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SOME EFFECTS OF PROCEDURAL VARIATIONS ON CHOICE RESPONDING IN CONCURRENT CHAINS

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The present research used pigeons in a three-key operant chamber and varied procedural features pertaining to both initial and terminal links of concurrent chains. The initial links randomly alternated on the side keys during a session, while the terminal links always appeared on the center key. Both equal and unequal initial-link schedules were employed, with either differential or nondifferential terminal-link stimuli across conditions. The research was designed to neutralize initial- and terminal-link spatial cues in order to gain a clearer understanding of the roles of conditioned reinforcement and delayed primary reinforcement in choice. With both equal and unequal initial links and with differential terminal-link stimuli, all pigeons reliably preferred the chain with the shorter terminal link. However, with equal initial links and nondifferential stimuli, all pigeons were indifferent. With unequal initial links and nondifferential stimuli, some pigeons were also indifferent, while others actually reversed and preferred the chain with the shorter initial link, even though it was followed by the longer terminal link. The decrease if not reversal of the previous preferences implies that preferences in concurrent chains are a function of the conditioned reinforcement afforded by terminal-link stimuli, rather than delayed primary reinforcement.

Key words: choice, concurrent chains, delay of reinforcement, conditioned reinforcement, key peck, pigeons

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The concurrent-chains procedure has long been used to study operant choice. The procedure itself consists of two phases: a choice phase followed by an outcome phase. A common implementation is with pigeons in a two-key operant chamber. During the choice phase, each key is illuminated by a stimulus associated with the initial link of a chain schedule of reinforcement. Occasionally, a response on one key produces a transition to the outcome phase. This phase is signaled by the appearance of an associated terminal-link stimulus on the initial-link key last pecked, and the darkening of the other key. During the outcome phase (i.e., when a terminal link is in effect), primary reinforcement occurs according to a specified schedule. At the conclusion of the terminal link, the initial links are reinstated for the next choice phase, and the cycle begins anew. An experimental session typically consists of a series of such cycles until a specified number of reinforcers is obtained. The dependent variable is the choice proportion, calculated as the percentage of responses made during the initial links to one of the chains.

Much concurrent-chains research over the years has investigated the effects of schedule parameters in the initial links, terminal links, or both, for example, in an effort to develop quantitative models. However, other research has investigated the effects of procedural variations. Procedural variations may be understood as important tools that address both methodological and theoretical questions relating to the processes underlying choice. As with research on schedule parameters, these variations can pertain to initial links, terminal links, or both.

One example of research that has investigated procedural variations is Cerutti and Catania (1986). These researchers used a three-key concurrent-chains procedure with initial links appearing on the side keys and terminal links always appearing on the center. The assignment of the initial links on the side keys randomly alternated during a session, in a kind of multiple schedule. When pluses were on both keys, the initial link of chain 1 was assigned to the left key and the initial link of chain 2 was assigned to the right key. When circles were on both keys, the assignments were reversed.

Employing equal initial-link schedules and differential stimuli during the terminal links,

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Cerutti and Catania (1986) found orderly preference for the shorter of two FI (fixed-interval) terminal-link schedules. Cerutti and Catania identified (p. 212) certain methodological advantages of their procedure. For example, it allowed them to assess preference within sessions, thereby eliminating the need for baseline determinations and sequential reversals in the contingencies in effect during the terminal links. Grace (1995) and Savastano and Fantino (1996) have reported similarly orderly results with related manipulations involving the random alternation of the locus of initial links in concurrent chains with differential terminal-link stimuli. However, unlike Cerutti and Catania, a terminal link in the latter two studies appeared on the key last pecked during the initial links, rather than always on a center key. Worth noting at this point is that none of these studies examined choice with nondifferential terminal-link stimuli.

An example of a procedural variation that pertains to the terminal links is Williams and Fantino (1978). These researchers used a two-key chamber and presented pigeons with a choice between two different terminal-link FI schedules. Equal initial-link variable-interval (VI) schedules were arranged on the left and right keys, as in the conventional procedure. In the conditions of interest, when a response satisfied an initial-link schedule, the terminal-link stimulus appeared randomly on the left or right key, instead of always on the initial-link key last pecked. In addition, the terminal-link stimuli could be either correlated (i.e., differential) or uncorrelated (i.e., nondifferential) with the terminal-link schedule that came into effect. By manipulating the locus of the terminal link and whether the terminal-link stimuli were differential or nondifferential, Williams and Fantino were able to dissociate at least partially the effects of overall delayed primary reinforcement from the effects of any immediate changes in stimuli that could be construed as conditioned reinforcement.

Williams and Fantino (1978) found greater preferences for the shorter FI schedule with differential rather than nondifferential terminal-link stimuli. Indeed, they reported the pigeons often had substantial difficulty in reversing their earlier preference with a reversal of the schedules when the terminal-link stimuli were nondifferential, although the pigeons did eventually reverse with much continued training. The manipulation involving terminal-link locus and nondifferential key color is theoretically relevant because it neutralized any control over choice by the consistent correlation between the positions of initial and terminal links and delayed primary reinforcement. Importantly, if delayed reinforcement was the sole determinant of choice, then choice should have been the same with nondifferential as with differential stimuli. That it was not presumably reflected some control by the conditioned reinforcement of the differential terminal-link stimuli.

Other procedural variations have also examined the contributions of position cues, delayed primary reinforcement, and conditioned reinforcement to choice responding in concurrent chains. For example, Colton and Moore (1997) arranged for the initial links to appear on the left and right side keys of an operant chamber, as is conventional, and then varied procedural features of the terminal links. They found preferences were comparable to those in the conventional procedure in several conditions: (a) when a terminal link always appeared on the opposite key from its initial link, regardless of whether the terminal-link stimuli were differential or nondifferential; (b) when different colored houselights instead of keylights were used as terminal-link stimuli; and (c) when terminal links randomly alternated on the side keys and terminal-link stimuli were differential. These results confirmed and extended the earlier results of Willliams and Fantino (1978). However, when terminal links randomly alternated on the side keys and terminal-link stimuli were nondifferential, Colton and Moore found the pigeons' behavior became less systematic. One of 4 pigeons did prefer the shorter terminal link on both initial and reversal determinations. However, of the remaining 3 pigeons, 1 preferred the shorter terminal link on the initial determination but did not reverse, and the other 2 apparently had a position bias, presumably lingering from the substantial preferences they had shown in the immediately preceding condition. Colton and Moore did not carry out extended training, as did Williams and Fantino, who as mentioned earlier had also found failures to reliably reverse with nondifferential stimuli.

In further conditions, Colton and Moore (1997) examined choice using a three-key procedure, instead of two. In these conditions, the initial links appeared on the side keys, as before, but the terminal links always appeared on the center key. Colton and Moore found that preferences for the shorter FI terminal link were strong and reliable with differential terminal-link stimuli. With a nondifferential stimulus, 1 of 4 pigeons did prefer the shorter terminal link in both initial and reversal determinations. Of the remaining 3 pigeons, 2 preferred the shorter terminal link on the initial determination but did not reverse, while the 3rd apparently persisted in a position bias, presumably lingering from the substantial preference shown in the immediately preceding condition. Colton and Moore did find that if differential houselights were added to the nondifferential center keylight during a terminal link, reliable preferences would emerge for the shorter terminal link.

Overall, Colton and Moore (1997) concluded that reliable preferences will emerge if some feature in the terminal links promotes a discrimination between the terminal-link schedules. That feature may be a differential visual stimulus or a reliable position cue. Absent such a feature, as when terminal-link stimuli were nondifferential and terminal links either (a) randomly alternated on the side keys or (b) always appeared on the center key, preferences were certainly lower and unreliable. Colton and Moore reviewed related findings by Alsop, Stewart, and Honig (1994), Omino (1993), and Omino and Ito (1993). For example, Colton and Moore noted that unlike their own findings, Alsop et al. did find some degree of preference on both initial and reversal determinations for 3 of 4 pigeons with a nondifferential terminal-link stimulus on a center key. Nevertheless, those preferences were lower than with differential stimuli.

The present two experiments continued to investigate effects of initial- and terminal-link procedural variations comparable to those reviewed in the studies above. In each experiment, the initial links always appeared on the side keys, and randomly alternated after each reinforcer during a session. The terminal links always appeared on the center key. In Experiment 1, when a given stimulus was present on both keys during the initial links, chain 1 was assigned to the left key and chain 2 to the right; when a different stimulus was present on both keys during the initial links, the assignments were reversed on the keys. In Experiment 2, one stimulus was always associated with the initial link of chain 1, and a different stimulus was always associated with the initial link of chain 2. One terminal-link schedule was FI 10 s, and the other was FI 20 s. Figure 1 presents an overview of the principal conditions in each experiment. Given the manipulation of initial- and terminal-link locus, across conditions the initial-link schedules were either equal or unequal, and terminal-link stimuli were either differential or nondifferential.

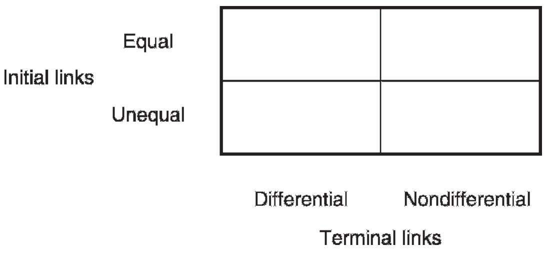

Fig. 1. The design of the principal comparisons in the two experiments. The initial links always appeared on the side keys, and across conditions the schedules could be equal or unequal. The terminal links always appeared on the center key, and across conditions the terminal-link stimuli could be differential or nondifferential. Each experiment involved a different procedure for arranging the initial links.

The present manipulations were designed to address both methodological and theoretical questions. With regard to methodological questions, there is first the intuitive question of whether the pigeons can even learn either or both of the procedures, given that the procedures are moderately complex and involve a kind of conditional discrimination for both initial and terminal links wherein position cues have been entirely removed. Position cues are strong stimuli, sometimes to the point of being problematic because they produce a side bias that interferes with the interpretation of results. Some of the studies reviewed above did find orderly behavior when either initial- or terminal-link position cues were neutralized. Consequently, it was plausible but not certain that the present research would find similar results when both were neutralized. Second, there is the question of whether the present multiple schedule arrangement would yield orderly data, without the necessity of reversals.

With regard to theoretical questions, an enduring issue in the analysis of choice in concurrent chains is whether delayed primary reinforcement or terminal-link conditioned reinforcers controls preference. The present research examines this issue once again. On the one hand, if preference is the same with differential and nondifferential terminal-link stimuli, then delayed primary reinforcement is implicated, and any appeal to conditioned reinforcement by terminal-link stimuli is superfluous. Perhaps the function of terminal-link stimuli is only discriminative, rather than reinforcing. On the other hand, if preference is stronger and more reliable with differential than with nondifferential terminal-link stimuli, given that position cues are neutralized in the present research, then conditioned reinforcement is indeed implicated. Data from previous studies showing reliable preference with nondifferential stimuli might indicate control derived from one or more complex discriminations involving (a) initial-link spatial cues, by virtue of their locus; (b) terminal-link spatial cues, by virtue of their locus; and (c) terminal-link visual cues, by virtue of the correlation between key color and schedule. Previous studies varied procedural features relating to one or two of these factors, but the remaining factor(s) could have been the basis for the observed behavior. The present research varied all three factors.

GENERAL METHOD

Subjects

Pigeons B-22, B-29, B-35, B-46 served as the subjects in both experiments. The pigeons were of mixed breeds and varying ages. The pigeons had prior experience with a variety of operant schedules, including concurrent chains. However, that prior experience did not include anything similar to the present procedural variations. The pigeons were housed in a room with a 16 h light, 8 h dark cycle, with constant access to water and grit in their home cages. They were maintained at approximately 80% of their free-feeding weight for motivational purposes throughout the two experiments.

Apparatus

Two operant conditioning chambers for pigeons were used in the present research. Chamber 1 was approximately 30 cm high, 30 cm deep and 30 cm wide. Chamber 2 was approximately 35 cm high, 35 cm deep, and 47 cm wide. A rectangular opening (approximately 5 cm by 6 cm), through which the bird gained access to an elevated food hopper, was centered on the intelligence panel in both chambers. Three circular response keys (2.5 cm diameter; approximately 10 cm apart in chamber 1, and 15 cm apart in chamber 2) were centrally mounted on the intelligence panel in each chamber. The response keys required approximately 0.15 N to operate. The distances from (a) floor to food-hopper opening and (b) floor to response keys in Chamber 1 were 3 cm and 20 cm; and in Chamber 2 were 6 cm and 22 cm. Chamber 1 was housed in a separate sound attenuation enclosure, whereas the walls of chamber 2 were sound attenuating material. Both chambers had a ventilation fan to provide fresh air and to provide a masking noise to further minimize interference from incidental external stimulation. Conventional 28-V DC electromechanical apparatus, located in a room adjacent to the chambers, controlled the events and recorded the data.

Procedure

The pigeons were trained in two experiments. Each used a variation of the concurrent- chains procedure involving all three keys of the operant chamber. Details of these variations are provided below in the Procedure section of each experiment. Sessions were conducted at approximately the same time of day, 5-6 days per week. Sessions typically lasted 30-45 min, during which the pigeons obtained 80 reinforcers. Unconditioned reinforcement consisted of 2.25-s access to mixed grain. The initial links were interdependent VI schedules, in the sense that whenever the interreinforcement interval (IRI) of one initial link elapsed, timing stopped for both until the correlated terminal link had been entered (e.g., Stubbs & Pliskoff, 1969). The dependent variable was the choice proportion, or the percentage of total initial-link responses made on one chain. Pigeons were trained in a given condition until the choice proportions satisfied a stability criterion. This criterion required a minimum of 15 sessions. On the 15th session, or every session thereafter if the criterion was not satisfied, the choice proportions of the last nine sessions were divided into three blocks of three sessions each, and a mean of each block was computed. If the means of the blocks did not differ by more than .05, and showed no monotonic trend, then behavior was considered stable and the pigeon was advanced to the next condition.

Two determinations of preference were made in the principal comparisons, with both differential and nondifferential terminal-link stimuli. In the first determination, an FI 10-s terminal-link schedule was brought about by responding on the initial link of one chain, and an FI 20-s schedule by responding on the other. Then the terminal-link FI schedules were reversed with respect to the initial links. Although the previous studies have reported that reversals of the initial links with respect to keys within a session automatically correct for position biases, and hence may make reversals with respect to stimuli unnecessary (see Cerutti & Catania, 1986, for discussion), reversals with respect to stimuli were nevertheless carried out in the present research to demonstrate reliable experimental control.

EXPERIMENT 1

Procedure

In Experiment 1, both initial-link stimuli were either pluses or circles. When both initial-link stimuli were pluses, the initial link of chain 1 was assigned to the left key and that of chain 2 to the right key. When both initial-link stimuli were circles, the initial link of chain 1 was assigned to the right key and that of chain 2 to the left key. The assignments of the initial links of the chains to the left and right side keys alternated with a probability of .5 after each reinforcer. When the terminal-link stimuli were differential, the center key was red when the terminal link of chain 1 was in effect, and green when the terminal link of chain 2 was in effect. In these respects, the procedure resembled Cerutti and Catania (1986; see also Grace, 1995). When the stimulus was nondifferential, the center key was illuminated with a triangle, regardless of which terminal link was in effect. This condition had not been previously examined.

As an illustration of the procedure for Experiment 1, suppose the pigeon was presented with pluses on both side keys. In this case, the initial link of chain 1 was in effect on the left key, and of chain 2, on the right key. If a response satisfied an initial-link schedule, both side keys went dark and the center key was illuminated. During differential conditions the center key was red if the terminal link of chain 1 was in effect, or green if the terminal link of chain 2 was in effect. During nondifferential conditions, a triangle was projected on the center key, regardless of which terminal link was in effect. When the center key was illuminated, further responding produced food according to the terminal-link schedule in effect, after which the initial links were reinstated. When the initial-link stimuli reappeared, randomly half the time they were again both pluses, and the other half they were both circles.

Now suppose circles appeared on both side keys. In this case, the initial link of chain 1 was in effect on the right key, and of chain 2, on the left key. If a response satisfied an initial-link schedule, the side keys went dark and the appropriate terminal-link stimulus appeared on the center key, as described above (during differential conditions: red if chain 1, green if chain 2; during nondifferential conditions: triangle). Terminal-link responding produced food, after which the initial links were reinstated, as described above.

Across conditions, the pigeons were presented with a choice between chain VI 30 s FI 10 s and chain VI 30 s FI 20 s (i.e., equal initial links), and between chain VI 20 s FI 10 s and VI 10 s FI 20 s (i.e., unequal initial links), with differential or nondifferential terminal-link stimuli. Note that overall IRIs of the chains were equivalent in the present comparisons when initial links were unequal. Of primary concern was the simple binary decision of whether the schedule reliably controlled a majority of the choice responding, defined as a choice proportion that exceeded 0.55 (i.e., .50, ± .05).

Choice was also examined in control conditions at the end of the principal comparisons. In the control conditions, the location of the initial links of the chains was occasionally fixed to one key, and alternative schedule parameters were chosen. The aim of these conditions was simply to demonstrate that the pigeons were responsive to known schedule parameters and that their behavior in the earlier conditions was not distorted by some unknown feature of the procedural variations employed here.

Table 1

Data for each pigeon in each condition of Experiment 1

Pigeon: B-22

Condition	Schedule	Order	Sessions	Term: Diff/ Non	Resp/ min: Initial	Resp/min: Term-1	Resp/min: Term-2	C. P.
1.1	1: chain VI 30 s FI 20 s	5	26	Diff	10	40	78	.27 (.01)
	2: chain VI 30 s FI 10 s				27	144		
1.2	1: chain VI 30 s FI 10 s	6	24	Diff	43	121		.65 (.03)
	2: chain VI 30 s FI 20 s				23	20	154	
1.3	1: chain VI 30 s FI 20 s	7	16	Non	32	92	157	.56 (.03)
	2: chain VI 30 s FI 10 s				25	98		
1.4	1: chain VI 30 s FI 10 s	8	21	Non	49	93		.64 (.04)
	2: chain VI 30 s FI 20 s				28	69	140	
1.5	1: chain VI 10 s FI 20 s	9	31	Diff	14	27	175	.19 (.04)
	2: chain VI 20 s FI 10 s				59	132		
1.6	1: chain VI 20 s FI 10 s	10	20	Diff	36	125		.67 (.06)
	2: chain VI 10 s FI 20 s				18	15	129	
1.7	1: chain VI 20 s FI 10 s	11	17	Non	20	52		.53 (.03)
	2: chain VI 10 s FI 20 S				18	34	142	
1.8	1: chain VI 10 s FI 20 s	12	15	Non	25	66	157	.58 (.03)
	2: chain VI 20 s FI 10 s				18	69		
1.9	1: chain VI 20 s FI 20 s	17	18	Non	7	12	100	.29 (.05)
(fixed)	2: chain VI 10 s FI 20 s				17	5	95	
1.10	1: chain VI 20 s FI 20 s	18	18	Non	37	21	131	.82 (.03)
(fixed)	2: chain VI 90 s FI 20 s				8	23	140	
1.11	1: chain VI 90 s FI 20 s	19	17	Non	23	52	164	.43 (.05)
	2: chain VI 20 s FI 20 s				31	35	172	

Pigeon: B-29

Condition	Schedule	Order	Sessions	Term: Diff/ Non	Resp/ min: Initial	Resp/min: Term-1	Resp/min: Term-2	C. P.
1.1	1: chain VI 30 s FI 20 s	5	23	Diff	5	16	103	.05 (.03)
	2: chain VI 30 s FI 10 s				92	54		
1.2	1: chain VI 30 s FI 10 s	6	27	Diff	54	93		.89 (.04)
	2: chain VI 30 s FI 20 s				7	24	160	
1.3	1: chain VI 30 s FI 20 s	7	23	Non	23	82	95	.47 (.04)
	2: chain VI 30 s FI 10 s				26	94		
1.4	1: chain VI 30 s FI 10 s	8	15	Non	14	53		.47 (.07)
	2: chain VI 30 s FI 20 s				16	58	111	
1.5	1: chain VI 20 s FI 10 s	9	15	Diff	52	99		.95 (.02)
	2: chain VI 10 s FI 20 s				3	10	131	
1.6	1: chain VI 10 s FI 20 s	10	31	Diff	6	16	83	.13 (.03)
	2: chain VI 20 s FI 10 s				42	57		
1.7	1: chain VI 10 s FI 20 s	11	20	Non	17	67	55	.39 (.05)
	2: chain VI 20 s FI 10 s				27	72		
1.8	1: chain VI 20 s FI 10 s	12	15	Non	12	95		.40 (.04)
	2: chain VI 10 s FI 20 s				18	80	66	

Table 1

(Continued)

Pigeon: B-35

Condition	Schedule	Order	Sessions	Term: Diff/ Non	Resp/ min: Initial	Resp/min: Term-1	Resp/min: Term-2	C. P.
1.1	1: chain VI 30 s FI 20 s	5	18	Diff	8	49	92	.11 (.04)
	2: chain VI 30 s FI 10 s				63	130		
1.2	1: chain VI 30 s FI 10 s	6	22	Diff	72	23		.92 (.03)
	2: chain VI 30 s FI 20 s				6	22	45	
1.3	1: chain VI 30 s FI 20 s	7	15	Non	18	18	54	.58 (.05)
	2: chain VI 30 s FI 10 s				13	25		
1.4	1: chain VI 30 s FI 10 s	8	16	Non	22	44		.50 (.04)
	2: chain VI 30 s FI 20 s				22	37	57	
1.5	1: chain VI 10 s FI 20 s	14	15	Diff	7	22	122	.09 (.02)
	2: chain VI 20 s FI 10 s				74	133		
1.6	1: chain VI 20 s FI 10 s	15	18	Diff	75	85		.90 (.03)
	2: chain VI 10 s FI 20 s				8	21	129	
1.7	1: chain VI 20 s FI 10 s	16	28	Non	17	99		.49 (.05)
	2: chain VI 10 s FI 20 s				18	75	217	
1.8	1: chain VI 10 s FI 20 s	17	19	Non	38	85	162	.75 (.02)
	2: chain VI 20 s FI 10 s				13	101		
1.9	1: chain VI 20 s FI 10 s	18	20	Non	19	92		.54 (.06)
	2: chain VI 10 s FI 20 s				16	65	175	
1.10	1: chain VI 20 s FI 20 s	19	31	Non	5	76	139	.26 (.12)
(fixed)	2: chain VI 10 s FI 20 s				14	78	167	
1.11	1: chain VI 10 s FI 20 s	20	15	Non	5	22	47	.42 (.10)
(fixed)	2: chain VI 20 s FI 20 s				7	27	96	

Pigeon: B-46

Condition	Schedule	Order	Sessions	Term: Diff/ Non	Resp/ min: Initial	Resp/min: Term-1	Resp/min: Term-2	C. P.
1.1	1: chain VI 30 s FI 20 s	Diff	18	Diff	23	30	92	.32 (.04)
	2: chain VI 30 s FI 10 s				50	133		
1.2	1: chain VI 30 s FI 10 s	Diff	30	Diff	55	50		.57 (.03)
	2: chain VI 30 s FI 20 s				41	74	155	
1.3	1: chain VI 30 s FI 20 s	Non	15	Non	28	81	80	.50 (.01)
	2: chain VI 30 s FI 10 s				27	81		
1.4	1: chain VI 30 s FI 10 s	Non	15	Non	26	111		.49 (.01)
	2: chain VI 30 s FI 20 s				28	113	85	
1.5	1: chain VI 20 s FI 10 s	Diff	29	Diff	28	145		.67 (.04)
	2: chain VI 10 s FI 20 s				14	65	147	
1.6	1: chain VI 10 s FI 20 s	Diff	23	Diff	23	75	115	.43 (.02)
	2: chain VI 20 s FI 10 s				30	147		
1.7	1: chain VI 10 s FI 20 s	Non	22	Non	41	58	84	.56 (.02)
	2: chain VI 20 s FI 10 s				32	79		
1.8	1: chain VI 20 s FI 10 s	Non	15	Non	29	71		.43 (.02)
	2: chain VI 10 s FI 20 s				38	72	84	
1.9	1: chain VI 20 s FI 20 s	Diff	18	Diff	49	57	130	.69 (.02)
	2: chain VI 90 s FI 20 s				22	74	134	

Note. Included are the chain schedules (chain 1 listed first), the order in training, the number of sessions, whether terminal-link stimuli were differential (Diff) or nondifferential (Non), responses per min in initial links, responses per min in the first half (term-1) and second half (term-2) of the FI 20 s schedule, responses per min in the FI 10 s schedule (under term-1), and the choice proportion (C. P.) for chain 1 with the standard deviation from the nine stability sessions in parentheses. The designation of ''fixed'' under a condition means a control condition in which the initial links did not randomly alternate after a reinforcer, but rather each initial link was fixed to one key.

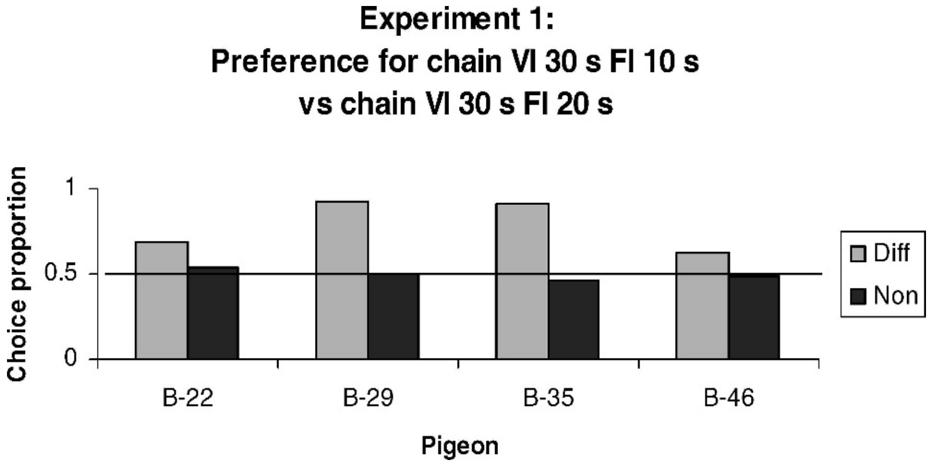

Fig. 2. The choice proportions in favor of chain VI 30 s FI 10 s when pitted against chain VI 30 s FI 20 s using the procedure of Experiment 1. The data are presented for each pigeon, when the terminal-link stimuli were differential (Diff) and nondifferential (Non), and are the averages of the individual conditions in Table 1.

Table 1 presents the details of the training conditions for the pigeons in Experiment 1. The conditions of Experiment 1 were intermixed with those of Experiment 2. Thus, the order of those conditions is not consecutive within Experiment 1, but rather across the two experiments. Listed for each pigeon in each condition are the chain schedules that were in effect, the order in the sequence of training, the number of sessions, and whether the terminal-link stimuli were differential (Diff) or nondifferential (Non). Also in Table 1 are the responses per min during the initial link of each chain, the responses per min during the terminal link of each chain (responding during the first 10 s and last 10 s of an FI 20-s terminal link is designated as term-1 and term-2; responding during an FI 10-s terminal link is listed under term-1), and the choice proportion from the last three sessions, with the standard deviation of choice proportions from the last nine stability sessions in parentheses. The obtained relative rates of terminal-link entry, and hence obtained relative rates of reinforcement, were equivalent throughout to the scheduled rates, owing to the Stubbs and Pliskoff (1969) initial-link scheduling procedure. Chain 1 is listed first for the schedules in each condition, then chain 2.

Results and Discussion

Figure 2 presents the choice proportions in favor of chain VI 30 s FI 10 s when pitted against chain VI 30 s FI 20 s using the procedure of Experiment 1. The data are presented for each pigeon, when the terminal-link stimuli were differential (Diff) and nondifferential (Non), and are the averages of the data from the individual conditions in Table 1. The average choice proportions in Figure 2 and the absolute response rates in Table 1 show a clear preference for the FI 10-s terminal link with the differential terminal-link stimuli for all pigeons. This finding is consistent with extant research (e.g., Cerutti & Catania, 1986; Grace, 1995), and is important insofar as it indicates the procedure did generate orderly behavior.

Figure 2 also shows that the average choice proportion for all pigeons decreased to indifference with nondifferential terminal-link stimuli. This finding is novel, as this combination of procedural variations had not been previously explored. Table 1 shows that absolute rate of initial-link responding also decreased in these conditions.

Figure 3 presents the choice proportions in favor of chain VI 20 s FI 10 s when pitted against chain VI 10 s FI 20 s. The data are presented for each pigeon, when the terminal-link stimuli were differential (Diff) and nondifferential (Non), and are averages of the data from the individual conditions in Table 1. The average choice proportions in Figure 3 and the absolute response rates in Table 1 show a clear preference for chain VI 20 s FI

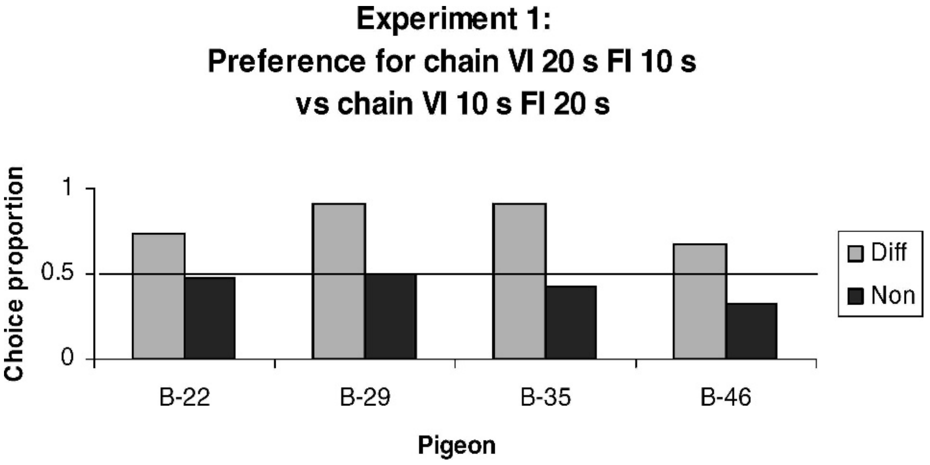

Fig. 3. The choice proportions in favor of chain VI 20 s FI 10 s when pitted against chain VI 10 s FI 20 s using the procedure of Experiment 1. The data are presented for each pigeon, when the terminal-link stimuli were differential (Diff) and nondifferential (Non), and are averages of the individual conditions in Table 1.

10 s with the differential terminal-link stimuli for all pigeons. This finding is also consistent with extant research (e.g., Fantino, 1969).

Figure 3 then shows that the average choice proportions decreased to indifference with nondifferential terminal-link stimuli for pigeons B-22, B-29, and B-35. Pigeon B-35 did appear to prefer chain VI 10 s FI 20 s on one determination (condition 1.8; see Table 1), but its behavior was not consistent in two other determinations (conditions 1.7 and 1.9). Pigeon B-46 went beyond indifference and reversed, preferring chain VI 10 s FI 20 s slightly on both determinations. As with conditions shown in Figure 2 involving equal initial links, the findings of substantially reduced preference (if not reversal) with nondifferential terminal link stimuli are novel, as this combination of procedural variations had not been previously explored. As before, Table 1 shows that absolute rate of initial-link responding decreased with a nondifferential terminal-link stimulus in these conditions.

Figure 4 presents terminal-link response rates from conditions in Experiment 1 with equal initial links. The data are presented for each pigeon, when the terminal-link stimuli were differential (top panel) and nondifferential (bottom panel), and are the averages of the data from the individual conditions in Table 1. The data with differential stimuli show the absolute rate of terminal-link responding with differential terminal-link stimuli was slower in the first half than in the second half of the FI 20-s terminal-link schedule, as well as slower than in the FI 10-s terminal link, in all cases. These data indicate clear discrimination relating to the terminal-link schedules with differential stimuli. The data with a nondifferential terminal-link stimulus show the absolute rate of responding in the terminal links continued to be slower in the first half than in the second half of the FI 20-s schedule, as well as slower in the first half of the FI 20-s schedule than in the FI 10-s schedule, for all but B-46. These data indicate less discrimination relating to the terminal-link schedules than with differential stimuli, but some discrimination nonetheless.

Figure 5 presents terminal-link response rates from conditions in Experiment 1 with unequal initial links. The data are presented for each pigeon, when the terminal-link stimuli were differential (top panel) and nondifferential (bottom panel), and are the averages of the data from the individual conditions in Table 1. The data with differential stimuli show the absolute rate of terminal-link responding was again slower in the first half than in the second half of the FI 20-s terminal-link schedule, as well as slower than in the FI 10-s terminal link, for all but B-46. As with equal initial links, these data indicate clear discrimination relating to the terminal-link schedules with differential stimuli. The

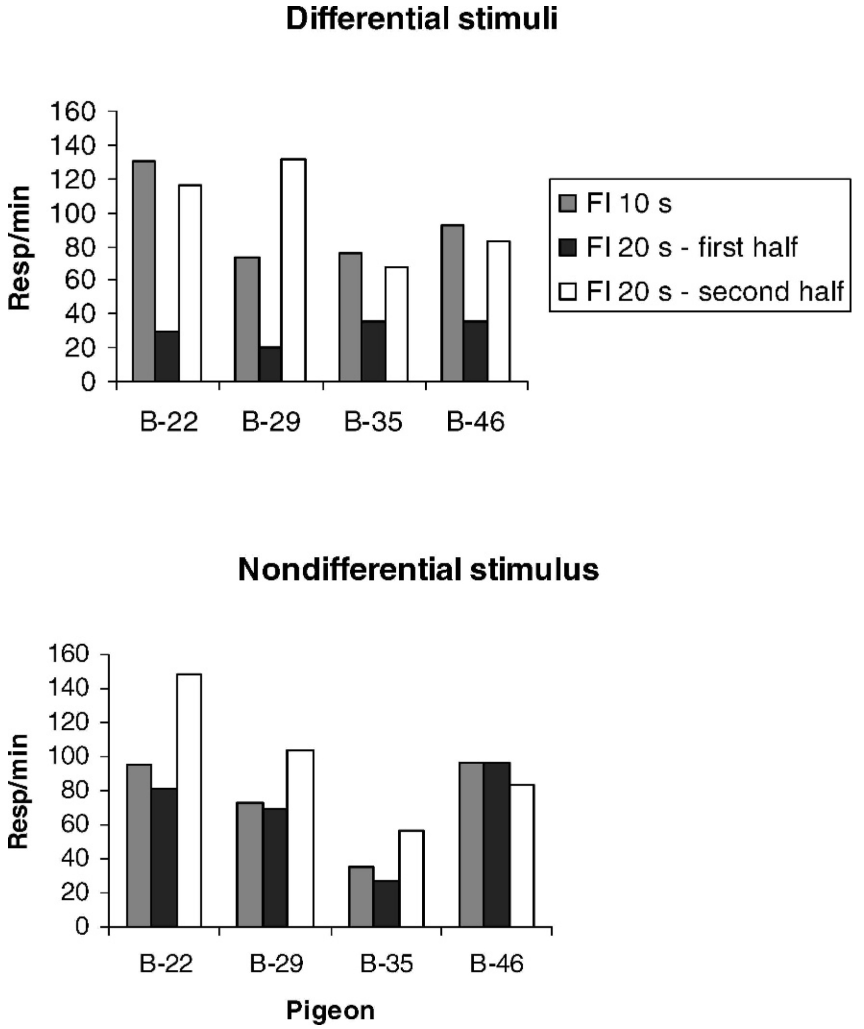

Fig. 4. Terminal-link response rates in Experiment 1 from conditions with equal VI 30-s initial links. The figure shows the rates of responding in the FI 10 s terminal link, and in the first and second halves of the FI 20 s terminal link, with differential stimuli (top panel) and a nondifferential stimulus (bottom panel) in the terminal links. The data are presented for each pigeon, and are averages of the individual conditions in Table 1.

data with a nondifferential terminal-link stimulus show the absolute rate of responding in the terminal links was slower in the first half than in the second half of the FI 20-s schedule, as well as slower in the first half of the FI 20-s schedule than in the FI 10-s schedule, for all but B-29. These data again indicate less discrimination relating to the terminal-link schedules than with differential stimuli, but some discrimination nonetheless.

Pigeons were also trained on control conditions. In a fixed condition, the initial links were assigned to one side key for the entire condition and did not randomly alternate during a session. Readers will note that the fixed condition resembles the conventional concurrent-chains procedure. Table 1 shows that B-22 preferred chain VI 10 s FI 20 s to chain VI 20 s FI 20 s with fixed locus of the initial links and a nondifferential terminal-link stimulus (condition 1.9). Pigeon B-22 then preferred chain VI 20 s FI 20 s over chain VI 90 s FI 20 s, in one condition with the fixed locus (condition 1.10) and in another with the randomly varying locus of the initial links (condition 1.11); the terminal-link stimulus was nondifferential in both conditions. Pigeon B-35 initially preferred chain VI 10 s FI 20 s

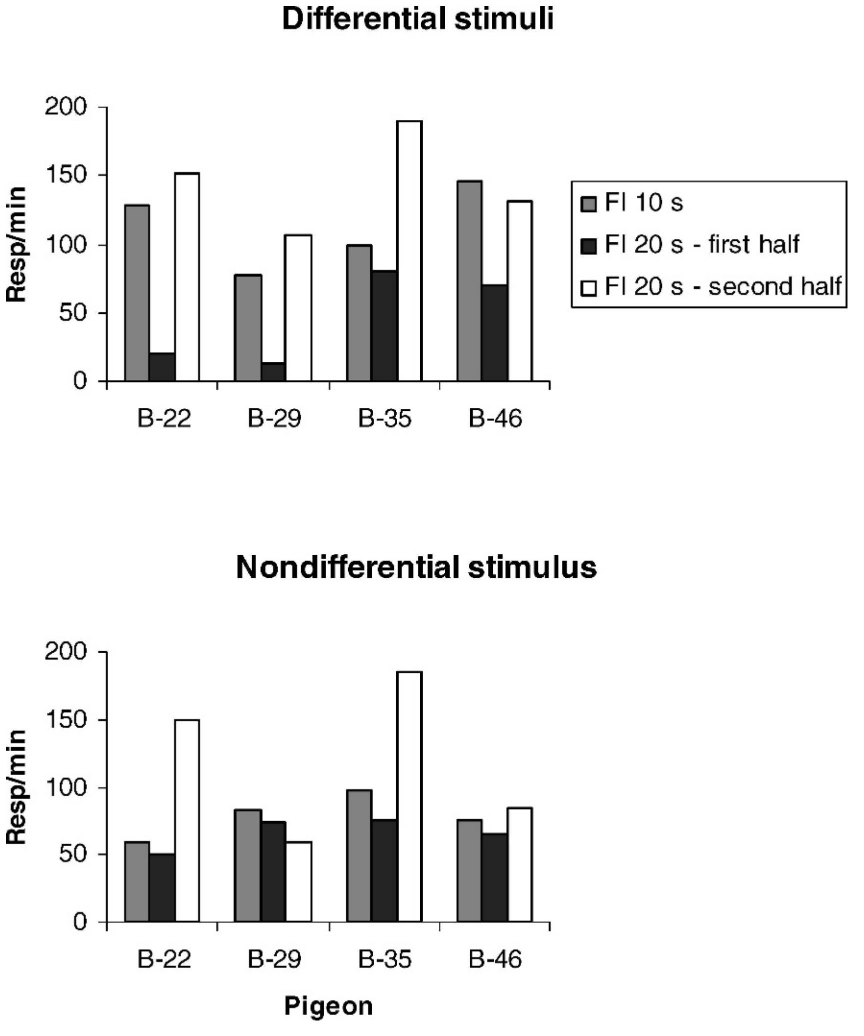

Fig. 5. Terminal-link response rates in Experiment 1 from conditions with unequal initial links. The figure shows the rates of responding in the FI 10 s terminal link, and in the first and second halves of the FI 20 s terminal link, with differential stimuli (top panel) and a nondifferential stimulus (bottom panel) in the terminal links. The data are presented for each pigeon, and are averages of the individual conditions in Table 1.

over chain VI 20 s FI 20 s with a fixed locus of the initial links and a nondifferential terminal-link stimulus (condition 1.10), but then anomalously did not reverse (condition 1.11). Pigeon B-22 did prefer chain VI 20 s FI 20 s to chain VI 90 s FI 20 s with a fixed locus of the initial links and a nondifferential terminal-link stimulus (condition 1.11) in its final determination. Pigeon B-46 preferred chain VI 20 s FI 20 s to chain VI 90 s FI 20 s with a fixed locus of the initial links and differential terminal-link stimuli (condition 1.9) in its final determination. The pigeons' preferences for the shorter initial link with equal terminal links in these conditions replicated a comparable condition in Alsop, Stewart, and Honig (1994).

In sum, Experiment 1 showed that with differential terminal-link stimuli, the pigeons reliably preferred chain VI 30 s FI 10 s over chain VI 30 s FI 20 s and chain VI 20 s FI 10 s over chain VI 10 s FI 20 s. These findings confirm and extend existing research, as reviewed above. However, the present research found novel results with a nondifferential terminal-link stimulus. Here, the pigeons' preference for the FI 10-s terminal link substantially decreased, with both equal and unequal initial links. Indeed, B-46 slightly preferred chain VI 10 s FI 20 s to chain VI 20 s FI 10 s. Importantly, the decreased preference obtained even though the overall relation between initial-link choice responding and ultimate delivery of the reinforcer is the same with differential stimuli as with a nondifferential stimulus.

EXPERIMENT 2

Procedure

In Experiment 2, the initial-link stimuli were again always presented on the side keys, and the terminal-link stimuli were again always presented on the center key. Unlike Experiment 1, a vertical line was the initial-link stimulus for chain 1, and a horizontal line for chain 2. As described in Experiment 1, the assignments of the initial links of the chains to the left and right side keys alternated with a probability of .5 after each reinforcer, and the terminal-link stimuli on the center key were either differential or nondifferential. Conditions with differential terminal- link stimuli resembled Savastano and Fantino (1996), except that the terminal links in the present research appeared on the center key instead of the side key last pecked during the initial links. Conditions with a nondifferential terminal-link stimulus had not been previously examined.

As an illustration of the procedure for Experiment 2, suppose the pigeon was presented with a vertical line on the left side key and a horizontal line on the right side key. In this case, the initial link of chain 1 was in effect on the left key, and of chain 2, on the right key. As in Experiment 1, if a response satisfied an initial-link schedule, both side keys went dark and the center key was illuminated. During differential conditions the center key was red if the terminal link of chain 1 was in effect, or green if the terminal link of chain 2 was in effect. During nondifferential conditions, a triangle was projected on the center key, regardless of which terminal link was in effect. When the center key was illuminated, further responding produced food according to the terminal-link schedule in effect, after which the initial links were reinstated. When the initial-link stimuli reappeared, randomly half the time a vertical line was again on the left key and a horizontal line was again on the right. For the other half, a vertical line was on the right key and a horizontal line was on the left.

Now suppose a vertical line was on the right key and a horizontal line was on the left. In this case, the initial link of chain 1 was in effect on the right key, and of chain 2, on the left key. If a response satisfied an initial-link schedule, the side keys went dark and the appropriate terminal-link stimulus appeared on the center key, as described above (during differential conditions: red if chain 1, green if chain 2; during nondifferential conditions: triangle). Terminal-link responding produced food, after which the initial links were reinstated, as described above.

As in Experiment 1, the pigeons were again presented across conditions with a choice between chain VI 30 s FI 10 s and chain VI 30 s FI 20 s (equal initial links), and between chain VI 20 s FI 10 s and VI 10 s FI 20 s (unequal initial links), with differential or nondifferential terminal-link stimuli. Control conditions comparable to those of Experiment 1 were added at the end of these comparisons.

Table 2 presents the details of the training conditions for the pigeons in Experiment 2, according to the same format as Table 1.

Results and Discussion

Figure 6 presents the choice proportions in favor of chain VI 30 s FI 10 s when pitted against chain VI 30 s FI 20 s using the procedure of Experiment 2. The data are presented for each pigeon, when the terminal-link stimuli were differential (Diff) and nondifferential (Non), and are averages of the data from the individual conditions in Table 2. The data are consistent with those of Experiment 1: The average choice proportions indicate substantial preference for chain VI 30 s FI 10 s for all pigeons with differential stimuli in all determinations, but indifference with nondifferential stimuli. Table 2 shows that as in Experiment 1, absolute rate of initial-link responding was faster with differential than nondifferential terminal-link stimuli.

Figure 7 presents the choice proportions in favor of chain VI 20 s FI 10 s when pitted against chain VI 10 s FI 20 s using the procedure of Experiment 2. The data are presented for each pigeon, when the terminal-link stimuli were differential (Diff) and nondifferential (Non), and are averages of data

Table 2

Data for each pigeon in each condition of Experiment 2

Pigeon: B-22

Condition	Schedule	Order	Sessions	Term: Diff/Non	Resp/min: Initial	Resp/min: Term-1	Resp/min: Term-2	C. P.
2.1	1: chain VI 30 s FI 10 s	1	17	Diff	69	181		.92 (.02)
	2: chain VI 30 s FI 20 s				6	116	x	
2.2	1: chain VI 30 s FI 20 s	2	21	Diff	5	145	x	.07 (.03)
	2: chain VI 30 s FI 10 s				64	181		
2.3	1: chain VI 30 s FI 10 s	3	29	Non	22	110		.46 (.08)
	2: chain VI 30 s FI 20 s				26	149	x	
2.4	1: chain VI 30 s FI 20 s	4	22	Non	24	94	x	.47 (.03)
	2: chain VI 30 s FI 10 s				27	92		
2.5	1: chain VI 20 s FI 10 s	13	17	Non	10	54		.33 (.05)
	2: chain VI 10 s FI 20 s				20	41	128	
2.6	1: chain VI 10 s FI 20 s	14	24	Non	23	55	137	.66 (.05)
	2: chain VI 20 s FI 10 s				12	64		
2.7	1: chain VI 10 s FI 20 s	15	21	Diff	7	12	118	.16 (.04)
	2: chain VI 20 s FI 10 s				38	63		
2.8	1: chain VI 20 s FI 10 s	16	20	Diff	52	104		.85 (.05)
	2: chain VI 10 s FI 20 s				9	9	119	

Pigeon: B-29

Condition	Schedule	Order	Sessions	Term: Diff/Non	Resp/min: Initial	Resp/min: Term-1	Resp/min: Term-2	C. P.
2.1	1: chain VI 30 s FI 10 s	1	18	Diff	102	161		.99 (.01)
	2: chain VI 30 s FI 20 s				1	188	x	
2.2	1: chain VI 30 s FI 20 s	2	20	Diff	15	172	x	.21 (.05)
	2: chain VI 30 s FI 10 s				55	129		
2.3	1: chain VI 30 s FI 20 s	3	28	Non	50	138	x	.55 (.02)
	2: chain VI 30 s FI 10 s				40	137		
2.4	1: chain VI 30 s FI 10 s	4	27	Non	39	110		.54 (.03)
	2: chain VI 30 s FI 20 s				33	129	84	
2.5	1: chain VI 20 s FI 10 s	13	15	Diff	119	129		.96 (.01)
	2: chain VI 10 s FI 20 s				5	8	180	
2.6	1: chain VI 10 s FI 20 s	14	25	Diff	6	8	57	.09 (.03)
	2: chain VI 20 s FI 10 s				60	54		
2.7	1: chain VI 10 s FI 20 s	15	18	Non	15	76	70	.65 (.04)
	2: chain VI 20 s FI 10 s				8	77		
2.8	1: chain VI 20 s FI 10 s	16	22	Non	14	64		.58 (.04)
	2: chain VI 10 s FI 20 s				10	68	95	
2.9	1: chain VI 90 s FI 20 s	17	15	Diff	11	31	136	.38 (.04)
(fixed)	2: chain VI 20 s FI 20 s				18	4	104	
2.10	1: chain VI 20 s FI 20 s	18	15	Non	29	2	47	.83 (.03)
	2: chain VI 90 s FI 20 s				6	1	65	

Table 2

(Continued)

Pigeon: B-35

Condition	Schedule	Order	Sessions	Term: Diff/ Non	Resp/ min: Initial	Resp/min: Term-1	Resp/min: Term-2	C. P.
2.1	1: chain VI 30 s FI 10 s	1	18	Diff	42	81		.88 (.08)
	2: chain VI 30 s FI 20 s				6	95	x	
2.2	1: chain VI 30 s FI 20 s	2	22	Diff	3	126	x	.08 (.04)
	2: chain VI 30 s FI 10 s				37	142		
2.3	1: chain VI 30 s FI 20 s	3	30	Non	20	98	x	.50 (.05)
	2: chain VI 30 s FI 10 s				20	90		
2.4	1: chain VI 30 s FI 10 s	4	15	Non	21	60		.44 (.08)
	2: chain VI 30 s FI 20 s				27	41	89	
2.5	1: chain VI 20 s FI 10 s	9	15	Diff	109	77		.98 (.02)
	2: chain VI 10 s FI 20 s				2	55	165	
2.6	1: chain VI 10 s FI 20 s	10	19	Diff	4	27	85	.05 (.02)
	2: chain VI 20 s FI 10 s				70	98		
2.7	1: chain VI 10 s FI 20 s	11	20	Non	28	63	83	.48 (.06)
	2: chain VI 20 s FI 10 s				30	82		
2.8	1: chain VI 20 s FI 10 s	12	21	Non	14	64		.34 (.07)
	2: chain VI 10 s FI 20 s				27	49	89	
2.9	1: chain VI 10 s FI 20 s	13	19	Non	23	66	128	.68 (.11)
	2: chain VI 20 s FI 10 s				11	75		
2.10	1: chain VI 90 s FI 20 s	22	15	Non	7	9	65	.33 (.05)
	2: chain VI 20 s FI 20 s				14	9	65	

Pigeon: B-46

Condition	Schedule	Order	Sessions	Term: Diff/ Non	Resp/ min: Initial	Resp/min: Term-1	Resp/min: Term-2	C. P.
2.1	1: chain VI 30 s FI 10 s	1	18	Diff	61	112		.92 (.02)
	2: chain VI 30 s FI 20 s				5	143	x	
2.2	1: chain VI 30 s FI 20 s	2	20	Diff	15	95	x	.20 (.01)
	2: chain VI 30 s FI 10 s				61	137		
2.3	1: chain VI 30 s FI 10 s	3	30	Non	38	50		.49 (.02)
	2: chain VI 30 s FI 20 s				39	53	x	
2.4	1: chain VI 30 s FI 20 s	4	15	Non	40	39	59	.54 (.02)
	2: chain VI 30 s FI 10 s				34	65		
2.5	1: chain VI 20 s FI 10 s	13	25	Diff	66	70		.86 (.03)
	2: chain VI 10 s FI 20 s				11	18	64	
2.6	1: chain VI 10 s FI 20 s	14	30	Diff	26	32	128	.33 (.06)
	2: chain VI 20 s FI 10 s				54	155		
2.7	1: chain VI 10 s FI 20 s	15	16	Non	40	41	92	.59 (.03)
	2: chain VI 20 s FI 10 s				28	57		
2.8	1: chain VI 20 s FI 10 s	16	17	Non	27	58		.34 (.05)
	2: chain VI 10 s FI 20 s				52	39	80	
2.9	1: chain VI 10 s FI 20 s	17	15	Diff	39	41	114	.60 (.02)
(fixed)	2: chain VI 20 s FI 20				26	81	133	
2.10	1: chain VI 90 s FI 20 s	18	17	Diff	15	63	126	.27 (.03)
	2: chain VI 20 s FI 20 s				41	63	137	

Note. See Table 1 note. The X in a term-2 cell indicates responses per min were not separated for first and second half of the FI 20 s schedule, and are listed for the entire schedule under term-1.

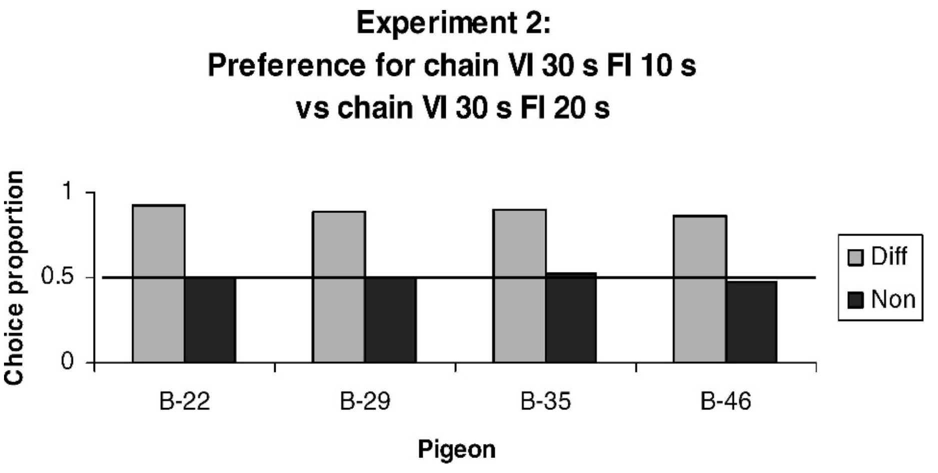

Fig. 6. The choice proportions in favor of chain VI 30 s FI 10 s when pitted against chain VI 30 s FI 20 s using the procedure of Experiment 2 (equal initial links). The data are presented for each pigeon, when the terminal-link stimuli were differential (Diff) and nondifferential (Non), and are averages of the data from the individual conditions reported in Table 2.

from the individual conditions in Table 2. The average choice proportions indicate substantial preference for chain VI 20 s FI 10 s with differential stimuli in all determinations. However, B-22, B-35, and B-46 now reversed and preferred chain VI 10 s FI 20 s with a nondifferential stimulus. Readers may recall that in Experiment 1, B-46 had previously evidenced a slight preference for chain VI 10 s FI 20 s. However, the choice proportion of B-29 remained in the range of indifference in Experiment 2, as it had in Experiment 1. Table 2 shows the reversal of preference, in favor of chain VI 10 s FI 20 s, in six of eight determinations—the exception is B-29. The preferences here were larger than that noted for B-46 in Experiment 1 that had also reversed.

Figure 8 presents terminal-link response rates from conditions in Experiment 2 with equal initial links. The data are presented for each pigeon, when the terminal-link stimuli were differential (top panel) and nondifferential (bottom panel), and are the averages of the data from the individual conditions in Table 2. The data with differential stimuli from the first and second halves of the FI 20-s terminal link are not separated, and are simply reported under a heading of the first half of the schedule. Responding was rapid on both FI 10-s and FI 20-s schedules with differential stimuli, with B-22 responding faster on the FI 10 s schedule, B-29 responding faster on the FI 20-s schedule, and B-35 and B-46 about the same on each schedule. With a nondifferential stimulus, rates of responding on the FI 10-s and first half of the FI 20-s schedule tended to be similar, and responding was slower on the FI 10-s schedule than on the second half of the FI 20-s schedule for all but B-46. The data with a nondifferential stimulus indicate that there was some discrimination relating to the terminal-link schedules.

Figure 9 presents terminal-link response rates from conditions in Experiment 2 with unequal initial links. The data are presented for each pigeon when the terminal-link stimuli were differential (top panel) and nondifferential (bottom panel), and are the averages of the data from the individual conditions in Table 2. The data with differential stimuli show the absolute rate of terminal-link responding was again slower in the first half than in the second half of the FI 20-s terminal-link schedule in all cases. Response rate was also slower in the FI 10-s terminal link than in the second half of the FI 20-s terminal link for all but B-46. The data with differential stimuli indicate a clear discrimination relating to the terminal-link schedules. The data with a nondifferential terminal-link stimulus show slower responding in the first half of the FI 20-s schedule than in the second half. Responding is also slower in the first half of the

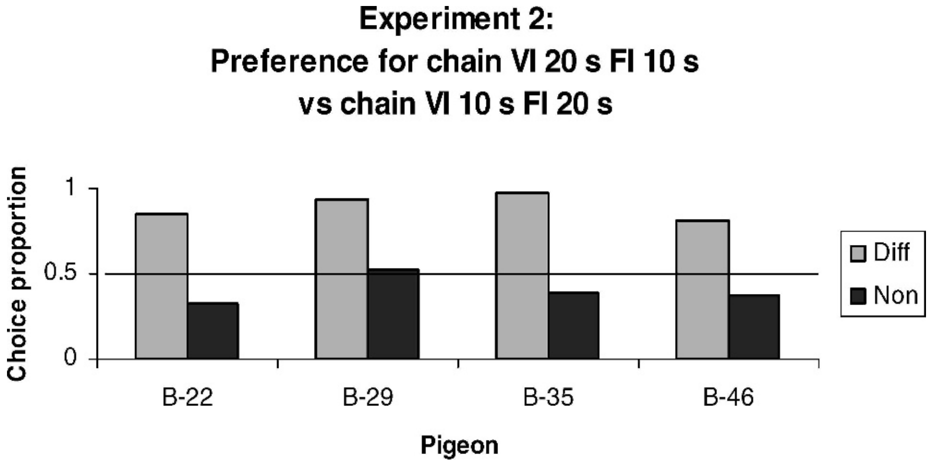

Fig. 7. The choice proportions in favor of chain VI 20 s FI 10 s when pitted against chain VI 10 s FI 20 s using the procedure of Experiment 2 (unequal initial links). The data are presented for each pigeon, when the terminal-link stimuli were differential (Diff) and nondifferential (Non), and are averages of the data from the individual conditions reported in Table 2.

FI 20-s schedule than in the FI 10-s schedule for all but B-29. These data indicate less discrimination relating to the terminal-link schedules than with differential stimuli, but some discrimination nonetheless.

In control conditions of Experiment 2, Table 2 shows that with a fixed locus of the initial links and differential terminal-link stimuli, B-29 preferred chain VI 20 s FI 20 s to chain VI 90 s FI 20 s (condition 2.9), as would be expected. When the initial-link stimuli again randomly alternated on the keys and the terminal-link stimulus was nondifferential, B-29 then preferred chain VI 20 s FI 20 s over chain VI 90 s FI 20 s (condition 2.10). Pigeon B-35 similarly preferred chain VI 20 s FI 20 s to chain VI 90 s FI 20 s with random alternation of the initial links and a nondifferential terminal-link stimulus (condition 2.10). Pigeon B-46 preferred chain VI 10 s FI 20 s to chain VI 20 s FI 20 s with fixed locus of the initial links and differential terminal-link stimuli (condition 2.9), showing its sensitivity in the conventional procedure to relative size of the initial links. Pigeon B-46 then preferred chain VI 20 s FI 20 s to chain VI 90 s FI 20 s when the randomly alternating locus of the initial links was reinstated, with differential terminal-link stimuli (condition 2.10). As in Experiment 1, the pigeons' preferences for the shorter initial link with equal terminal links in these conditions replicated Alsop, Stewart, and Honig (1994).

Overall, the findings of Experiment 2 confirm and extend those of Experiment 1. The one difference between Experiments 1 and 2 is that 3 of 4 pigeons now preferred chain VI 10 s FI 20 s to chain VI 20 s FI 10 s with a nondifferential terminal-link stimulus, instead of 1 of 4.

GENERAL DISCUSSION

The present two experiments used pigeons in a three-key operant chamber and varied procedural features pertaining to both initial and terminal links of concurrent chains. Each experiment used a different way of randomly alternating the initial links on the side keys during a session, and both equal and unequal initial-link schedules were employed. The terminal links always appeared on the center key, with either differential or nondifferential stimuli across conditions. The research was designed to better understand the contributions to preference made by initial-link spatial cues, terminal-link spatial cues, delayed primary reinforcement, and conditioned reinforcement.

The random alternation of the locus of the initial links and the use of the center key for the terminal links meant that, unlike the conventional two-key procedure, the left or right locus of responding in either initial or terminal links was not correlated with a delayed primary reinforcer. In addition, the use of differential

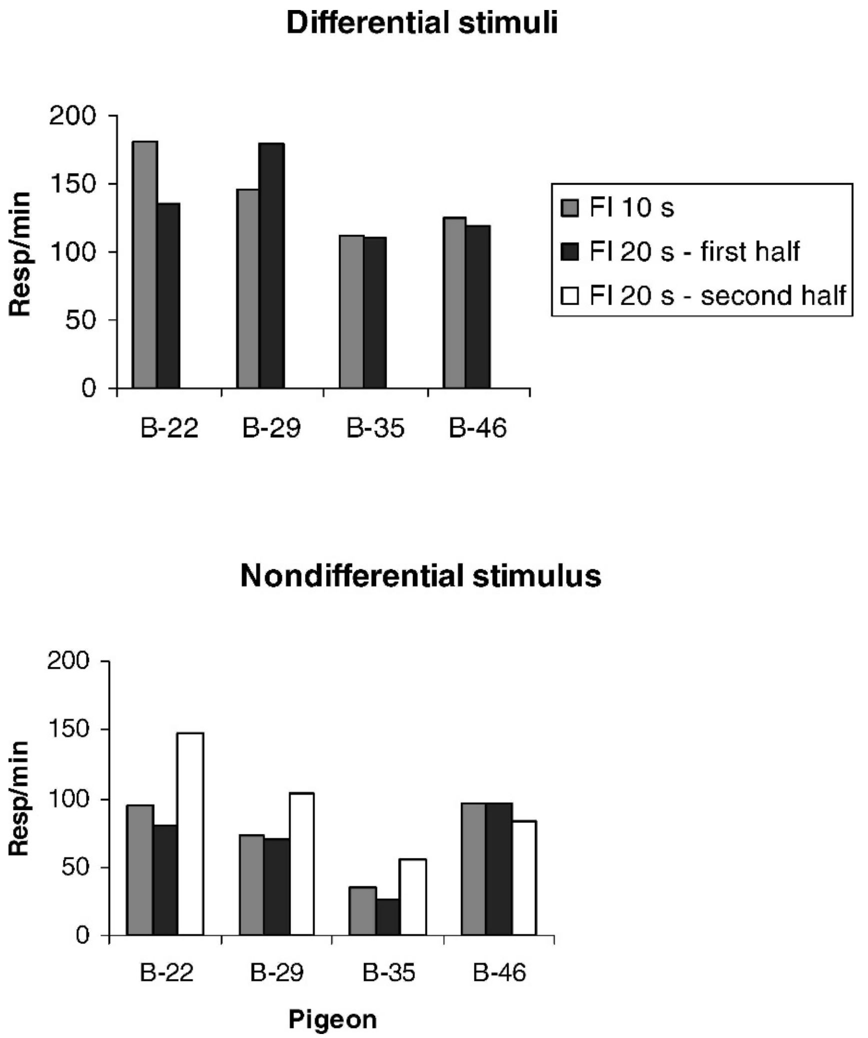

Fig. 8. Terminal-link response rates in Experiment 2 from conditions with equal VI 30-s initial links. The figure shows the rates of responding in the FI 10 s terminal link, and in the first and second halves of the FI 20 s terminal link, with differential stimuli (top panel) and a nondifferential stimulus (bottom panel) in the terminal links. The data are presented for each pigeon, and are averages of the individual conditions in Table 2.

and nondifferential terminal-link stimuli meant that any control by conditioned reinforcement versus delayed primary reinforcement could be more readily assessed, given that spatial cues in both initial and terminal links had been neutralized. As outlined in the Introduction, previous experiments had varied some of these features, but none had varied all.

Both of the present experiments found that with equal initial links and differential stimuli during the terminal links, the pigeons reliably preferred the FI 10-s to the FI 20-s terminal link. These results confirmed and extended the findings of Cerutti and Catania (1986), Grace (1995), and Savastano and Fantino (1996), although the procedures of the latter two studies differed in certain respects from those of the present research. In addition, both of the present experiments found that with equal initial links and a nondifferential stimulus during the terminal links, none of the formerly observed preferences continued. Rather, both experiments found that the pigeons were indifferent.

Both of the present experiments further found that with unequal initial links and differential

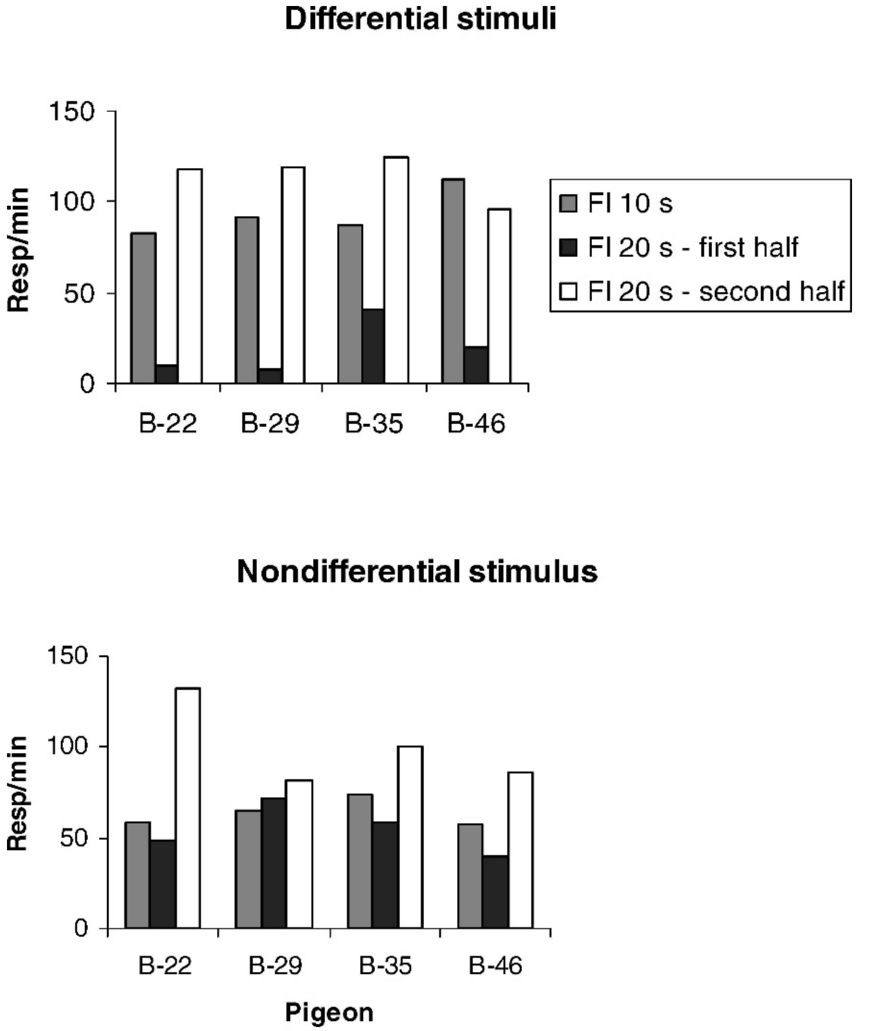

Fig. 9. Terminal-link response rates in Experiment 2 from conditions with unequal initial links. The figure shows the rates of responding in the FI 10 s terminal link, and in the first and second halves of the FI 20 s terminal link, with differential stimuli (top panel) and a nondifferential stimulus (bottom panel) in the terminal links. The data are presented for each pigeon, and are averages of the individual conditions in Table 2.

stimuli during the terminal links, the pigeons again preferred the FI 10-s terminal link. As noted earlier, the preference for a chain with a longer initial link followed by a shorter terminal link replicated Fantino (1969), who used the conventional concurrent-chains procedure.

However, both of the present experiments found that with unequal initial links and a nondifferential stimulus during the terminal links, none of the formerly observed preferences continued. Experiment 1 found that 1 pigeon reversed and actually preferred chain VI 10 s FI 20 s, while the remaining 3 pigeons were indifferent. Experiment 2 found that 3 pigeons reversed and actually preferred chain VI 10 s FI 20 s, while 1 was indifferent.

More now needs to be said about the present failures to maintain previous preferences when terminal-link stimuli were nondifferential. One explanation is that with the randomly reversing initial links and the use of the center key for the terminal links, neither spatial cues during initial links nor spatial or visual cues during terminal links nor delayed primary reinforcement provided the basis for the continued control of choice by the shorter terminal link. This possibility can be understood as an implication of a personal communication from Mazur cited in Williams and Dunn (1991, p. 43), to the effect that subjects can become ''confused'' when the same stimulus (e.g., in what amounted to a terminal link in Williams and Dunn) is correlated with different events. Noteworthy is that Williams and Dunn argued against this interpretation of their results. In any event, given the parameters employed here, and with equal initial links, it appears the present procedure in effect undermined the discrimination of the schedules, with indifference the result. Indeed, readers will note that Navarick and Fantino (1976) found their pigeons readily demonstrated a preference for the shorter of two terminal-link FI schedules or the larger of two amounts of food when differential terminal-link stimuli were used. However, their pigeons were indifferent in these same choices when both terminal links were signaled by blackout, a common stimulus milieu that presumably made the terminal links less discriminable.

Following from Mazur's communication in Williams and Dunn (1991) and such other results as Navarick and Fantino (1976), one explanation for at least some of the present outcomes with nondifferential stimuli in the terminal links is that the terminal links became something like FI X s, where 10 s $<$ X $<$ 20 s. In the case of equal initial links, the randomly reversing procedures and nondifferential terminal-link stimuli on a center key may have rendered the two schedules indiscriminable at some intermediate value resulting in indifference. In the case of the reversals with the unequal initial links, the present procedure may have devolved to something like a choice between chain VI 10 s FI X s and chain VI 20 s FI X s. Since the initial links were now explicitly unequal and the terminal links were not readily discriminable from spatial or visual cues, control for these pigeons might then be exerted by whichever chain had the shorter initial link. It may be that the procedure of Experiment 2 was better at producing this state of affairs than that of Experiment 1, since preference reversed more often. Readers will note that in control conditions of the present research, B-29 and B-35 both preferred chain VI 20 s FI 20 s to chain VI 90 s FI 20 s with a nondifferential terminal-link stimulus, showing that control can be exerted by the shorter of two initial links when terminal links are explicitly equated, although the degree of control appears much less than that exerted by the shorter of two terminal links, given differential terminal-link stimuli (see Alsop, Stewart, & Honig, 1994, for comparable results).

Analysis of absolute rates of terminal-link responding yields some support for the possibility suggested above. As noted earlier in the present report, when responding during the first half of the FI 20 s terminal link was compared with the second half and with the FI 10 s terminal link, responding was generally more similar with nondifferential than with differential stimuli. This outcome is what would be expected if the terminal links had become functionally similar or if the pigeons had become ''confused.''

However, the support mentioned above is not unequivocal, as there still was some degree of discrimination, such that rate of responding with a nondifferential stimulus was still slower on average during the first half of the FI 20-s terminal link as compared with the second half and as compared with the FI 10-s terminal link. If the terminal links had become altogether similar, the question remains as to why absolute rates of terminal link responding would still differ. When B-22, B-35, and B-46 reversed their preferences in Experiment 2, they nevertheless had some degree of discrimination of the terminal-link schedules, whereas B-29, which did not reverse its preference, had less discrimination. Presumably, this outcome is exactly the opposite of what would be expected if the terminal links had become functionally similar for these pigeons.

Whether some form of more local discrimination was taking place also is not clear. According to this sense of discrimination, subjects might respond rapidly for some short period of time after the onset of a terminal link, and if a reinforcer was not produced, respond even more rapidly until a reinforcer was produced. Again, Alsop, Stewart, and Honig (1994) found that even with a nondifferential terminal-link stimulus, absolute rate of responding increased during successive bins of the longer FI terminal link, but was still generally slower than during the shorter terminal link, although again they did not randomly alternate the locus of the initial links. Alsop et al. also found that the 1 pigeon that was indifferent in their study did respond faster on the shorter FI terminal links. Noteworthy is that after finding a less definitive difference between responding in short and long terminal links with a nondifferential stimulus in their study, Williams and Fantino (1978) concluded that ''The mechanism by which preference was maintained, or modulated, in the absence of terminal-link discrimination remains unclear'' (pp. 85-86). Further, it is also unclear which prior experiences are responsible for whatever preference might develop with unequal initial links and a nondifferential terminal-link stimulus, as not all pigeons evidenced a preference in all conditions of the present research.

As mentioned in the Introduction, the present data speak to both methodological and theoretical issues. Regarding methodological issues, the data confirm that the present procedures, derived from earlier research reviewed in the Introduction, are a useful means for examining choice. In particular, they avoid the necessity of many time-consuming conditions involving a baseline determination followed by one or more sequential reversals, sometimes necessary to rule out position bias in the interpretation of the results. In the variations of the procedure used here and previously, the reversals are conducted within the same session, and any troublesome effect of position bias can be circumvented in just the one condition. Overall, the initial-link procedures in the two experiments appear to be roughly equivalent. The only difference is that the procedure of Experiment 2 produced more reversals of preference with unequal initial links and a nondifferential terminal-link stimulus than did that of Experiment 1.

Regarding theoretical issues, the present data speak to the enduring question of how much does conditioned reinforcement contribute to responding in concurrent chains. As is well known, in any chain schedule, ostensible conditioned reinforcing effects are difficult to dissociate from discriminative effects of stimuli, as well as from effects that could simply be a function of delayed primary reinforcement. This difficulty has led some analysts to conclude that conditioned reinforcement plays virtually no role in the control of choice behavior, if indeed conditioned reinforcement can be said to exist at all (see discussion of this point in Williams & Dunn, 1991).

The present procedural variations meant that delayed primary reinforcement could not contribute to discriminative control over choice exerted by differential spatial cues associated with initial and terminal links. A comparison of preferences with differential and nondifferential terminal-link stimuli then permitted a relatively uncomplicated assessment of conditioned reinforcement versus simply delayed primary reinforcement in the control of choice. As reviewed in the Introduction, if the preferences were the same with nondifferential as with differential terminal-link stimuli, then delayed primary reinforcement is the relevant variable, and conditioned reinforcement plays no role. If preferences were lower with nondifferential than with differential stimuli, then conditioned reinforcement is implicated. The present research found that preferences were indeed lower, tending at least toward indifference if not a reversal when compared with differential stimuli. These data implicate a conditioned reinforcement interpretation. This interpretation is further supported by the higher absolute rate of initial-link responding when terminal-link stimuli were differential rather than nondifferential. Similar effects on both absolute and relative rate of initial-link responding have long been noted in studies more directly concerned with the ''informativeness'' of terminal-link stimuli (e.g., Moore, 1976, 1985). The data clearly suggest that if there are spatial cues and differential stimuli, then preference will reliably emerge, as in conventional procedures. If one of these features is absent, then control may be exerted by the other, although typically that control will be weaker. If both of the features are absent, it appears that terminal-link schedule parameters exert their former control of behavior only with great difficulty, if at all.

A final point is that analyses of choice in concurrent chains have often assumed that behavior is controlled by either one factor or the other—by either delayed primary reinforcement or conditioned reinforcement, and the two possibilities as they are formulated are exhaustive and mutually exclusive. Analyses have often further assumed that if one factor can be negated, the other is automatically implicated. At issue is whether the two factors are in fact exhaustive and mutually exclusive. This stance may be said to involve a false assumption and the fallacy of the ''excluded middle.'' The middle that is excluded in this case is that the effects of delayed primary reinforcement are exerted through greater or lesser degrees of conditioned reinforcement. After all, when reinforcement is delayed after a response, some stimuli are present during that delay period. The degree of control exerted by those stimuli may then differ, depending on the nature of the stimuli and the events during the delay period with which the stimuli are correlated. This middle position now appears quite reasonable.

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