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EFFECTS OF DELAYED CONDITIONED REINFORCEMENT IN CHAIN SCHEDULES

PAUL ROYALTY, BEN A. WILLIAMS, AND EDMUND FANTINO

UNIVERSITY OF CALIFORNIA-SAN DIEGO

The contingency between responding and stimulus change on a chain variable-interval 33-s, variable-interval 33-s, variable-interval 33-s schedule was weakened by interposing 3-s delays between either the first and second or the second and third links. No stimulus change signaled the delay interval and responses could occur during it, so the obtained delays were often shorter than the scheduled delay. When the delay occurred after the initial link, initial-link response rates decreased by an average of 77% with no systematic change in response rates in the second or third links. Response rates in the second link decreased an average of 59% when the delay followed that link, again with little effect on response rates in the first or third links. Because the effect of delaying stimulus change was comparable to the effect of delaying primary reinforcement in a simple variable-interval schedule, and the effect of the unsignaled delay was specific to the link in which the delay occurred, the results provide strong evidence for the concept of conditioned reinforcement.

Key words: unsignaled delay of reinforcement, chain schedules, conditioned reinforcement, key peck, pigeons

A chain schedule consists of a series of schedule requirements, each correlated with a unique stimulus, only the last of which terminates in primary reinforcement. Transition between the successive links of the chain is contingent upon the fulfillment of each separate schedule requirement. Chain schedules thus involve stimulus change, a contingency between responding and component transition, and a contingency between responding and stimulus change. Such schedules have been commonly used to study conditioned reinforcement, based on the premise that behavior in the early links of the chain is maintained by the reinforcing properties of the stimulus that accompanies the next link of the schedule. A given stimulus in the chain has been assumed to serve both as a discriminative stimulus for its own correlated schedule and as a conditioned reinforcer for the behavior maintained during the stimulus that preceded it.

In order to validate the premise of conditioned reinforcement in chain schedules, the effects of the contingency between responding and stimulus change must be dissociated from the effects of the contingency between responding and component transition (i.e., between responding in the early links of the chain and eventual primary reinforcement) and from the effects of stimulus change alone (in the absence of contingency). The most frequent approach for effecting such a dissociation has been to eliminate the role of stimulus change by converting the chain schedule to a tandem schedule. In his review of experiments comparing performance under tandem and chained schedules, Gollub (1977) claimed that, "For two-component chains of FI schedules, the rate in the first component under chain was generally higher than tandem (Gollub, 1958), but not always (Malagodi, DeWeese, & Johnston, 1973)" (pp. 294–295). (The latter study found no difference between chain and tandem rates.) Subsequently, Wallace, Osborne, and Fantino (1982) reported a higher rate in the initial link of the tandem than in the initial link of the chain schedule. Those authors' review of Gollub's earlier study also suggested that their own findings were the more typical result in two-link chain–tandem comparisons. Other published studies involving chain–tandem comparisons have consistently found lower response rates in the initial link of a chain schedule than in the initial link of the corresponding tandem schedule. This result has been obtained regardless of whether the comparison involved three fixed-interval (FI)

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components (Kelleher & Fry, 1962; Thomas, 1964), five FI components (Gollub, 1958), three fixed-ratio (FR) components (Jwaideh, 1973; Thomas, 1967), or five FR components (Jwaideh, 1973). In summary, the comparison of chain and tandem schedules offers little or no support for the concept of conditioned reinforcement.

A second approach to examining conditioned reinforcement in chain schedules has been to investigate the effects of response-independent stimulus change. That is, a chain schedule is converted into a comparable multiple schedule. For example, a chain FI 30-s FI 30-s FI 30-s schedule would be converted into a multiple extinction (EXT) 30-s EXT 30-s FI 30-s schedule. The major difficulty with such a procedure as a control for a chain schedule is that removal of the contingency between responding and stimulus change also breaks the contingency between responding and component transition. Specifically, the dependency between responding in the early links of the chain and the time of the primary reinforcer is altered in ways that could influence response rate. A multiple-schedule control cannot, therefore, rule out the possibility that responding in the early links of a chain schedule is maintained by the dependency between responding in early links and eventual primary reinforcement alone, rather than by conditioned reinforcement.

In an attempt to circumvent this liability of the multiple-schedule control procedure, Catania, Yohalem, and Silverman (1980) compared not only chain and multiple schedules but tandem and mixed schedules as well. Higher rates of responding were maintained by the contingency between responding and stimulus change (chain schedule) than by stimulus change without contingency (multiple schedule). In the absence of any stimulus change, the contingency between responding and primary reinforcement (tandem schedule) did not produce a higher response rate than the absence of that contingency (mixed schedule). Catania et al. argued that the latter result demonstrated that the contingency between responding and primary reinforcement was unimportant in the maintenance of behavior in the early links of the chain schedule and that the difference found between the chain and multiple schedules was therefore direct support for the role of conditioned reinforcement.

The problem with using the tandem–mixed schedule comparison to control for contingency in the chain–multiple schedule comparison is that the response rates in the first two links of the tandem and mixed schedules were much higher than the corresponding rates in the first two links of the chain and multiple schedules (see Figure 1 of Catania et al., 1980). These high rates prevented the subject from encountering the difference in the contingencies between responding and component transition on the tandem and on the mixed schedules. The consequence of responding at a moderately high rate was the same on both the tandem and the mixed schedule—namely, the schedule advanced. Only the consequence of not responding differed on these two schedules; the only way to have contacted this contingency would have been to not respond for a period of time, but the high response rates prevented that contact. By contrast, the near-zero response rates in the initial links of both the chain and multiple schedules ensured contact with the differential consequences of not responding on those two schedules. Thus, the tandem–mixed schedule comparison did not rule out contingency between responding and primary reinforcement as a plausible explanation of the response-rate differences between the chain and multiple schedules.

In summary, the experimental analysis of stimulus functions in chained schedules of reinforcement has failed to make a totally convincing case for the concept of conditioned reinforcement because the control procedures most frequently used, tandem and multiple schedules, have either often produced response-rate differences in the wrong direction (tandem schedules) or have failed to preclude possible alternative interpretations (multiple schedules). Perhaps because of these difficulties, the concept of conditioned reinforcement has fallen into ill repute. For example, in a recent textbook Staddon (1983) has written:

> The concept of conditioned reinforcement (that is, the response contingency between pecking and stimulus change) adds nothing to our understanding of chain schedules. . . . Providing the response contingency for food in the terminal links is maintained, it can be omitted in earlier links with little effect on key pecking, as long as stimulus changes continue to take place as before. . . . Behavior on chained schedules is determined by temporal proximity to food in the same way as behavior on multiple schedules. (p. 466)

What is needed is a new method for demonstrating the action of conditioned reinforcement in chain schedules that avoids the pitfalls of tandem and multiple schedule comparisons. One such alternative approach to studying the role of conditioned reinforcement in chain schedules involves a comparison between delayed versus immediate transition between components. As suggested by Dinsmoor and Clayton (1966), the reinforcing properties of a stimulus can be indexed by whether its effects are diminished by increasing the delay between responding and stimulus presentation. Thus, to the extent that stimulus transitions during a chain schedule constitute conditioned reinforcers, the behavior during the early links of the chain should be decreased if the presentation of the stimulus for the succeeding link of the chain is delayed rather than immediately contingent on the response. The efficacy for using delay of reinforcement as a tool for investigating conditioned reinforcement is suggested by results from the unsignaled delay-of-reinforcement procedure (Catania & Keller, 1981; Sizemore & Lattall, 1977, 1978; Williams, 1976b). With this procedure, typically studied on interval schedules, the first response after a primary reinforcer is set up begins a delay timer and the reinforcer is delivered at the end of delay-timer operation. No stimulus change signals the delay interval and responses can occur during it, so the obtained delays are often shorter than those scheduled. Nevertheless, this procedure typically produces large decrements (on the order of 70% to 90%) in response rates with even very short (2- to 3-s) delays.

The current study investigated unsignaled delays of conditioned reinforcement by interposing 3-s unsignaled delays between the first and second and the second and third links of a chain of variable-interval schedules (chain VI 33-s VI 33-s VI 33-s). This procedure minimized possible confounding factors because the discriminative functions of the component stimuli and the contingencies between responding, schedule advancement, and eventual primary-reinforcer delivery were present during both baseline and delay conditions. Interreinforcement intervals were held constant across baseline and delay conditions by shortening each interval in the VI schedule by 3 s whenever the delay contingency was in effect. Thus, the delay contingency postponed presentation of the stimulus correlated with the next link of the chain by 3 s or less but did not alter the relation between responding in early links of the chain and food delivery in a way that could be influential. If presentation of each stimulus correlated with the chain does indeed serve to reinforce responding in the link that precedes it, then one would expect that the unsignaled delay of one of these stimuli would have the same effect as the unsignaled delay of primary reinforcement—namely, a substantial response-rate decrement in the preceding link.

METHOD

Subjects

Six adult male White Carneaux pigeons, all with extensive experimental histories, served as subjects. Throughout the experiment, all subjects were housed individually and had free access to water and grit. The birds were weighed after each experimental session and were fed measured amounts of Universal Feeds Pigeon Pellets to maintain them at 80% of their free-feeding body weights.

Apparatus

Six identical, rectangular, operant-conditioning chambers were used. The chambers consisted of opaque black plastic side walls, sheet aluminum front and back walls, a plywood ceiling, and a wire mesh floor. Each chamber was 32 cm high, 35 cm wide, and 36 cm deep and had three response keys, each 2.5 cm in diameter, mounted 23 cm from the floor and 7.25 cm apart, center to center, on the front wall. Each key 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 100 ms. Only the right key was used; the left and center keys remained dark and responses on them were not recorded. Access to a solenoid-operated grain hopper, when activated, was available through a rectangular opening, 5 cm high and 6 cm wide, located 9.5 cm below the center key. Reinforcers consisted of 3.5-s access to milo. While the hopper was raised, it was illuminated by a white light and the keylights were extinguished. General chamber illumination was provided by a dim blue houselight mounted 4 cm above the right key. A ventilation fan and continuously present white noise masked extraneous

Table 1

Order of conditions, schedules (in seconds), and number of sessions per condition.

Condition	Schedule	Sessions
1. Baseline	Chain VI 33 VI 33 VI 33	25
2. Initial-link delay	Chain (VI 30 delay) VI 33 VI 33	20
3. Baseline	Chain VI 33 VI 33 VI 33	20
4. Middle-link delay	Chain VI 33 (VI 30 delay) VI 33	25
5. Baseline	Chain VI 33 VI 33 VI 33	30
6. Terminal-link delay	Chain VI 33 VI 33 (VI 30 delay)	30

sounds. Scheduling of experimental events and data recording were performed by a PDP-8E® (Digital Equipment Corporation) computer located in an adjacent room.

Procedure

Although all subjects had extensive experimental histories, they had not been active for approximately 6 months prior to the beginning of the current experiment. To reestablish key pecking, all subjects were placed on a VI 30-s schedule for five sessions. The key was white during this pretraining period and sessions terminated after 60 reinforcers had been delivered. After pretraining, subjects were exposed successively to the conditions shown in Table 1. Key colors that accompanied the initial, middle, and terminal links were blue, red, and white, respectively, throughout the experiment.

During baseline conditions, the VI schedules consisted of intervals pseudorandomly selected from a modified, 20-interval, Fleshler and Hoffman (1962) distribution. This distribution consisted of a standard, 20-interval, VI 30-s Fleshler and Hoffman distribution with 3 s added to each of the 20 intervals. When an unsignaled delay followed a given link, the standard, unmodified VI 30-s distribution was substituted for the modified distribution in that link. In this manner, the scheduled interreinforcement interval (IRI) remained constant between baseline and delay conditions. Each delay condition was preceded and followed by the immediate-transition baseline condition as indicated in Table 1.

During baseline conditions, after a given interval had elapsed, the next peck was followed immediately by the stimulus correlated with the next link in the chain. During a delay condition, the first peck after the completion of an interval started a 3-s delay timer. At the end of the timer operation, stimulus change and component transition occurred independently of behavior. Thus, during a delay condition, the schedule in the designated component was changed from a simple VI 33-s schedule to a tandem VI 30-s FT 3-s schedule. No stimulus change signaled the delay interval and responses were free to occur during it, so the obtained delays between the last key peck and stimulus change were often shorter than the 3-s scheduled delay. A measure of the actual delays was obtained by having the key peck that started the delay timer also start a second timer. Each subsequent peck during the delay interval reset this second timer. Upon component transition, the elapsed time on the second timer was recorded on a cumulative timer from which the average delay-per-stimulus change was computed.

Sessions were conducted 5 to 7 days per week and were terminated after 60 reinforcers had been delivered. Each condition was conducted for a minimum of 20 sessions after which response rate as a function of sessions was plotted for each subject and visually examined for stability. If the data from any subject were judged unstable, all subjects received an additional five training sessions after which the data were reexamined and either the condition was terminated or an additional five sessions were conducted for a maximum of 30 sessions.

RESULTS

Figure 1 shows the mean response rate in each component of the chain during the last five sessions of the initial-link delay condition (hatched bars) and the corresponding rate in each component during baseline (solid bars). Baseline rates shown were obtained by averaging together the mean response rates during the last five sessions of the baseline conditions immediately preceding and following the ini-

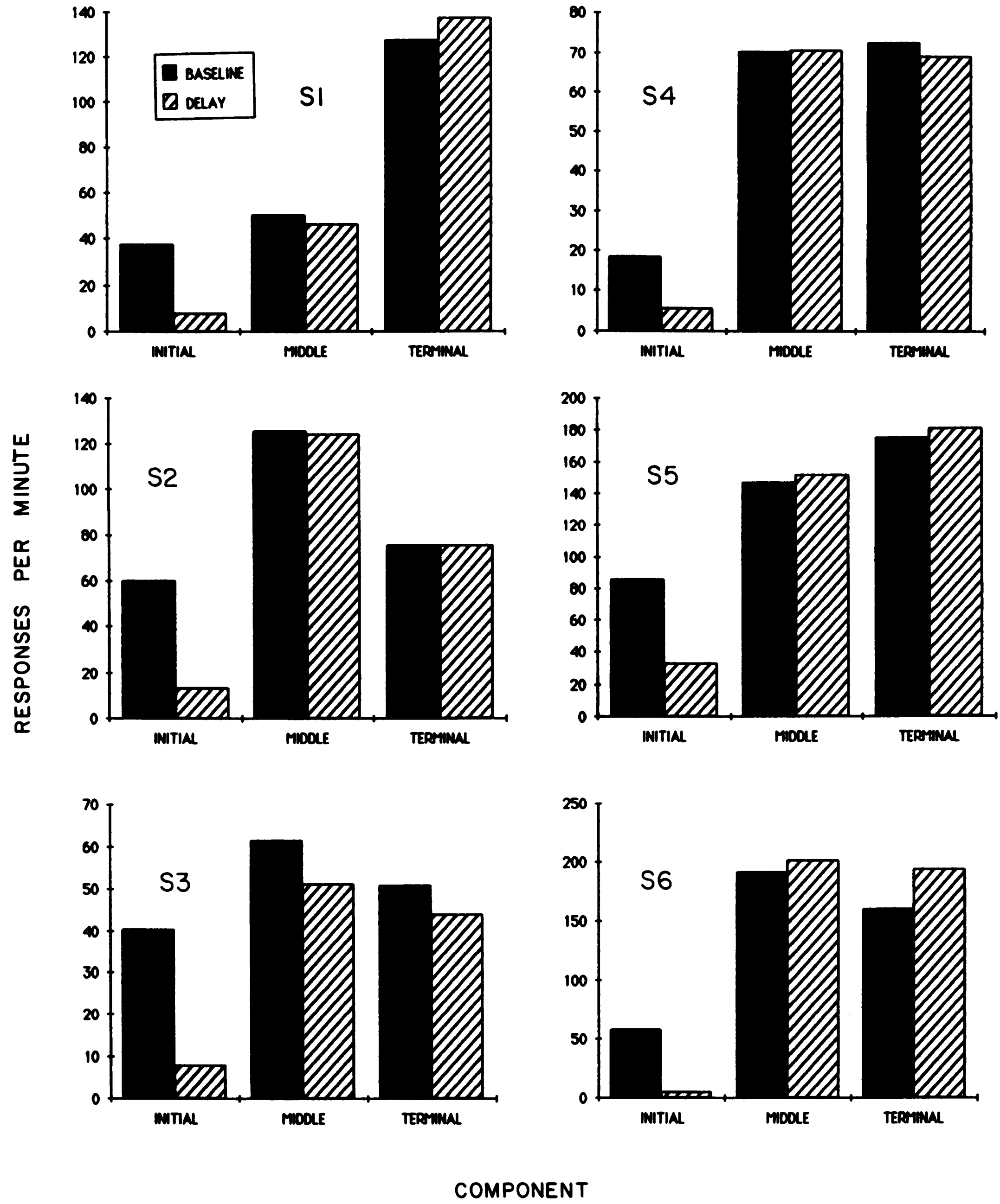

Fig. 1. Response rates (responses/minute) for each of 6 pigeons in each component of the chain during baseline (solid bars) and during the condition where the delay to stimulus change was imposed on initial-link responding (hatched bars). Ordinate scaling varies among subjects.

tial-link delay condition. The data for the individual conditions are shown in the Appendix. As may be seen in Figure 1, initial-link response rates decreased during the delay condition for all 6 subjects with an average decrease of 77% from baseline levels. There was no systematic effect of the initial-link delay contingency on response rates in either the middle or terminal links.

Session-by-session initial-link response rates

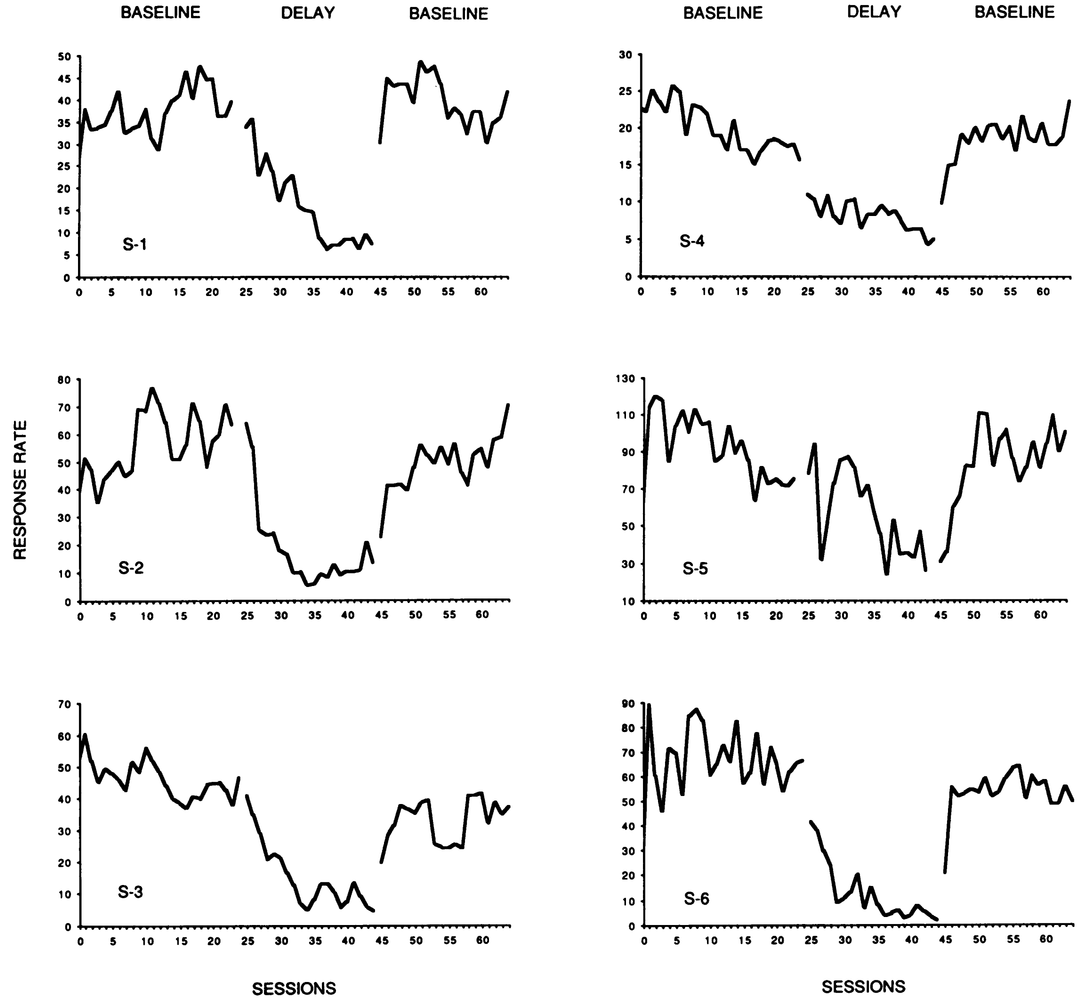

Fig. 2. Initial-link response rates as a function of sessions during the initial-link delay condition and adjacent baseline conditions.

for each of the 6 subjects are shown in Figure 2. For all subjects the delay contingency took effect quickly, with large response-rate decreases evident after only one to five sessions of exposure. Response rate then continued to decrease for the next 15 to 20 sessions and became generally stable during the last 10 sessions for 4 of the 6 subjects. For 2 subjects (S-4, S-6), however, response rates were still decreasing at the end of exposure to the delay condition. Recovery from the delay contingency was quite rapid during the return-to-baseline condition, as the level of responding from the preceding baseline was typically reached within five sessions following removal of the delay contingency.

Figure 3 shows the mean response rate in each component of the chain during the last five sessions of the middle-link delay condition (hatched bars) and the corresponding rate in each component during baseline (solid bars). Again, baseline rates were averaged over the baseline conditions immediately before and after the middle-link delay condition. Middle-link response rates decreased during the delay condition for all subjects, with an average decrement of 59%. Terminal-link response rates decreased slightly for all subjects during the delay condition, and a slight initial-link response rate decline was also evident for 4 of the 6 birds.

Figure 4 shows the middle-link response

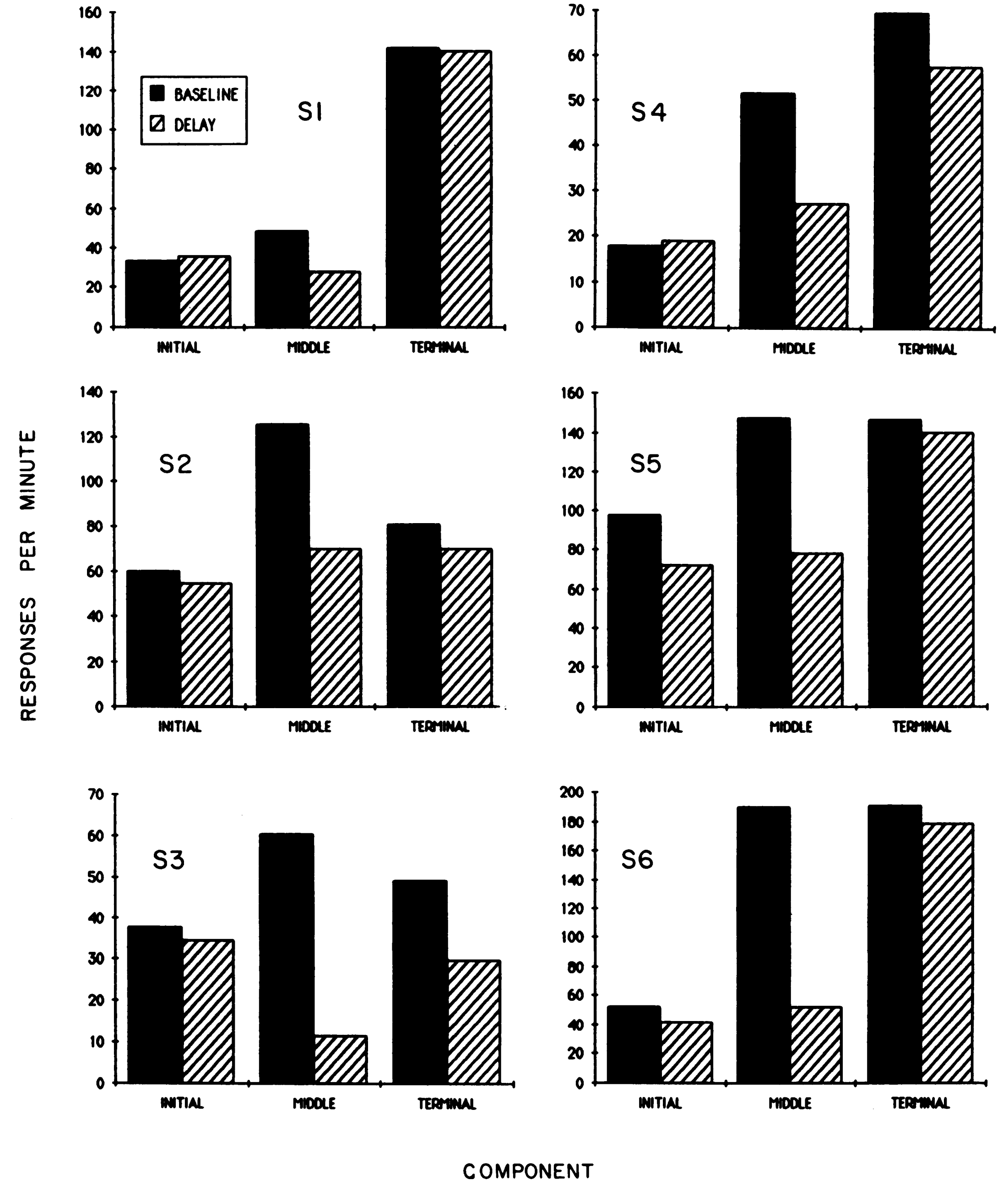

Fig. 3. Response rate (response/minute) in each component of the chain during baseline (solid bars) and during the middle-link delay condition (hatched bars). Ordinate scaling varies from subject to subject.

rates during sessions of the middle-link delay condition and its adjacent baseline conditions. As in the initial-link delay condition, response rates dropped quickly for all 6 subjects, although the rate of decline was notably smaller for some subjects than was the rate of decline evident in Figure 2 for the initial-link delay condition. Because of the slower rate of decline, response rates after 25 sessions were still decreasing for 4 of the 6 subjects, suggesting that still lower response rates would have been obtained had the delay condition been contin-

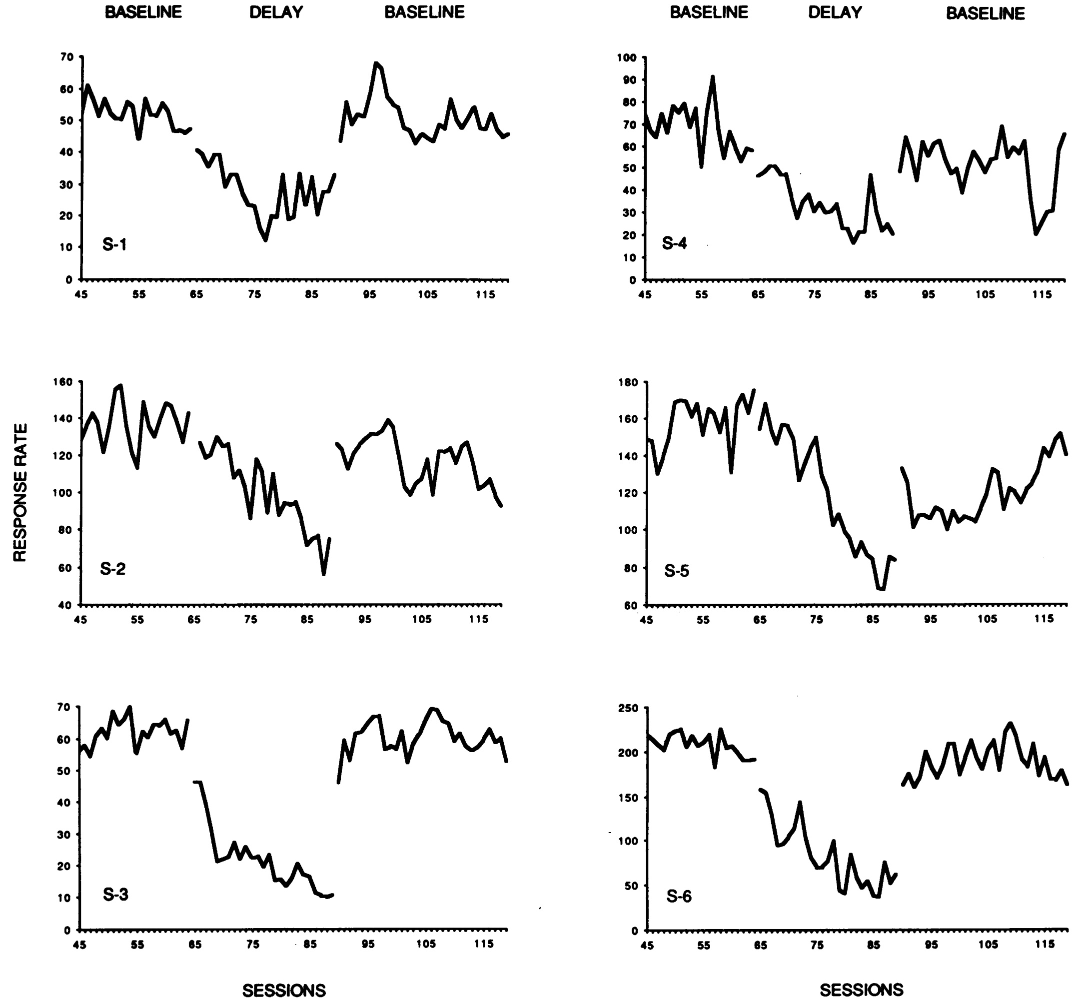

Fig. 4. Middle-link response rates as a function of sessions during the middle-link delay condition and during adjacent baseline conditions.

ued further. Return to baseline after the delay condition produced an immediate increase in rate for all subjects. The rates of responding finally attained during the postdelay baseline were generally comparable to response rates during the predelay baseline.

Figure 5 shows the mean response rates in each component of the chain during the last five sessions of the terminal-link delay condition (hatched bars) and the mean response rate in each component during the last five sessions of the immediately preceding baseline condition (solid bars). A decline in terminal-link response rates during the terminal-link delay condition was evident for 4 subjects, whereas terminal-link response rates increased for the remaining 2 subjects. There was no systematic effect of the terminal-link delay contingency on response rates in either the initial or middle links.

Session-by-session terminal-link response rates during the terminal-link delay condition and its preceding baseline are plotted in Figure 6. Response rates were considerably more variable than were those shown in Figures 2 and 4, both across sessions and across subjects. For 2 subjects (S-3, S-4), there was a regular decline across sessions, much like that seen in the earlier conditions. For 2 others (S-2, S-5), there was an increase in rate, which occurred during the first 5 to 10 sessions of exposure to the delay condition. Response rates for these

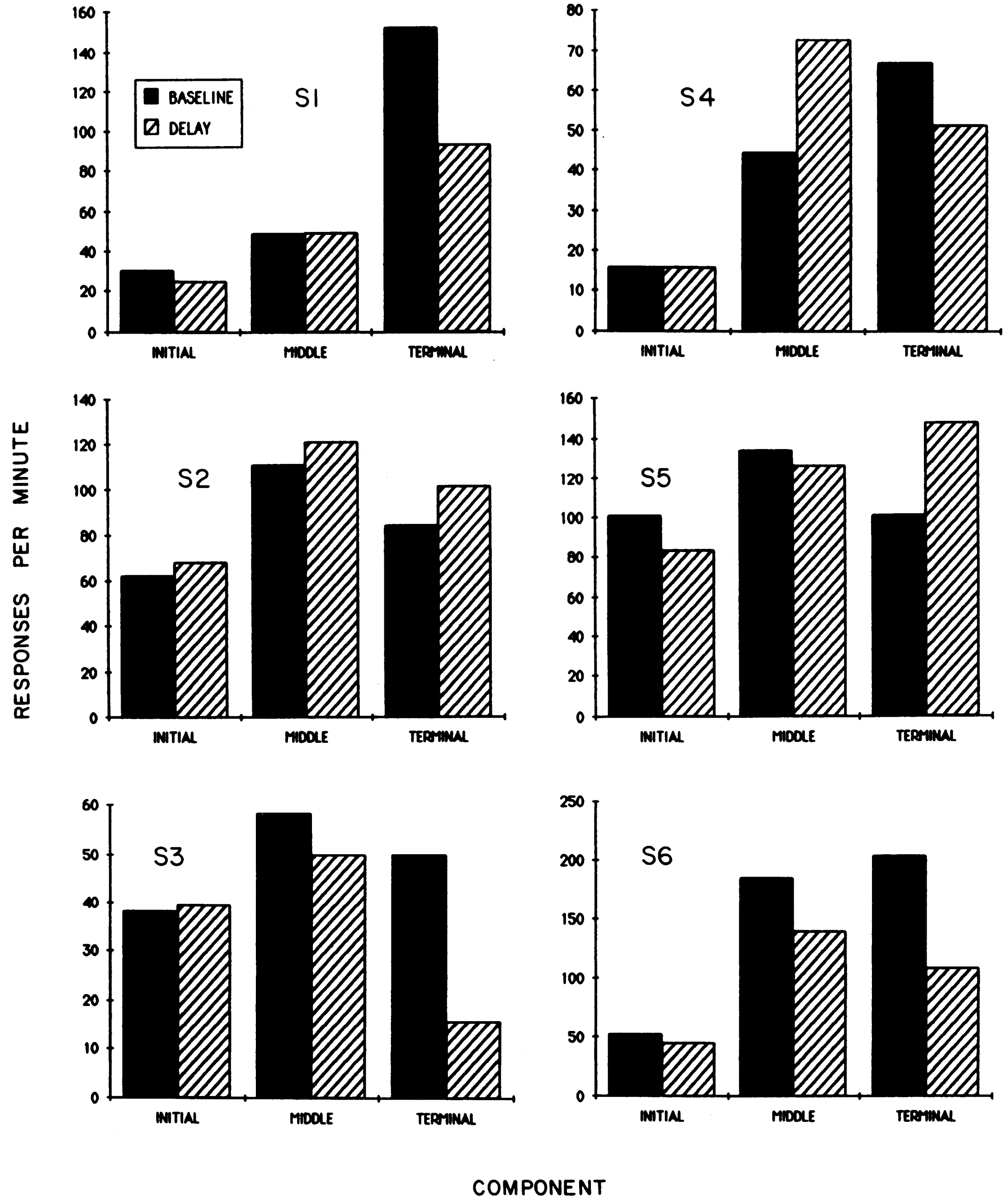

Fig. 5. Response rate (responses/minute) in each component of the chain during baseline (solid bars) and during the terminal-link delay condition. Ordinate scaling varies across subjects.

2 subjects then remained elevated for the duration of the delay condition. For the remaining 2 subjects (S-1, S-6), there was an overall decrease in rate, but performance was highly erratic across sessions, often changing by 30 to 50 responses per minute across successive sessions. Possible reasons for this variability will be considered in the Discussion.

Figure 7 summarizes the above findings by averaging response rates in each component across all 6 subjects for each of the three delay conditions and their corresponding baselines.

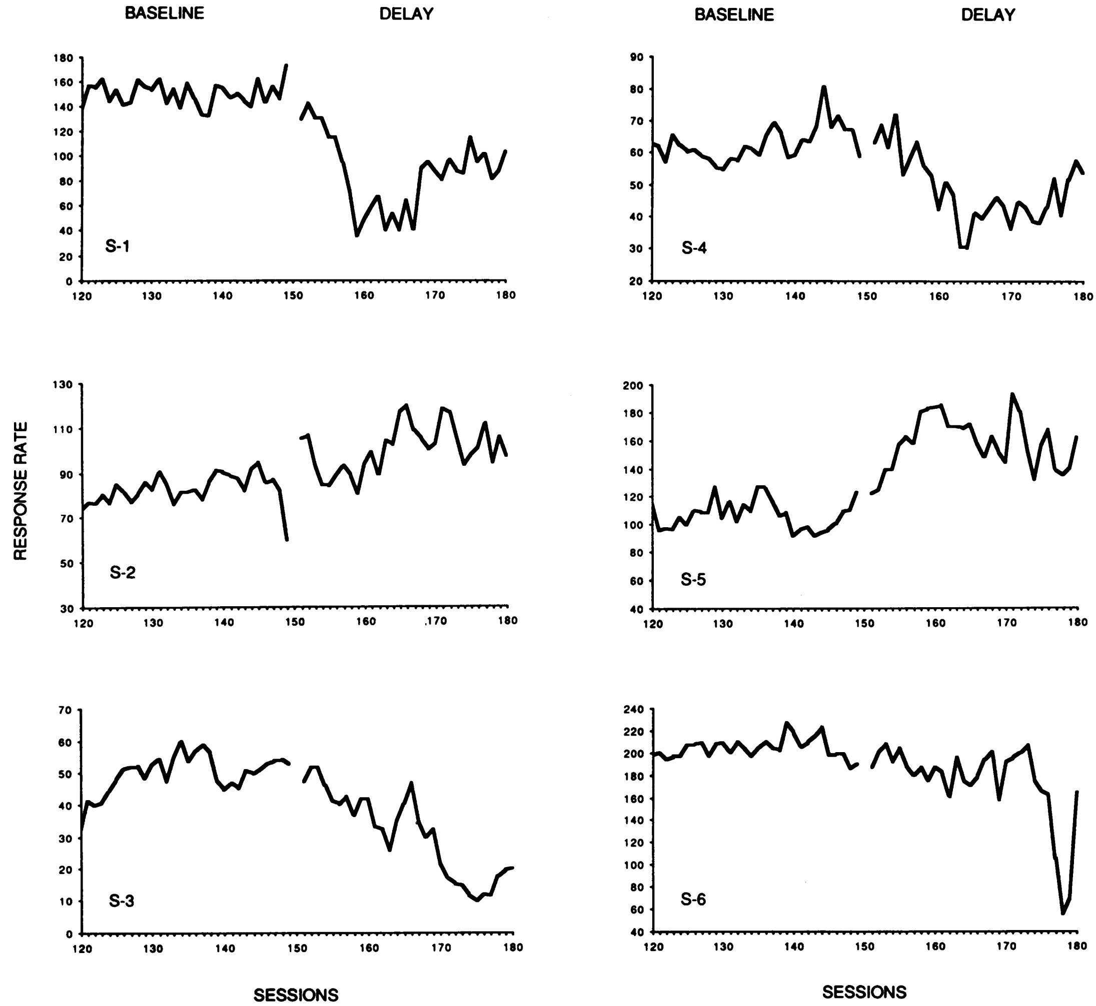

Fig. 6. Session-by-session terminal-link response rates during the terminal-link delay condition and during the immediately preceding baseline condition.

The upper panel shows the rates during the initial-link delay condition; middle-link delay-condition rates are shown in the middle panel; and terminal-link delay-condition response rates are found in the lower panel. Evident in this figure is the specificity of the effect of the unsignaled delay contingency. Within each panel, response rates in the component followed by the delay decreased dramatically from baseline levels, whereas the rates in the remaining two components were largely unaffected by the delay contingency.

Recall that the unsignaled delay contingency specifies only the maximum delay between the last response in one component and the onset of the next component. Table 2 shows the average delays actually occurring in each of the three delay conditions, recorded as described above. Although there is some variability, in general the longest obtained delays occurred in the initial-link delay condition, and the shortest obtained delays were found in the terminal-link delay condition. An exception to this trend may be seen in the data for Subject 5 where the shortest obtained delay, 0.68 s, occurred in the initial-link delay condition, and the longest delay, 1.14 s, occurred in the middle-link delay condition. Note, however, that even this modest initial-link delay was nevertheless sufficient to produce a robust response rate decrease of 53 responses per minute.

Table 3 shows the obtained interreinforcement intervals for each of the three delay conditions and the mean of the obtained interreinforcement intervals (IRIs) for the three baseline conditions. In general, the increase in obtained IRIs over baseline levels was greatest when the delay occurred after the initial link and smallest when the delay occurred after the terminal link. With the exception of the initial-link delay condition for Subject 6, however, in no instance did the obtained IRI during a delay condition exceed the baseline IRI by more than 7.5 s, and in six instances, the obtained IRIs during delay conditions were actually less than the baseline IRIs.

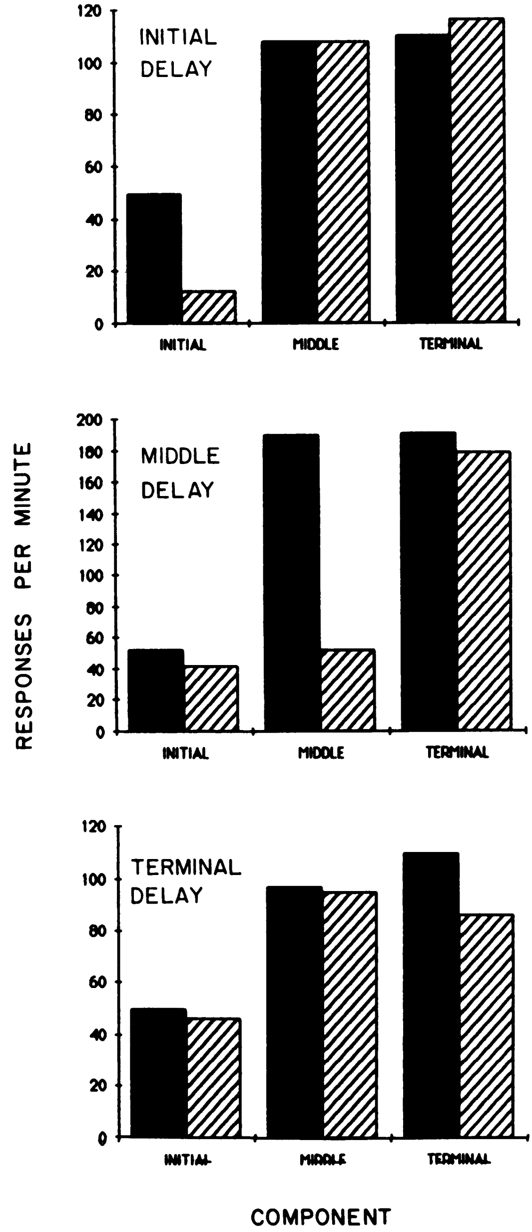

Fig. 7. Response rate (response/minute) in each component of the chain averaged across subjects for the initial-link delay condition and corresponding baseline (upper panel), middle-link delay condition and corresponding baseline (middle panel), and terminal-link delay condition and corresponding baseline (bottom panel). Ordinate scaling varies among panels.

Table 2

Mean obtained delays (in seconds).

	Subject					
Condition	1	2	3	4	5	6
Initial-link delay	2.52	2.18	2.29	1.64	0.68	2.80
Middle-link delay	1.84	1.51	2.01	2.53	1.14	1.95
Terminal-link delay	1.09	0.63	2.11	1.07	0.73	1.13

DISCUSSION

The present data demonstrate that behavior in the initial and middle links of a three-link chain schedule is maintained by the contingency between responding and access to the succeeding stimulus of the chain. Interposing a brief delay between responding and access to the succeeding stimulus produced major decrements in response rate. Such effects cannot be explained by increases in the temporal distance to primary reinforcement signaled by the different stimuli correlated with the different links, because the delay procedure had no effect on the overall time to reinforcement. Slight increases in the obtained interreinforcement interval did occur, but these were clearly due to the delay procedure having produced large decreases in response rates, including substantial periods of no responding. The magnitude of the present effects thus suggests that a major determinant of responding in chain schedules is the conditioned reinforcement value of the succeeding stimulus of the chain.

The large and consistent conditioned reinforcement effects seen in the present study raise the question of why comparable effects have not been found in the past. For example, in the study by Catania et al. (1980), which demonstrated higher response rates in a chain FI FI FI than in a corresponding multiple EXT EXT FI, the effects of conditioned reinforcement were evident only in the middle

Table 3

Mean obtained interreinforcement intervals (in seconds). Baseline IRIs shown are the means of the three baseline conditions.

	Subject					
Condition	1	2	3	4	5	6
Baseline	100.9	101.0	101.9	103.1	97.5	101.8
Initial delay	108.4	105.7	102.6	106.5	104.9	122.8
Middle delay	105.5	100.4	107.4	103.8	100.3	105.1
Terminal delay	98.5	96.6	98.8	102.3	100.3	94.1

link of the chain (there was no difference in response rates in the initial link) and were small in magnitude (although consistent across subjects). The smaller differences reported in that study are puzzling, because in the present study the contingency between responding and component transition was merely degraded by the addition of the unsignaled delay, whereas in the multiple-schedule condition of the study by Catania et al., the contingency between component transition and responding was completely absent. The most likely explanation of this difference in the magnitude of the respective findings was the use of very brief training periods (either four or eight sessions per condition) in the study of Catania et al. Several of their subjects' responding did not show discriminative control during the four or eight sessions per condition with the new schedule contingencies: Responding at substantial rates occurred during the second EXT component of their multiple EXT EXT FI condition. Had training continued until responding during that component ceased (as it did for some of their subjects), a larger difference between their chain and multiple schedules might have been apparent.

The present results are also in ostensible conflict with studies comparing chain and tandem schedules; those studies have reported higher response rates during the initial links of the tandem (see introduction). This finding has been interpreted as evidence that the discriminative properties of the initial-link stimuli, rather than conditioned reinforcement, are the major determinant of responding in the initial links of the chain. Most prior studies have typically used chain schedules consisting of FI components. Given that the subjects discriminate the temporal properties of the FI schedule, the onset of the stimulus correlated with the next link of the chain should be a cue for nonreinforcement with respect to the next conditioned reinforcer, just as it appears that the onset of a stimulus correlated with a simple FI schedule is a cue for nonreinforcement with respect to the primary reinforcer (see Schneider, 1969). Thus, such a stimulus event should not be an effective conditioned reinforcer, so behavior leading to that stimulus should, not surprisingly, be weakly maintained. The result is that there should be less responding in the initial link of a chain FI FI FI schedule than during the initial link of a corresponding tandem schedule. The present analysis suggests that chain VI VI VI schedules (and the corresponding tandem) would produce a different outcome—that is, little difference in the initial-link response rates. Support for this speculation comes from a comparison of the data of Duncan and Fantino (1972) with those of Schneider (1972) obtained from studies of choice between single-stimuli and chain schedules (in the terminal links of concurrent-chains schedules). In Duncan and Fantino's study, choice was assessed between simple FI 2*x* and chain FI *x* FI *x* schedules. Pigeons showed dramatic preference for the simple FI. Schneider, however, assessed choice between tandem and chain VI VI schedules, and found indifference. Moreover, there is no evidence from Schneider's study (see his Table 1, page 49) that response rates in the initial link of the tandem VI *x* VI *y* schedule differed from those in the initial link of the chain VI *x* VI *y* schedule. (For a more complete discussion of these findings, see Duncan & Fantino, 1972, and Fantino, 1977.) It should be acknowledged, however, that although the comparison of the data of Schneider with those of Duncan and Fantino (1972) supports the present emphasis on conditioned reinforcement, other results from studies of segmentation of reinforcement intervals show strong discriminative effects even with VI schedules (e.g., Fantino

& Duncan, 1972; Leung & Winton, 1985; Moore, 1982).

A more fundamental problem with the comparison of chain and tandem schedules as evidence for the role of conditioned reinforcement is that such a comparison depends critically on implicit assumptions about the tradeoff between reinforcement rate and reinforcement type (primary vs. conditioned). As is well known, the function relating response rate to reinforcement rate is hyperbolic in shape (Catania & Reynolds, 1968; Herrnstein, 1970). This is important because to the extent that subjects trained with a tandem schedule fail to discriminate elapsed time as a result of the contingencies for component transitions, their schedule effectively becomes a simple interval schedule equal to the sum of the times required to complete the tandem requirements. Thus, the tandem–chain comparison becomes equivalent to one between a simple interval schedule of primary reinforcement versus a second, shorter interval schedule of conditioned reinforcement. With a chain FI 30 FI 30 FI 30 versus tandem FI 30 FI 30 FI 30, for example, the comparison would be between a 30-s interval schedule of conditioned reinforcement versus a 90-s interval schedule of primary reinforcement. The problem is that we do not know beforehand what the relative strengths of behavior maintained by each of the two schedules should be, even assuming that conditioned reinforcement is a potent determinant of behavior. Given a hyperbolic function relating response rate to reinforcement rate, which implies that there are large regions of the function in which different frequencies of reinforcement produce very similar response rates, a VI 90-s schedule of primary reinforcement may produce response rates similar to those of a VI 30-s schedule of primary reinforcement. Such a possibility would preclude the use of the chain–tandem comparison as a meaningful index of conditioned reinforcement because presumably a VI 30-s schedule of primary reinforcement would produce higher response rates than would a VI 30-s schedule of conditioned reinforcement. More generally, until the separate functions relating response rate to the frequency of primary versus conditioned reinforcement are specified, the comparison between chain and tandem schedules as an index of conditioned reinforcement can mean very little.

The present results are also in apparent conflict with findings from studies of FI schedules in which subjects could produce brief presentations of "clock" stimuli correlated with successive segments of the FI. Such schedules are similar to chain schedules in that there is a contingency between responding and access to stimuli correlated with temporal distances from primary reinforcement. Despite the similarity, however, such studies (Auge, 1977; Kendall, 1972) have suggested that stimuli that accompany the initial and middle segments of the interval are not conditioned reinforcers and may be in fact conditioned punishers. For example, Auge presented pigeons an FI 32-s schedule divided into three segments cued by individual stimuli. In addition to the constant stimulus in each segment, responses during a given segment could produce brief presentations of the stimuli correlated with other segments. Thus, presentations of the middle stimulus were arranged contingent on responding during both the initial and terminal segments of the FI. Whereas the present data suggest that the middle stimulus should have been a conditioned reinforcer for responding in the initial segment and thus should have enhanced responding during the initial segment, little change was observed and responding continued at a near-zero rate.

Although such results seem in conflict with the present findings, a closer analysis suggests that the conflict is only superficial. It is uncertain, for example, whether "brief" stimulus presentations are functionally similar to the ostensibly same stimulus when presented for longer durations. Similarly, presentations of brief stimuli not only add a new stimulus to the situation, they also change the existing stimulus situation. Thus, it is possible that the lack of an apparent conditioned-reinforcement effect was due to these complexities. The present procedure did not contain these possible disruptive influences, and the resulting large effects of the delay contingency suggest strongly that the middle stimuli of a chain (and possibly of a segmented FI) have strong conditioned reinforcing properties for responding in the initial link.

An aspect of the present results that bears comment is the smaller and less consistent effect of the delay contingency when it was imposed between responding in the terminal link and access to food (see Figures 5 and 6). Only 4 of the 6 subjects revealed an effect of the delay contingency, whereas all subjects had shown reliable effects when the delay had been presented in either the initial or middle links of the chain. Such a result seems surprising because the terminal link of the chain was most similar to a simple VI food schedule, which previous studies have used to demonstrate strong effects of the unsignaled delay-of-reinforcement contingency. Two possible reasons for the discrepancy can be suggested. The first considers the role of elicited behavior. If both the response contingency and the occurrence of conditioned reinforcement are ignored, a three-link chain schedule is comparable to a multiple EXT EXT VT schedule, which often has been used to study autoshaped pecking. This suggests that at least part of the behavior maintained in the terminal link of the chain schedule in the present study was controlled by the Pavlovian signal properties of the terminal-link stimulus. Consequently, interposing the delay between responding and food during the terminal link should be expected to have less effect than during a comparable simple VI schedule, because in the latter the Pavlovian contingency is absent. The relatively weak delay effects seen during the terminal link may thus reflect the relative influence of Pavlovian versus operant contingencies in controlling behavior in that link. Control of behavior in the terminal link by Pavlovian contingencies would also help to explain the greater variability (noted above) in response rates in the terminal-link delay condition than in the two previous delay conditions, as behavior maintained by stimulus–reinforcer contingencies is frequently more variable than behavior maintained by response–reinforcer contingencies (e.g., Williams, 1976a).

The second possibility is that the discrepancy between the present results and those from previous studies of the unsignaled delay of reinforcement in simple VI schedules is more apparent than real. Sizemore and Lattal (1978) plotted functions relating percentage change in response rate to obtained rather than programmed unsignaled delays. The present results are quite comparable to these functions from simple VI schedules. For example, the 3 subjects in the current study whose obtained delays in the terminal-link condition were approximately 1 s (S-1, S-4, and S-6) showed response-rate decrements relative to baseline of 38%, 68%, and 46%, respectively, which compare favorably with the decrements of 30%, 35%, and 55% observed by Sizemore and Lattal at obtained delays of 1 s (percentages estimated from Figure 2 of Sizemore & Lattal). Likewise, the decrement of 69% in the response rate of Subject S-3 in the current study with an obtained terminal-link delay of 2.1 s compares well with the 45%, 60%, and 65% decrements observed by Sizemore and Lattal at a 2-s obtained delay. Indeed, even the seemingly paradoxical response-rate increases of Subjects S-2 and S-5 in the present study (obtained delays of 0.6 and 0.7 s) are compatible with the response-rate increases observed by Sizemore and Lattal and by Lattal and Ziegler (1982) at their shortest (0 to 0.5-s) delay values. Such response-rate increases with very short delays are apparently due to the shaping of response bursts (Lattal & Ziegler).

Finally, the present study has implications for the level of analysis appropriate for reinforcement schedules in general. Rejection of the concept of conditioned reinforcement has occurred partly because of its alliance with a molecular analysis, wherein behavior is assumed to be determined by the cumulation of the individual effects of temporally contiguous events. In contrast, molar levels of analysis have invoked concepts such as stimulus–reinforcer contingency, response–reinforcer correlations, and the like. Staddon's (1983) account provides an example of this approach with respect to chain schedules, insofar as he suggested, in lieu of conditioned reinforcement, that the variable controlling response rate is the "relative temporal proximity" to food. Such a molar notion cannot easily explain the large effects of the brief delay contingencies used in the present study, for in this case the molar temporal properties of the various discriminative stimuli were left intact. Whether a similar molecular analysis will be successful in other schedule situations remains to be seen, but the present findings provide strong encouragement for such an attempt.

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APPENDIX

Response rate (responses/minute) in each component for all conditions of the experiment.

		Subject					
Condition	Link	1	2	3	4	5	6
Baseline	Initial	39.12	63.08	43.45	17.56	76.52	62.87
	Intermediate	52.47	110.68	60.75	81.73	132.14	186.88
	Terminal	123.43	73.65	52.80	72.36	159.43	141.73
Initial delay	Initial	7.81	12.78	7.58	5.53	32.67	4.24
	Intermediate	46.64	124.50	51.04	70.50	151.81	201.79
	Terminal	137.58	75.66	43.93	68.92	180.75	193.10
Baseline	Initial	35.95	57.96	37.03	19.62	94.84	52.05
	Intermediate	48.00	140.49	62.37	58.93	161.06	195.31
	Terminal	131.63	77.39	48.27	72.93	191.98	178.95
Middle delay	Initial	35.57	54.89	34.25	19.23	71.83	41.74
	Intermediate	28.04	70.01	11.41	27.39	78.02	51.80
	Terminal	140.57	70.11	29.80	57.91	139.77	178.27
Baseline	Initial	30.32	62.53	38.17	15.86	101.07	51.64
	Intermediate	48.72	110.68	58.32	44.52	133.87	184.52
	Terminal	151.63	84.49	50.03	66.66	101.15	203.89
Terminal delay	Initial	25.11	68.25	39.42	15.91	83.26	44.01
	Intermediate	49.40	121.19	49.76	72.46	126.12	139.34
	Terminal	93.34	101.70	15.72	51.23	147.39	109.19