A MOLECULAR ANALYSIS OF CHOICE ON CONCURRENT-CHAINS SCHEDULES

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Six pigeons responded on concurrent-chains schedules with either independent or interdependent equal variable-interval schedules in the initial links and unequal variable-interval schedules, always in a 2:1 ratio, in the terminal links. Relative response rates in the initial links increased across conditions as initial-link duration was shortened and decreased across conditions as terminal-link duration was shortened, replicating previous findings. Responses in the initial links were recorded in 5-s bins, and local or molecular relative response rates were calculated in order to ascertain how relative response rate varied as a function of time since the onset of the initial links. Two distinct molecular patterns were found. With interdependent initial links, relative response rates for the preferred key were elevated for the first 10 or 20 s of the initial links and then declined to an asymptotic value. With independent initial links, a negative recency effect was found similar to that reported by Killeen (1970). These two molecular patterns were related to the different momentary reinforcement probabilities resulting from independent and interdependent scheduling.

Key words: choice, molecular analysis, conditioned reinforcement, delay-reduction hypothesis, concurrent-chains schedules, variable-interval schedules, forced-choice procedure, key peck, pigeons

The concurrent-chains schedule has been used widely in research during the last 25 years (see Fantino, 1977, for a review). Although it was originally developed for study of conditioned reinforcement (Autor, 1960, 1969), the concurrent-chains schedule has more often been used to investigate preference between different schedules of reinforcement, a task to which the procedure seems particularly well suited because it allows a measure of choice uncontaminated by the particular patterns of responding generated by the schedules that are chosen. In this procedure, the subject responds on two concurrently available alternatives (the initial links or "choice phase") usually correlated with equal variable-interval (VI) schedules. Responses on each alternative occasionally produce another stimulus, correlated with entry into the terminal link of the chain on that alternative (the "outcome phase"). Responses in the terminal link are reinforced with food. The independent variable has generally involved some difference in the conditions arranged during the terminal links, such as differing rates of reinforcement.

The measure of choice is the distribution of responses in the initial links.

Studies of choice with the concurrent-chains procedure have typically assessed only the molecular or overall relative rate of responding in the initial links of the schedule, calculated by dividing the total number of responses on one alternative by the sum of responses on both alternatives. Such an overall measure may not reflect the actual distribution of responding between the response alternatives at any given moment, however. For example, an overall relative rate of .75 might be representative of the behavior at every point in the initial links or it might be an average of two or more very different relative rates at different points within the interval.

The only published data that bear directly on this question come from Killeen's (1970) study of preference for fixed-interval (FI) schedules of reinforcement contingent upon pigeons' key pecking. In one condition, chain VI 60-s FI 20-s versus chain VI 60-s FI 14-s, Killeen recorded the ordinal pattern of responding in the initial links. When the data were separated into responses following reinforcement on the right key and responses following reinforcement on the left key, a pattern was found that Killeen termed negative recency. Immediately after reinforcement on one key, the relative rate of responding in-

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creased on the other key. This negative recency effect, also known as "win-shift behavior," lasted for 20 to 30 responses from the onset of the initial links.

Additional evidence that relative response rate in the initial links of a concurrent-chains schedule may vary systematically with time within a given exposure to the initial links is provided by the existence of nonuniform relative response rates on simple concurrent schedules. Evenden and Robbins (1984), Menlove (1975), Morgan (1974), and Shimp (1966) all reported a positive recency effect of reinforcement on immediately subsequent responding. Menlove, using a standard concurrent VI VI schedule, found that the relative frequency of responding, calculated with respect to the key with the higher density of reinforcement, was elevated in the first 5 s following reinforcement on the high-density key whereas the relative response rate during the first 5 s after reinforcement on the low-density key was either depressed or equal to its overall average value. Shimp, using a discrete-trials, successive discrimination procedure roughly equivalent to a concurrent schedule, reported that there was a greater probability of a given choice on trial $n + 1$ if that choice had been reinforced on trial n . Morgan, using concurrent random ratio schedules, found that the first two responses after reinforcement tended to be on the same lever that had just produced reinforcement. Evenden and Robbins systematically replicated Morgan's study using rats and three different responses (lever pressing, nose poking, and maze running) and found significant positive recency or "win-stay behavior" in all three situations, although the appearance of win-stay behavior in the maze was preceded by an initial tendency to alternate. Positive recency was not observed, however, in a study by Nevin (1969). Instead, Nevin found that the relative frequency of responding in the first postreinforcement trial was independent of which choice was reinforced on the preceding trial. A possible reason for these discrepant results is that Evenden and Robbins, Menlove, Morgan, and Shimp used a single reinforcement-scheduling mechanism to assign reinforcement to the two keys. Known as interdependent scheduling (Stubbs & Pliskoff, 1969), such schedules require responses on both keys, because once the schedule assigns a reinforcer to one key, reinforcement on the

other key cannot occur until some time after that reinforcer is obtained. This results in the probability of reinforcement on a given key being independent of where the preceding reinforcer had been assigned. In Nevin's study, separate VI schedules assigned reinforcers to the two keys (known as independent scheduling) and probability of reinforcement depended on the location of the preceding reinforcer. Specifically, the probability of reinforcement on a key was lowest immediately following reinforcement on the same key.

A complicating factor in this interpretation is the fact that Killeen (1970) also used independent scheduling but found negative recency rather than independence. Two possibilities for the resolution of this second discrepancy seem plausible. First, the effects of independent and interdependent scheduling may be different in simple concurrent and concurrent-chains schedules. Second, perhaps negative recency does indeed result from independent scheduling on simple concurrent schedules, but Nevin (1969), for unspecified reasons, failed to observe this effect. The present study sought to clarify the conditions under which positive and negative recency are observed by examining the molecular patterns of responding in the initial links of concurrent-chains schedules using both independent and interdependent scheduling.

In addition, we felt that a molecular examination of initial-link responding in concurrent-chains schedules might shed some light on the origin of the so-called initial-link effect. This effect, first reported by Fantino (1969), is the increase in relative rate of responding in the equal initial links of concurrent-chains schedules that is observed when the initial-link schedules are shortened while the terminal links are held constant but unequal. With sufficiently short initial links, relative rates of responding approach 1.0; with sufficiently long initial links, relative rates of responding approach .50. An analogous "terminal-link effect" has been reported whereby relative response rates increase in the constant and equal initial links when the unequal terminal links are *lengthened* (with the ratio of terminal-link values constant across conditions, e.g., MacEwen, 1972).

Both the initial-link and terminal-link effects are implications of the delay-reduction hypothesis (Fantino, 1969), which has evolved

into the following equation describing choice between two alternatives in the concurrent-chains procedure (Fantino & Davison, 1983):

$$\frac{R_L}{R_L + R_R} = \frac{\sqrt{r_L}(T - t_{2L})}{\sqrt{r_L}(T - t_{2L}) + \sqrt{r_R}(T - t_{2R})}, \quad (1)$$

$$\begin{array}{ll} 1.0 & t_{2L} < T, t_{2R} < T, \\ 0 & t_{2L} < T, t_{2R} > T, \\ & t_{2L} > T, t_{2R} < T, \end{array}$$

where R_L and R_R represent the number of responses during the choice phase on the left and right key, respectively, t_{2L} and t_{2R} specify the average time to reinforcement in the corresponding terminal links, r_L and r_R are the rates of primary reinforcement on the left and right keys, respectively, and T represents the average delay to primary reinforcement from the onset of the initial links. Thus, $(T - t_{2L})$ represents the delay reduction correlated with the onset of the left terminal link, and $(T - t_{2R})$ represents the delay reduction correlated with the onset of the right terminal link.

Although the initial-link effect is well documented when equal independent VI schedules are used in the initial links (Fantino, 1969; Fantino & Davison, 1983; Wardlaw & Davison, 1974), none of the concurrent-chains studies using interdependent (Stubbs & Pliskoff, 1969) initial links have systematically varied initial-link length (e.g., Gentry & Marr, 1980; Heyman & Bouzas, 1980; MacEwen, 1972; Snyderman, 1983; Williams & Fantino, 1978). Consequently, it is possible, though somewhat unlikely, that the initial-link effect occurs only with an independent arrangement of the initial-link schedules.

The present study examined local relative response rates in both independently and interdependently scheduled initial links in order to assess, first, whether these different methods of arranging the initial-link schedules produced corresponding differences in the molecular patterns of responding; second, whether the initial-link effect could be replicated with interdependent initial links, and, third, whether the molar initial-link effect could be understood as a simple result of the molecular pattern of responding. Because the two common ways of arranging variable-interval schedules (the arithmetic and the Fleshler-Hoffman, 1962, series) provide slightly different molecular patterns of reinforcement probability, some

conditions were studied with both of these procedures.

METHOD

Subjects

Six adult male white Carneau pigeons, all with extensive experimental histories, served as subjects. Throughout the experiment, each subject was housed individually and had free access to water and grit. The birds were weighed after each experimental session and fed measured amounts of Universal Feeds Pigeon Pellets to maintain them at 80% of their free-feeding body weights. Bird R15 died of unknown causes between Conditions 11 and 12 and was not replaced with another subject.

Apparatus

Six identical cylindrical operant conditioning chambers constructed of PVC pipe were used. Each chamber measured 36 cm high and 35 cm in diameter and had three response keys, 2 cm in diameter, mounted 24 cm above the floor and 7 cm apart. 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 left and right keys in each chamber were used; the center key remained dark and responses on it were not recorded. A solenoid-operated grain hopper was located 10 cm below the center key in each chamber. Reinforcers consisted of 3-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 32 cm above the floor on the side of the chamber opposite the keys and hopper. A ventilation fan and continuously present white noise masked extraneous sounds. Scheduling of experimental events and data recording were performed by a PDP-8E® computer (Digital Equipment Corporation) located in an adjacent room.

Procedure

A concurrent-chains schedule with equal VI schedules in the initial links and unequal VI schedules in the terminal links was used. Figure 1 presents a diagram of this procedure.

Fig. 1. Diagram of the concurrent-chains procedure. The left panel indicates the sequence of events when the left terminal link was entered. The right panel represents the analogous sequence when the right terminal link was entered.

During the initial links, both response keys were transilluminated with white light. After a terminal-link entry had been scheduled for a key, the first response on that key occasioned two events: (a) the key peck changed the key-light from white to the stimulus correlated with the terminal link of the chain on that key (right key—red, left key—green), and (b) the other key became dark and inoperative. Responding on the terminal-link key resulted in reinforcement according to the terminal-link schedule on that key. Following reinforcement, the initial links were reinstated.

Terminal-link entry was scheduled by either independent or interdependent VI schedules. In the interdependent case, at the inception of each initial-link period, an interval was selected in a pseudorandom manner from either a 13-interval arithmetic distribution or a 20-interval Fleshler-Hoffman (1962) distribution, depending on the experimental condition, and assigned in a pseudorandom manner with equal probability to either the left or right key in the manner of Stubbs and Pliskoff (1969). Once a terminal-link entry was assigned to either key, it had to be collected in order for the schedule to progress; responses on the non-assigned key were ineffective in producing terminal-link entries. In the independent case,

the arithmetic and Fleshler-Hoffman distributions were the same as in the interdependent case except that all intervals were doubled (to equate the scheduled overall rate of terminal-link entry). When a terminal-link entry was scheduled by one timer, the other timer continued to operate until it scheduled a terminal-link entry or until either terminal link was entered. If when one terminal link was entered, access to the other terminal link had also been arranged, the latter terminal link remained available upon return to the initial links. The initial-link timers operated only during the initial links.

Throughout the experiment, regardless of whether the initial links were scheduled independently or interdependently, terminal-link schedules consisted of intervals pseudorandomly selected from 20-interval Fleshler-Hoffman distributions.

The sequence of conditions for each subject and the number of sessions in each condition are presented in Table 1. For the purposes of data recording, time in the initial links was divided into consecutive 5-s intervals, and responses were recorded according to the interval in which they occurred. Sessions were conducted from 5 to 7 days per week and were terminated after 60 reinforcers had been obtained. Initially, each condition consisted of a minimum of 25 sessions with the additional stipulation that the last five sessions of each condition be conducted on consecutive days. If, for any reason, a session was missed after 20 sessions of a condition had occurred, additional sessions were conducted until the criterion of five consecutive sessions was met. After the first three conditions, the criterion was raised to 40 sessions plus the last five sessions of a condition on consecutive days in order to reduce carry-over effects.

RESULTS

Before examining molecular response rate patterns, inspection of the molar relative response rates is in order, to ensure that the present data are comparable on the molar level with results from previous concurrent-chains studies. Specifically, with a given pair of terminal links, relative response rate should increase with decreases in the duration of the equal initial links. In addition, with constant and equal initial links, relative response rate

Table 1

Initial and terminal-link schedules (in s), predicted (Equation 1) and obtained choice proportions (in terms of outcome with higher reinforcement rate) and the number of sessions and order of conditions.

Con- dition	Initial- link schedules	Arithmetic (AR) or Fleshler- Hoffman (FL) interdepen- dent (Inter) or indepen- dent (Ind)	Terminal-link schedules		Pre- dicted choice prop.	Mean ob- tained choice prop.	Individual obtained choice proportions						Number of sessions and order of conditions (in parentheses)	
			Left	Right			R60	R61	R62	R63	Y87	R15	R60, R61, R62	R63, Y87, R15
1	VI 60	Inter (AR)	VI 20	VI 40	.69	.69	.53	.72	.71	.70	.67	.81	25 (1)	25 (1)
2	VI 30	Inter (AR)	VI 20	VI 40	.85	.82	.81	.71	.78	.91	.89	.81	29 (2)	33 (3)
3	VI 120	Inter (AR)	VI 20	VI 40	.58	.63	.60	.61	.71	.60	.61	.66	33 (3)	29 (2)
4	VI 60	Inter (AR)	VI 20	VI 40	.69	.75	.63	.74	.71	.79	.85	.80	40 (4)	40 (4)
5	VI 60	Inter (AR)	VI 45	VI 90	.90	.84	.76	.86	.85	.84	.85	.91	44 (5)	43 (6)
6	VI 60	Inter (AR)	VI 10	VI 20	.60	.71	.78	.72	.58	.70	.82	.65	43 (6)	44 (5)
7	VI 60	Inter (AR)	VI 20	VI 10	.60	.55	.56	.41	.38	—	—	—	45 (7)	—
8	VI 60	Inter (AR)	VI 90	VI 45	.90	.64	—	—	—	.66	.68	.58	—	45 (7)
9	VI 60	Ind (AR)	VI 20	VI 40	.69	.70	.69	.66	.53	.72	.80	.81	56 (8)	56 (8)
10	VI 30	Ind (AR)	VI 20	VI 40	.85	.82	.70	.87	.71	.90	.95	.79	28 (9)	28 (9)
11	VI 120	Ind (AR)	VI 20	VI 40	.58	.65	.68	.67	.53	.65	.73	.65	43 (10)	43 (10)
12	VI 60	Ind (FL)	VI 20	VI 40	.69	.73	.69	.77	.67	.67	.83	—	50 (11)	50 (11)
13	VI 60	Inter (FL)	VI 20	VI 40	.69	.73	.65	.80	.72	.56	.91	—	50 (12)	50 (12)

should increase with increases in the duration of unequal terminal links (with the ratio of terminal-link values constant across conditions). The overall relative response rates, shown in Table 1, support these predictions. Each entry in the table was calculated from data summed over the last five sessions of each condition. When initial-link duration decreased, preference increased with both interdependent and independent initial links (Conditions 1 to 4 and 9 to 11, Table 1). Specifically, in the independent case, as initial-link size decreased from 120 s to 60 s to 30 s, the mean obtained choice proportion increased from .63 (Condition 3) to .72 (mean of Conditions 1 and 4) to .82 (Condition 2). In the independent case, choice proportions increased from .65 (Condition 11) to .70 (Condition 9) to .82 (Condition 10) as the initial-link schedules went from 120 s to 60 s to 30 s. When the initial-link schedules were held constant and the terminal-link duration varied, mean relative response rates increased from .71 (Condition 6) to .75 (Condition 4) to .84 (Condition 5) as the terminal-link schedules corresponding to these conditions increased from 10–20 s to 20–40 s to 45–90 s, respectively. An alternate

method of judging the typicality of the present molar results is to compare the obtained overall choice proportions with those predicted by Equation 1 (Columns 6 and 7 of Table 1). The mean absolute deviation of the choice proportions from those predicted by Equation 1 was .05 for the nine conditions to which all six pigeons were exposed (.06 if the other conditions are included). The mean deviation in the six conditions with the interdependent VI schedules was .05 (.07 if the others are included); the mean deviation in the three conditions with independent VI schedules was .04. Thus, Equation 1 provided an adequate description of the molar relative response rates in this experiment, indicating that the molar results of the present experiment are roughly comparable with those obtained in previous studies.

Given that the initial-link effect was replicated on the molar level, the molecular data may be inspected for evidence of the sensitivity of choice to time spent in a given exposure to the initial links (i.e., time since the last reinforcer). For the first set of conditions, in which the duration of the interdependent arithmetic initial links was varied, relative response rate

Fig. 2. Relative response rate on the left key as a function of time since the preceding reinforcement for the chain VI 60-s VI 20-s versus chain VI 60-s VI 40-s condition with interdependently scheduled arithmetic initial links. Responses are categorized as to whether the previous reinforcer was obtained on the left key (open circles) or right key (closed circles).

as a function of time from the onset of the initial links is shown in Figure 2 for the individual subjects and in Figure 5A for the group data. As may be seen in Figure 5A, the only

difference in the shape of the curves for the 30-s, 60-s, and 120-s conditions is the length and height of the horizontal portion of the curves. To avoid redundancy, curves for in-

Fig. 3. Relative response rate on the left key as a function of time since the preceding reinforcement for the chain VI 60-s VI 10-s versus chain VI 60-s VI 20-s condition with interdependently scheduled arithmetic links. Responses are categorized as to whether the previous reinforcer was obtained on the left key (open circles) or right key (closed circles).

dividual subjects are shown only for the 60-s condition. (Data for individual subjects for the remainder of the conditions are available from the authors upon request.) These data are summed over five sessions with 60 exposures

to the concurrent chain in each session. The sample size on which each data point is based decreases, of course, as time since the last reinforcer increases. In Figure 2, responses of individual subjects are distinguished with respect

Fig. 4. Individual relative response rate functions for the chain VI 60-s VI 20-s versus chain VI 60-s VI 40-s condition with independently scheduled arithmetic initial links. Responses are presented separately with respect to the location of the previous reinforcement as in Figures 2 and 3.

to whether the last reinforcer was obtained on the left key (open circles) or on the right key (filled circles). In all cases, the lines joining the filled circles and joining the open circles are essentially coincident. For this reason, responses in the group data are not segregated

by the position of the reinforcer. Although there is individual variation, the most typical pattern is that reflected in the group data: Relative response rate is highest at the onset of the initial links, declines rather sharply for the first 20 s, and then declines much more gradually

Fig. 5. Group relative response rate functions: Panel A shows data from conditions in which the duration of the interdependently scheduled arithmetic initial links was varied; Panel B shows effects of varying the duration of the terminal links; Panels C and D show effects of varying the duration of the independently scheduled initial links. Responses following left and right reinforcements are aggregated in the first three panels and separated in the final panel. Points for the VI 120-s condition in Panel D are displaced downward to avoid overlapping. The correct scale for the ordinate appears on the right. Data are means of data from six subjects.

or not at all. Note that the molar initial-link effect is readily evident in Figure 5A: Relative response rate increased as initial-link size decreased, shown by the vertical displacement of the three curves.

Data for the second set of conditions, in

Fig. 6. Absolute response rates as a function of time since the previous reinforcement for conditions with interdependently scheduled initial links (Panel A) and independently scheduled initial links (Panel B). Data are means of data from six subjects.

which the duration of the interdependent arithmetic initial links was held constant at VI 60 s while the duration of the unequal terminal links was varied, are shown in Figure 3 (individual data) and Figure 5B (group data). Again, to avoid duplication, individual curves are shown only for Condition 6 with VI 10-s, VI 20-s terminal links. The shapes of these functions are representative of the remaining two conditions. (Data for individual subjects for the remainder of the conditions are available from the authors upon request.) As may be seen in the figures, the molecular patterns of relative responding are substantially the same as in the first set of conditions: elevated preference for the first 20 s of the initial links and essentially flat relative rate functions thereafter. The molar terminal-link effect is readily evident in Figure 5B for the group data: Relative response rate increased as terminal-link duration increased, again shown by the vertical displacement between the curves. This same terminal-link effect was evident in the individual data from 4 of the subjects (R61, R62, R63, and R15) whereas the remaining 2 subjects (R60 and Y87) did not show the effect. The increase in relative response rate as the terminal links were lengthened was re-

Fig. 7. Individual and group relative response rate functions for Condition 13 with constant probability initial links interdependently scheduled. Responses following left and right reinforcements are indicated separately as in Figures 2 and 3.

flected primarily as an increase in the asymptotic relative rate (the flat portion of the curve); the magnitude of the initial elevation above the asymptotic rate stayed roughly constant across

conditions except when the initial elevation was obscured by a ceiling effect as in the case of R62. The individual curves for subject R62 appeared to flatten out as one moved from the

Fig. 8. Individual and group relative response rate functions for Condition 12 with constant probability initial links independently scheduled. Responses are separated by the location of the previous reinforcer as in Figures 2 and 3.

10–20 to the 45–90 condition, but this apparent flattening was due to an increase in the asymptotic rate, not to a decrease in the degree of the initial elevation.

Figure 4 shows individual relative rate functions for the penultimate set of conditions, in which the duration of the independent initial links was varied; corresponding group func-

tions are presented in Figures 5C and 5D. For brevity of presentation, only individual functions from Condition 11 with VI 120-s initial links are presented in Figure 4. Functions for Conditions 9 and 10 were similar. Note that the molecular patterns are very different from those obtained with interdependent schedules. When responses following left and right reinforcers are combined as in Figure 5C, the relative rate functions are flat and virtually featureless. When responses are separated by the location of the last reinforcer, as in Figure 5D for the group data and Figure 4 for the individual data, a pronounced negative recency pattern emerges: Preference for the right key was temporarily elevated following a left reinforcer and, to a lesser extent, preference for the left key was augmented following a right reinforcer. To avoid overlapping of the curves for the VI 60-s and VI 120-s conditions in Figure 5D, which would obscure the negative recency effect, the curves for the VI 120-s condition are displaced downward. The correct scale for the ordinate for these curves appears at the right of the figure.

Absolute response rates, averaged over the 6 subjects, are shown as a function of time since the onset of the initial links for the three interdependent initial-link conditions in Figure 6A. Two aspects of these data deserve comment. First, absolute response rate was a function of initial-link duration, with higher rates occurring on shorter schedules. (The first determination of the VI 60-s condition is an exception to this generalization, but this was the first condition of the experiment and may be the result of insufficient exposure to the procedure.) Second, except for the VI 30-s condition, an initial elevation in absolute response rate is evident, corresponding to the initial elevation observed with the relative rate measure. Corresponding absolute rate functions for the three independent initial-link conditions are shown in Figure 6B. Although there is a monotonic relationship between response rate and schedule duration similar to that observed with interdependent initial links, the elevation in response rate during the first 10 s of the initial links is absent.

Conditions 12 and 13 replicated Conditions 1 and 9, but used constant probability rather than arithmetic schedules in the initial links. Individual and group functions showing relative response rate are presented in Figure 7

for the interdependent condition; Figure 8 shows comparable data for the independent condition. As may be seen in the figures, the functions obtained with the constant probability schedules have shapes similar to those functions obtained with arithmetic schedules. However, inspection of Figure 7 shows some evidence for negative recency in the interdependent condition (especially for R60, R63, and R61: relative response rates on the left are higher following a right-key reinforcer in at least the first two bins). In contrast, evidence for negative recency is marginal at best in Figure 2, the corresponding figure with arithmetic initial links (there is slight evidence of negative recency for R63 and R62 in the first bin only, whereas Y87 shows equally slight positive recency). Overall, the data do not permit us to decide whether this difference is attributable to the difference between constant-probability and arithmetic scheduling.

DISCUSSION

Inspection of Figures 2, 3, and 4 shows a much clearer separation in relative response rates immediately following reinforcement on the relatively dense and lean terminal links for conditions with independent VI initial links (Figure 4) than in conditions using interdependent (Stubbs-Pliskoff) VI schedules (Figures 2 and 3). This effect has been termed negative recency by Killeen (1970) who reported the same phenomenon with independent VI schedules in the initial links and fixed-interval schedules in the terminal links of concurrent-chains schedules. Killeen noted that such negative recency was consistent with momentary maximizing principles (e.g., Shimp, 1966) and that one way of decreasing behavior's dependency on the locus of the last reinforcement would be the use of initial-link schedules that would make the probability of reinforcement on either key independent of the locus of the prior reinforcement. The use of interdependent VI schedules in the first seven conditions of the present experiments satisfies this requirement. The probability of terminal-link entry is equal on both keys following reinforcement with interdependent schedules. As noted, negative recency is much less evident in Figures 2 and 3 than in Figure 4 (independent VI schedules), supporting Killeen's conjecture.

Our current knowledge of molecular pat-

terns of responding on simple concurrent and concurrent-chains schedules may be summarized as follows: When the probability of reinforcement is independent of the location of the previous reinforcer, such as occurs when interdependent scheduling is used, positive recency or win-stay behavior occurs on simple concurrent schedules (Evenden & Robbins, 1984; Menlove, 1975; Morgan, 1974; Shimp, 1966) whereas a transient elevation in preference for the key with the shorter terminal link occurs on concurrent-chains schedules (at least with equal initial links). When the probability of reinforcement does depend on the location of the previous reinforcer, as in the case of independent scheduling, negative recency or win-shift behavior is observed on concurrent-chains schedules, whereas the only evidence to date indicates that in simple concurrent schedules relative response rate is independent of which response was just reinforced (Nevin, 1969). When the above observations are arranged in a two-by-two table, the following relationship emerges: Schedule type (simple concurrent vs. concurrent chain) and method of schedule arrangement (independent vs. interdependent) are two orthogonal variables each of whose effects are consistent across both levels of the other variable. Changing from a simple concurrent to a concurrent-chains schedule moves one in a negative direction along the recency continuum. Changing from independent to interdependent scheduling moves one in a positive direction along the recency continuum. Obviously, both the upper left and lower right cells of Table 2 need to be replicated before much confidence can be placed in this generalization, but the pattern of results is intriguing.

Occurrence of decreasing choice proportions within initial-link exposures, at least with interdependent schedules (Figures 2, 3, 5, and 7), raises the possibility that the molar initial-link effect might be an artifact of schedule duration. Assume that the pattern of declining choice proportions occurs for unspecified reasons independent of delay reduction. With short initial-link schedules the period of relatively high choice proportions would constitute a larger portion of total time in the initial links than with longer initial-link schedules. Assume further that whatever the scheduled initial-link duration, the asymptotic choice pro-

Table 2

Two factors affecting recency effects in choice: type of choice (simple or concurrent chain) and type of concurrent scheduling (independent or interdependent VI schedules).

	Independent	Interdependent
Simple concurrent	Independent of location of last reinforcer (Nevin, 1969)	Positive recency (Evenden & Robbins, 1984; Menlove, 1975; Morgan, 1974; Shimp, 1966)
Concurrent chain	Negative recency (Killeen, 1970; present study)	Independent of location of last reinforcer (present study)

portion within initial-link exposures (i.e., the relatively flat portion in Figures 2 through 5) is determined only by the *terminal-link* schedules. In this event, the molar initial-link effect would prove to be an uninteresting artifact.

There are three reasons to reject this possibility. In the first place, the initial-link effect occurs with independent VI schedules in the absence of decreasing choice proportions within initial-link exposures (e.g., Figures 5C and 5D). Second, evidence for the molar initial-link effect can be seen from the fact that, even with interdependent VI schedules, the asymptotic choice proportions are ordered according to scheduled initial-link duration (and in the direction required by Equation 1). Third, Equation 1 predicts the effects not only of varying initial-link duration on (molar) choice but also of varying terminal-link duration with constant initial-link duration. Obviously, these latter effects could not be explained in terms of initial-link schedule duration. Yet, the results in Table 1 (and in Figure 5B) and in prior work with concurrent-chains procedures (e.g., MacEwen, 1972) shows that choice does vary with terminal-link duration in the direction required by Equation 1.

The present study permits a comparison of relative response rates in analogous conditions with independent and interdependent initial-link VI schedules. As Fantino (1981) noted, the delay-reduction hypothesis was developed in the context of concurrent-chains schedules using independent VI schedules (the choice phase) to arrange access to the outcome phase (terminal links). Under certain conditions, Equation 1 predicts that responding should

occur exclusively on one key. Exclusive responding should never occur, however, with interdependent initial links (termed "forced-choice" by Fantino, 1981) because exclusive responding would result in perpetual extinction. Thus, Fantino (1981) stated "the delay-reduction hypothesis should make accurate quantitative predictions only with independent VIs" (p. 180). Fantino cited the data from one experimental condition in MacEwen (1972) that permitted a comparison between choice proportions on comparable independent and forced-choice procedures. In that comparison, for each of two pigeons choice proportions were lower in the forced-choice procedure (mean of .83 for forced-choice and .94 for the independent VI procedure). However, this was a condition where the predicted relative response rates were above .90. The present experiment permits comparison of points in the less extreme range. In fact, little difference is seen in relative response rates from Conditions 1 through 4 and 9 through 11 in Table 1 (with 120-s initial links, the mean in the forced-choice procedure, Condition 3, is .63 and for the independent procedure, Condition 11, .65; with 60-s initial links, the mean averaged over two determinations on the forced-choice procedure, Conditions 1 and 4, is .72 and for the independent procedure, Condition 9, .70; with 30-s initial links the means on the forced-choice procedure, Condition 2, and the independent procedure, Condition 10, are both .82). Thus, these data suggest no systematic difference between relative response rates from comparable conditions with the two types of procedures.

It should be noted, however, that the largest deviation of the obtained choice proportions from those predicted by Equation 1 occurred with interdependent VI schedules in the only condition in which the predicted choice proportion was as high as .90 (and, therefore, closest to the value in MacEwen's comparison): the 6 pigeons in the fifth condition (Table 1) produced a mean choice proportion of .84 and the 3 pigeons in the eighth condition a mean choice proportion of only .64. Although these conditions were not studied with independent VI schedules, it remains tenable that the forced-choice procedure produces lower choice proportions when Equation 1 predicts choice proportions around .90 and above.

In conclusion, the salient findings of the present study may be summarized as follows:

First, relative response rate in the initial links of a concurrent-chains schedule is not uniform across time within a given exposure. This is particularly evident after responses are separated according to the position of the last reinforcer. Second, independent and interdependent scheduling procedures produce different molecular patterns of responding in the initial links of concurrent-chains schedules. Finally, the initial-link effect and the corresponding terminal-link effect occur in concurrent-chains schedules with interdependently scheduled initial links as well as in concurrent-chains schedules with independently scheduled initial links. One implication of this finding is that the initial-link effect is not a consequence of a particular molecular response pattern. A related implication is that the delay-reduction hypothesis (Equation 1) provides an adequate description of the molar choice proportions observed in all phases of this experiment, even though the molecular patterns of responding differed among conditions.

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