CUED AND UNCUED TERMINAL LINKS IN CONCURRENT-CHAINS SCHEDULES

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Pigeons were trained on a concurrent-chains schedule. The initial links were concurrent variable-interval schedules arranged on two side keys. Each terminal link was a fixed-interval schedule arranged on the center key. In cued conditions, different center-key colors signaled the two terminal-link schedules. In uncued conditions, the same center-key color appeared for both terminal links. Experiment 1 arranged unequal initial links and equal terminal links. Preference for the shorter initial-link schedule was greater when the terminal links were uncued. Experiment 2 arranged equal initial links and unequal terminal links. Preference for the shorter terminal-link schedule was greater when the terminal links were cued. Although the results of Experiment 2 successfully replicated previous research, the results of Experiment 1 are not easily reconciled with conditioned-reinforcement or discriminative-stimulus accounts of the role of terminal-link cues. Rather, terminal-link cues appear to decrease sensitivity to initial-link contingencies.

Key words: choice, concurrent-chains schedules, conditioned reinforcement, terminal-link cues, key peck, pigeon

Herrnstein (1961) showed that animals allocate behavior between concurrently available schedules of reinforcement in an orderly manner; that is, the relative rate of responding matches the relative rate of reinforcement. Further research has seen this strict one-to-one relation replaced by a more general expression relating choice behavior and its consequences, known as the generalized matching law (e.g., Baum, 1974). This model has proved to be a robust descriptor of choice behavior in many concurrent-schedule experiments (for reviews, see Baum, 1979; Davison & McCarthy, 1988; Taylor & Davison, 1983; Wearden & Burgess, 1982).

However, there has been less success accounting for the data from more complex choice procedures such as the concurrent-chains schedule. In this procedure, the concurrent variable-interval (VI) schedules do not arrange immediate primary reinforcers. Instead, completing a VI schedule leads to the exclusive presentation of another schedule that terminates in the reinforcer. Following reinforcement, the concurrent schedules are reinstated.

The concurrent VI schedules are known as the initial links of the chains, and the schedules terminating in reinforcement are known as the terminal links.

A number of models have been developed to describe performance in concurrent-chains schedules. Some models describe performance by simple extensions to the generalized matching law (e.g., Davison, 1983). Other models provide more complex mathematical accounts—for example, Fantino's delay-reduction hypothesis and Killeen's incentive theory (e.g., Killeen, 1982; Killeen & Fantino, 1990; Squires & Fantino, 1971). All of these models, and their related experiments, have focused primarily on the effects of schedule parameters. However, a second line of research has concentrated on the contribution of stimulus parameters to performance in concurrent-chains schedules, with particular interest in the effects of the stimuli used to signal the terminal links (e.g., Omino, 1993; Omino & Ito, 1993; Williams & Fantino, 1978).

A study by Williams and Fantino (1978) provides a good example of this approach. The initial links were concurrent VI 60-s schedules arranged on the side keys of a two-key chamber. When an initial-link response produced a terminal link, this terminal link appeared with equal probability on either of the two side keys so that location could not function as a discriminative stimulus. In cued conditions, the two terminal links were signaled by different colors. The terminal link following a

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right-key initial link produced a blue side key and a fixed-interval (FI) schedule. The terminal link following a left-key initial link produced a white side key and a different FI schedule. The pigeons showed large preferences for the initial link leading to the shorter of the two terminal links. In uncued conditions, the side keys were white in both terminal links; that is, there was no arranged stimulus difference (location or key color) to signal which of the two FI schedules was available. Preference for the initial link leading to the shorter terminal link was substantially reduced in these uncued conditions.

Williams and Fantino (1978) attributed the effects of the cues to the conditioned-reinforcement value of the terminal-link stimuli. In the cued conditions, the two terminal-link stimuli had different conditioned-reinforcement values because of their association with different reinforcement schedules. The subjects responded more to the initial-link schedule that led to the higher valued conditioned reinforcer. In the uncued conditions, there was no difference in the value of the conditioned reinforcer produced by the two initial links, because the same stimulus was used for both FI terminal links. Hence, preference was less extreme.

More recently, Williams and Dunn (1991) provided further evidence for the conditioned-reinforcement effects of terminal-link stimuli. The initial links of their concurrent-chains procedure arranged concurrent VI 120-s schedules. The uncued terminal links were both FI 20-s schedules presented on the center key. In some conditions, the initial-link responses also produced 20-s presentations of the terminal-link stimulus, but without food reinforcement at the end. In other words, initial-link responses sometimes produced terminal links that ended with a reinforcer (arranged at equal rates on the two alternatives), and sometimes produced presentations of the terminal-link stimulus without a reinforcer (arranged at different rates across the two alternatives). Preference tracked the relative frequency with which the extra stimulus presentations were assigned to the initial links.

Initial-link responding seems to be determined by more than the conditioned-reinforcement value of the terminal-link stimuli, however. Even when uncued terminal links are arranged, a preference for the shorter of the two terminal links often remains. Williams

and Fantino (1978) and Williams and Dunn (1991) attributed these differences to the effects of the delayed primary reinforcers.

Williams and Dunn (1991) noted that only one model of concurrent-chains performance makes qualitative predictions consistent with their results and those of Williams and Fantino (1978). This model, known as incentive theory (Killeen, 1982; Killeen & Fantino, 1990), can be written

$$\frac{B_1}{B_2} = \frac{R_1(P_1 + C_1)}{R_2(P_2 + C_2)}. \quad (1)$$

In Equation 1, initial-link responding (B) is determined by the rates of reinforcement (R) and by the combination of the effects of delayed primary reinforcers (P) and conditioned reinforcers obtained upon entering a terminal link (C). The terminal-link duration determines the value of P and C . The shorter the terminal link, the larger the effects of P and C . The ratio of these values across the two alternatives (Subscripts 1 and 2) predicts preference during the initial links (for more detail see Killeen, 1982; Killeen & Fantino, 1990). When the same stimulus is used to signal both terminal links, the effects of the conditioned reinforcers C_1 and C_2 should tend to be equal in value, so preference should be less extreme under these conditions.

Equation 1 makes another testable prediction. If the terminal links are equal in duration, then $P_1 = P_2$ and $C_1 = C_2$, and the component of Equation 1 dealing with their effects can be disregarded. Therefore, if an experiment arranged unequal initial links and equal terminal links, then the proportion of responding allocated to the shorter of the initial links should be the same, regardless of whether the terminal links are cued or uncued.

On the other hand, the terminal-link stimuli might serve a discriminative function in addition to any reinforcing function. These stimuli provide a signal that is correlated with the last response emitted during the initial links. In uncued procedures, the removal of these stimuli might decrease the control of initial-link responding by the delayed reinforcers. This idea is related to an experiment by Alsop and Davison (1992). They arranged a switching-key concurrent schedule (see Findley, 1958), in which pigeons could switch between two VI schedules arranged on one key by responding

to a second key (the switching key). When a VI schedule was completed, a discrimination test was presented. Reinforcers were delivered only if the subject correctly identified on which of the two VI schedules it had last responded. Subjects displayed typical concurrent-schedule performance, and accuracy during the discrimination test was very high. In later conditions, a 10-s delay was arranged between the responses that completed the concurrent VI schedules and presentations of the discrimination test. The delay had two effects. First, there was a decrease in accuracy during the discrimination test. Second, behavior allocation during the concurrent schedules was less extreme. In other words, discrimination between the concurrent schedules at the time of primary reinforcement was correlated with the extent to which the relative reinforcement rate controlled initial-link responding.

This discriminative-stimulus approach and the conditioned-reinforcement approach make different predictions. Consider the previous example of an experiment with unequal initial links and equal terminal links. If the terminal-link cues also serve a discriminative function by linking initial-link responses and the delayed primary reinforcers, then the proportion of responding allocated to the shorter of the initial links should be greater for cued conditions than for uncued conditions. As noted earlier, the conditioned-reinforcement approach predicts no difference in initial-link responding under these conditions.

The present study further investigated the effects of uncued and cued terminal links on concurrent-chains performance. Experiment 1 tested the predictions of the conditioned-reinforcement approach and the discriminative-stimulus approach. Experiment 2 was a systematic replication of the study by Williams and Fantino (1978) using the same general procedure arranged in Experiment 1.

EXPERIMENT 1

Experiment 1 arranged unequal initial links on two side keys and equal terminal links on the center key. In uncued conditions, the center key was lit with the same stimulus, irrespective of which terminal link was operating. Therefore, in uncued conditions, the key, the key color, and the FI schedule were the same for the two terminal links. In cued conditions, dif-

ferent key colors signaled which terminal link was in effect. Also varied across conditions were the relative frequency with which the two initial-link schedules could be completed and the duration of the FI schedule in the terminal links.

METHOD

Subjects

Three adult White Carneau pigeons, numbered 51, 52, and 54, were maintained at approximately 80% of their free-feeding body weights. Water and grit were freely available in their home cages, and mixed grain was provided after sessions when necessary to maintain their set weights. The pigeons had been used for other research, but none had involved the procedure or the stimuli used in the present study.

Apparatus

Three standard operant conditioning chambers for pigeons (width 31 cm, depth 35 cm, height 33 cm) each contained three response keys (2.5 cm in diameter, 8.5 cm apart, and 25 cm above the grid floor). The center key could be transilluminated white, red, or blue, and the two side keys could be transilluminated yellow. An effective response on any key required a force of approximately 0.1 N and produced a click. Responses to darkened keys were ineffective and were not recorded. A reinforcer consisted of 3-s access to a grain hopper situated 10 cm below the center key. During reinforcement, the hopper was illuminated and all keys were darkened. No other sources of illumination were provided. A ventilation fan provided masking noise. A PDP 8A® computer in a separate room arranged experimental events and recorded data using SUPERSKED® software.

Procedure

During the concurrent initial links, the center key was dark and both side keys were lit yellow. When a response on a side key completed a VI schedule and produced a terminal-link entry, both side keys were darkened, the center key was lit, and a reinforcer was presented upon completion of an FI schedule. The duration of the FI schedule was the same for both terminal links. In cued conditions, the center key was lit red if the left-key initial link

Table 1

The conditions in Experiment 1. The initial-link VI schedules (seconds), the terminal-link FI schedules (seconds), and the type of terminal links (cued or uncued) are given. The order in which the subjects received the conditions is also shown.

Condition	Initial links		Terminal links	
	VI left	VI right	FI schedule	Type
A	25	100	no terminal link	
B	100	25	no terminal link	
C	25	100	30	cued
D	100	25	30	cued
E	25	100	30	uncued
F	100	25	30	uncued
G	25	100	45	cued
H	100	25	45	cued
I	25	100	45	uncued
J	100	25	45	uncued
K	25	100	60	cued
L	100	25	60	cued
M	25	100	60	uncued
N	100	25	60	uncued
Subject	Order of conditions			
51	CDEF, GHIJ, AB, KLMN			
52	DEFC, HIJG, BA, LMNK			
54	FCDE, JGHI, BA, NKLM			

produced the terminal link, or blue if the right-key initial link produced the terminal link. In uncued conditions, the center key was lit white, irrespective of which initial-link schedule had produced the terminal link.

The concurrent initial-link schedules were arranged by a single VI 20-s schedule. Once an interval had elapsed, the next terminal-link entry was assigned probabilistically to the left key or the right key, in the manner of Stubbs and Pliskoff (1969). The next effective response (see below) on the appropriate key produced the terminal-link schedule. Once the reinforcer had been obtained, the initial links were reinstated and the next VI began timing. There was a 3-s changeover delay (COD); that is, if the subject switched between side keys, then a response could not produce a terminal link until 3 s had elapsed since the first response on that key.

Table 1 shows the particular schedules and stimuli used in each of the 14 experimental conditions. Across conditions, three different FI schedule durations were used in the terminal links: 30 s, 45 s, and 60 s. For each FI

duration, two conditions used cued (red and blue) terminal links, and two conditions used uncued (white) terminal links. For both pairs of cued and uncued terminal links, one condition arranged concurrent VI 25-s (left key) and VI 100-s (right key) schedules in the initial links, and the other condition reversed these contingencies. In two other experimental conditions (Conditions A and B, Table 1), there were no terminal links; the initial-link VI schedules produced immediate reinforcers. In other words, these two conditions were simple concurrent VI schedules. Each subject received the experimental conditions in a different order. Each condition lasted for at least 30 sessions and until session-to-session relative response rates (left-key initial-link responses divided by total initial-link responses) were stable. For the stability criterion, when the medians of adjacent but nonoverlapping sets of three sessions were within .05 of each other, a minor stability criterion had been reached. When a subject reached such a minor criterion five (not necessarily consecutive) times, the experimental condition was changed.

The daily sessions began in blackout and ended in blackout after 1 hr had elapsed or 40 reinforcers were obtained, whichever occurred first. At the end of each session, the computer recorded the number of responses to each initial link and terminal link, the number of times each terminal link was entered, changeovers between the concurrent initial links, and the amount of time the initial links were in operation. The data summed across the last five sessions of each condition were used in the analyses.

RESULTS

The critical data from Experiment 1 were the proportions of responses emitted in the shorter initial-link schedule in the cued and uncued conditions. A conditioned-reinforcement approach of the sort proposed by Killen (1982) predicts that there should be no difference between these measures. On the other hand, if the cues also act as discriminative stimuli during the terminal-link delays, preference for the shorter initial link should be greater for the cued conditions than for the uncued conditions. Contrary to both predictions, the data from Experiment 1 indicated that preference for the shorter initial link was greater when the terminal links were uncued.

Table 2

The results from cued and uncued conditions of Experiment 1. The proportion of responses emitted to the shorter initial link, the proportion of entries into that terminal link, the overall initial-link response rate (responses per minute), and the initial-link changeover rate (changeovers per minute) are shown.

Subject	Initial-link response proportion		Initial-link completion proportion		Initial-link response rate		Initial-link changeover rate	
No terminal links								
51	.77		.79		92.0		4.2	
52	.78		.82		59.7		3.9	
54	.74		.84		76.5		3.8	
<i>M</i>	.77		.82		76.3		4.0	
	Cued	Uncued	Cued	Uncued	Cued	Uncued	Cued	Uncued
FI 30 terminal links								
51	.64	.72	.81	.82	45.8	29.9	3.3	2.2
52	.74	.73	.79	.77	36.6	15.1	1.8	1.2
54	.56	.80	.82	.82	20.1	17.6	2.1	1.3
<i>M</i>	.66	.74	.81	.80	32.7	19.6	2.3	1.5
FI 45 terminal links								
51	.57	.72	.74	.80	43.4	43.8	2.8	2.7
52	.69	.79	.80	.76	14.7	25.4	1.2	1.7
54	.55	.70	.79	.82	21.7	14.8	1.8	1.4
<i>M</i>	.59	.74	.78	.79	24.4	26.5	1.8	1.9
FI 60 terminal links								
51	.62	.74	.76	.83	48.7	28.4	3.4	1.6
52	.63	.66	.83	.78	18.7	16.7	1.7	1.8
54	.57	.61	.77	.78	23.4	18.2	2.1	1.8
<i>M</i>	.61	.65	.79	.80	28.8	19.5	2.3	1.7

Table 2 shows the results from Experiment 1. The data from the initial-link reversals (i.e., concurrent VI 25 s VI 100 s and concurrent VI 100 s VI 25 s) were combined to minimize any effects of position preferences and of the different orders of condition presentation. Figure 1 plots the proportion of responding to the shorter initial link as a function of terminal-link FI schedule and stimulus condition (cued or uncued). For eight of the nine comparisons between cued and uncued conditions, the proportion of responding to the shorter initial link was greater in the uncued condition. The exception, Subject 52 with the FI 30 terminal link, had very similar proportions of responding for both the cued (.74) and uncued (.73) conditions. These results were not simply a function of collapsing the data across initial-link reversals. Preference for the shorter initial link was greater in the uncued conditions in 15 of the 18 uncollapsed comparisons.

These effects were the only systematic differences between initial-link responding in the cued and uncued conditions. Overall response rates and changeover rates in the initial links

tended to be greater for the cued conditions (seven of nine comparisons in both cases), but these differences were not statistically significant (Table 2). Furthermore, neither of these measures changed systematically as a function of terminal-link duration.

Terminal-link responding can be compared in a number of ways; that is, as a function of the terminal-link schedule, the terminal-link key color, and the initial-link schedule leading to that terminal link. Figure 2 shows the terminal-link response rates for each bird in each condition. Each pair of panels corresponds to a particular initial-link schedule combination (e.g., upper left panels, concurrent VI 100 s VI 25 s). The terminal-link response rates are then plotted for the respective FI schedule that followed each initial-link schedule (e.g., upper left, blue FI and red FI) and for each of the terminal-link schedules (e.g., upper left, FI 30 s, FI 45 s, and FI 60 s). The results from the cued conditions are shown in the upper panels, and the results from the corresponding uncued conditions are shown in the lower panels.

Figure 2 shows that response rates during

Fig. 1. Experiment 1. The proportion of initial-link responding to the shorter initial link as a function of ter-

each of the two terminal links in each condition did not differ systematically as a function of either the initial-link schedule leading to that terminal link or the key color (in cued conditions). This is shown by comparing the data within each pair of panels. For example, the response rates during the blue FI schedule following the VI 100-s initial link were similar to those during the red FI schedule following the VI 25-s initial link (Figure 2, upper left panels). This similarity is evident in each pair of panels.

On the other hand, Figure 2 suggests that the terminal-link response rates for cued conditions (upper panels) were greater than those in the corresponding uncued conditions (lower panels). A more detailed comparison indicates that this interpretation of the results warrants caution. When each response rate in cued conditions was compared to the corresponding data in uncued conditions, the cued response rates were greater in 25 of 36 cases. However, this result is largely attributable to the data from the FI 30-s schedules (cued greater in 10 of 12 cases), whereas the results from the FI 45-s and FI 60-s schedules were less convincing (cued greater in seven of 12 and eight of 12 cases, respectively). A comparison of this effect across subjects also showed inconsistencies; that is, cued response rates were greater in six of 12 comparisons for Subject 51, 11 of 12 for Subject 52, and eight of 12 for Subject 54. Furthermore, there seems to be no consistent relation between differences in cued and uncued terminal-link response rates and preference for the shorter initial link (Figure 1). For example, although Subject 52 produced the most consistent difference between cued and uncued terminal-link response rates (open circles in Figure 2), it showed the least difference between its preferences for the shorter initial link in cued and uncued conditions (Figure 1).

DISCUSSION

The results of Experiment 1 present difficulties for both sets of predictions. If the cues during the terminal links serve a discriminative function mediating the delay between ini-

←
terminal-link delay. Results from cued terminal links (circles), uncued terminal links (triangles), and conditions with no terminal links (squares) are shown separately.

Fig. 2. Experiment 1. The terminal-link response rates for each subject in each condition. The data from Subjects 51, 52, and 54 are shown by filled circles, open circles, and open triangles, respectively, and the solid line shows the means across subjects. See text for more details.

tial-link responses and the primary reinforcer, then preference for the shorter initial link should be greater in the cued conditions. This approach cannot accommodate the finding that preference was greater in the uncued conditions. The conditioned-reinforcement approach has similar problems. If the conditioned-reinforcement value of the terminal links is determined by the delay to the primary reinforcer (e.g., Killeen, 1982; Killeen & Fantino, 1990), then there should be no difference between preference for the shorter initial link in the cued and uncued conditions. Again, this approach is at odds with the data.

The results from Experiment 1 are consistent with the results of previous research using concurrent-chains schedules. Squires and Fantino (1971) showed that increasing the duration of equal, cued, terminal links decreases

preference for the shorter initial link. Moreover, some conditions from their study are directly comparable with the cued conditions in the present study. They arranged a condition with equal VI 15-s terminal links and concurrent VI 30-s and VI 60-s initial links, and another condition with these initial-link contingencies reversed. Two further conditions used the same initial links but arranged equal VI 60-s terminal links. The arranged rate of initial-link completions in these conditions was three per minute, which is the same rate as that in the present Experiment 1. However, the arranged relative rate of left initial-link completions in Squires and Fantino's study was .66 (or .33 for the reversals), whereas it was .80 (or .20) in the present study. Therefore, the results of these two studies were compared by calculating an estimate of sensitivity

Fig. 3. Estimates of the sensitivity of the initial-link response ratio to changes in the initial-link completion ratio, based on the group data from Experiment 1, from Squires and Fantino (1971), and from Williams and Dunn (1991).

of initial-link responding to changes in the relative rate of initial-link completion. For each terminal-link duration, the difference between the logarithm of the ratio of initial-link responses across the two conditions (B_1/B_2 and its reversal B_{1r}/B_{2r}) was divided by the difference between the logarithm of the ratio of initial-link completions (R_1/R_2 and its reversal R_{1r}/R_{2r}), summarized by the equation:

$$a = \left[\log\left(\frac{B_1}{B_2}\right) - \log\left(\frac{B_{1r}}{B_{2r}}\right) \right] \div \left[\log\left(\frac{R_1}{R_2}\right) - \log\left(\frac{R_{1r}}{R_{2r}}\right) \right]. \quad (2)$$

This provides a measure equivalent to the parameter a used in the generalized matching law, and it provides an estimate of the sensitivity of behavior to changes in the initial-link completion ratio.

The same analysis was conducted on two relevant conditions from the study by Williams and Dunn (1991). In both conditions, the terminal links were equal, uncued, FI 20-s schedules leading to primary reinforcement. In one condition, the left-key initial link was a VI 120-s schedule with a VI 37.5-s schedule superimposed; the right-key initial link was a VI 120-s schedule with a VI 150-s schedule

superimposed. In another condition, these initial-link contingencies were reversed. These values reduce to an overall arranged initial-link completion rate of three per minute (the same as the present study) and a relative initial-link completion rate of .70 (or .30 for the reversal).

Figure 3 plots the measures of the sensitivity parameter a as a function of the terminal-link duration for the group data from the present study (cued and uncued conditions shown separately), from Squires and Fantino (1971), and from Williams and Dunn (1991). The data from the previous studies are consistent with the results from the present study. The results from the cued conditions of Squires and Fantino lay on the same general function as those from the cued condition in Experiment 1. Indeed, the a value from Squires and Fantino's FI 60-s conditions was the lowest of all three studies. On the other hand, the a value from the uncued condition of Williams and Dunn was the highest of all three studies. Some caution is necessary because there are so few data points to compare across studies. However, the fact that the results from the three studies were at least consistent provides some supporting evidence for the findings of Experiment 1.

EXPERIMENT 2

The difference between the results of Experiment 1 and the introductory predictions requires a comparison of the procedures that generated the germane data. The procedure of the present study differed in a variety of ways from that used in Williams and Fantino's (1978) study of cued and uncued terminal links. For example, the terminal links and initial links were different durations, and different stimuli signaled initial links and terminal links. Furthermore, in the present study, there was a 3-s changeover delay, and the terminal links were arranged on the center key. Williams and Fantino used no changeover delay and arranged the terminal links on the side keys. Some of these differences may have contributed to the results obtained in Experiment 1. Therefore, Experiment 2 systematically replicated Williams and Fantino's study using the same general procedure as that in Experiment 1. The initial links were concurrent VI 40-s schedules, and the terminal links were FI 20-s and FI 40-s schedules. Cued and uncued ter-

minal links were arranged across conditions. Unlike Williams and Fantino's study, responses to terminal-link schedules were recorded in 5-s bins. This allowed a more detailed analysis of responding during cued and uncued terminal links.

METHOD

Subjects

Four adult White Carneau pigeons, numbered 71, 72, 73, and 74, were maintained at approximately 80% of their free-feeding body weights. Water and grit were freely available in their home cages, and mixed grain was provided after sessions when necessary to maintain their set weights. They had been used for other research, but none had involved either the procedure or the stimuli used in the present study.

Apparatus and Procedure

The apparatus was identical to that used in Experiment 1, as was the general procedure. However, the initial links were always concurrent VI 40-s schedules. This provided the same overall rate of initial-link completions as used in Experiment 1. An FI 20-s schedule followed completion of one initial link, and an FI 40-s schedule followed the other. Table 3 shows the arrangement of the cued and uncued terminal links, the FI schedules, and the order of presentation of these conditions for each subject.

At the end of each session, the computer recorded the number of responses to each initial link, the number of times each terminal link was entered, the number of changeovers between the concurrent initial-link schedules, and the amount of time the initial links were in operation. Responses in the terminal links were recorded in 5-s bins.

Each subject received the experimental conditions in a different order (Table 3). On the basis of our experience in Experiment 1, training in each condition lasted for 35 sessions. Post hoc analysis of the last five sessions indicated that this amount of training typically produced stable performance; that is, there were no obvious trends in the relative response rates across these sessions, and the standard deviations of these daily relative response rates were less than .05 in 14 of 16 cases (the exceptions were Subject 71 in Condition 3 [$SD = .09$] and Subject 73 in Condition 4 [$SD = .09$]). The

Table 3

The conditions in Experiment 2. The concurrent initial links were always VI 40-s schedules. The terminal-link FI schedules (seconds) arranged on the center key and the type of terminal links (cued or uncued) are given. The order in which the subjects received the conditions is also shown.

Condition	Terminal links		
	FI from left	FI from right	Type
A	20	40	Cued
B	40	20	Cued
C	20	40	Uncued
D	40	20	Uncued
Subject	Order of conditions		
71	A B C D		
72	B C D A		
73	C D A B		
74	D A B C		

data summed across the last five sessions of each condition were used in the analyses.

RESULTS

The results of Experiment 2 replicated the results of Williams and Fantino (1978). Preference for the shorter terminal link was greater in cued conditions than in uncued conditions for all subjects. The proportion of initial-link responses for the initial link leading to the FI 20-s schedule, collapsed across reversals, is plotted in the left panels of Figure 4. These measures of preference, the proportion of initial-link completions, the overall initial-link response rate, and changeover rate are shown in Table 4. There were no other systematic differences in initial-link performance between the cued and uncued conditions (Table 4).

Although all subjects showed a decrease in preference for the shorter terminal link in the uncued conditions, this effect was greater for some subjects than others. For example, Subject 72 showed only a small decrease between the cued and uncued conditions (.85 to .82), whereas Subject 74's measure of preference dropped to indifference (.76 to .50). Furthermore, these differences were correlated with the subjects' respective terminal-link performances. The right panels of Figure 4 show the response rate during the terminal links measured in successive 5-s bins. Subjects 71 and 74 showed clear differences in response rates between the FI 20-s and FI 40-s sched-

Fig. 4. Experiment 2. The left panels show the proportion of responding to the initial link that led to the shorter (FI 20-s) terminal link for cued and uncued conditions. The remaining panels show the response rates during the FI 20-s and FI 40-s terminal links, measured in successive 5-s bins. Data from the cued conditions and uncued conditions are shown separately.

Table 4

Data from the initial-link performance of Experiment 2. The proportion of responses emitted to the initial link that led to the shorter (FI 20-s) terminal link, the proportion of entries into that terminal link, the overall initial-link response rate (responses per minute), and the initial-link changeover rate (changeovers per minute) are given.

Subject	Response proportion		Entry proportion		Response rate		Changeover rate	
	Cued	Uncued	Cued	Uncued	Cued	Uncued	Cued	Uncued
71	.84	.58	.49	.53	31.7	20.1	2.0	2.0
72	.85	.82	.53	.49	158.2	176.6	3.2	3.8
73	.77	.64	.52	.48	69.2	45.0	2.2	2.2
74	.76	.50	.53	.45	75.3	70.3	4.7	3.2

ules during cued terminal links. However, their response rates to the two terminal links were much more similar in the uncued conditions. These 2 subjects also showed the largest changes in preference across the cued and uncued conditions (Figure 4, left panels).

On the other hand, Subject 72's response rates to the FI 20-s and FI 40-s terminal links were markedly different in both cued and uncued conditions (Figure 4, right panels). This subject showed the smallest change in preference across cued and uncued conditions (Figure 4, left panels).

The results from Subject 73 are more difficult to interpret. This subject showed some preference for the FI 20-s schedule during the uncued conditions, but the response rates during the uncued terminal links were very similar (Figure 4). However, this subject also had the most similar response rates to the two cued terminal links. Therefore, one could argue that the relative change in response rates to the two terminal links across the cued and uncued conditions was not as extreme as it was for Subjects 71 and 74.

DISCUSSION

In Experiment 2, the general procedure used in Experiment 1 replicated the major findings of Williams and Fantino's (1978) study; that is, preference for the shorter terminal link was greater with cued terminal links than with uncued terminal links. This provides some assurance that the findings of Experiment 1 are not procedural artifacts, and they may be safely compared to previous studies. We will consider the wider implications of Experiments 1 and 2 for research in this area in the General Discussion.

Experiment 2 provided detailed data com-

paring performance during cued and uncued terminal links. Previous studies (e.g., Williams & Dunn, 1991; Williams & Fantino, 1978) have reported only the overall rates of responding in these terminal links. Recording terminal-link responses in 5-s bins in Experiment 2 showed how the cues controlled responding in the terminal links (Figure 4). Response rates in the first 20 s of the terminal links were higher during the FI 20-s terminal link than during the FI 40-s terminal link in cued conditions. For 3 subjects, these response rates were more similar in uncued terminal links. The same 3 subjects also showed a marked decrease in preference for the shorter FI schedule.

It is important to note that there were some differences in the response rates to the FI 20-s and FI 40-s terminal links for all subjects, even in the uncued conditions. Response rates in the first 5-s bin, and to some extent the second 5-s bin, were very similar for the cued and uncued conditions. Subject 72, of course, maintained a clear difference in response rates throughout the uncued terminal links. In other words, early in the terminal links there was some differential responding to the FI 20-s and FI 40-s terminal links.

The discriminative stimuli controlling this differential responding in uncued conditions must be related to the previous responding to the initial-link keys. The side key to which the subject last responded may have acted as a discriminative stimulus for terminal-link responding, and this control decayed with time as the terminal link elapsed. This is analogous to the results from studies of animal short-term memory, in which control by sample stimuli on choice behavior decreases as the delay between the sample and comparison stim-

uli increases (e.g., Harnett, McCarthy, & Davison, 1984; McCarthy & White, 1987). On the other hand, behavior following the last initial-link response may have acted as a discriminative stimulus. For example, the subject would be standing on the left side of the chamber after completing a left-key initial link. Until the subject moved, position could serve as a discriminative stimulus. This type of stimulus control can explain the continued differential responding in the terminal links by Subject 72. Unfortunately, it is not possible to identify the controlling stimuli post hoc. In fact, either of the above suggestions might have controlled a particular subject's behavior.

GENERAL DISCUSSION

A conditioned-reinforcement account of the effect of terminal-link stimuli accommodates the results of Experiment 2 (e.g., Killeen, 1982; Williams & Dunn, 1991; Williams & Fantino, 1978). Similarly, the data from Experiment 2 do not preclude the idea that the terminal-link cues also serve a discriminative function (e.g., Alsop & Davison, 1992). However, the results of Experiment 1 are not easily reconciled with either of these approaches.

The results of Experiment 1 are incompatible with the idea that the terminal-link stimuli have the discriminative function of bridging the gap between the last initial-link response and the primary reinforcer. This approach makes the opposite prediction to the results of Experiment 1; that is, it predicts that uncued terminal links should produce less extreme preference during the initial links.

A conditioned-reinforcement approach is also inconsistent with the results from Experiment 1. If the conditioned-reinforcement value of the terminal-link stimuli is simply a function of the delay to the primary reinforcer, as it appears in Killeen's (1982) model, then this approach predicts no difference between the cued and uncued conditions in Experiment 1. This prediction, of course, was not supported by the data. One way to resolve this problem is to reconsider the factors contributing to the conditioned-reinforcement value of terminal-link stimuli. For example, perhaps the conditioned-reinforcement value of the terminal-link cues is a function of the frequency with which they appear as well as the delay to the primary reinforcer that they signal. The white center key might have a greater conditioned-

reinforcement value in uncued conditions because it is presented more frequently than either the red or blue center keys used in the cued conditions. However, this type of approach immediately runs into difficulties. In the cued conditions of Experiment 1, one of the terminal-link cues (e.g., red) appeared four times more often than the other cue (blue). Therefore, if absolute frequency were modifying the conditioned-reinforcement value of the cues in Experiment 1, then preference in cued terminal links still should be more extreme than in uncued terminal links. Alternatively, a conditioned-reinforcement explanation of the results can be salvaged by assuming that the conditioned-reinforcement value of a terminal-link stimulus was reduced by more frequent presentation; that is, the less frequent terminal-link stimulus was the more valuable one. Although we cannot discount this possibility, such an explanation seems to be better suited to situations in which the relation between terminal-link stimuli and reinforcer presentation is intermittent, whereas in the present study this pairing was always 100%. Furthermore, if the various terminal links did have different values, these differences do not appear to have affected terminal-link performance. The terminal-link response rates gave no indication that the subjects were behaving differently during the two cued terminal links, and provided only weak evidence of any difference between cued and uncued terminal-link performance when equal FIs were programmed in those links (Figure 2).

There is another conceptual level at which the results of Experiment 1 are compatible with the results of Experiment 2 and with previous research (e.g., Navarick & Fantino, 1976; Williams & Fantino, 1978). In all cases, uncued terminal links gave rise to greater control of initial-link responding by the initial-link contingencies. When equal initial links (VI 40 s) led to unequal, uncued terminal links in Experiment 2, the relative initial-link response rate was closer to the relative initial-link completion rate (i.e., .5) than it was in cued conditions (Figure 4). When unequal initial links (e.g., VI 25 s and VI 100 s) led to equal, uncued terminal links in Experiment 1, the relative initial-link response rate was again closer to the relative initial-link completion rate (e.g., .8) than it was in cued conditions (Figure 1).

This simple idea is supported by, and par-

tially explains, some other inconsistencies in studies of concurrent-chains performance. Squires and Fantino (1971) showed that the sensitivity of choice behavior to changes in the initial-link completion ratio decreased as the duration of equal VI terminal links was increased. Representative data were shown previously in Figure 3. Davison (1976) varied the ratio of initial-link completions across a variety of constant FI terminal links (5 s vs. 5 s, 5 s vs. 15 s, and 15 s vs. 5 s). Again, sensitivity of initial-link choice responding to changes in the initial-link completion ratio varied as a function of the terminal-link schedules. In contrast to the findings of these studies, Davison (1983) found that sensitivity to the initial-link completion ratio did not vary systematically across a range of fixed-delay terminal links (0 s vs. 0 s, 0 s vs. 3 s, 0 s vs. 10 s, 5 s vs. 5 s, and 15 s vs. 30 s). The terminal links in Squires and Fantino (1971) and Davison (1976) were cued. However, no stimuli were presented during the terminal links in Davison (1983); that is, they were uncued. The differences in the results of these studies are consistent with the results of Experiment 1 and with the conjecture that uncued terminal links increase sensitivity to initial-link contingencies.

It is less clear how cued or uncued terminal links produce these differences in sensitivity to the initial-link contingencies. Perhaps the answer does lie with factors such as the conditioned-reinforcement role of terminal-link stimuli (e.g., Williams & Dunn, 1991). Indeed, we do not want to preclude a role for conditioned reinforcement in concurrent-chains procedures. It does not, however, seem to offer a compelling solution to the problems posed by the results of the present study.

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