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# *CONDITIONED REINFORCEMENT VERSUS TIME TO REINFORCEMENT IN CHAIN SCHEDULES*

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Pigeons were trained on three-component chain schedules in which the initial component was either a fixed-interval or variable-interval schedule. The middle and terminal components were varied among fixed-interval fixed-interval, variable-interval variable-interval, and an interdependent variable-interval variable-interval schedule in which the sum of the durations of the two variable-interval components was always equal to the sum of the fixed-interval fixed-interval components. At issue was whether the response rate in the initial component was controlled by its time to primary reinforcement or by the temporal parameters of the stimulus correlated with the middle terminal link. The fixed-interval initial-link schedule maintained much lower response rates than the variable-interval initial-link schedule regardless of the schedules in the middle and terminal links. Nevertheless, the intervening schedules played some role: With fixed-interval schedules in the initial links, response rates were consistently highest with independent variable-interval schedules in the middle and terminal links and intermediate with the interdependent variable-interval schedules; these initial-link differences were predicted by the response rates in the middle link of the chain. With variable-interval schedules in the initial links, response rates were lowest with the fixed-interval fixed-interval schedules following the initial link and were not systematically different for the two types of variable-interval variable-interval schedules. The results suggest that time to reinforcement itself accounts for little if any variance in initial-link responding.

*Key words:* chain schedules, conditioned reinforcement, time to reinforcement, fixed-interval schedules, variable-interval schedules, key peck, pigeons

Many previous analyses of chain schedules have assumed that the major variable controlling response rate in early components of the chain is the temporal distance to food correlated with the component stimuli (Gollub, 1977). Although this empirical description captures the usual correlation between response rate and component order, the processes underlying this correlation remain a subject of disagreement. Some investigators (Staddon, 1972, 1983) have argued that *relative temporal proximity* is the fundamental principle controlling the strength of a reinforcement contingency and hence is a primitive process not reducible to more molecular events. Others (Kelleher & Gollub, 1962) have argued that performance in chain schedules should be understood in terms of the discriminative properties of the component stimuli with regard to the conditioned reinforcement effects of the stimuli in the successive links of the chain. The major issue separating these two approaches, apart from the appropriate level of analysis, is whether the concept of conditioned reinforcement is useful as an explanatory concept for chain schedule behavior.

Strong evidence supporting the involvement of conditioned reinforcement in chain schedules was provided by Royalty, Williams, and Fantino (1987), who presented pigeons three-component chain variable-interval (VI) schedules. The transition between pairs of components was varied by having the succeeding link of the chain immediately contingent on the response or by having a 3-s unsignaled delay between the response producing the next link and the actual stimulus onset. Time from the target component to primary reinforcement was held constant regardless of whether the unsignaled delay was in effect. Response rates in the initial and middle components were reduced 60% to 80% by the delay contingency, in much the same manner as previously had been shown when unsignaled delays are added to simple schedules of primary reinforcement (cf. Williams, 1976). This major effect of the delay contingency with respect to onset of the succeeding link of the chain provides strong

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support for the conclusion that conditioned reinforcement by the component stimuli, not time to the primary reinforcer of food, is a major controlling variable.

The issue raised by the results of Royalty et al. (1987) is how the strong effects of conditioned reinforcement evident in their study are to be reconciled with previous results in which conditioned reinforcement effects appear to be absent. Chain schedules with more than two links are known to maintain little behavior in the initial links of the chain (e.g., Kelleher & Fry, 1962); this suggests that any conditioned reinforcement effect of the onset of the succeeding link is at best very weak. On the basis of the difficulty of maintaining behavior in extended chains, Staddon (1983) has suggested that chain schedules are functionally similar to fixed-interval (FI) schedules, with the major difference being that the early parts of the interval are better discriminated because they are correlated with distinct cues. Such an analysis assumes that the discriminative properties of the initial-link cues are based on their discriminated time to primary reinforcement rather than to their relation to the next link in the chain.

In general, previous studies that have shown weak behavior in the initial link of a three (or more) link chain have used FI schedules in each component of the schedule. This may be important because direct comparisons of chains with VI versus FI components have shown that the former produce substantially higher response rates in the initial links (Gollub, 1958, as summarized by Kelleher & Gollub, 1962). This difference, combined with the conditioned reinforcement effects obtained by Royalty et al. (1987) with VI components, suggests that chain schedules with FI components may be much less sensitive to conditioned reinforcement effects. One possible reason for such a difference is that temporal discrimination of the availability of reinforcement is easier with FI components, because with VI components the time to reinforcement can be highly variable. Thus, the conditioned reinforcement effects that occur with VI schedules may be overriden by the temporal discrimination possible when FI schedules are involved.

An alternative explanation of the weak initial-link behavior in chain FI FI FI schedules is that the conditioned reinforcement properties of the stimulus onset of the second link are themselves very weak. The lack of effective conditioned reinforcement would be expected on the basis of the pattern of response rate maintained by FI schedules. The onset of the FI typically produces a near-zero response rate, presumably because it is temporally distant from reinforcement (whether food or access to the succeeding link of the chain) and thus is a period of discriminated extinction. It should, then, not be surprising that the behavior producing that stimulus onset is maintained very weakly.

A critical issue for understanding the role of conditioned reinforcement in chain schedules is whether the controlling variable for initial-link behavior is the "value" of the following-link stimulus or the temporal relation of the initial link itself to primary reinforcement. A simple comparison of chain FI FI FI and chain VI VI VI schedules does not separate these alternatives because the schedules differ both with respect to time to food and time to the succeeding links of the chain. This is true even when the nominal values of the FI and VI components are the same, because the chain with VI components is comprised of a variable distribution that includes several short intervals (both to food and the following link), which a variety of evidence implicates as the important variable (e.g., Killeen, 1968). What is needed to separate the alternatives is a schedule in which the time from the initial link to food is held constant, as it is with FI components, while the time in the succeeding link is variable, as it is with VI components. To the extent that response rate in the initial link varies as a function of the temporal properties of the middle link, independent of changes in time to food, then presumably it is the value of the middle-link stimulus that controls initial-link responding.

The present study compared the effects of three types of chain schedules. The first two were initially chain FI 33 FI 33 FI 33 (all values in seconds) and chain FI 33 VI 33 VI 33. In the second phase the initial links for both were changed to VI 33. The expectation, on the basis of the results of Royalty et al. (1987), was that initial-link response rates would be high when the middle and terminal links were VI schedules, whereas based on other data (e.g., Kelleher & Fry, 1962), the initial-link response rates with FI schedules in the intervening links generally would be low. The critical test was the effect of a third type of chain in which the middle and terminal links were VI schedules with intervals that always summed to the same value as the corresponding FI schedules. That is, the interval of the middle component varied randomly from zero to the sum of the two FI components (in this case 66 s), while the interval of the terminal component was always the difference between the 66 s and the middle-link interval. The time between the initial link and food was thus kept constant in this third schedule, as it was when the middle and terminal links consisted of FI components. But the times between the onset of the middle link and the onset of the terminal component were variable and included a number of short intervals. Given previous data showing that such variable intervals enhance reinforcement effectiveness in comparison to fixed intervals of the same mean value (Killeen, 1968), the conditioned reinforcement properties of the middle-link stimulus with this interdependent schedule should be greater than the stimulus correlated with the FI middle-link stimulus. At issue was the strength of behavior maintained in the initial link of the interdependent schedule. If more like the chain with FI components, the controlling variable would be shown to be time to food; if more like the chain with VI components, the controlling variable would be the conditioned reinforcement properties of the middle-link stimulus.

## METHOD

### *Subjects*

The same 6 adult male White Carneau pigeons used by Royalty et al. (1987) were continued as subjects. All were maintained at 80% of their free-feeding weights by additional feeding, when necessary, after the experimental sessions.

### *Apparatus*

Six identical operant chambers were used. The chambers had opaque black 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. Reinforcement 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 sounds. Scheduling of experimental events and data recording were performed by a PDP-8E® (Digital Equipment Corporation) computer located in an adjacent room.

### *Procedure*

The procedure was a continuation of that of Royalty et al. (1987). Between the termination of the previous study and the beginning of the present study was a period of 5 months in which unsignaled delay contingencies were studied with chain FI FI FI schedules. These data will not be reported. Because the subjects already had extensive training with the schedules and keylights, they were begun immediately on the sequence of conditions shown in Table 1. For all conditions, a three-component chain was used in which the sequence of stimuli was always blue, red, and white for the three links of the chain.

In Phase 1 the initial-link schedule was always FI 33 s, while the schedules during the middle links were varied. In the first condition both the middle and terminal links were also FI 33-s schedules. During the third condition, independent VI 33-s schedules occurred in the middle and terminal links. The intervals constituting these schedules were drawn from a modified 20-interval Fleshler and Hoffman (1962) distribution. This distribution consisted of a standard 20-interval VI 30-s distribution with 3 s added to each of the 20 intervals. This modification was used because it had been used previously in the study of Royalty et al. (1987). The second and fourth conditions used interdependent VI schedules,

Table 1

Order of conditions.

| Order | Schedule in middle and terminal links (in seconds) | Number of sessions |
|---|---|---|
| Phase 1: Initial-link schedule = FI 33 s | | |
| 1 | FI 33 FI 33 | 50 |
| 2 | (VI + VI) = 66 | 25 |
| 3 | VI 33 VI 33 | 20 |
| 4 | (VI + VI) = 66 | 20 |
| Phase 2: Initial-link schedule = VI 33 s | | |
| 5 | (VI + VI) = 66 | 60 |
| 6 | FI 33 FI 33 | 30 |
| 7 | VI 33 VI 33 | 35 |
| 8 | FI 33 FI 33 | 25 |
| 9 | (VI + VI) = 66 | 25 |

in which the sum of the intervals for each progression through the chain always equaled 66 s. This meant that the longest interval could not exceed 66 s, so that an arithmetic rather than exponential distribution of intervals was used. The 23 intervals comprising this schedule were spaced in 3-s steps, with 0s as the shortest interval and 66 s as the longest. For an entry into the middle component of the chain, the interval was chosen randomly from this distribution, and the complement of that interval was used during the following terminal-link component.

In Phase 2 the schedule during the initial link was changed to VI 33 s, while the schedules during the middle and terminal links were varied among the same set as in Phase 1. A change also occurred in the arithmetic distribution of intervals for the conditions in which the VI schedules summed to 66 s. The shortest interval was now 3 s, as it was with the modified expontential distribution used for the independent VI schedules (because of the addition of 3 s to each interval). Minor adjustments in the remaining intervals were then made in order to produce an arithmetic mean of 33 s. These changes were made to equate the harmonic mean of the interdependent schedule with that of the regular VI distribution. Because of the inclusion of the zero interval in the distribution used in Phase 1, the harmonic mean had been substantially shorter than the regular VI. With the change in intervals in Phase 2, the harmonic means, as well as the arithmetic means, were approximately equal.

Sessions were conducted 5 to 7 days per week and were terminated after 60 reinforcers had been delivered or after 75 min had elapsed. Each condition was conducted for a minimum of 20 sessions, after which response rate 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. The actual numbers of sessions presented are shown in Table 1.

## RESULTS

### *FI Initial Links*

The top portion of Figure 1 shows the mean response rates during the last five sessions of each condition from Phase 1. The chains with FI FI FI and FI VI VI were presented only once; that with interdependent VI schedule in the middle and terminal links was presented twice. In general, response rates were quite low, with a mean of 2.8 responses per minute with FI components in the middle and terminal components, 6.5 with independent VI components, and 4.1 with the interdependent VI components. Such low response rates were often manifested as frequent long pauses in the initial link. The bottom portion of Figure 1 shows the average times spent in the initial links, plotted on a log scale in order to encompass the large range across subjects. In general, the time data are consistent with the response-rate data, as the times in the independent VI VI condition were consistently shorter than in the FI FI condition, whereas those with the interdependent VI were, on average, intermediate. Complete data are provided in the Appendix. The major feature to note in the appended data is that the long times spent in the initial links substantially reduced the obtained reinforcement rates, so that the differences that are shown may be due partly to the correlated differences in reinforcement rate in addition to the actual schedule contingencies. Also note that the standard deviations were substantial, indicating that the between-session variability was often considerable.

Figure 1 shows that response rates in the initial links were higher for all 6 subjects when the independent VI schedules were used in the middle and terminal links, in comparison to

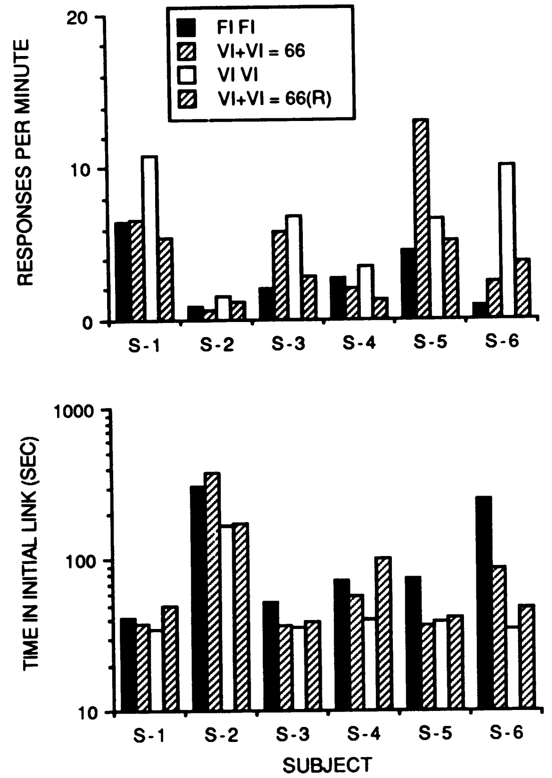

Fig. 1. Data from the last five sessions of each condition in Phase 1, in which FI schedules occurred in the initial link. The top panel shows the initial-link response rates; the bottom panel shows the average times spent in the initial links.

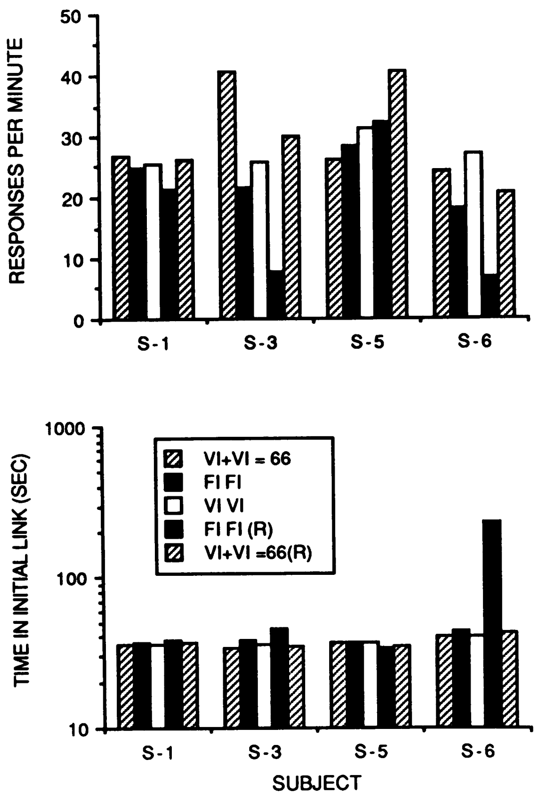

Fig. 2. Data from the last five sessions of each condition in Phase 2, in which VI schedules occurred in the initial link. The top panel shows the response rates during the initial links; the bottom panel shows the average times spent in the initial links.

the FI FI schedules. Response rates with the interdependent VI were intermediate between these two conditions, not only in terms of average rate but also in the performance of individual subjects. Three subjects (S-1, S-2, and S-4) had response rates with the interdependent schedule that were comparable to those with the FI FI schedule, whereas the rates for the remaining subjects (S-3, S-5, and S-6) were substantially higher with the interdependent VI schedule. The rates with the interdependent VI schedule were lower than with the independent VI schedules for 5 of the 6 subjects, whereas the exceptional subject (S-5) had substantially different response rates with the interdependent schedule across its two presentations.

### *VI Initial Links*

Figure 2 shows the corresponding data when the FI schedules in the initial links were replaced by VI schedules. This training included only 4 of the original 6 subjects, because Subjects S-2 and S-4 failed to recover from the pattern of frequent long pauses in the initial link that had developed from the earlier training and were finally dropped from the study after the failure of various efforts to produce higher response rates. It should be noted that these 2 subjects did have high initial-link rates with chain VI VI VI schedules when studied by Royalty et al. (1987). For the remaining subjects, response rates in the initial links were increased substantially by the change to VI schedules. Averaged over all conditions, the initial-link response rates for those subjects were 5.8 responses per minute during Phase 1 but were 25.6 in Phase 2, an increase of over 400%.

Shown in the top portion of Figure 2 are the response rates during the last five sessions of each condition, which included two exposures to the interdependent VI And FI sched-

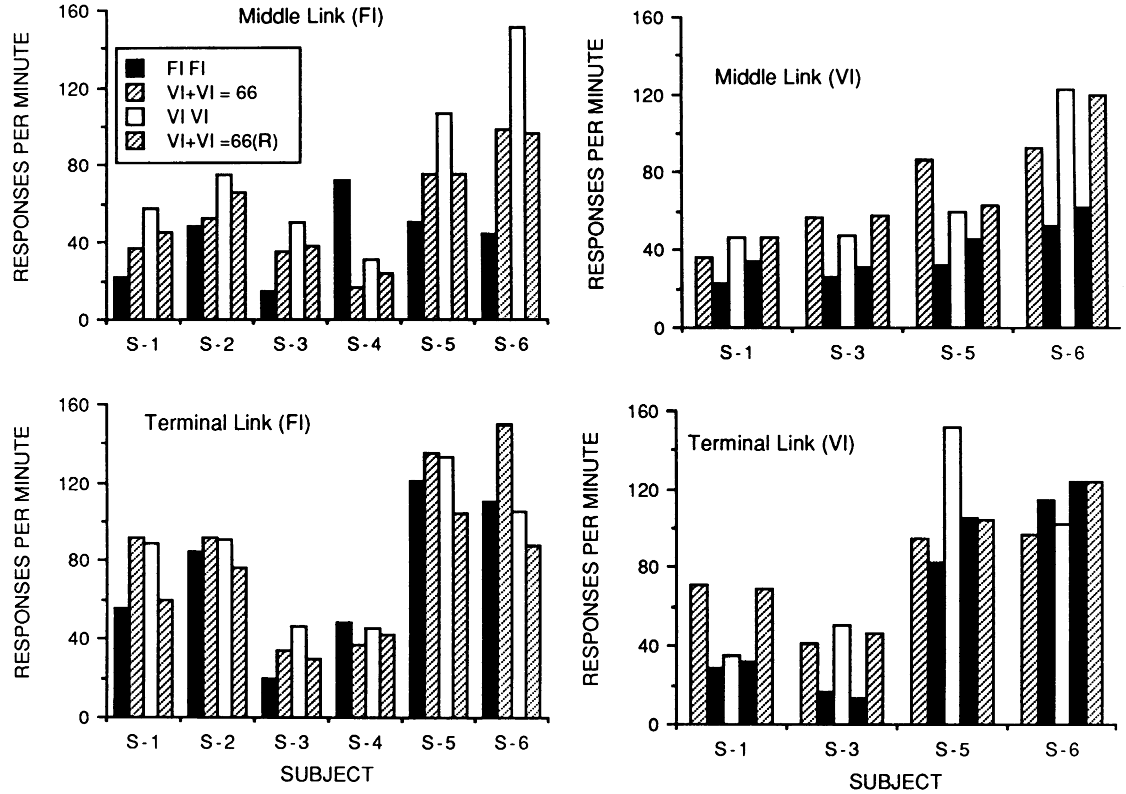

Fig. 3. Response rates from the middle and terminal links. The panels on the left are from Phase 1 with an FI initial-link schedule; the panels on the right are from Phase 2 with a VI initial-link schedule.

ules and only one exposure to the independent VI condition. The mean rates across subjects (and replications of the same condition) were 19.9 in the FI condition, 29.3 in the interdependent VI condition, and 27.4 in the independent VI condition. The differences between the FI and both VI conditions, although small, were consistent across all 4 subjects. With one exception (S-5), the lowest response rates occurred during both exposures to the FI condition, and for that subject, the exception was due to the low rates that occurred in the interdependent VI condition during its first presentation after the extended training with FI schedules in the initial link. Even for that subject, the average of the two replications of the interdependent VI condition was higher than the average for the replications of the FI condition.

The FI condition produced lower response rates than the interdependent VI condition; the FI condition also produced lower rates, in every case, than the independent VI condition, although for S-1 and S-5 this difference was very small. There was no consistent difference between the two VI conditions.

The bottom portion of Figure 2 shows the average times spent in the initial links of the schedule. The differences were much smaller than those seen in Figure 2 when the initial link schedule was an FI, because with few exceptions the subjects completed the initial link in 33 to 36 s (minimum 33 s). In every case in which longer times occurred, the schedule in the succeeding links was FI FI.

### *Middle and Terminal Links*

The differences in initial-link performance seen in Figures 1 and 2 were correlated with differences in behavior during the middle and terminal links of the chain. Figure 3 shows those response rates for both the FI (left panels) and VI initial links (right panels). The time data are not presented because in every case the subjects completed the middle and terminal links in very near the minimum times (see

Appendix). Considering first the data for which the initial-link schedule was FI, the middle-link response rates show a pattern quite similar to that seen in Figure 1 for the initial-link rates. For 5 of the 6 subjects, response rates in the middle link were lowest with the FI FI schedule, often substantially below those from either of the two VI conditions. The behavior for the remaining subject (S-4) is difficult to interpret because its middle-link response rate was also substantially higher than its terminal-link rate. There was also a consistent difference between the independent VI and the interdependent VI conditions; the former produced higher response rates for all 6 subjects. The mean rates in the middle links (responses per minute) averaged over subjects were 40.0 for the FI FI, 55.6 for the interdependent VI, and 78.7 for the independent VI schedules. The differences in the terminal-link rates were generally less consistent across subjects, although the pattern of mean rates was similar: FI FI = 70.0, interdependent VI = 78.2, independent VI schedules = 85.1.

Considering next the middle-link response rates for the conditions when the initial-link schedule was VI, the pattern of differences was even more well defined. For all subjects, there was a substantially lower response rate with the FI schedule in the middle link, whereas there was no consistent difference between the two VI conditions. The results for the terminal component were more variable, with no consistent differences across subjects, although the pattern obtained in the middle link occurred during the terminal link for Subjects S-1 and S-3.

The pattern of results seen in Figure 3 suggests that induction may have played a role in producing the results seen for the initial links in Figures 1 and 2. Given that the pattern of differences in the initial links also occurred in the middle and terminal links, the possibility arises that the schedules in the middle and terminal links themselves produced the differences in response rates, which then generalized to the initial-link component as well. An alternative account of the similarities across the successive links of the chain is that the initial-link response rates were determined by the conditioned reinforcement effectiveness of the stimuli correlated with the succeeding links of the chain, and this conditioned reinforcement value was correlated with the discriminative stimulus properties of those stimuli and hence the response rates they controlled.

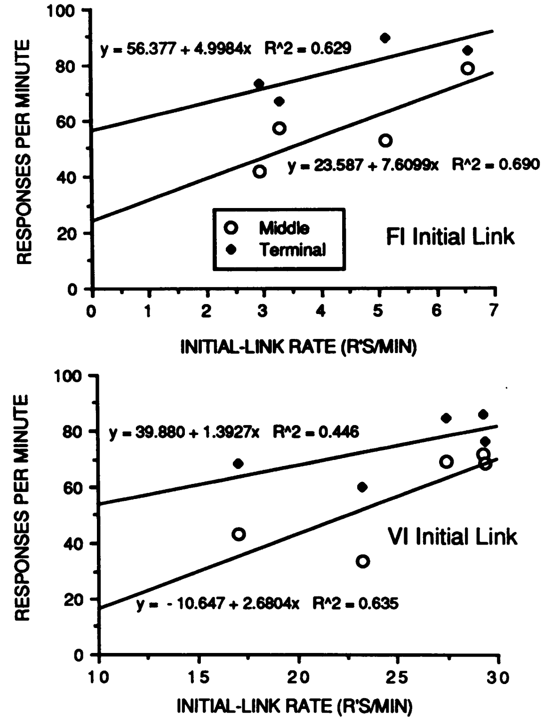

Fig. 4. Regression of middle- and terminal-link response rates on initial-link rates. The top panel is from Phase 1; the bottom panel is from Phase 2. Data points are the means across subjects for each condition.

One method to distinguish between these two accounts is to determine whether the pattern of initial-link response rates was better predicted by the middle- or by the terminal-link rates. If induction were responsible for the initial-link rates, and it is assumed that the pattern of food-reinforced behavior during the terminal link is the source of induction, then the initial-link rates should be better correlated with the terminal-link rates. But if the conditioned reinforcement properties of the middle-link stimulus determine initial-link responding, the rate should be better predicted by the pattern of middle-link responding. Comparison of Figure 3 with Figures 1 and 2 suggests that the latter possibility was the case, because the pattern of response rates in the middle links of the schedules was generally more similar to the initial-link pattern than was the pattern of response rates in the terminal links. For a more quantitative analysis of this difference, Figure 4 shows the separate regression lines of the middle- and terminal-link rates on the initial-link rate, presented separately for the FI initial-link schedule (top portion) and the VI initial-link schedule (bottom portion). The data shown are the means across subjects for each schedule condition. Individual subject data were not aggregated because this would introduce a spurious correlation due to organismic variables (i.e., a given subject would be likely to have a low or high response rate across successive components of the schedule simply because of its response topography or general vigor of behavior). Figure 4 shows that all four regression lines were positive, indicating that the initial-link response rates were positively correlated with response rates in both of the succeeding links. But it also shows that the regression line was much steeper for the middle-link response rates; its slope was approximately 1.5 greater than that for the terminal-link rate for the FI initial-link schedule and approximately 2.0 greater for the VI initial-link schedule. Hence, middle-link response rate predicted initial-link response rate better than did the terminal-link response rate.

## DISCUSSION

The dominant variable controlling response rate in the initial link of three-component chain schedules was the schedule in the initial link itself. Regardless of the intervening schedules in the middle and terminal links, response rate with an initial-link FI schedule was generally 10% to 25% of that with an initial-link VI schedule. These differences were much larger than those typically obtained with FI versus VI schedules of primary reinforcement (cf. Catania & Reynolds, 1968). The major problem for explaining the poor maintenance of behavior in the initial link of chain FI FI FI schedules thus appears not to be so much an issue of the strength or weakness of the reinforcer contingent on initial-link responding, but rather why the nature of the schedule itself appears to be critical in the initial links of a chain but not in its later components.

One possible explanation of the fact that FI schedules in the initial link of a chain maintain behavior so poorly is that the period just after primary reinforcement may be especially discriminable as a period of extinction because the food stimulus is highly memorable and hence more easily established as a negative discriminative stimulus due to its long temporal separation from the food reinforcer. However, the time between the onset of a chain VI FI FI and food versus a chain FI FI FI and food does not appear to be sufficiently different to cause the major differences in initial-link responding maintained by the two schedules.

An alternative hypothesis is that the combination of FI schedules with a conditioned reinforcer (the middle-link onset) as the response consequence enhances the inhibitory aftereffects of primary reinforcement. That is, the degree of temporal discrimination may be a function of the value of the contingent reinforcer, so that weaker reinforcers are more likely to produce longer pauses at the onset of the interval. Such an explanation is in fact predicted from the extension of the matching law to single-response situations, on the basis of the role played by reinforcers not under experimenter control (Herrnstein's $R_0$: Herrnstein, 1970). If the contingent reinforcer (the onset of the middle link) is assumed to be weak, the value of the extraneous reinforcers would be large in comparison and thus, in combination with the temporal discrimination contingencies implicit in the FI, would more strongly suppress behavior in the period after food delivery.

The differences in initial-link response rates obtained as a function of the middle- and terminal-link schedules were smaller and often inconsistent. Regardless of the initial-link schedule itself, higher response rates occurred with VI schedules in the succeeding links than with FI schedules. This difference alone does not isolate the controlling variable, because the VI schedules allowed the time between the initial link and food to include several short intervals, and such inclusion could have produced higher response rates in their own right. Alternatively, the onset of the VI schedule in the middle link of the chain was paired occasionally with short times to the onset of the terminal link, which should have enhanced its conditioned reinforcement properties. In contrast, the onset of the FI middle-link schedule was never paired with either the terminal-link entry or food and thus should be a period of discriminated extinction.

The critical data are from the interdependent VI schedules, which excluded variation in time to food by always keeping the time to food from the initial link the same as when FI components were employed. When FI schedules were used in the initial link, response rates with the interdependent VI components were intermediate between those produced by the FI and VI components. Thus, the time to food and the value of the middle-link onset may have played separate roles. But when VI schedules were the initial-link schedules, there was no evidence that time to food influenced responding: Response rates maintained by interdependent VI and independent VI schedules were similar, and both were higher than with the FI schedules. The use of VI schedules in the initial link thus suggests that conditioned reinforcement by the middle-link onset was the major variable controlling initial-link responding. However, it should be noted that the size of these differences was quite small for 2 of the 4 subjects, suggesting that other variables may have played a significant role.

The reason that the performance of some subjects was similar under the FI FI and interdependent VI VI schedules in Phase 1 but not in Phase 2 is unclear. Part of the reason may be that 2 of the 3 subjects that showed such similarity in Phase 1 (S-2 and S-4) were dropped from the study in Phase 2 because they continued to behave erratically during the initial links, with frequent very long pauses, even when the FI initial-link schedule was changed to a VI. A second possible reason is that the order of conditions in Phase 1 was not counterbalanced, so that the absence of a difference in Phase 1 might be due to a generally decreasing response rate with increasing training, although inspection of Figure 1 offers little evidence for this suggestion. A third factor is that the intervals constituting the interdependent VI schedules were changed between phases in order to make the shortest interval in the middle link of the interdependent schedule equal to the shortest interval in the independent VI. But this change (eliminating the zero interval) should have served to decrease the rate maintained in the interdependent VI condition and hence make it more similar to the FI FI condition in Phase 2 rather than less so. It is possible that the presence of the zero interval in the interdependent VI VI increased initial-link responding in Phase 1, so that, had it not been present, the interdependent VI and FI FI conditions would have been even more similar. Such a possibility implicitly assumes that conditioned reinforcement is the controlling variable, because time between middle-link onset and food presentation was independent of the nature of the interval distribution and remained constant for the interdependent condition throughout the experiment. Regardless of the factors contributing to the differences in results between the two phases of the experiment, any conclusion about the results of Phase 1 must remain tentative, given the combination of extremely low response rates and confounding effects of overall reinforcement rate.

The small difference between the interdependent and independent VI schedules with FI initial-link schedules may itself be due partially to differences in conditioned reinforcement. If the response rate maintained in the middle link of the chain is regarded as an index of the value of that component, the conditioned reinforcement properties of middle-link onset should be indexed by middle-link response rates. Accordingly, initial-link response rates should be predicted by middle-link response rates. In fact, middle-link response rates were higher for all subjects in Phase 1 with the independent VI schedules than with the interdependent VI schedules. This was not true in Phase 2, with VI initial-link schedules, because the middle-link response rates were generally similar for both types of VI schedule and both were substantially higher than with the FI middle link. In general, therefore, the pattern of differences in the initial links of the schedules was predicted by the pattern of differences in middle-link response rates. Why the interdependent VI schedules produced lower middle-link response rates in Phase 1 and not in Phase 2 is unclear. One possibility is that there could have been effects of delayed primary reinforcement with the independent VI VI schedule that did not occur with the interdependent VI VI. Because short intervals could occur occasionally in both the middle and terminal components of the independent VI VI schedule, the separation between food and the onset of the middle link of that schedule could be as short as 6 s, if the shortest intervals were sampled within a particular exposure to the entire chain. Such short temporal separations from food might then be sufficient to make the middle-link onset a more effective conditioned reinforcer. In contrast, the onset of the middle link of the interdependent schedule was always 66 s, so that delayed reinforcement effects from food presentation were unlikely. The problem with this interpretation is that it does not explain why there were differences in Phase 1 but not in Phase 2. Whatever the cause of the differences in the middle-link response rates, the correlation between those differences and the pattern of initial-link responding nevertheless is consistent with an interpretation based on the conditioned reinforcement properties of the middle-link stimulus.

Although the present data are consistent with an analysis of chain schedules based on the conditioned reinforcement role of the successive links of the chain, it can be argued that they do not require such an analysis. The present data establish that there is some effect of the temporal intervals correlated with the onsets of the successive links of the chain, but such effects need not be interpreted as the result of conditioned reinforcement. Instead, the present data show only that time to reinforcement, as measured from the initial link to food, is not the controlling variable. But it should be noted that the present data are complemented by the results of Royalty et al. (1987), who showed that response rates in similar chain schedules were greatly reduced when the onset of the successive link was briefly delayed, and by the results of Dunn, Williams, and Royalty (1987), who demonstrated that the choice of stimulus associated with a terminal link of a concurrent chains schedule was also greatly reduced when that stimulus was devalued by separate extinction preparations. In combination with those previous results, the present findings argue strongly that conditioned reinforcement is indeed an essential concept for understanding chain schedule performance.

If the foregoing analysis is accepted, the present data suggest that the time to primary reinforcement cued by the initial-link stimulus has little influence on the behavior maintained by that stimulus. This finding has important implications for models of choice between different chain schedules (concurrent chains), because various models postulate that choice is determined by the dynamics of temporal discrimination and omit any role for conditioned reinforcement. For example, Gibbon (1977) assumes that choice is determined by the combined estimates of time in the initial and terminal links of the chain. Similarly, Mazur (1984) has proposed that discrete-trial choice can be predicted by the times to food correlated with the choice alternatives, without regard for the conditioned reinforcement properties of the stimuli immediately contingent on choice. In combination with the results of Royalty et al. (1987) and Dunn et al. (1987), the present results challenge such models and argue instead that any adequate account must in some way incorporate the concept of conditioned reinforcement.

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## APPENDIX

Means of response rates (in responses per minute) and time (in seconds) in each component of each condition. Standard deviations are in parentheses. Data are from the last five sessions of each condition.

| | Phase 1: FI initial links | | | | | |
|---|---|---|---|---|---|---|
| Condition | S-1 | S-2 | S-3 | S-4 | S-5 | S-6 |
| FI FI, initial link | | | | | | |
| Rate | 6.5 | 0.9 | 2.0 | 2.7 | 4.6 | 1.0 |
| | (3.8) | (0.7) | (0.4) | (1.5) | (4.9) | (0.7) |
| Time | 41.4 | 303.0 | 52.7 | 73.6 | 74.5 | 250.3 |
| | (5.7) | (69.5) | (6.1) | (21.3) | (48.1) | (227.7) |
| FI FI, middle link | | | | | | |
| Rate | 21.5 | 48.2 | 14.3 | 72.1 | 50.1 | 44.4 |
| | (3.4) | (5.9) | (3.8) | (19.1) | (1.9) | (24.9) |
| Time | 37.1 | 37.3 | 35.0 | 34.6 | 34.0 | 35.0 |
| | (0.6) | (2.3) | (1.0) | (0.8) | (0.4) | (1.4) |
| FI FI, terminal link | | | | | | |
| Rate | 56.0 | 84.9 | 19.2 | 48.3 | 121.0 | 110.4 |
| | (5.2) | (8.5) | (2.9) | (1.0) | (13.0) | (21.2) |
| Time | 33.3 | 33.4 | 35.0 | 40.5 | 33.2 | 33.1 |
| | (0.1) | (0.3) | (0.8) | (15.7) | (0.3) | (0.1) |
| VI + VI = 66, initial link | | | | | | |
| Rate | 6.6 | 0.7 | 5.8 | 2.0 | 13.0 | 2.5 |
| | (2.7) | (0.3) | (0.9) | (0.5) | (5.9) | (1.8) |
| Time | 38.0 | 371.7 | 37.3 | 57.5 | 36.7 | 86.8 |
| | (2.8) | (75.1) | (1.0) | (11.5) | (1.5) | (45.8) |
| VI + VI = 66, middle link | | | | | | |
| Rate | 37.3 | 52.4 | 35.5 | 16.6 | 75.8 | 98.3 |
| | (1.1) | (18.6) | (4.3) | (1.7) | (16.9) | (9.4) |
| Time | 33.0 | 36.2 | 34.5 | 35.1 | 34.5 | 35.8 |
| | (2.2) | (3.7) | (1.7) | (1.5) | (2.1) | (2.8) |
| VI + VI = 66, terminal link | | | | | | |
| Rate | 91.8 | 92.1 | 34.0 | 37.4 | 135.0 | 149.7 |
| | (5.4) | (6.3) | (4.1) | (3.0) | (10.4) | (10.2) |
| Time | 35.6 | 32.2 | 34.4 | 34.7 | 32.6 | 31.9 |
| | (2.5) | (4.4) | (1.9) | (1.5) | (2.5) | (2.2) |
| VI VI, initial link | | | | | | |
| Rate | 10.9 | 1.6 | 6.8 | 3.5 | 6.5 | 10.0 |
| | (1.8) | (0.5) | (0.7) | (0.7) | (2.7) | (1.9) |
| Time | 35.3 | 170.5 | 35.4 | 40.0 | 38.9 | 35.0 |
| | (0.5) | (25.7) | (0.7) | (2.0) | (2.2) | (0.5) |
| VI VI, middle link | | | | | | |
| Rate | 58.2 | 75.1 | 50.3 | 31.0 | 105.9 | 150.3 |
| | (3.4) | (3.5) | (5.6) | (2.5) | (4.9) | (13.1) |
| Time | 33.8 | 42.8 | 36.1 | 32.9 | 33.3 | 35.5 |
| | (3.2) | (19.2) | (6.1) | (4.3) | (2.0) | (4.8) |
| VI VI, terminal link | | | | | | |
| Rate | 88.7 | 90.6 | 46.1 | 45.2 | 132.7 | 105.8 |
| | (5.1) | (4.8) | (3.6) | (9.5) | (7.6) | (8.3) |
| Time | 32.6 | 36.5 | 34.9 | 32.7 | 32.4 | 35.9 |
| | (2.6) | (4.4) | (4.3) | (2.9) | (4.7) | (3.4) |
| VI + VI = 66, initial link | | | | | | |
| Rate | 5.4 | 1.2 | 2.9 | 1.3 | 5.1 | 3.8 |
| | (1.2) | (0.9) | (0.8) | (1.0) | (1.6) | (3.9) |
| Time | 49.7 | 173.8 | 39.2 | 102.4 | 41.2 | 48.4 |
| | (14.3) | (109.0) | (2.7) | (51.5) | (1.7) | (8.8) |

APPENDIX (*Continued*)

|  | Phase 1: FI initial links |  |  |  |  |  |
|---|---|---|---|---|---|---|
| Condition | S-1 | S-2 | S-3 | S-4 | S-5 | S-6 |
| VI + VI = 66, middle link |  |  |  |  |  |  |
| Rate | 45.6 | 66.5 | 38.0 | 23.7 | 75.9 | 96.0 |
|  | (3.5) | (11.4) | (1.0) | (4.6) | (11.6) | (19.2) |
| Time | 35.2 | 35.7 | 34.7 | 34.8 | 33.4 | 35.4 |
|  | (2.8) | (4.2) | (3.0) | (2.0) | (1.3) | (1.4) |
| VI + VI = 66, terminal link |  |  |  |  |  |  |
| Rate | 59.6 | 76.4 | 29.9 | 42.7 | 104.2 | 87.9 |
|  | (11.0) | (16.8) | (3.8) | (2.9) | (5.1) | (10.3) |
| Time | 34.4 | 33.5 | 34.2 | 34.4 | 33.7 | 31.9 |
|  | (2.6) | (4.5) | (3.1) | (1.5) | (1.2) | (1.6) |

|  | Phase 2: VI initial links |  |  |  |
|---|---|---|---|---|
| Condition | S-1 | S-3 | S-5 | S-6 |
| VI + VI = 66, initial link |  |  |  |  |
| Rate | 26.6 | 40.8 | 26.0 | 24.1 |
|  | (2.5) | (2.9) | (6.3) | (18.7) |
| Time | 36.3 | 33.4 | 36.5 | 41.0 |
|  | (2.1) | (2.1) | (2.9) | (7.1) |
| VI + VI = 66, middle link |  |  |  |  |
| Rate | 36.0 | 56.7 | 86.5 | 93.4 |
|  | (2.7) | (6.5) | (10.6) | (17.5) |
| Time | 35.3 | 33.3 | 35.1 | 31.8 |
|  | (2.8) | (2.6) | (2.2) | (2.1) |
| VI + VI = 66, terminal link |  |  |  |  |
| Rate | 71.7 | 40.9 | 94.8 | 96.8 |
|  | (8.1) | (4.5) | (8.1) | (5.7) |
| Time | 33.5 | 34.3 | 32.0 | 35.1 |
|  | (2.3) | (2.6) | (2.5) | (1.9) |
| FI FI, initial link |  |  |  |  |
| Rate | 24.8 | 21.6 | 28.2 | 18.2 |
|  | (2.1) | (2.0) | (5.4) | (3.6) |
| Time | 37.2 | 38.0 | 36.6 | 44.0 |
|  | (3.2) | (3.5) | (2.3) | (3.7) |
| FI FI, middle link |  |  |  |  |
| Rate | 22.8 | 25.7 | 32.1 | 52.4 |
|  | (2.5) | (2.7) | (8.2) | (9.4) |
| Time | 36.1 | 34.0 | 34.2 | 34.2 |
|  | (0.3) | (0.3) | (0.1) | (0.4) |
| FI FI, terminal link |  |  |  |  |
| Rate | 29.2 | 16.6 | 82.2 | 114.6 |
|  | (4.3) | (3.3) | (5.1) | (7.8) |
| Time | 33.9 | 38.0 | 33.2 | 33.0 |
|  | (0.2) | (1.1) | (0.1) | (0.0) |

APPENDIX (*Continued*)

| Condition | Phase 2: VI initial links | | | |
|---|---|---|---|---|
| | S-1 | S-3 | S-5 | S-6 |
| VI VI, initial link | | | | |
| Rate | 25.5 | 25.8 | 31.2 | 27.0 |
| | (2.0) | (4.5) | (17.4) | (14.8) |
| Time | 35.8 | 36.1 | 36.9 | 40.1 |
| | (2.0) | (1.2) | (2.1) | (2.5) |
| VI VI, middle link | | | | |
| Rate | 46.2 | 47.5 | 60.3 | 122.9 |
| | (4.5) | (6.3) | (13.5) | (44.4) |
| Time | 34.6 | 34.0 | 32.7 | 34.9 |
| | (2.6) | (1.3) | (1.2) | (1.7) |
| VI VI, terminal link | | | | |
| Rate | 34.7 | 50.2 | 151.3 | 102.3 |
| | (3.2) | (4.5) | (25.4) | (8.5) |
| Time | 34.6 | 36.0 | 33.7 | 33.6 |
| | (2.4) | (4.5) | (2.2) | (2.1) |
| FI FI, initial link | | | | |
| Rate | 21.2 | 7.9 | 32.1 | 6.9 |
| | (2.4) | (3.3) | (4.2) | (6.6) |
| Time | 38.6 | 45.9 | 33.7 | 231.2 |
| | (1.3) | (5.0) | (1.7) | (266.0) |
| FI FI, middle link | | | | |
| Rate | 34.1 | 31.1 | 45.3 | 61.5 |
| | (2.2) | (3.0) | (13.7) | (19.7) |
| Time | 35.0 | 35.0 | 34.0 | 33.9 |
| | (0.3) | (0.3) | (0.4) | (0.5) |
| FI FI, terminal link | | | | |
| Rate | 32.1 | 13.1 | 105.4 | 123.5 |
| | (8.4) | (2.5) | (11.9) | (31.6) |
| Time | 36.1 | 39.2 | 33.1 | 33.1 |
| | (0.8) | (2.0) | (0.0) | (0.0) |
| VI + VI = 66, initial link | | | | |
| Rate | 26.1 | 30.0 | 40.6 | 20.5 |
| | (3.4) | (4.2) | (6.7) | (6.0) |
| Time | 37.1 | 35.2 | 35.0 | 43.5 |
| | (2.3) | (3.8) | (4.2) | (7.5) |
| VI + VI = 66, middle link | | | | |
| Rate | 46.9 | 58.0 | 62.7 | 119.4 |
| | (5.6) | (5.1) | (6.9) | (15.9) |
| Time | 37.5 | 34.8 | 33.6 | 33.9 |
| | (1.0) | (2.6) | (3.4) | (1.3) |
| VI + VI = 66, terminal link | | | | |
| Rate | 68.8 | 46.9 | 104.7 | 124.1 |
| | (15.1) | (1.0) | (4.9) | (10.0) |
| Time | 31.2 | 32.2 | 33.5 | 32.7 |
| | (1.4) | (2.6) | (3.1) | (1.4) |