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EFFECTS OF UNSIGNALED DELAY OF REINFORCEMENT ON PREFERENCE AND RESISTANCE TO CHANGE

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In Phase 1, pigeons were trained on a concurrent chain in which a 3-s unsignaled delay of reinforcement was imposed on responding in a terminal link in some conditions. Preference for that terminal link was always reduced in comparison with conditions in which there was no delay, substantially so for 3 of the 4 pigeons. In Phase 2, pigeons responded in a two-component multiple schedule. The scheduled rates of reinforcement were equal, but a 3-s unsignaled delay was imposed in one component. Resistance of responding to prefeeding and extinction was reduced in the delay component for the same 3 subjects for which the data had shown strong effects of delay on preference. Systematic observation revealed differences in response topography. In the delay component, subjects oriented more closely to the key and responses were less forceful compared with the no-delay component. Our results give further evidence that preference and resistance to change covary within subjects. However, they challenge the premise that the critical determiners of preference (i.e., terminal-link value) and resistance to change (behavioral mass) may be quantified purely in terms of stimulus–reinforcer relations.

Key words: choice, resistance to change, unsignaled delay of reinforcement, concurrent chains, multiple schedules, key peck, pigeons

Recent models of preference in concurrent chains and resistance to change in multiple schedules emphasize the importance of molar, Pavlovian stimulus–reinforcer relations as determiners of operant behavior (Grace, 1994; Nevin, 1992b). These models quantify the effects of reinforcement history with respect to a particular stimulus as a function of the delay to reinforcement signaled by that stimulus (or equivalently, the rate of reinforcement in its presence), and include no explicit role for the response–reinforcer relation.

For example, Grace (1994) proposed the contextual choice model, an extension of the generalized matching law, as a model for preference in concurrent chains (Baum, 1974; Davison, 1983). In this procedure, subjects' responses during concurrently available initial links are reinforced by access to mutually exclusive terminal-link schedules of primary reinforcement. Choice in the initial links has typically been interpreted as a measure of the relative effectiveness of the terminal-link stimuli as conditioned reinforcers or the relative value of the terminal-link schedules. Grace (1994) showed how the assumption that terminal-link value was determined solely by the delay to reinforcement signaled by its onset gave an excellent account of much archival data, when the temporal context of reinforcement (i.e., overall initial- and terminal-link durations; Fantino, 1969) was included as an additional exponent in the model and assumed to be independent of value.

In several experiments, Grace and Savastano (1997) tested the independence of temporal context and value and found that the delay to reinforcement signaled by a terminal-link stimulus was generally a good predictor of preference for that stimulus in different types of novel-pair probe tests. In addition, prior studies have shown that the terminal-link response–reinforcer contingency often has little or no effect on preference. For example, Herrnstein (1964) arranged a

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concurrent chain in which pigeons chose between variable-interval (VI) and variable-ratio (VR) terminal links; preference was determined by relative reinforcement rate in the terminal links despite greater overall response rates during the VR schedules (see also Autor, 1969). Neuringer (1969) obtained indifference between fixed-interval (FI) and fixed-time (FT) terminal links of equal duration, indicating that the contingency between responding and reinforcement did not affect preference. These studies suggest that terminal-link value in concurrent chains is determined by the Pavlovian stimulus–reinforcer relation independently of the response–reinforcer relation.

Resistance to change in multiple schedules, measured as the decrease in response rate relative to baseline when a disrupter such as extinction or prefeeding is applied, has similarly been shown to depend on stimulus–reinforcer relations. For example, Nevin, Tota, Torquato, and Shull (1990, Experiment 1) arranged a multiple schedule in which pigeons' responding in both components produced reinforcers at the same rate according to VI schedules, but additional reinforcers were delivered in one component according to a variable-time (VT) schedule. Although response rate was lower in the component with the VT reinforcers, resistance to both prefeeding and extinction was greater compared to the component without the VT reinforcers. Nevin, Smith, and Roberts (1987) found no difference in resistance to extinction in the initial component of a serial schedule, regardless of whether transitions to a second component were contingent on responding or not. They concluded that response–reinforcer contingency did not strengthen responding (as indexed by resistance to change) above and beyond the effect of the stimulus–reinforcer contingency. To integrate these and other results, Nevin (1992b) proposed a model for behavioral momentum that was able to describe all the data on resistance to change in multiple, serial, and chained schedules collected in his laboratory.

In Nevin's (1992b) model, the resistance to change of discriminated operant responding (*behavioral mass* in momentum theory) is a positive function of the stimulus–reinforcer contingency, as quantified by a version of Gibbon's (1981) contingency ratio: the rate of reinforcement in the presence of a stimulus divided by the rate of reinforcement in the session as a whole. Behavioral momentum theory is based on the premise that resistance to change and response rate are independent aspects of operant behavior, with the former controlled by stimulus–reinforcer contingencies and the latter by response–reinforcer contingencies (Nevin, Mandell, & Atak, 1983; see also Nevin, 1992a).

Thus, the models proposed by Grace (1994) and Nevin (1992b) are similar in that the theoretical constructs used to represent reinforcement history (i.e., value and behavioral mass) are defined in terms of molar stimulus–reinforcer relations. Moreover, Grace and Nevin (1997) have provided evidence that preference and resistance to change are independent measures of a single construct. They arranged a procedure with concurrent chains in one half of a session and a multiple schedule in the other half. The critical feature of the procedure was that the terminal links were identical, in terms of stimuli and schedules, to the components of the multiple schedule. After baseline training in each of eight conditions, resistance to change was assessed by delivering VT food during the interval between components of the multiple schedule. Grace and Nevin found that not only were preference and resistance to change positive functions of relative reinforcement rate, consistent with prior research, but also that unsystematic variation in preference and resistance to change was positively correlated within subjects. They argued that this was evidence that preference and resistance to change were converging measures of a single construct representing reinforcement history, or in other terms, learning about the conditions of reinforcement prevailing during a particular stimulus.

Here, we address the effects of unsignaled delay of reinforcement on preference in concurrent chains and resistance to change in multiple schedules. Williams (1976) showed that imposing a nonresetting 3-s unsignaled delay between the response that satisfied the requirements of a VI schedule and reinforcer delivery was sufficient to reduce response rate by approximately 70%, compared with a control condition of no delay. He argued that this finding challenged conceptions of operant behavior as being controlled primarily by the molar correlation between responding and rate of reinforcement (e.g., Baum, 1973), because the delay disrupted response–reinforcer contiguity while keeping the overall rate of reinforcement constant. However, there has been comparatively little research exploring potential effects of unsignaled delay on preference and resistance to change. If present, such effects could be problematic for the models of Grace (1994) and Nevin (1992b), because response–reinforcer contiguity ought to be irrelevant if stimulus–reinforcer relations are the critical determiners of preference and resistance to change.

Only two prior studies have investigated unsignaled delay of reinforcement in concurrent chains. Marcattilio and Richards (1981) trained pigeons on a concurrent chain with equal VI 60-s terminal links, and studied various durations of signaled and unsignaled delays for those schedules. In general, subjects demonstrated a preference for the terminal link with the signaled delay, and this preference was greater when the initial links were short than when they were long. However, Leung and Winton (1986) reported that pigeons preferred tandem FI FT terminal links to the equivalent chain FI FT schedule in 25 of 28 separate comparisons. Because chain and tandem FI FT schedules constitute signaled and unsignaled delay of reinforcement procedures, respectively, it is unclear how to reconcile these results with those of Marcattilio and Richards. Most importantly for present purposes, however, neither study included a control condition that compared an unsignaled delay with no delay in the terminal links. Thus the effects on preference of disrupting response–reinforcer contiguity remain unclear.

Although no published studies to date have examined the effect of unsignaled delay of reinforcement on resistance to change, Bell (in press) has recently reported that responding in a component of a multiple schedule with an unsignaled delay was less resistant to prefeeding and VT food than was responding in components with no delay or a signaled delay. However, Bell did not arrange analogous concurrent-chains conditions, and it is of interest, given the results of Grace and Nevin (1997), to discover whether any effects of unsignaled delay on preference and resistance to change are correlated within subjects.

In Phase 1 of the experiment, pigeons were trained on a concurrent chain in which a 3-s unsignaled delay was imposed on a terminal link in alternate conditions. In Phase 2, the pigeons responded on a two-component multiple schedule in which the scheduled rates of reinforcement were equal but a 3-s unsignaled delay was added to one component. After sufficient baseline training, resistance to change was assessed using prefeeding and extinction as disrupters. At issue was whether unsignaled delay of reinforcement had reliable effects on preference and resistance to change. Because striking differences in response topography between the multiple-schedule components were noted during casual observation of baseline sessions, we had systematic observations made by individuals who were naive to the purpose of the experiment.

METHOD

Subjects

Four White Carneau pigeons, numbered 008, 963, 969, and 967, participated as subjects, and were maintained at 85% ad libitum weight ±15 g. All had previous experience with a variety of experimental procedures. They were housed in individual cages in a vivarium with a 12:12 hr light/dark cycle (lights on at 7:00 a.m.). Water and grit were continuously available in the home cages.

Apparatus

Four typical three-key operant chambers were used. The chambers measured 35 cm in length, 35 cm in width, and 35 cm in height, and the keys were located 26 cm above the floor. The keys could be transilluminated red, white, or green. All chambers were equipped with a houselight 7 cm above the center key for general illumination and a grain magazine with an aperture (6 cm by 5 cm) located 13 cm below the center key. The magazine was illuminated when wheat was made available. A force of approximately 0.10 N was required to operate each key, and effective responses produced an audible feedback click. Chambers were enclosed in sound-attenuating boxes that were fitted with ventilation fans for masking extraneous noises. The experiment was controlled and data collected using a MED-PC® system and an IBM-compatible microcomputer located in an adjacent room.

Procedure

The experiment consisted of two phases, which were conducted successively. In Phase 1, preference was studied in concurrent chains. In Phase 2, a multiple schedule was used to assess resistance to prefeeding and extinction. Because subjects were experienced, training began immediately on the concurrent-chains procedure. Sessions were conducted daily with few exceptions.

Concurrent chains. Sessions consisted of 72 initial- and terminal-link cycles, each of which ended with the delivery of food reinforcement. At the start of a cycle, the side keys were illuminated white, signifying the initial links or choice phase of the procedure. A terminal-link entry was assigned randomly to either the left or right key, with the restriction that three out of every six were assigned to each key. The initial-link schedule was a single VI 20 s that did not begin timing until the first peck to either key had occurred. The VI 20-s schedule contained 12 intervals constructed from an arithmetic progression, a, $a + d$, $a + 2d$, . . ., in which a equals one 12th and d equals one sixth the schedule value. An arithmetic rather than exponential (e.g., Fleshler & Hoffman, 1962) progression was used to limit the variability in initial-link time over cycles. The intervals were sampled randomly without replacement, and separate lists of intervals were maintained for cycles with left and right terminal-link entries.

An initial-link response was reinforced by terminal-link entry if (a) it was to the preselected key, (b) the interval selected from the VI 20-s schedule had timed out, and (c) a 1.5-s changeover delay (COD) was satisfied (i.e., at least 1.5 s had elapsed following a changeover to the side for which terminal-link entry was arranged). Terminal-link entry was signaled by changing the color of the side key to red or green, coupled with extinguishing the other key. For Birds 963 and 969, the left terminal-link stimulus was red and the right terminal-link stimulus was green; these assignments were reversed for Birds 008 and 967. Terminal-link responses were reinforced according to VI schedules containing 12 intervals sampled without replacement and constructed from exponential progressions. Reinforcement for terminal-link responding consisted of 2.5 s of access to grain, during which the only source of illumination in the chamber was the magazine light. After reinforcement the houselight and initial-link keylights were reilluminated, and the next cycle began.

Phase 1 consisted of several conditions. The right terminal-link schedule was always a VI 15-s schedule. In baseline conditions, the left terminal link was an equivalent VI 15-s schedule, but in test conditions the left terminal link was changed to a VI 12-s schedule with an unsignaled, nonresetting 3-s delay of reinforcement. The VI 15-s schedule was defined by adding 3 s to each of the intervals comprising the VI 12-s schedule. By defining the VI 15-s schedule in this way, the programmed distributions of delays to reinforcement from terminal-link onset were always equal for both terminal links (Royalty, Williams, & Fantino, 1987). Baseline and test conditions alternated, and conditions were terminated individually when initial-link preferences had met a stability criterion. That criterion was that the median relative initial-link response rate over the last five sessions (measured as a choice proportion) did not differ by more than .05 from the median of the five sessions immediately preceding these. When this criterion had been met five times (not necessarily consecutively), the conditions were changed for that subject. Table 1 lists the order of conditions and number of sessions of training for all subjects.

Multiple schedule. Phase 2 of the experiment began immediately after completion of Phase 1. Subjects now received training on a two-component multiple schedule in which components were signaled by red and green illumination of the center key. Components were 1 min in duration and were separated by a 30-s intercomponent interval during which the houselight remained on. The identity of the first component was random, but components strictly alternated thereafter. Sessions were terminated after 48 components. Reinforcers that were scheduled but not earned when a component finished were made available at the beginning of the next occurrence of that component.

Subjects initially received seven sessions of

Table 1

Order of conditions for all subjects in the concurrent-chains procedure (Phase 1). Numbers of sessions of training are given in parentheses.

	Terminal-link schedule		
Bird	Left	Right	
008	VI 15 s	VI 15 s	(37)
	VI 12 + 3-s delay	VI 15 s	(22)
	VI 15 s	VI 15 s	(29)
963	VI 12 + 3-s delay	VI 15 s	(35)
	VI 15 s	VI 15 s	(17)
	VI 12 + 3-s delay	VI 15 s	(24)
969	VI 12 + 3-s delay	VI 15 s	(19)
	VI 15 s	VI 15 s	(24)
	VI 12 + 3-s delay	VI 15 s	(15)
	VI 15 s	VI 15 s	(14)
967	VI 15 s	VI 15 s	(17)
	VI 12 + 3-s delay	VI 15 s	(20)
	VI 15 s	VI 15 s	(35)
	VI 12 + 3-s delay	VI 15 s	(42)

pretraining in which responding in both components was reinforced by separate VI 40-s schedules. These were constructed by adding 3 s to each interval comprising a VI 37-s schedule, which contained 12 intervals determined by an exponential progression (Fleshler & Hoffman, 1962). As in Phase 1, the intervals were sampled without replacement. Next, the schedule in one component was changed to a VI 37 s with a nonresetting 3-s unsignaled delay of reinforcement, and baseline training began. So that the color of the stimulus associated with the unsignaled delay component would match that for the unsignaled delay terminal link in the first phase, for Birds 008 and 969 the schedule during the green component was changed, whereas for Birds 963 and 967 the schedule during the red component was changed. In Phase 2, the stimuli accompanying reinforcement were the same as in Phase 1 (i.e., the magazine light was the only source of illumination in the chamber).

Because casual observation of subjects during baseline of Phase 2 indicated that there were consistent differences in response topography between the components, systematic observations were made by individuals who were naive to the purpose of the experiment. In each session that was observed, each bird's behavior was studied for 12 components, and a set of questions pertaining to response topography in the red and green components was answered. The order in which birds were observed was counterbalanced across sessions. The questions included (a) whether the pigeon made a downward head movement towards the hopper at the end of each component, (b) whether the pigeon frequently made downward head movements towards the hopper after nonreinforced responses, (c) the modal beak-to-key distances for responses, and (d) whether pecking seemed more forceful in the red or green component. The questions, rating scales, and instructions for observers are listed in the Appendix. A total of eight sessions were observed (by five different observers).

After subjects had completed at least 90 sessions of baseline training, resistance-to-prefeeding and resistance-to-extinction tests were carried out. The prefeeding tests were conducted first. Over five consecutive sessions, the birds were fed 20, 40, 60, 60, and 60 g of Purina pigeon chow 30 min prior to session time. After subjects' weights had returned to pretest levels, an additional 8 to 10 sessions of baseline training were given prior to the extinction test. The extinction test consisted of seven consecutive sessions in which no reinforcers were delivered in either component.

RESULTS

Phase 1: Concurrent Chains

The major question regarding the concurrent-chains data is whether the imposition of a 3-s unsignaled delay of reinforcement on the left terminal-link schedule had reliable effects on preference. The left panels of Figure 1 show relative initial-link response rate, scaled as a log ratio, for all subjects and conditions. It is clear that preference shifted away from the left terminal link in all conditions with the unsignaled delay, compared with the baseline of no delay. The magnitude of the effect varied across subjects, being largest for Birds 008 and 963 and smallest for Bird 969. Although baseline preferences for Birds 008 and 963 showed a consistent bias towards the right terminal link and those for Bird 969 were biased towards the left terminal link, in each case the difference in preference between baseline and delay conditions is clear.

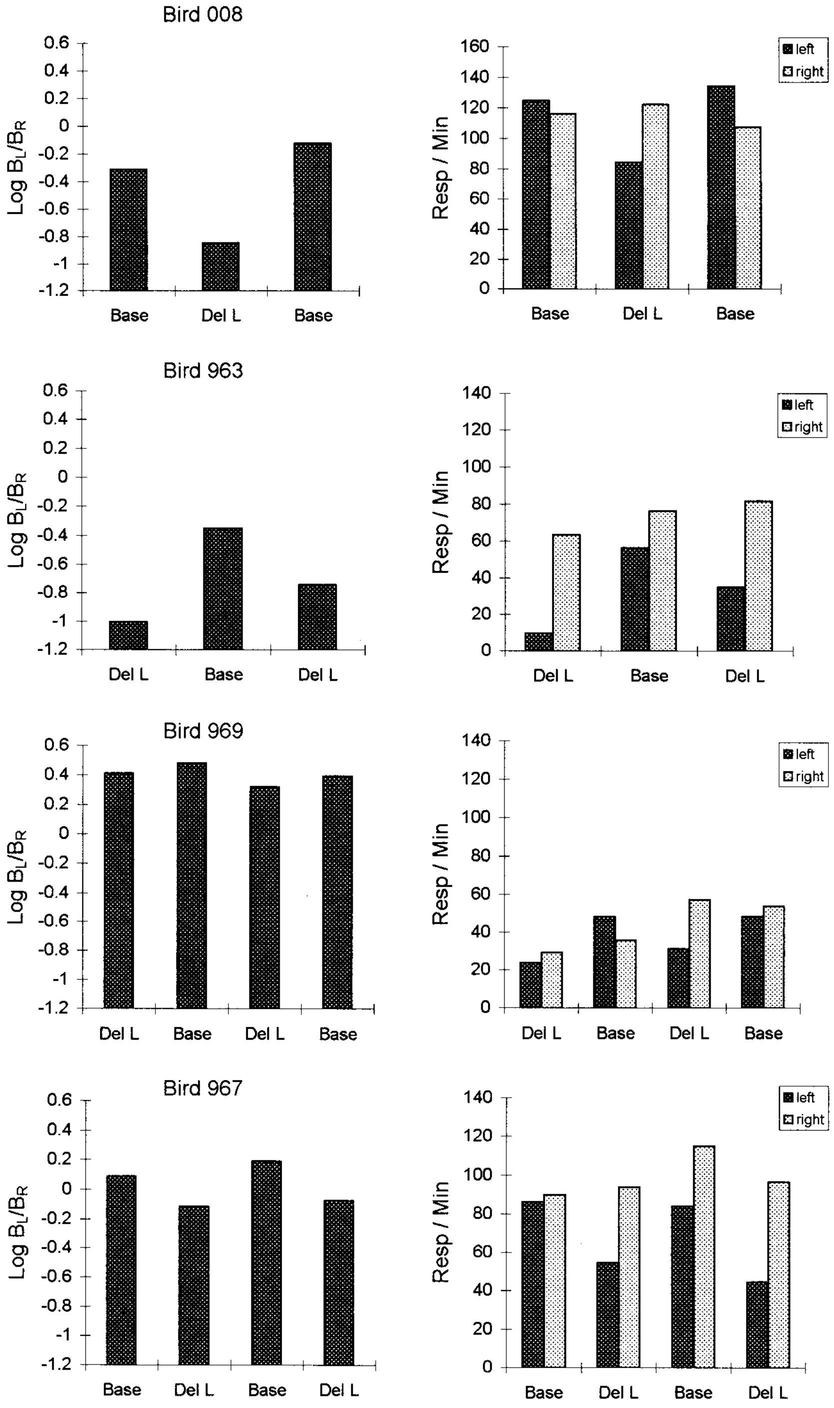

Fig. 1. The left panels show the logarithm of the initial-link response-rate ratio, for all subjects and conditions in Phase 1. "Base" refers to baseline conditions in which both terminal links provided reinforcement according to VI 15-s schedules with no delay; "Del L" refers to conditions in which the left terminal link was a VI 12-s schedule with a 3-s unsignaled delay of reinforcement. The right panels show the corresponding terminal-link response rates. Data for the left and right terminal links are shaded dark and light gray, respectively. Data were summed over the last five sessions of training.

The shifts in preference away from the terminal link with the unsignaled delay occurred despite the fact that the obtained times to reinforcement measured from terminal-link onset were quite similar. Averaged over all exposures to delay and no-delay terminal links, these times were for Bird 008, 15.92 s and 15.31 s; for Bird 963, 19.43 s and 16.49 s; for Bird 969, 17.03 s and 16.19 s; and for Bird 967, 16.28 s and 15.34 s. Reinforcement rate decreased by an average of 7.4% in the unsignaled delay terminal link, so the tactic of constructing the no-delay schedule by adding 3 s to the intervals comprising the VI 12-s schedule was not completely successful in equating reinforcement rates. However, these decreases are too small to be responsible for the shifts in preference seen in Figure 1. Moreover, the largest effect on preference was accompanied by the smallest decrease in reinforcement rate (Bird 008). Thus, the shifts in preference must be attributed to the unsignaled delay contingency.

The right panels in Figure 1 present the terminal-link response rates averaged over the last five sessions of each condition. The delay contingency was effective in reducing response rates in the left terminal link. On average, response rate was reduced, compared with baseline, by 35% for Bird 008, 60% for Bird 963, 43% for Bird 969, and 48% for Bird 967. These reductions are less than the median of 69% reported by Williams (1976) for a 3-s unsignaled delay imposed on a VI 2-min schedule, but are nevertheless substantial.

The data from Phase 1 demonstrate that a brief unsignaled delay of reinforcement produced a shift in preference away from a terminal link, even though the overall time to reinforcement in that terminal link remained approximately constant. This result is problematic for any model, such as that of Grace (1994), that attempts to characterize terminal-link value entirely in terms of the temporal relation between terminal-link onset and reinforcer delivery.

Phase 2: Multiple Schedule

Given that unsignaled delay of reinforcement had detrimental effects on preference in Phase 1, we expected to find that it would also reduce resistance to change. This is because prior work has shown that preference and resistance to change depend similarly on parameters of reinforcement such as rate, immediacy, and magnitude (see Nevin, 1979, for review), and Grace and Nevin (1997) found that when measured for the same pair of schedules, preference and resistance to change were correlated within subjects.

Table 2

Response rates (per minute) and reinforcement rates (per hour) for both components of the multiple schedule in Phase 2. Data are averaged over the last 10 sessions of baseline. Standard deviations of response rates are shown in parentheses.

	No delay		Delay	
Bird	Response	Reinforcement	Response	Reinforcement
008	79.40 (6.77)	83.25	29.11 (6.68)	77.84
963	44.67 (6.33)	83.45	39.81 (10.04)	76.87
969	34.52 (3.22)	84.50	17.36 (4.28)	77.90
967	44.28 (3.55)	85.75	32.92 (5.07)	81.29

Response rates and topographies. The response rates and reinforcement rates for both components are listed in Table 2. Response rates were reduced in the delay component by 63% for Bird 008, 11% for Bird 963, 50% for Bird 969, and 26% for Bird 967. Moreover, response rates were more variable day to day in the delay component; the absolute standard deviations were higher for 3 birds and were higher for all birds relative to mean response rates (Williams, 1976). As in Phase 1, the tactic of equating programmed interreinforcement intervals was largely effective; although obtained reinforcement rates were higher in the no-delay component for all subjects, the differences were small, averaging 6.8% compared with baseline.

As baseline training in Phase 2 progressed, casual observation suggested that there were reliable and consistent differences in response topography between the components. For 3 birds (008, 963, and 967), responses in the no-delay component consisted of typical vigorous ballistic head movements, whereas in the delay component the head remained closer to the key between responses and the force with which the beak struck the key appeared to be less than in the no-delay component (the birds often seemed to be ''tickling'' the key with their beaks). Bird 969's response topography was similar to those of the other birds in the no-delay component,

Table 3

Average responses of observers to questions regarding response topography in both components of the multiple schedule for Phase 2.

Bird	No delay	Delay
1. "Did the pigeon make a downward head movement when the keylight turned off?" (Average percentage of "yes" responses)		
008	35	27
963	31	40
969	4	21
967	58	52
2. "The pigeon often moved its head down towards the hopper after a peck, even when food was not being delivered." (Percentage of observers who said that this statement "strongly" characterized the pigeon's behavior)		
008	25	25
963	50	0
969	0	63
967	0	0
3. "What was the (approximate) modal distance (in inches) that the pigeon moved its beak away from the key between pecks?" (Average of categorical responses, where 1 = <½; 2 = ½–1; 3 = 1–2; 4 = 2–3; 5 = 3–4; 6 = 4–6; 7 = >6)		
008	3.06	2.06
963	3.25	1.25
969	3.00	2.31
967	2.50	1.25
4. "In which component did pecking seem more forceful?" (Percentage of observers who said "no delay")		
008	94	
963	94	
969	100	
967	75	

but was idiosyncratic in the delay component. Frequently, this bird, after making a single peck to the key, would move its head down towards the grain magazine in apparent expectation of food. This topography was highly adaptive because when a response was reinforced and the magazine was illuminated after the unsignaled delay, the bird was able to begin eating very quickly.

Table 3 summarizes the results of the systematic observations. At issue is whether the observers reported reliable differences in response topography between the delay and no-delay components, consistent with our casual observations noted above.

Question 1. Observers were asked to note if the pigeon made a downward head movement after the offset of the keylight at the end of each component. The rationale for this question was to determine whether keylight offset (which accompanied reinforcement) had acquired differential stimulus control in the two components. However, the data in Table 3 indicate that there were no systematic differences observed across subjects in the likelihood that the keylight offset at the end of a component would evoke a downward head movement.

Question 2. Observers were asked whether the statement that the pigeon frequently made a downward head movement toward the hopper after a nonreinforced response "strongly" or "weakly" characterized responding in each component. This item was intended to document Bird 969's idiosyncratic topography in the delay component, described above. In accord with our initial observations, responding for Bird 969 in Phase 2 was "strongly" characterized thus by 63% of the observers in the delay component, compared with 0% in the no-delay component. Responding for Bird 963 in the no-delay component of Phase 2 was also noted as "strongly" characterized by downward head movements by 50% of observers. However, this bird's topography appeared to be different from that of Bird 969. In comparison, its head movements were more to the right of the key and seemed to be "air pecks." Several observers confirmed during postsession debriefings that the response topographies of Birds 963 and 969 were different.

Question 3. The modal maximum beak-to-key distance during responses was estimated. Table 3 shows that for all subjects, the beak-to-key distance was judged, on average, to be greater for the no-delay component than for the delay component. Moreover, there were no counterinstances in which an observer judged the distance to be greater for the delay component (one tie for Bird 008; no ties for Bird 963; one tie for Bird 969; one tie for Bird 967).

Question 4. Observers were asked to indicate in which component responding seemed more forceful. Averaged across observers, for all subjects responding was judged to be more forceful in the no-delay component. Similar to Question 3, there were no counterinstances in which responding was judged to be more forceful in the delay component (one tie for Bird 008; one tie for Bird 963; no ties for Bird 969; four ties for Bird 967).

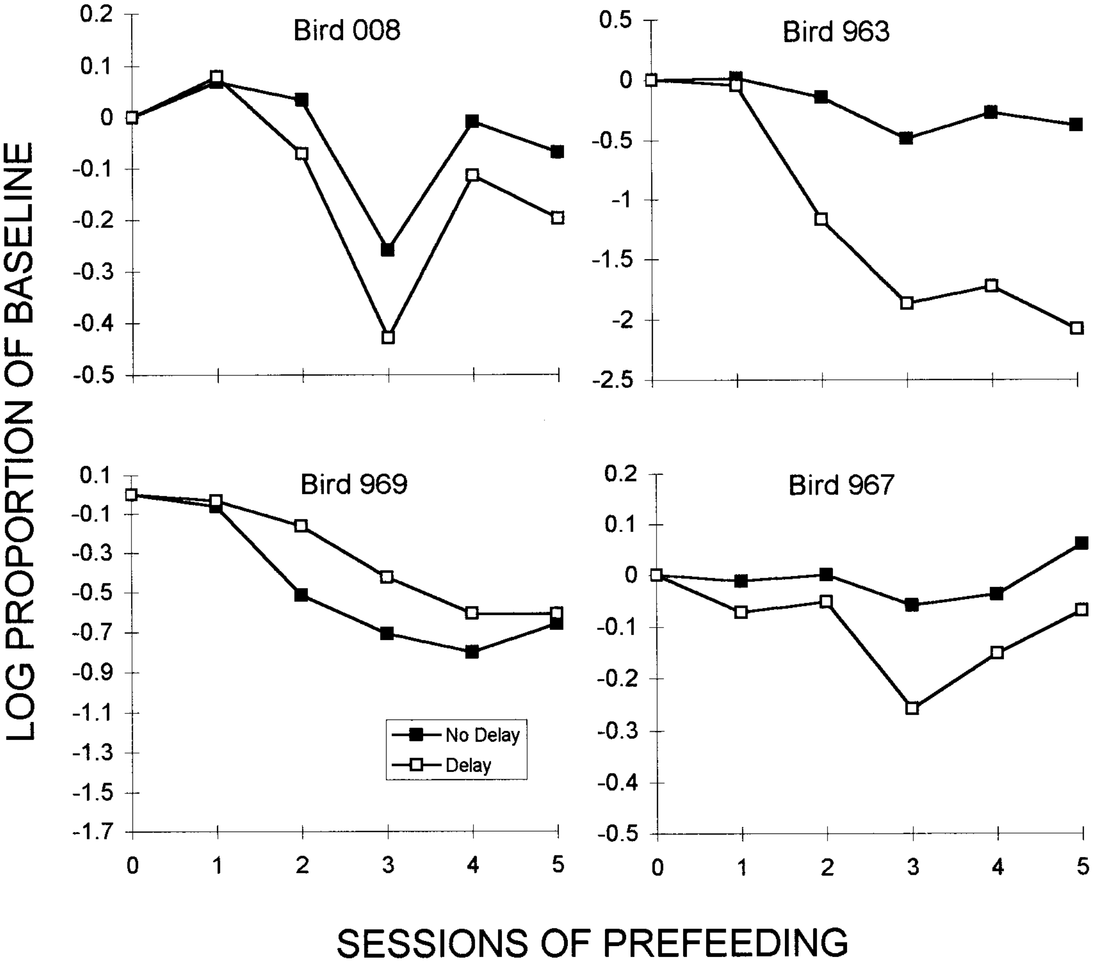

Fig. 2. Response rates during prefeeding test sessions in Phase 2, expressed as logarithms of the proportion of the rate averaged over the five preceding baseline sessions. Data for the VI 40-s component (no delay) are represented by filled squares; data for the VI 37-s with 3-s unsignaled delay component (delay) are represented by open squares.

With the exception of Question 1, the data in Table 3 are consistent with expectations based on our initial observations. Subjects oriented more closely to the key in the delay component and responded more forcefully in the no-delay component. This documents that response topographies were different in the two components.

Resistance-to-change tests. After baseline training in Phase 2, prefeeding and extinction tests were conducted to obtain measures of resistance to change for responding in both components. The data from the prefeeding tests are shown in Figure 2. For each component, response rates were expressed as a log proportion of the average rate for the 10 immediately preceding baseline sessions. Figure 2 shows that in Phase 2, responding for 3 birds (008, 963, and 967) was more resistant to prefeeding (i.e., was greater as a proportion of baseline) in the no-delay component compared with the delay component.

Figure 3 presents the analogous data from the extinction tests. Response rates were expressed as a log proportion of the rate in the first extinction session. Nevin (1988) has suggested this to be an appropriate measure of resistance to extinction, because it controls for the potentially confounding effects of generalization decrement during the initial session of transition from reinforcement to extinction. The extinction data in Figure 3

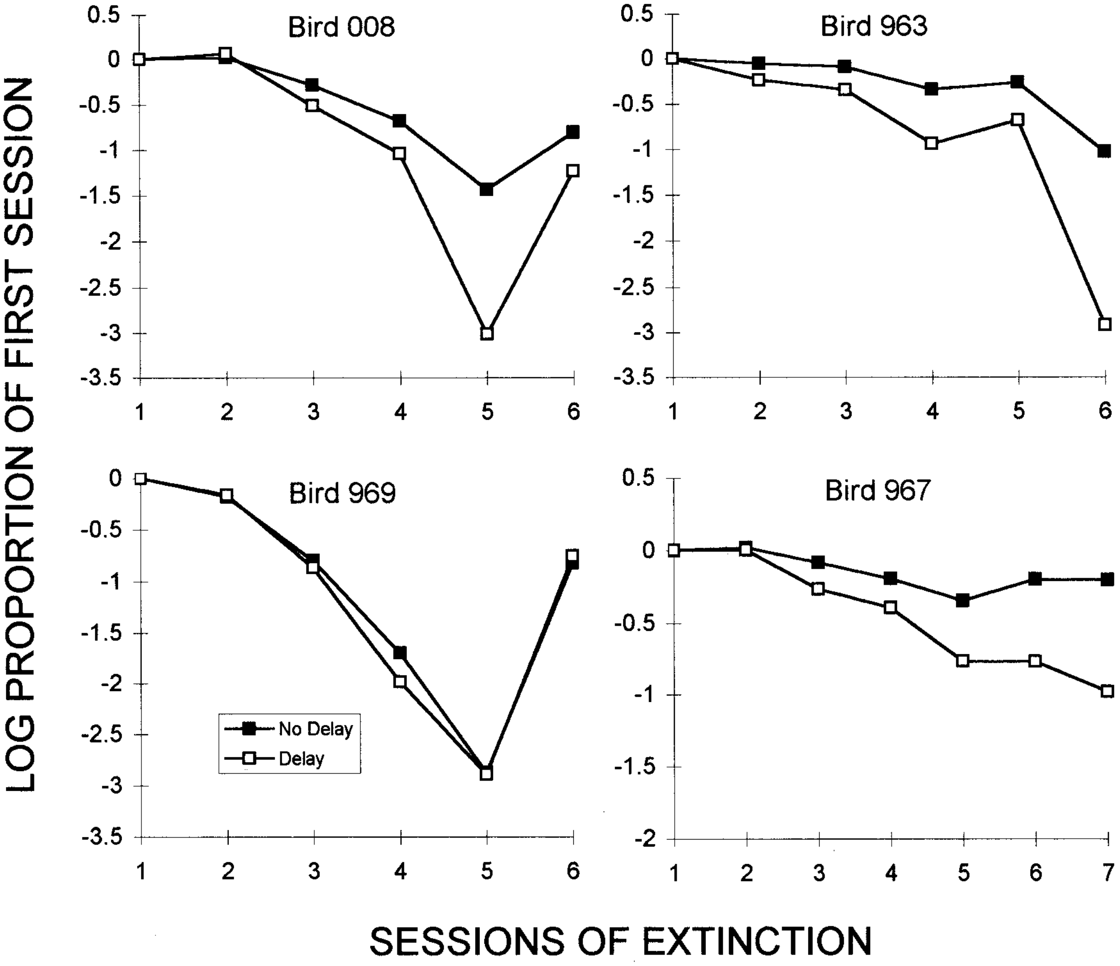

Fig. 3. Response rates during extinction test sessions in Phase 2, expressed as logarithms of the proportion of the rate during the first extinction session. Data for the VI 40-s component (no delay) are represented by filled squares; data for the VI 37-s with 3-s unsignaled delay component (delay) are represented by open squares.

appear to be quite consistent with those from the prefeeding tests. The same birds (008, 963, and 967) showed greater resistance in the no-delay component in Phase 2, whereas data for Bird 969 showed similar decreases in response rate in both components.

To facilitate a quantitative comparison of relative resistance to change across the two conditions, we calculated slopes of linear regressions performed on the prefeeding and extinction data shown in Figures 2 and 3. The log ratio of the reciprocals of these slopes gives a measure of relative resistance to change (Nevin, 1992b). Computing slopes for the prefeeding data was complicated by the fact that, sometimes, response rate increased in the fourth and fifth sessions (e.g., see Bird 008). It is of interest to note that the birds typically consumed very little of the 60 g of chow that constituted prefeeding on the 4th and 5th days. Therefore, for the two cases in which responding recovered in prefeeding (Birds 008 and 967), slopes were calculated over the first three sessions only. Also, to avoid floor effects for the extinction data, if response rate dropped below one response per minute in either component in a session, slopes were calculated for both components only through that session.

The slopes of responding in the prefeeding and extinction tests in both components, as well as the log ratio of the reciprocals of the

Table 4

The resistance to change of responding in each component, measured as the slope across test sessions of the log response rate as a proportion of baseline (prefeeding) or of the first test session (extinction), for all subjects in Phase 2. Relative resistance values are the log ratio of the reciprocals of the slopes for the no-delay and delay components. See text for more explanation.

Bird	No delay	Delay	Relative resistance
Prefeeding test			
008	−.08	−.14	.25
963	−.09	−.46	.72
969	−.16	−.14	−.05
967	−.02	−.08	.66
Extinction test			
008	−.36	−.71	.30
963	−.17	−.47	.44
969	−.73	−.76	.02
967	−.05	−.18	.58

slopes, are shown in Table 4. For 3 subjects (Birds 008, 963, and 967) the slopes for both prefeeding and extinction were less steep (i.e., less negative) in the no-delay component than in the delay component. There were no consistent differences in slopes for Bird 969. However, this bird showed the smallest effect of unsignaled delay on preference in Phase 1. Because preference is generally a more sensitive measure than relative resistance (Grace & Nevin, 1997), it is not surprising that the resistance data for Bird 969 failed to show a difference between the components.

Figure 4 summarizes and compares the results of Phases 1 and 2. Shown are the effect sizes of unsignaled delay on preference and resistance to change. Effect sizes were calculated for preference as the difference in log relative initial-link response rate averaged across all determinations of baseline and delay conditions for a particular subject; effect sizes for resistance to change were calculated as the log ratio of the reciprocals of the slopes given in Table 4. In each case, positive values mean greater preference or resistance to change for the no-delay schedule. The covariation of effect sizes across subjects is evident in Figure 4, in that data for 3 birds (008, 963, and 967) showed substantial effects of delay on both preference and resistance to prefeeding and extinction, whereas data for Bird 969 revealed minimal or no effects.

DISCUSSION

Grace (1994) and Nevin (1992b) proposed models for preference in concurrent chains

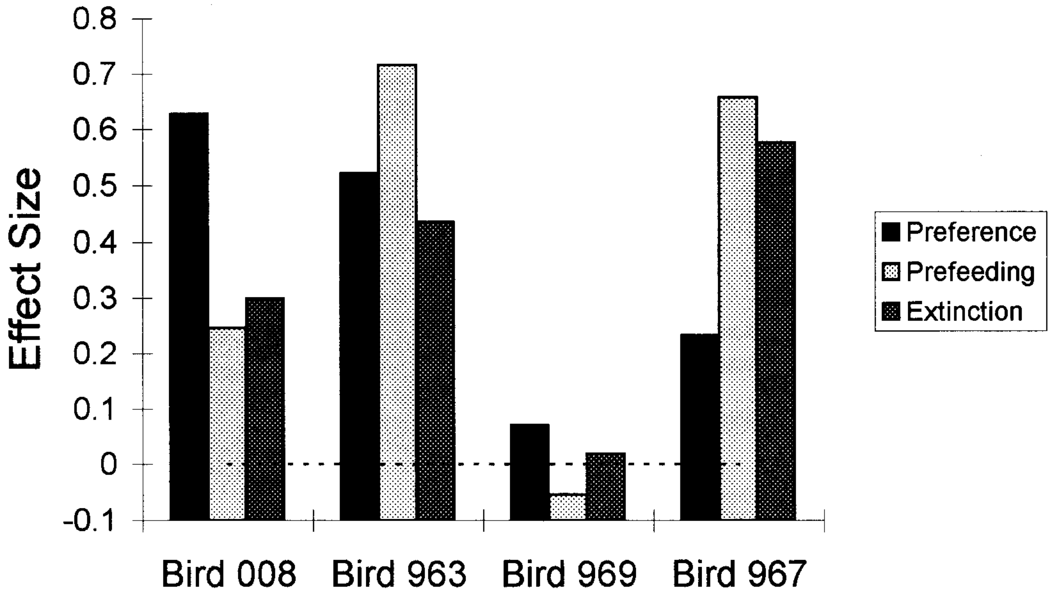

Fig. 4. Comparison of effect sizes for unsignaled delay on preference and relative resistance to prefeeding and extinction. Positive values refer to greater preference or resistance for the schedule without the delay. See text for more explanation.

and resistance to change in multiple schedules that were able to describe successfully much extant data by assuming that the history of reinforcement in the presence of a particular stimulus could be modeled purely in terms of molar Pavlovian stimulus–reinforcer relations. As a strong test of this assumption, the present experiment explored the effects of unsignaled delay of reinforcement on both preference and resistance to change. In Phase 1, pigeons' preference for a terminal link with an added unsignaled delay was reduced in comparison with baseline conditions with no delay. In Phase 2, the pigeons responded in a multiple schedule in which an unsignaled delay was imposed in one component. For 3 of 4 birds, resistance to prefeeding and extinction was consistently lower in the delay component; significantly, these were the same birds that demonstrated substantial preferences for the no-delay terminal link in Phase 1. Because the obtained rates of reinforcement were approximately equal in the components of the multiple schedule and terminal links in concurrent chains, the implication is that response–reinforcer contiguity affects preference and resistance to change independently of the stimulus–reinforcer relation. This result challenges the premise of the models of Grace (1994) and Nevin (1992b) that the critical determiners of preference (i.e., terminal-link value) and resistance to change (behavioral mass) may be defined purely in Pavlovian terms. At issue now is what factors are responsible for the effects of disrupting response–reinforcer contiguity on preference and resistance to change, and whether these effects can be reconciled with a Pavlovian view.

One possibility is response topography. Systematic observation revealed consistent differences in pigeons' topographies between the components of the multiple schedule in Phase 2 (see Table 3): Both the modal beak-to-key distance for a response and the physical force with which the beak struck the key were reduced in the delay component. Responding in the no-delay component was more similar to the vigorous, ballistic head movements that have been reported as typical for hungry pigeons pecking for food reinforcement (Jenkins & Moore, 1973; Wolin, 1968). There is evidence that response topography per se affects preference; Starin (1989) found that in concurrent chains pigeons strongly preferred a terminal link in which they pecked for food over one in which they pressed a treadle, even though both provided food at about the same rate.

Response topographies may also be shaped by different contingencies of immediate reinforcement that establish high or low response rates. For example, Blackman (1968) and Lattal (1989) found that low-rate contingencies established greater resistance to change than high-rate contingencies, and Nevin (1974, Experiment 5; 1979) observed a modest within-subject correlation between relative resistance and preference under such contingencies. It may be that high- and low-rate contingencies of immediate reinforcement establish topographically different response units that are differentially susceptible to disruption and that also affect preference.

A second possible factor is that to the extent the pigeons were able to discriminate the first response after terminal-link entry in concurrent chains or after reinforcer delivery in the multiple schedule, the unsignaled delay schedule required responding at a time when no reinforcement was immediately forthcoming (i.e., the first response after reinforcement could never be immediately followed by food). Evidence that such required responding is aversive for pigeons comes from a study by Moore and Fantino (1975). They arranged a concurrent chain in which one terminal link was an FT schedule and the other was a tandem fixed-ratio (FR) FI schedule. The value of the FT was adjusted daily to match the obtained average delay on the tandem schedule. Pigeons consistently preferred the FT to the tandem schedule. Moore and Fantino reconciled their results with those from other studies that either obtained (Fantino, 1968) or did not obtain (Killeen, 1968; Neuringer, 1969) effects of terminal-link response contingencies on choice by showing that such contingencies affected choice only if the birds were forced to respond during a discriminable period of nonreinforcement (i.e., during the early portion of an FI schedule). In Pavlovian terms, these required responses might be analogous to conditioned inhibition trials, because the putative conditional stimulus (CS) (i.e., the keylight) signals nonreinforcement in an otherwise excitatory context. These pairings ought to counteract, to some extent, the strength of excitatory conditioning caused by temporal contiguity between the keylight and food.

The idea that the unsignaled delay stimulus undergoes inhibitory conditioning is consistent with the results of Richards and Hittesdorf (1978). They trained pigeons on a multiple schedule in which responding in both components was reinforced according to a VI 1-min schedule. In one component, signaled by a white key, responses produced immediate reinforcement, whereas in the other component, signaled by a black vertical line on a white background, reinforcers were delivered after a 10-s unsignaled delay. After baseline training, a generalization test for line orientation was conducted in extinction. Richards and Hittesdorf found that 4 of 5 pigeons produced incremental gradients of responding, with the nadir obtained for the orientation used for the delay component in training. This is evidence that the stimulus for the delay component had acquired inhibitory control (Rilling, 1977).

Another possibility is that some portion of the reinforcers in the delay component were presented while the birds were not observing the key.[1] These reinforcers may have become conditioned to contextual stimuli, thus weakening the Pavlovian contingency for the keylight. Evidence that failure to observe the CS can weaken the strength of Pavlovian responding comes from a study by Locurto, Travers, Terrace, and Gibbon (1980). They showed that physically restraining pigeons so that they were forced to remain facing the key increased the rate of acquisition of autoshaped key pecking, compared with pigeons that were free to move about the chamber.

Finally, it is worth noting that Moore and Fantino's (1975) proposal that required responding during a discriminable period of nonreinforcement is aversive may help to explain the results of Leung and Winton (1986). In their study, pigeons chose between chain and tandem FI FT terminal links. Although the pigeons preferred the tandem schedule in 25 of 28 cases, consistent with prior research on segmentation effects on choice, these preferences were much smaller than those reported previously (Duncan & Fantino, 1972; Leung & Winton, 1986). Because the tandem FI FT terminal link delivers reinforcers after an unsignaled delay, the reduced preferences for the tandem versus chain schedule in Leung and Winton's study may be due to the fact that responding was required when reinforcement was not immediately forthcoming.

In any case, it is clear that more research is required to determine the extent to which response topography, responses during discriminable periods of nonreinforcement, and conditioned inhibition influence preference and resistance to change when reinforcement is available with and without a delay. Regardless of the possible interpretations of these results, the tendency for the preference and resistance data to covary within subjects (see Figure 4) is consistent with the results of Grace and Nevin (1997). For 3 subjects (Birds 008, 963, and 967), the data throughout displayed strong effects of unsignaled delay on preference and resistance to both prefeeding and extinction, whereas the data for Bird 969 showed minimal effects on preference and none at all on resistance to prefeeding and extinction. Such consistency within individual subjects is further evidence that preference and resistance to change are independent measures of a single construct representing reinforcement history in the presence of a stimulus, as Grace and Nevin (1997) argued.

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[1] We are indebted to Scott T. Gaynor for this suggestion.

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APPENDIX

Form used to collect observational data on pigeons' response topographies in the multiple schedule (Phase 2).

Instructions: Observe 12 components (6 red and 6 green) for this box, tallying responses for Question 1 after each component finishes. Then answer the remaining questions before moving on to the next box. You'll have (approximately) only 30 seconds to record your answers before the next component starts. For Question 2 please indicate whether the statement strongly or weakly characterizes the bird's responding in each component.

1. Did the pigeon make a downward head movement when the keylight turned off? (tally for each instance of a component)

Red	Green
Yes No Don't know	Yes No Don't know

2. The pigeon often moved its head down towards the hopper after a peck, even when food was not being delivered.

Red	Green
Strongly/Weakly	Strongly/Weakly

3. What was the (approximate) modal distance (in inches) that the pigeon moved its beak away from the key between pecks?

Red	Green
<½ ½–1 1–2 2–3 3–4 4–6 >6	<½ ½–1 1–2 2–3 3–4 4–6 >6

4. In which component did pecking seem more forceful?

Red Green About the same
