (if any) were averaged with the

Table 1

Schedule values and results for each condition in the order of presentation. Responding in the initial and terminal links is presented in responses per second. For conditions in which extinction was correlated with the blue (B) or the cross (+) stimuli, the response rate during extinction periods is presented as a ratio based on the rate during the left terminal link. For conditions in which extinction periods were correlated with the red (R) stimulus, including such conditions in which the extinction periods were presented after reinforcement (RFT/EXT), the ratio for the extinction response rate is based on the rate during the right terminal link.

Series	Schedule of extinction presentation	Proportions on the left alternative:			Absolute rate in initial links	Response rates terminal links		Normal-ized rates in extinc-tion	Sessions to stability
		Resp.	Time	Reinf.		Left	Right		
Subject R-5									
I	VT 90 (B)	.05	.13	.31	1.83	1.11	1.79	0.89	16
	None	.44	.52	.50	0.92	2.01	2.07	—	15
	VT 90 (B)	.26	.36	.49	0.95	1.66	2.29	1.02	15
	VI 90 (B)	.14	.18	.48	1.19	1.64	2.19	1.02	15
	VT 90 (B)	.21	.21	.52	0.96	1.84	2.41	0.89	18
II	VT 90 (+)	.41	.44	.53	1.08	2.53	2.41	0.01	21
	VI 90 (+)	.39	.44	.48	1.28	2.80	2.66	0.01	18
III	VI 30 (B)	.06	.16	.40	2.98	1.98	2.50	0.84	26
	VI 180 (B)	.31	.34	.46	1.04	1.93	2.02	0.95	15
IV	RFT/EXT (B)	.28	.35	.43	0.84	1.90	1.85	0.22	30
	RFT/EXT (R)	.36	.41	.47	0.98	1.74	1.22	0.16	27
V	VT 90 (R)	.43	.51	.45	1.11	0.87	0.78	0.88	30
	None	.36	.46	.47	0.96	0.47	0.53	—	30
	VT 30 (R)	.47	.53	.43	1.15	0.28	0.35	1.06	28
	None	.37	.41	.44	0.68	0.29	0.49	—	22
Subject S-8									
I	None	.52	.55	.51	0.66	2.02	2.17	—	25
	VT 90 (B)	.39	.43	.54	0.72	1.78	2.06	0.89	23
	VI 90 (B)	.29	.27	.51	0.89	1.57	1.91	0.97	30
	VT 90 (B)	.29	.33	.52	0.84	1.51	1.85	0.82	30
II	VT 90 (+)	.46	.49	.51	0.90	1.86	2.10	0.01	15
	VI 90 (+)	.47	.49	.50	1.11	2.32	1.96	0.00	19
III	VI 30 (B)	.17	.14	.46	1.62	1.10	1.77	0.95	22
	VI 180 (B)	.45	.46	.52	0.95	1.06	1.44	1.03	20
	VT 30 (B)	.07	.13	.43	1.60	1.20	1.07	0.61	30
IV	RFT/EXT (B)	.37	.35	.49	0.98	1.96	1.51	0.18	18
	RFT/EXT (R)	.45	.42	.51	1.08	2.04	1.52	0.16	30
V	VT 90 (R)	.56	.59	.50	0.80	0.67	0.43	0.91	29
	VT 30 (R)	.94	.89	.54	1.63	1.03	0.69	0.54	28
	None	.55	.57	.49	0.96	0.98	1.08	—	17
Subject S-10									
I	VI 90 (B)	.14	.15	.45	2.07	1.90	2.18	0.97	24
	VT 90 (B)	.13	.15	.46	1.70	2.01	2.21	0.88	19
II	VT 90 (+)	.57	.52	.51	1.33	2.34	2.32	0.00	30
	VI 90 (+)	.48	.48	.49	1.22	2.39	2.28	0.00	20
III	VI 30 (B)	.10	.16	.42	2.00	1.78	1.98	0.94	30
	VI 180 (B)	.19	.19	.41	1.88	2.17	2.00	0.94	27
IV	RFT/EXT (B)	.26	.23	.50	1.08	2.16	1.94	0.09	30
	RFT/EXT (R)	.30	.20	.48	1.07	2.27	1.96	0.18	18
V	None	.43	.55	.50	1.11	1.59	1.27	—	30
	VT 90 (R)	.48	.51	.52	1.26	2.29	1.89	0.97	29
	VT 30 (R)	.76	.82	.51	1.62	2.47	1.89	0.89	28
	None	.44	.47	.49	1.30	2.56	2.38	—	23

Table 1
(Continued)

Series	Schedule of extinction presentation	Proportions on the left alternative:			Absolute rate in initial links	Response rates terminal links		Normal-ized rates in extinction	Sessions to stability
		Resp.	Time	Reinf.		Left	Right		
Subject S-11									
I	VT 90 (B)	.18	.33	.48	1.27	3.60	2.71	0.94	17
	None	.41	.56	.53	1.22	2.94	3.23	—	26
	VT 90 (B)	.38	.45	.50	1.04	3.56	3.34	0.96	22
	VI 90 (B)	.36	.45	.49	1.07	4.94	3.80	0.94	24
	VT 90 (B)	.33	.39	.52	1.02	3.98	4.48	0.95	19
II	VT 90 (+)	.44	.59	.45	1.37	3.24	3.13	0.01	20
	VI 90 (+)	.52	.55	.53	1.45	3.11	2.93	0.01	22
III	VI 180 (B)	.30	.49	.50	0.84	1.81	1.57	0.96	16
IV	RFT/EXT (B)	.25	.42	.51	1.41	2.65	1.89	0.17	28
	RFT/EXT (R)	.34	.50	.50	1.12	2.55	2.04	0.13	18
V	None	.45	.63	.51	1.09	1.31	1.10	—	18
	VT 90 (R)	.59	.74	.56	0.95	1.98	1.98	0.86	21
	VT 30 (R)	.41	.53	.50	1.57	3.27	2.35	0.49	30
	None	.45	.51	.52	1.17	2.20	2.37	—	16

results of the earlier exposure to that condition. Also shown for comparison are the mean choice proportions from the baseline conditions in which no extinction periods were presented and the results from conditions in which the cross pattern, presented at no other time, was paired with extinction. The results are shown in an order different from the actual sequence of presentation to facilitate the critical comparisons. A more detailed presentation of the results is provided in Table 1.

The effects of different frequencies of extinction presentation may be seen in Figure 1. In general, the relative rate of initial-link responding on the side that produced the blue terminal link decreased regularly as the frequency of blue extinction presentations was increased. Averaged over all 4 subjects the choice proportions for the different frequencies of extinction-stimulus presentation were 0.31, 0.23, and 0.09 as the average interval between presentations decreased from 180 to 90 to 30 s. In comparison the average relative rate of responding was 0.45 during the baseline conditions without extinction periods and 0.47 during conditions with the cross pattern correlated with extinction. Thus, whereas extinction presentations correlated with a different stimulus had no effect on preference, extinction paired with the blue terminal-link

stimulus decreased preference for that terminal link, with this effect monotonically related to the frequency with which the blue stimulus was paired with extinction.

Figure 1 also shows that there was no systematic difference between VI and VT presentations of the extinction periods, when accompanied either by the cross stimulus or by the blue keylight. The mean preference with the cross pattern was 0.46 with the VI schedule and 0.47 with the VT schedule of extinction periods. When the blue stimulus was presented during extinction, the preference (averaged first across replications for each subject and then across subjects) was 0.23 with the VI 90 schedule and 0.24 with the VT 90 schedule.

Figure 2 shows results obtained when the additional extinction periods were correlated with presentations of the red keylight, the stimulus for the terminal link of the right chain, on a response-independent schedule. Also shown for comparison are the average results from conditions without extinction periods (baseline). In comparison to the extinction presentations with the blue stimulus, the effects are more variable and generally weaker, although 3 of the 4 subjects showed effects in the analogous direction as before, namely, decreasing preference for the right alternative

Fig. 1. Choice proportions for the left alternative for conditions in which both the left terminal link and the 15-s extinction periods, presented within the initial link, were correlated with the blue keylight. Also presented are the mean choice proportion for each subject in the baseline conditions (no extinction periods) and the proportions for conditions in which extinction was correlated with a cross pattern (+).

Fig. 2. Choice proportions for the left alternative for conditions in which the right terminal link and 15-s extinction periods, presented within the initial link, were both correlated with the red keylight. The diagonally striped bar for Subject S-11 represents the mean choice proportion from the last nine sessions prior to evidence of a discrimination of the extinction contingency in the VT 30 condition. The unfilled bar represents the choice proportion after stability in subsequent sessions in the VT 30 condition. For comparison, the mean baseline proportion for each subject is also presented.

(and hence increasing preference for the left alternative) as the frequency of extinction periods signaled by the right terminal-link stimulus increased. The pattern of results for the remaining subject (S-11) differed, with evidence of discrimination based on the extinction contingency, and is discussed below. It should be noted that, for all subjects, these conditions were presented late in training after many conditions in which preference had been in the opposite direction. This extensive training may have contributed to the more variable results during the reversal. In any event, the results of the manipulation of the frequency of extinction periods signaled by the red keylight are generally symmetrical to the results obtained by varying the frequency of extinction signaled by the blue stimulus.

Figure 3 shows the effects of extinction periods presented after reinforcement in the left terminal link. Presented for comparison are the average results from the baseline conditions without extinction periods. Note that the terminal-link extinction periods, whether correlated with the blue or the red keylight, always followed the blue terminal link and thus served to increase the delay to the next food presentation on the left alternative. However, the relative delay from onset of the red keylight

(combined over presentations of the stimulus) is longer and the relative rate of reinforcement in the presence of the red keylight is lower when extinction periods were signaled by red. Thus, in this comparison, the relative response rate on the left alternative should be greater when extinction is signaled by red than when extinction is signaled by blue. Figure 3 confirms this prediction. The average relative response rate on the left alternative was 0.45 during baseline, 0.29 when blue accompanied the extinction period, and 0.36 when red accompanied extinction. If the average rate of reinforcement in the presence of the stimulus influences conditioned reinforcement value, the effect of reinforcement rate can be separated from the effect of the delay to the next reinforcer if it is assumed that the two effects are additive and independent of whether red or blue was correlated with extinction. Thus, the deviation from baseline when blue signaled extinction ($0.45 - 0.29 = 0.16$) should be the sum of two effects, decreased rate of reinforcement in the presence of the stimulus and increased delay to reinforcement from stimulus onset, whereas the corresponding deviation when red signaled extinction (0.09) should represent the difference between the two effects. Accordingly, the isolated effects of the rate of reinforcement in the presence of the stimulus should be one-half the difference between the two deviations ($0.07/2 = 0.035$), whereas the effect of the stimulus-reinforcer delay should be the deviation from the baseline minus the effects of reinforcement rate when blue was the stimulus correlated with extinction (thus, the delay effects = 0.125). These calculations apply to the mean data. Corresponding calculations for individual Subjects R-5, S-8, S-10, and S-11 showed the effect of the delay to the next reinforcer to be 0.07, 0.13, 0.16, and 0.14, and the effect of the rate of reinforcement in the presence of the stimulus to be 0.04, 0.04, 0.02, and 0.05, respectively. Note that for all subjects the effect of the correlation between the stimulus and extinction in these two manipulations was much smaller than the effect of increased delay to the next reinforcer and also smaller than the effect of the stimulus-extinction correlation when extinction periods were presented during the initial links. Given the low rates of responding during the extinction periods presented after reinforcement, this latter result is consistent

Fig. 3. Choice proportions for the left alternative for conditions in which extinction periods followed reinforcement on the left alternative. Baseline data from sessions in which no extinction periods were presented are included in the figure for comparison.

with the correlation (discussed below) between the degree of discrimination and the magnitude of the effects observed for Subject S-11 when extinction periods interrupted the initial links.

Evidence of the degree of discrimination based on the extinction contingency is provided in Table 1. For comparison, response rates during the extinction periods have been normalized with respect to either the rate during the left terminal link or, for those conditions with a red extinction stimulus, the rate during the right terminal link. When the extinction presentations interrupted the initial links and were correlated with the blue keylight, the response rates during extinction were similar (with ratios close to 1.00) to the rates during the terminal link of the left alternative. That is, there was no evidence of unequal response rates (discrimination) in the presence of the blue stimulus during the extinction period and the blue stimulus during the terminal link. There was not a consistent difference between the ratios from the VT versus VI schedules of extinction presentations when extinction was correlated with the blue keylight. In contrast, the response rates during extinction correlated with the cross pattern were uniformly very low (no ratio greater than 0.01). When extinction, correlated with either the blue or red stimulus, followed reinforcement, the response rates during extinction were substantially lower than the rates during the corresponding terminal link (a mean ratio of 0.16). Thus, response rates during extinction correlated with the blue

keylight and presented during the initial links reflect a general absence of a discrimination based on the extinction contingency. Rates during extinction correlated with the cross pattern indicate clear discrimination and the rates during extinction following reinforcement suggest an intermediate, generally high degree of discrimination.

For 2 subjects (S-8 and S-11), a discrimination appears to have developed during the course of response-independent presentations of extinction periods during the initial links in the final series of conditions when extinction was correlated with the red keylight. In both cases the ratio of the response rate during extinction to the rate during the right terminal link dropped substantially following transition to the more frequent (VT 30-s) schedule of extinction periods. For S-8, the effect of the correlation between the red stimulus and extinction was apparently unaffected by the discrimination; the choice proportion for the left alternative increased to 0.94 despite the development of a discrimination during the VT 30-s condition. For S-11, in contrast, over the course of the VT 30-s condition the levels of preference paralleled the discrimination ratio. That is, following preliminary training on the VT 30-s condition, response rates during extinction generally approximated the rates in the right terminal link (mean ratio of 0.75), and choice proportions for the left alternative were nearly stable at 0.79. Over the final nine sessions of the condition, the ratio of extinction to terminal-link response rates was 0.49, and the mean choice proportion was down to 0.41. The discrepancy between the levels of preference with and without evidence of discrimination based on the extinction contingency is represented in the rightmost columns for Subject S-11 in Figure 2.

The response rates for both terminal links are shown in Table 1. When the extinction presentations interrupted the initial links, the response rate during the terminal link correlated with the extinction stimulus (whether blue or red) was lower than the response rate during the alternative terminal link in 23 of 30 possible comparisons. Thus, in those conditions in which the level of preference indicated a substantial effect of the correlation between extinction and the terminal-link stimulus, the terminal-link response rate during that stimulus generally reflected that effect.

Moreover, the discrepancy between response rates in the terminal links was usually greater as the frequency of extinction presentation increased. When extinction followed reinforcement on the left chain schedule, the response rate during the terminal link of the left alternative was higher than the rate during the terminal link of the right alternative in every comparison, despite the reduced (from baseline) preference for the left alternative in these conditions. The latter finding may be interpreted as a contrast effect produced by a following period of extinction.

Other features of Table 1 deserve mention. The allocation of time on the two alternatives followed the pattern of relative response rates. With the exception of the first condition for Subject R-5, the obtained distributions of reinforcement did not vary substantially from the programmed distribution (0.50). Finally, absolute response rates during the initial links tended to vary directly with the rate of presentation of the extinction periods.

DISCUSSION

The principal finding of this study was that the relative rate of responding in a concurrent-chains procedure is affected by the presentation of extinction periods paired with a terminal-link stimulus in the absence of changes in the response-reinforcer contingencies in the initial links. Reductions in the correlation between a terminal-link stimulus and reinforcement reduced the relative rate of initial-link responses leading to that stimulus. The relative rate of responding was unaffected by presentation of extinction periods correlated with a different stimulus. There was no systematic difference between the effects of VI and VT presentations of extinction periods.

The results clearly reveal the inadequacy of any account of choice that does not include provision for the role of the terminal-link stimuli (e.g., Mazur *et al.*, 1985). The delay between choice responding and reinforcement in the terminal links is an inadequate predictor of relative response rate, as shown by two major findings. First, the failure to find any effect of the extinction periods correlated with a unique stimulus, although large effects were obtained when extinction was correlated with one of the terminal-link stimuli, demonstrates that the delays from the initial-link response

to reinforcement alone were not the important variable. The response-reinforcer delays were identical in the two cases. Second, the use of a VI schedule for presentation of extinction periods differentially increased the time to subsequent reinforcers for the response alternative on which it was contingent. Nevertheless, the relative rate of responding for that alternative was not reduced relative to when a response-independent schedule was used for presenting the extinction periods. Thus, again the differential times to reinforcement from the two choice responses did not predict relative response rate.

Given that some provision must be made for the role of the terminal-link stimuli, the issue posed is how such a role should be characterized. One possibility is that the conditioned reinforcement value is a function of the time to reinforcement measured from stimulus onset. The combined effects of different delays would then be determined by some averaging that weights the shorter delays more heavily (e.g., Equation 1). Such a view is consistent with the majority of the present data and has been utilized by Shull and Spear (1987) to account for other data from comparable procedures. Thus, the reason that the addition of extinction periods decreased preference may be that the time to reinforcement signaled by stimulus onset was increased in direct proportion to the frequency of the extinction presentations.

Some aspects of the present findings provide strong support for the stimulus-onset view of conditioned reinforcement. In two conditions (shown in Figure 3) extinction followed reinforcement in one of the terminal links. In one of these conditions extinction was correlated with the preceding terminal-link stimulus; in the other condition, extinction was correlated with the stimulus presented during the terminal link on the alternative chain schedule. In both cases preference was reduced for the terminal link followed by extinction. This effect was somewhat reduced when the stimulus correlated with extinction was the same as that of the terminal link of the alternative chain, but the effect of the particular stimulus correlated with extinction was small in comparison to the delay effect per se. Moreover, the effect of the particular stimulus correlated with extinction is itself consistent with the stimulus-onset view: The following ex-

tinction period increased the delay between the onset of the terminal-link stimulus and the subsequent reinforcers only for the stimulus preceding the extinction period when the stimulus correlated with extinction was the same as the preceding terminal-link stimulus (when blue was correlated with extinction), but increased the delay for both terminal-link stimuli when the stimulus correlated with extinction was that of the alternative terminal link (when red was correlated with extinction). The latter is true because the onset of red after reinforcement for responding during blue not only increased the time between the onset of blue and reentry into the initial links but also increased the average time between the onset of red (averaged over both types of presentations) and food. Thus, the effect of the delay variable should be smaller in the latter case, as shown in Figure 3.

However, there are other data that pose difficulties for the stimulus-onset view of reinforcement. The most important is that delays to reinforcement signaled by stimulus onset differ in their effects as a function of whether or not the same stimulus continues throughout the delay period. As shown by several studies (Duncan & Fantino, 1972; Leung & Winton, 1985, 1986; Wallace, 1973), pigeons strongly prefer a simple FI schedule over a chain FI FI when the two schedules are of the same total duration. Thus, time from stimulus onset per se does not accurately predict the conditioned reinforcement value of stimulus onset.

An alternative to the stimulus-onset view of conditioned reinforcement is that the conditioned reinforcement value of a terminal-link stimulus is simply a function of the average rate of reinforcement in its presence. The present data (with the exception of those in Figure 3) are generally consistent with this description, but it appears to be severely challenged by previous demonstrations that subjects strongly prefer VI schedules over comparable FI schedules (see the discussion in the Introduction regarding the harmonic mean and Equation 1). Although such findings provide *prima facie* evidence against reinforcement frequency in the presence of the stimulus as a predictor of conditioned reinforcement value, it is possible that they reflect the effects of discrimination of the FI component. That is, previous work with FI schedules (B. A. Schneider, 1969) has shown that, functionally,

these are two-stage schedules, because the first part of the FI interval can be regarded as extinction, followed by a variable schedule of reinforcement of virtually constant responding. Given this interpretation, the FI terminal link of a concurrent-chains procedure should be regarded as a multiple extinction VI component, and preference for a VI versus the FI terminal link would then be expected simply on the basis of segmentation effects (e.g., Duncan & Fantino, 1972). The remaining data against a simple rate-of-reinforcement interpretation—those showing that later reinforcers in a terminal link with multiple reinforcers have a substantially diminished impact on behavior as a function of the time from terminal-link onset (e.g., Davison, 1968; Hursh & Fantino, 1973; Shull *et al.*, 1981)—could be incorporated in a similar fashion. The nominal stimulus present throughout the terminal link could be regarded as functionally quite different after successive reinforcers because of the salient stimulus properties of those events within the terminal link. These interpretations are of course quite speculative, but Vaughan's (1985) recent theoretical analysis suggests that such effects are compatible with an analysis of choice that depends solely on the conditioned value of the terminal-link stimulus as determined by the rate of reinforcement in its presence. However, whether such an approach can match the predictive accuracy of quantitative descriptions such as Equation 1 remains uncertain.

One facet of the present data presents some difficulties for the notion of conditioned reinforcement, regardless of how conditioned value is calculated. As noted in the Introduction, the comparison between the VI and VT presentations of the extinction periods was designed to separate simple response-reinforcer delay effects from those of conditioned reinforcement value. Thus, the delay hypothesis predicts that the VI presentations would produce the lower level of preference for the terminal link associated with the extinction stimulus, whereas the conditioned reinforcement notion predicts that VT presentations would produce the lower level of preference. The rationale for the latter prediction is that the terminal-link stimulus should be devalued by extinction on either schedule, but since it should retain some value, the increased number of response-contingent presentations on the VI schedule should par-

tially compensate for the devaluation effect. But, as shown in Figure 1, there was no consistent difference between the two types of schedules. The reasons for this failure are unclear and must be considered a problem for a conditioned reinforcement account.

Regardless of the correct theoretical interpretation of the present data, they have implications for the analysis of a variety of previous findings. First, they seem to conflict with the results of Rescorla (1982, Experiment 3) who studied conditioning with serial conditioned stimulus (CS) compounds in an auto-shaping procedure. The issue was whether the beneficial effects of a second CS intervening between the initial CS and the reinforcer (compared to a trace conditioning procedure in which the initial CS was separated from the reinforcer by an equivalent delay interval) were due to second-order conditioning. In other words, was the facilitory effect engendered by the intervening stimulus due to the "value" of that stimulus? As a test of the second-order conditioning interpretation, Rescorla explicitly devalued the intervening stimulus element by separate extinction training. Nevertheless, the facilitory effect of the intervening stimulus continued unabated; the degree of responding elicited by the initial CS was similar to that when no extinction training had occurred. On the basis of these and other results, Rescorla argued that the intervening stimulus facilitated conditioning not because of its own reinforcing properties but because it served a "catalytic" function for the association between the initial CS and the primary reinforcer.

Rescorla's autoshaping procedure was quite similar to a chain schedule except that the transitions between successive stimuli were response independent. Thus it is somewhat surprising that the devaluation of the intervening stimulus, which was at least ostensibly similar to the extinction presentations in the present procedure, had no differential effect, although substantial effects were evident here. The reason for this discrepancy is unclear, but several procedural differences are apparent. Perhaps most important is that Rescorla presented his extinction training after the initial conditioning had occurred, whereas in the present study the extinction presentations continued throughout training. In addition, the delay between the initial CS and the food reinforcer was only 5 s in Rescorla's study and the delay

between terminal-link entry and food delivery was 15 s in the present procedure, a difference that may be important in light of the findings of Cronin (1980) and Winter and Perkins (1982) that the impact of conditioned reinforcement "value" becomes more apparent with longer delays. Whatever the reason for the difference in the results, the present findings do demonstrate that the extinction contingencies employed here can alter the degree of conditioning maintained by a delay-of-reinforcement procedure.

The present findings have implications for the study of percentage reinforcement. If only the conditions involving the response-dependent (VI) extinction presentations are considered, the procedure is equivalent to a concurrent chain in which one of the terminal links ends in reinforcement some percentage of the time. For example, the conditions in which the extinction presentations occurred on a VI 90-s schedule were similar to a choice between 100% and 50% reinforcement in the terminal links. Thus, preference for the alternative providing 100% reinforcement might be expected. However, this prediction is uncertain because the partially reinforced terminal link occurred more frequently. Just as there was a 2:1 ratio in the percentage of reinforcement in the presence of the 100% terminal link, there was a 1:2 ratio in the frequency of that terminal link contingent on the choice response. That is, choice involved a trade-off between the percentages of reinforcement and the frequency of the terminal-link stimuli. Given that frequency of reinforcement is typically more potent than amount in simple concurrent schedules (J. W. Schneider, 1973; Todorov, 1973; Todorov, Hanna, & Bittencourt de Sá, 1984), frequency might be expected to dominate here as well. But the obtained results were just the opposite: Preference for the partially reinforced terminal link decreased regularly with the frequency of its presentation, presumably because the frequency of presentation was inversely correlated with the percentage of reinforced stimulus presentations. Moreover, the failure to obtain a difference between the VI and VT conditions suggests that the response contingency per se for presentation of the 50% stimulus had little or no impact.

A second point worth noting is that the response-dependent presentation of extinction signaled by a unique stimulus did not reduce

the level of preference from baseline levels. Again the role of the terminal-link stimulus seems to be important. Here, the frequency of extinction periods was not correlated with the percentage of reinforced presentations of the terminal-link stimulus and preference was not affected. One implication of these results may be that in percentage reinforcement procedures with differential signals for the outcomes of the terminal links (Fantino, Dunn, & Meck, 1979; Kendall, 1985; Moore 1976), preference may vary with the frequency (and other parameters) of terminal links that include primary reinforcement, rather than with the frequency of terminal links in which primary reinforcement does not occur. When the outcomes, reinforcement or extinction, are not differentially signaled (Kendall, 1974; Moore, 1976; J. W. Schneider, 1968; Spetch & Dunn, 1987; and in most conditions of the present study), preference is determined by the relative strength of the terminal-link stimuli.

Finally, the present results are consistent with previous studies showing that preference is not necessarily predicted by the rate of responding in the presence of the terminal-link stimuli. Although there was generally a correlation between response rate and preference when extinction presentations interrupted the initial links, the opposite effect occurred with other manipulations. Presentations of the blue or red keylights following the terminal-link reinforcers increased the response rate prior to reinforcement (always in the presence of the blue keylight); yet preference for that terminal link was reduced below baseline level. The most likely cause of the increase in response rate is a contrast effect caused by the following period of extinction (see Williams, 1979, 1981). This finding suggests that increases in terminal-link response rate attributable to contrast need not correspond to increases in the conditioned reinforcement value of the terminal-link stimuli. A similar dissociation between contrast and preference in a related choice procedure has been demonstrated by Williams (1982, Table 13-3).

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