JOURNAL OF THE EXPERIMENTAL ANALYSIS OF BEHAVIOR 1990, 53, 219-234 NUMBER 2 (MARCH)

SUBOPTIMAL CHOICE IN A PERCENTAGE-REINFORCEMENT PROCEDURE: EFFECTS OF SIGNAL CONDITION AND TERMINAL-LINK LENGTH

MARCIA L. SPETCH, TERRY W. BELKE, ROBERT C. BARNET, ROGER DUNN, AND W. DAVID PIERCE[1]

UNIVERSITY OF ALBERTA AND SAN DIEGO STATE UNIVERSITY

Pigeons' choice between reliable (100%) and unreliable (50%) reinforcement was studied using a concurrent-chains procedure. Initial links were fixed-ratio 1 schedules, and terminal links were equal fixed-time schedules. The duration of the terminal links was varied across conditions. The terminal link on the reliable side always ended in food; the terminal link on the unreliable side ended with food 50% of the time and otherwise with blackout. Different stimuli present during the 50% terminal links signaled food or blackout outcomes under signaled conditions but were uncorrelated with outcomes under unsignaled conditions. In signaled conditions, most pigeons displayed a nearly exclusive preference for the 100% alternative when terminal links were short (5 or 10 s), but with terminal links of 30 s or longer, preference for the 100% alternative was sharply reduced (often to below .5). In unsignaled conditions, most pigeons showed extreme preference for the 100% alternative with either short (5 s) or longer (30 s) terminal links. Thus, pigeons' choice between reliable and unreliable reinforcement is influenced by both the signal conditions on the unreliable alternative and the duration of the terminal-link delay. With a long delay and signaled outcomes, many pigeons display a suboptimal tendency to choose the unreliable side.

Key words: choice, percentage reinforcement, signaled outcomes, conditioned reinforcement, delay-reduction hypothesis, risk, concurrent chains, key peck, pigeons

The concurrent-chains procedure has been used extensively for the experimental analysis of choice behavior (e.g., Autor, 1969; Fantino, 1969, 1977). In one variation of this procedure, the probability of obtaining reinforcement at the end of the terminal link differs for the alternative chains (e.g., Spetch & Dunn, 1987). Typically, the chains terminate with either food reinforcement or blackout, and one alternative provides a higher percentage of reinforcement than the other alternative. With all other schedule parameters equal for the two alternatives, this procedure allows investigation of an organism's choice between reliable and unreliable reinforcement. One important variable in percentage-reinforcement procedures is the correlation between terminal-link stimuli and outcomes. In signaled procedures (also known as correlated or multiple procedures), stimuli present during the terminal links differentially signal whether a food or a blackout outcome will occur. In unsignaled procedures (also known as uncorrelated or mixed procedures), the terminal-link stimuli do not differentially signal outcomes.

In unsignaled procedures, the typical finding is that pigeons tend to choose an alternative associated with a higher percentage of reinforcement over one associated with a lower percentage of reinforcement (e.g., Fantino, Dunn, & Meck, 1979; Kendall, 1974, 1985; Menlove, Inden, & Madden, 1979; Schneider, 1968; Spetch & Dunn, 1987). Spetch and Dunn recently investigated the generality of this preference by manipulating the initial-link and terminal-link schedules across a range of values. They found that pigeons reliably showed a preference for 100% over 33% reinforcement, but the level of this preference increased systematically with increases in terminal-link duration and decreased systematically with in-

[1] Roger Dunn is at San Diego State University; all others are affiliated with the University of Alberta. This research was supported by a Natural Sciences and Engineering Research Council of Canada operating grant (OGP0038861) held by M. Spetch and by an NIMH grant (MH 40853) to San Diego State University. Smit Sinha and Linda Scharr provided assistance with testing subjects. Terry Belke is now at the Department of Psychology, Harvard University, and Robert Barnet is now at the Department of Psychology, State University of New York at Binghamton. Correspondence and reprint requests should be addressed to M. Spetch, Department of Psychology, University of Alberta, Edmonton, Alberta T6G 2E9, Canada (Bitnet: USERSRAM@UALTAMTS).

creases in the initial-link duration. These trends were consistent with the delay-reduction hypothesis (Fantino, 1969, 1981) as modified by Spetch and Dunn to deal with unsignaled percentage reinforcement. Thus, the generality of preference for higher percentages of reinforcement in unsignaled procedures seems to be firmly established, and results obtained with these procedures may be described by the delay-reduction model of choice.

In signaled percentage-reinforcement procedures, however, preference for higher percentages of reinforcement does not always occur. In fact, an opposite preference has been reported. Kendall (1974) investigated pigeons' choice for 100% versus 50% reinforcement using a signaled concurrent-chains percentage-reinforcement procedure with fixed-ratio (FR) 1 schedules in the initial links. Under these conditions, choice of the 50% alternative reduces the overall rate of reinforcement that can be obtained and therefore is suboptimal from a molar maximizing perspective. Yet Kendall reported that pigeons preferred the alternative that provided 50% reinforcement over the one that provided 100% reinforcement. This counterintuitive preference for the lower percentage-reinforcement alternative was shown only with the signaled procedure; when outcomes were not differentially signaled by the terminal-link stimuli, the pigeons displayed extreme preference for the higher percentage-reinforcement alternative.

Kendall's (1974) findings were challenged by Fantino et al. (1979) because, in the procedure used by Kendall (1974), both initial-link keys were darkened and the key on the alternative that was not chosen remained dark during the terminal-link component. Fantino et al. attempted to replicate Kendall's findings within a more traditional procedure in which both initial-link stimuli were illuminated, but found no consistent preference for alternatives providing lower percentages of reinforcement. However, it should be noted that the initial-link parameters they used were not exactly the same as those used in Kendall's (1974) study. In a recent replication with illuminated initial-link stimuli, Kendall (1985) again reported that, with a signaled procedure, preference for an alternative providing a lower percentage of reinforcement tended to emerge. Kendall (1985) also reported that this preference tended to be most extreme in conditions with short initial links and longer terminal links.

Dunn and Spetch (1990) have recently reported evidence consistent with Kendall's (1974, 1985) findings. In their studies, pigeons showed a very reduced preference for the higher percentage-reinforcement alternative in signaled procedures compared to unsignaled procedures. The duration of the initial links was varied systematically in the signaled procedure, and preference for the higher percentage-reinforcement alternative was found to vary directly with initial-link duration. Moreover, with FR 1 schedules in the initial links, 3 of 5 birds displayed a preference for the lower percentage-reinforcement alternative.

Dunn and Spetch (1990) have offered an interpretation of these results in terms of conditioned-reinforcement effects due to local reductions in delay (cf. Fantino, 1977). They proposed that a terminal-link stimulus may function as a conditioned reinforcer only when its onset signals a reduction in delay over that signaled by other stimuli in the local context of that alternative. With FR 1 initial links, onset of the terminal-link stimulus on the 100% alternative should not function as a conditioned reinforcer because it does not signal a reduction in delay over that signaled by the initial-link peck that produced it. Similarly, onset of a terminal-link stimulus on a 50% alternative in unsignaled procedures also does not signal a delay reduction. However, in signaled procedures, onset of the positive terminal-link stimulus on the 50% alternative does signal a reduction of delay over that signaled by the initial-link peck and therefore should function as a conditioned reinforcer.

Dunn and Spetch (1990) further proposed that choice behavior in these procedures is controlled by both conditioned reinforcement and delayed primary reinforcement. In unsignaled procedures, conditioned reinforcement does not favor either alternative differentially, but primary reinforcement favors the more reliable alternative. Therefore consistent preference for higher percentage-reinforcement alternatives should occur in unsignaled procedures. In signaled procedures, however, conditioned reinforcement favors the less reliable alternative (particularly when FR 1 schedules are used), whereas delayed primary reinforcement favors the higher percentage-reinforcement alternative.

The situation in signaled percentage-reinforcement procedures may thus be partially analogous to a self-control procedure (e.g.,

Ainslie, 1974; Fantino, 1966; Navarick & Fantino, 1976). The unreliable alternative provides an immediate conditioned reinforcer followed by an uncertain delayed primary reinforcer. The reliable alternative provides no immediate reinforcement, but the delayed primary reinforcer is certain. From this analysis, one would expect that choice between these alternatives would depend upon the duration of the delay to the primary reinforcer. That is, pigeons should be more likely to choose the unreliable alternative (i.e., the alternative that provides immediate conditioned reinforcement) when there is a long delay to primary reinforcement. Increasing the terminal-link duration should therefore decrease preference for the reliable alternative.

Kendall (1985) has provided some preliminary evidence that is consistent with this prediction. As noted above, he examined the effect of terminal-link delay on the choice of 2 pigeons in a signaled percentage-reinforcement procedure and found that both pigeons showed a greater tendency to choose the unreliable alternative with longer terminal-link durations. The present research was designed to extend the investigation of terminal-link duration effects.

GENERAL METHOD

Subjects

The subjects were 11 adult White King and 5 adult Silver King pigeons. The birds were maintained at 80 to 85% of their free-feeding weights with supplemental feeding in home cages when necessary. The birds were housed individually in wire-mesh cages and allowed free access to grit and water.

Apparatus

Half the birds were tested in three-key operant chambers, and the remaining birds were tested in two-key operant chambers. The pecking keys were mounted horizontally in a row approximately 20 cm above the floor in each of the chambers. Projectors mounted behind each key were used to project colored fields onto the pecking keys. The houselight was centered above the pecking keys and was directed towards the aluminum ceiling of the chamber. A grain feeder was mounted below the center pecking key of the three-key chambers. In the two-key chambers, the grain feeder was centered below the two pecking keys. Each test chamber was enclosed in a light- and sound-attenuating enclosure. Masking noise was provided by an exhaust fan in the enclosure. The presentation of events in each chamber and the recording of data were accomplished with the use of microcomputers.

Procedure

Preliminary training. For experimentally naive birds, preliminary training consisted of magazine training, followed by a few sessions with an autoshaping procedure. During autoshaping, each side key was transilluminated individually with a color field that was to serve as the initial-link stimulus and was paired with food presentation (i.e., 4-s access to mixed grain). Trials with each side-key stimulus occurred equally often in a randomly determined order within a session. Once pecking at both side keys had emerged, the birds were given additional training sessions in which pecks to the individually illuminated side keys were reinforced according to a continuous reinforcement schedule, until reliable pecking was observed. Following this training regimen, the birds were introduced to the concurrent-chains schedules described below.

Concurrent-chains percentage-reinforcement procedure. During the initial link of the chain, both side keys were illuminated with the same color field. A single response on either initial-link key completed the FR 1 requirement and resulted in the onset of a terminal-link schedule and a change in the color on that key; the other key became dark and inoperative. The terminal-link component ended with an outcome (i.e., a 4-s food presentation or 4-s blackout) according to a fixed-time (FT) schedule. The terminal link on one side always ended with a food outcome (100% reinforcement). The terminal link on the other side ended with food on a randomly determined half of the outcomes and blackout on the remaining outcomes (50% reinforcement). The FT values used in the terminal links varied across conditions and are described in each experiment. The stimulus conditions associated with the initial- and terminal-link components and the side associated with 100% reinforcement varied across birds and are shown in Table 1.

Signaled percentage reinforcement. In the signaled procedure, a unique terminal-link stimulus was associated with each type of outcome on each key. In the example shown in

Table 1

Initial- and terminal-link stimuli for each subject.

Bird	Initial-link (both) color	Terminal links				
		100%		50%		
		Side	Color	Side	S+ color	S− color
Experiment 1						
1	yellow	right	orange	left	red	green
2	red	right	white	left	yellow	green
3	red	right	white	left	green	orange
4	red	right	white	left	green	orange
Experiment 2						
5	yellow	left	orange	right	green	red
6	red	left	yellow	right	white	green
7	red	left	yellow	right	green	white
8	red	left	yellow	right	green	white
9	yellow	left	orange	right	green	red
10	red	left	yellow	right	white	green
11	red	left	yellow	right	green	white
12	red	left	yellow	right	green	white
Experiment 3						
13	yellow	right	orange	left	red	green
14	red	right	white	left	yellow	green
15	red	right	white	left	green	yellow
16	red	right	white	left	green	yellow

Note: Under signaled conditions, S+ terminal-link stimuli ended with reinforcement and S− terminal-link stimuli ended with blackout. Under unsignaled conditions, reinforcement and blackout occurred equally often after both S+ and S− terminal-link stimuli.

the right portion of Figure 1, responding on the right initial-link stimulus always produced illumination of a red terminal-link keylight and reliable reinforcement (100% reinforcement upon completion of the terminal link), whereas responding on the left initial-link stimulus sometimes produced illumination of a green terminal-link keylight that signaled a food outcome and sometimes produced a blue terminal-link stimulus that signaled a blackout outcome. This procedure is sometimes referred to as a multiple (e.g., Moore, 1976) or correlated (e.g., Kendall, 1974, 1985) percentage-reinforcement procedure.

Unsignaled percentage reinforcement. The unsignaled procedure was similar to the signaled procedure described above with one notable exception: The terminal-link stimuli presented on the unreliable side were not correlated with the specific outcome (food or blackout). In the example shown in the left portion of Figure 1, responding on the left initial-link stimulus produced illumination of either a green terminal-link keylight or a blue terminal-link keylight, each of which was associated with 50% reinforcement. This procedure is sometimes referred to as a mixed (e.g., Moore, 1976) or uncorrelated (e.g., Kendall, 1974, 1985) percentage-reinforcement procedure.

Whenever the signal contingencies were altered between conditions, the bird was first exposed to one forced-choice session to ensure exposure to the new terminal-link contingencies. During forced-choice sessions, only one randomly selected initial-link stimulus was presented on each cycle.

Measure of Preference

Preference for the reliable outcome (i.e., 100% reinforcement) was measured by calculating choice proportions for responses during initial links, that is, the number of responses on the initial-link stimulus on the reliable side divided by the sum of responses made on the initial-link stimuli on the reliable and unreliable side. Each condition was in effect for a given bird until the following stability criteria were satisfied: After 15 sessions (and each session thereafter until stability was reached), the choice proportions for the nine preceding sessions were divided into blocks of three sessions. Preference was considered sta-

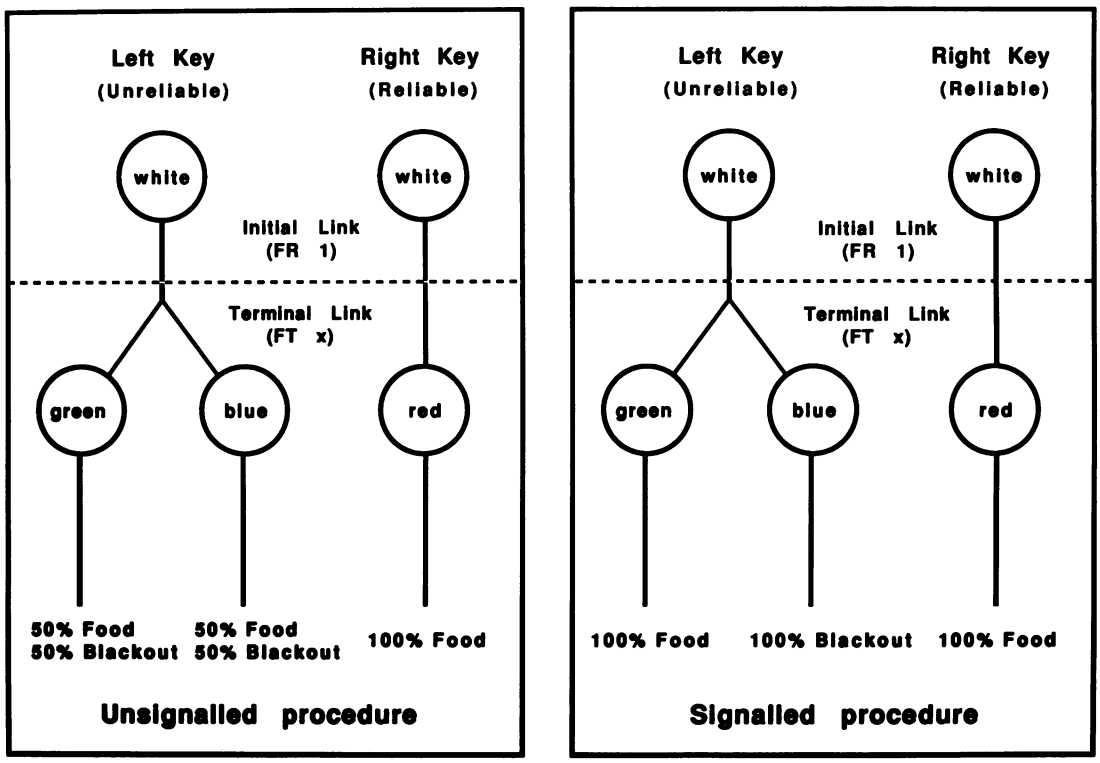

Fig. 1. Illustration of concurrent-chains percentage-reinforcement procedure. (x signifies that the FT duration varied, Unreliable = 50% reinforcement alternative, Reliable = 100% reinforcement alternative.)

ble when the block means (M) did not differ by more than ± 0.05 and showed neither an upward trend ($M1 < M2 < M3$) nor a downward trend ($M1 > M2 > M3$). All values reported are the means of the nine sessions that satisfied these stability criteria. Sessions lasted for 75 min or 61 reinforcers (whichever came first) and were usually conducted 6 days per week.

EXPERIMENT 1

The findings of Kendall (1974, 1985) and Dunn and Spetch (1990) have indicated that preference for lower percentage reinforcement in signaled concurrent-chains procedures depends on the use of short initial-link values (e.g., FR 1). Kendall's (1985) results suggested that this suboptimal preference may also depend on the use of long terminal links. Phases 1 and 3 of Experiment 1 investigate the effect of terminal-link value on preferences for lower percentage reinforcement by employing FR 1 initial links and systematically varying the terminal-link length across a range of values. Phase 2 provides a comparison of preference for reliable over unreliable reinforcement under signaled and unsignaled percentage-reinforcement procedures.

METHOD

Subjects

The subjects were 4 naive adult White King pigeons.

Procedure

Phase 1. All birds were exposed to the signaled percentage-reinforcement procedure. The terminal-link durations were varied across an exploratory range (10 s, 30 s, 50 s, and 90 s). The chain providing reinforcement on 50% of the trial outcomes was always presented on the left alternative, and the chain providing reinforcement on 100% of the trial outcomes was always presented on the right alternative. The color fields used as initial- and terminal-link stimuli varied across birds and are presented in Table 1. The order of conditions was counterbalanced such that each of the 4 birds

Table 2

Results and signal conditions from Experiment 1.

Bird	TL duration	Signal condition	C.P.	TL responses (peck/min) 100% S+	TL responses (peck/min) 50% S+	TL responses (peck/min) 50% S−	Obt % rf 50%	Obt % rf Overall	Session
1	10	sig	.99	1.04	12.00	2.00	25.00	99.46	20
	30	sig	.23	2.57	11.80	0.69	51.28	61.80	46
	90	sig	.28	1.39	2.21	0.03	49.24	63.77	31
	50	sig	.26	0.44	1.74	0.19	47.65	61.22	17
	50	unsig	.85	0.79	2.00	2.70	51.76	92.60	36
	50	sig	.31	0.57	2.94	0.75	46.03	63.39	31
	5	sig	.99	0.76	—	0.00	0.00	99.28	15
	30	sig	.42	0.79	2.51	4.44	49.28	70.80	22
2	30	sig	.29	0.52	3.80	0.10	49.77	64.28	83
	50	sig	.50	0.33	2.00	0.00	50.38	75.38	29
	10	sig	.98	0.72	12.00	0.00	24.81	98.39	16
	90	sig	.50	0.23	1.02	0.01	50.77	73.70	17
	90	unsig	.58	0.58	0.32	0.31	47.71	77.91	23
	90	sig	.30	0.23	1.02	0.02	46.44	62.33	23
	30	sig	.52	0.42	3.31	0.01	50.72	76.35	29
	5	sig	.99	0.09	18.00	0.00	50.00	99.64	15
3	50	sig	.31	0.04	0.31	0.02	51.22	66.67	26
	90	sig	.13	0.03	0.12	0.00	51.64	57.59	27
	30	sig	.15	0.00	0.27	0.10	52.67	59.98	15
	10	sig	.18	0.03	1.40	0.06	50.66	59.63	17
	10	unsig	.97	0.00	1.64	5.25	66.67	98.86	17
	10	sig	.97	0.01	2.00	2.80	43.75	98.55	15
	30	sig	.16	0.00	0.14	0.14	49.61	57.66	15
	5	sig	.45	0.68	0.30	0.06	50.32	72.36	27
4	90	sig	.50	0.39	1.45	0.52	52.36	76.24	31
	10	sig	.99	3.22	—	2.00	0.00	99.46	15
	50	sig	.60	0.37	2.23	1.09	48.80	79.49	23
	30	sig	.52	0.69	4.94	1.83	49.23	75.50	15
	30	unsig	.86	0.16	0.74	0.56	54.26	93.42	24
	30	sig	.69	0.21	3.61	0.90	53.77	85.59	29
	5	sig	.99	5.52	24.00	0.00	33.33	99.64	15
	30	sig	.66	0.33	3.35	1.17	49.40	82.88	27

Note: TL = terminal link, sig = signaled, unsig = unsignaled, C.P. = choice proportion, 100% S+ = stimulus signaling food on reliable side, 50% S+ = stimulus signaling food on unreliable side, 50% S− = stimulus signaling blackout on unreliable side, Obt % rf = obtained percentage of reinforcement. Dashes indicate that particular terminal-link stimulus was not entered.

was exposed to a different sequence of terminal-link durations. After exposure to all four terminal-link durations each bird was moved on to Phase 2.

Phase 2. Following completion of the signaled procedure in Phase 1, each bird was moved to an unsignaled condition with the same terminal-link duration as last used in Phase 1. Once preference became stable under unsignaled percentage reinforcement, each bird was returned to a signaled procedure employing the same terminal-link duration. Thus, in Phase 2, each bird was exposed to a unique terminal-link duration (i.e., 10 s, 30 s, 50 s, or 90 s), first under conditions of unsignaled percentage reinforcement and then under conditions of signaled percentage reinforcement. Once a bird reached stability on the signaled percentage-reinforcement chain in Phase 2, that bird was moved on to Phase 3.

Phase 3. All birds were tested under conditions of signaled percentage reinforcement with terminal-link durations of 5 s and 30 s. The birds were exposed to each terminal-link duration only once (until stability was reached) in a counterbalanced order. The progression of each bird through Phase 1, Phase 2, and Phase 3 is presented in Table 2.

Results

Choice proportions for the 100% side are shown as a function of terminal-link duration in Figure 2. Detailed results for each condition, in order of exposure, are shown in Table

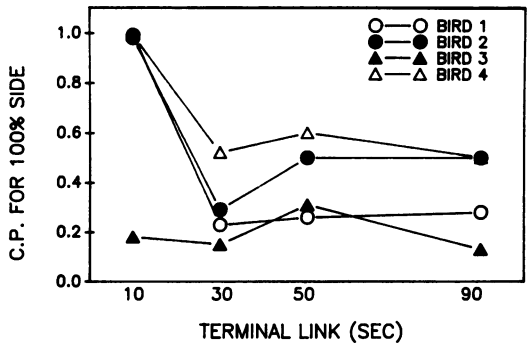

Fig. 2. Choice proportion (C.P.) for the 100% reinforcement side as a function of terminal-link duration under conditions of signaled percentage reinforcement in Phase 1 of Experiment 1.

2. During Phase 1, Birds 1, 2, and 4 showed a strong preference for the 100% side at the 10-s terminal-link duration; at longer terminal-link durations, these birds displayed a very reduced preference for the 100% side. Bird 3 showed a strong preference for the 50% side at all terminal-link durations. Preference levels did not change systematically across the terminal-link durations in the range of 30 s to 90 s.

Results from Phase 2 are presented in Figure 3. This figure also shows the choice proportions from the last condition of Phase 1. Birds 1, 2, and 4 showed an increase in preference for the 100% side when shifted to the unsignaled condition and a decrease in preference when returned to the signaled condition. Bird 3 showed an increase in preference for the 100% side when shifted to the unsignaled condition but did not show a decrease in preference when returned to the signaled condition.

Results from Phase 3 are presented in Figure 4. The finding of primary interest represented in Figure 4 is that all animals demonstrated a reduction in preference for reliable reinforcement at the 30-s terminal link relative to their preference for reliable reinforcement at the 5-s terminal link. The absolute levels of preference, however, showed considerable variability across birds. Bird 4 demonstrated a preference for reliable reinforcement at both the 5-s and the 30-s terminal links, whereas Bird 3 showed a preference for unreliable reinforcement at both terminal-link values. Birds 1 and 2 both showed extreme preference for the reliable side at the 5-s terminal link and

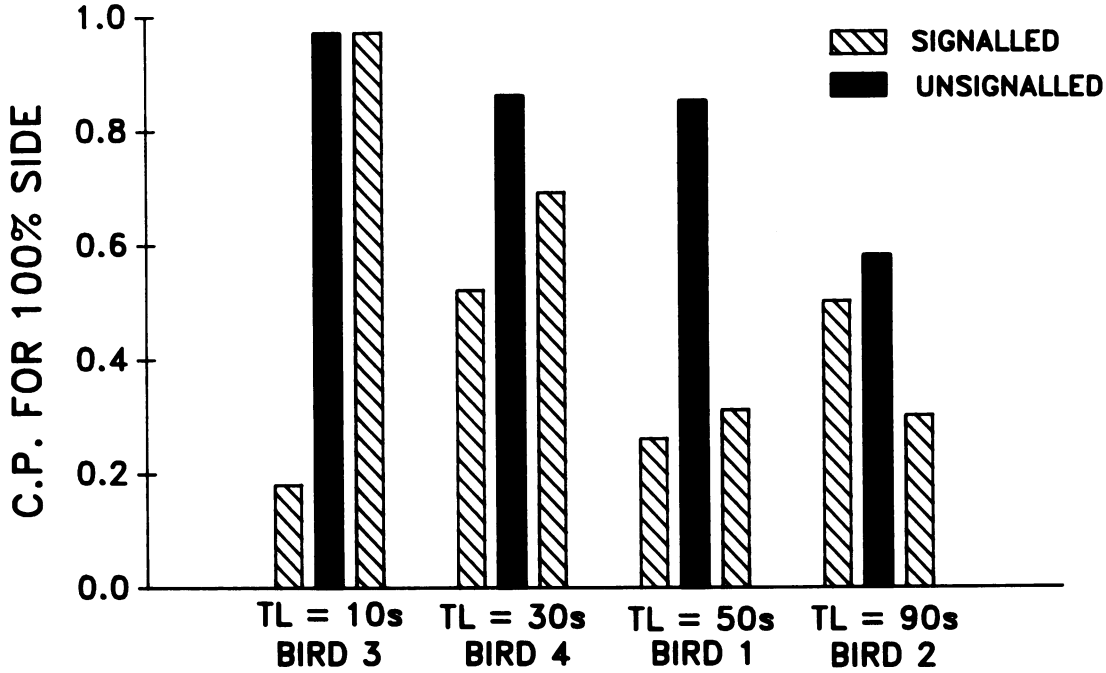

Fig. 3. Choice proportion (C.P.) for the 100% reinforcement side during the last condition in Phase 1 (signaled percentage reinforcement) and the two conditions of Phase 2 (unsignaled and then signaled percentage reinforcement) for the 4 birds in Experiment 1.

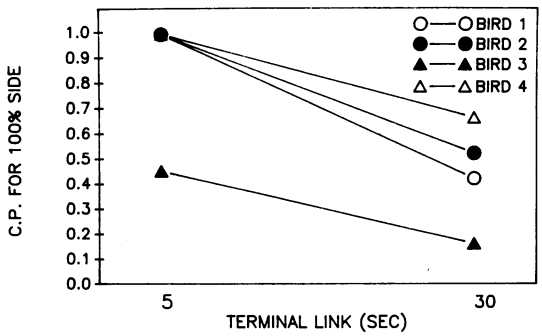

Fig. 4. Choice proportion (C.P.) for the 100% reinforcement side as a function of terminal-link duration under conditions of signaled percentage reinforcement in Phase 3 of Experiment 1.

near indifference at the 30-s terminal link. These absolute preference levels must be interpreted with caution because side or color reversals were not conducted.

Discussion

Results from Experiment 1 replicate the finding of Kendall (1974, 1985) and Dunn and Spetch (1990) that preference for unreliable reinforcement will sometimes develop under a concurrent-chains procedure employing signaled percentage reinforcement. In general, the tendency to respond on the unreliable side was greater with 30-s terminal links than it was with 5-s or 10-s terminal links. Increases in the terminal link beyond 30 s did not systematically increase the tendency to choose the unreliable side. In general, preference for the 100% side was more extreme under the unsignaled condition than under the signaled condition.

EXPERIMENT 2

The results of Experiment 1 suggested that both signal conditions and terminal-link duration affect pigeons' preference for 100% over 50% reinforcement. Experiment 2 extends the investigation of these effects with a larger group of subjects.

Method

Subjects

The subjects were 8 adult White King pigeons. All pigeons had served previously in a timing experiment that employed a delayed matching-to-sample procedure, but none had prior experience with concurrent-chains procedures.

Procedure

In this experiment the left chain provided 100% reinforcement and the right chain provided 50% reinforcement. The stimulus conditions associated with each component of these chains are presented in Table 1. Otherwise, the procedure was identical to that employed in Phase 3 of Experiment 1, but with the inclusion of signaled and unsignaled conditions in a counterbalanced design. Each bird was tested under two terminal-link durations (5 s and 30 s) in both signaled and unsignaled conditions. The order of exposure to terminal-link conditions is presented in Table 3.

Results

Choice proportions for the 100% side are shown as a function of terminal-link duration in Figure 5. Detailed results for each condition, in order of exposure, are shown in Table 3.

Signaled versus unsignaled conditions. Figure 5 reveals that, at the 30-s terminal link, preference for the 100% side was considerably lower under conditions of signaled percentage reinforcement than under conditions of unsignaled percentage reinforcement. This finding was consistent across all birds. At the 5-s terminal link, the mean data presented in Figure 5 indicate that preference for 100% reinforcement was lower under the signaled conditions than under the unsignaled conditions. However, this is primarily due to 2 birds (Bird 5 and Bird 12) and does not reflect the group as a whole. Birds 5 and 12 showed nearly exclusive preference for the 50% side when the outcomes were signaled.

Terminal-link conditions. Under conditions of signaled percentage reinforcement, 7 of the 8 birds showed a reduction in preference for the 100% side at the 30-s terminal link. Birds 6 through 11 showed nearly exclusive preference (M = .98) for the 100% reinforcement alternative at 5-s terminal links. When the terminal links were extended to 30 s, declines in preference ranging from .20 to .97 (M = .48) occurred for this group of birds. Birds 5 and 12 showed changes in preference that differed from the other birds. Neither bird demonstrated a preference for 100% reinforcement at 5-s terminal links. When the terminal links

Table 3

Results and signal conditions from Experiment 2.

Bird	TL dura-tin	Signal condition	C.P.	TL responses (peck/min)			Obt % rf		Ses-sion
				100% S+	50% S+	50% S−	50%	Overall	
5	5	unsig	1.00	121.90	36.00	—	100.00	100.00	15
	30	unsig	.98	0.65	1.33	1.33	39.64	98.91	15
	30	sig	.43	0.04	2.03	0.07	48.18	70.44	44
	5	sig	.01	0.00	37.09	0.96	50.47	50.65	24
6	5	unsig	.99	38.70	—	0.00	0.00	99.64	15
	30	unsig	.97	1.40	0.83	1.00	54.92	99.10	16
	30	sig	.73	0.85	4.41	0.02	52.33	87.14	20
	5	sig	.97	28.27	47.20	0.60	47.09	98.39	15
7	30	unsig	.91	0.99	16.80	36.70	47.30	94.91	29
	5	unsig	.99	44.20	16.00	12.20	75.00	99.82	15
	5	sig	.99	20.50	168.00	6.00	33.33	99.67	15
	30	sig	.45	0.77	4.85	0.94	48.82	71.93	51
8	30	unsig	.88	0.65	0.06	1.10	48.68	93.78	17
	5	unsig	1.00	0.15	—	0.00	0.00	99.82	15
	5	sig	.98	3.62	117.00	2.00	43.75	98.55	15
	30	sig	.66	1.14	6.76	3.22	49.13	82.69	26
9	5	sig	.99	109.30	36.00	120.00	50.00	99.64	15
	30	sig	.79	0.73	2.51	3.25	51.22	90.24	22
	30	unsig	.99	0.97	2.44	0.00	80.00	99.79	28
	5	unsig	.96	32.60	3.83	0.67	65.54	98.39	15
10	5	sig	.97	10.60	15.00	0.00	18.64	97.69	36
	30	sig	.38	38.90	21.50	0.10	50.93	69.38	44
	30	unsig	.86	4.49	6.84	5.06	52.27	93.51	29
	5	unsig	.99	3.23	—	0.00	0.00	99.46	15
11	30	sig	.01	9.07	4.81	0.74	49.52	49.99	15
	5	sig	.98	198.70	66.00	0.00	19.82	98.56	29
	5	unsig	.99	202.70	0.00	114.00	28.20	99.09	17
	30	unsig	.80	3.64	2.07	1.12	50.00	90.19	25
12	30	sig	.06	0.84	3.97	0.19	50.43	53.28	20
	5	sig	.11	8.60	35.90	0.82	49.49	55.05	20
	5	unsig	.95	3.05	78.40	47.60	40.67	97.17	22
	30	unsig	.94	0.13	1.66	1.00	41.75	96.32	45

Note: TL = terminal link, sig = signaled, unsig = unsignaled, C.P. = choice proportion, 100% S+ = stimulus signaling food on reliable side, 50% S+ = stimulus signaling food on unreliable side, 50% S− = stimulus signaling blackout on unreliable side, Obt % rf = obtained percentage of reinforcement. Dashes indicate that particular terminal-link stimulus was not entered.

were extended to 30 s, Bird 5 showed an increase in preference for the 100% alternative, and Bird 12 showed a marginal decline in preference for this alternative.

Under conditions of unsignaled percentage reinforcement, a slight reduction in preference for the 100% side at the 30-s terminal link was shown in 7 of the 8 birds tested. Declines in preference ranged from .01 to .19 with a mean value of .08. Bird 9 showed a marginal (.03) increase in preference for the 100% side when the terminal links were extended. None of the birds showed a preference for the 50% side at either terminal-link duration with unsignaled percentage reinforcement.

Discussion

The overall pattern of results from Experiment 2 was quite consistent with those from Experiment 1. Taken together, the results of Experiments 1 and 2 indicate that both the terminal-link duration and the signal conditions are important determinants of pigeons' preference for reliable over unreliable reinforcement. It appears that the tendency to choose the unreliable (50% reinforcement) alternative over the reliable (100% reinforcement) alternative is generally greater with a signaled procedure than with an unsignaled procedure and with long terminal-link dura-

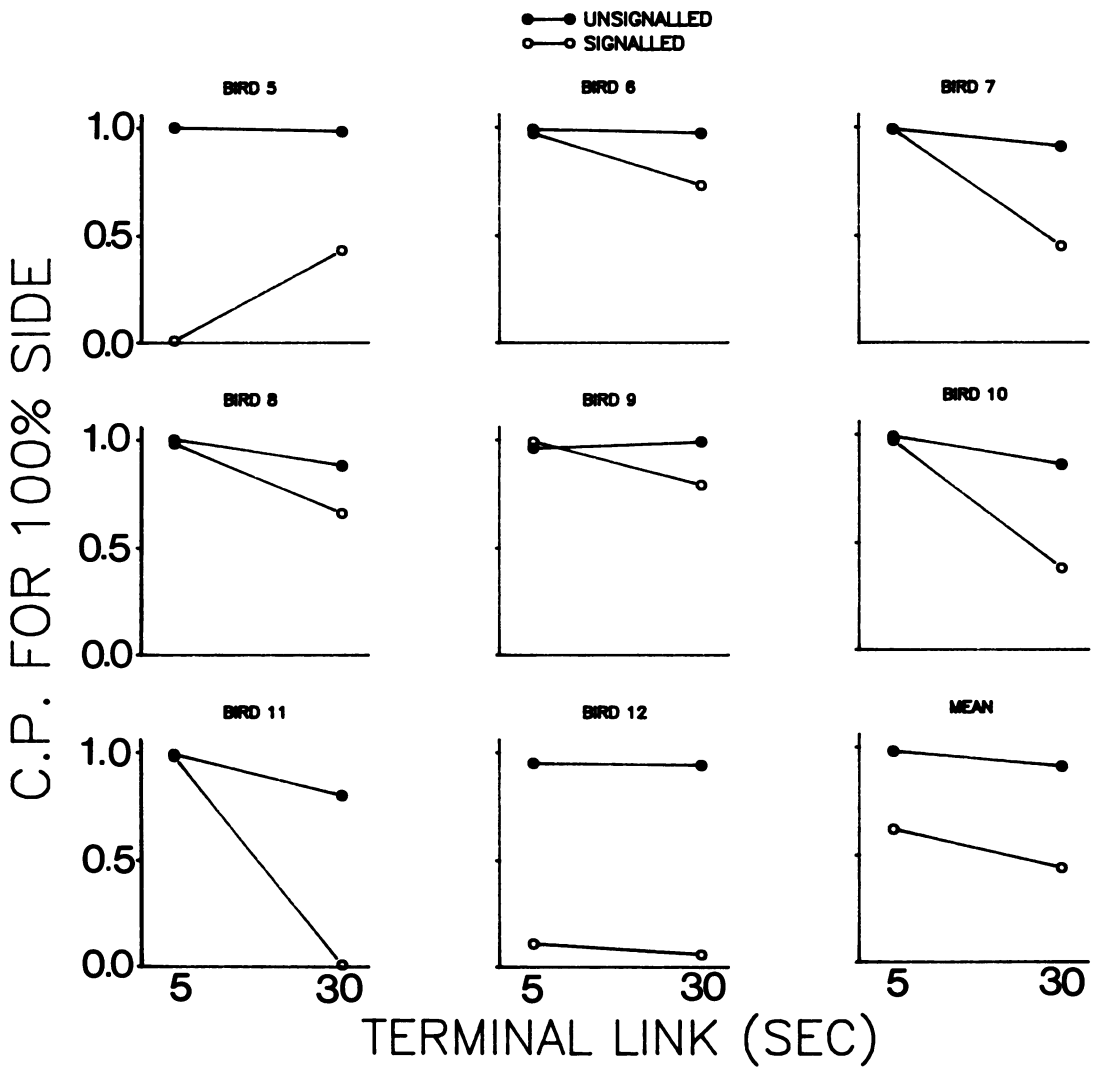

Fig. 5. Choice proportion (C.P.) for the 100% reinforcement side as a function of terminal-link duration under conditions of signaled percentage reinforcement in Experiment 2.

tions (i.e., 30 s or more) than with short (5 s or 10 s) terminal-link durations.

It should be noted that the slight reduction in preference for the reliable alternative with longer terminal links in the unsignaled procedure is counter to results reported by Spetch and Dunn (1987). They investigated choice between 100% and 33% reinforcement in an unsignaled procedure, but with variable-interval 60-s initial-link schedules, and found that preference for 100% reinforcement increased with increases in the terminal-link duration. It is possible that terminal-link duration effects depend on the initial-link schedule.

EXPERIMENT 3

The results of Experiments 1 and 2 indicated that, in signaled percentage-reinforcement procedures, terminal-link duration is an important determinant of choice behavior. It is still unclear, however, what underlies this effect of terminal-link duration. There are three temporal differences between short and long terminal-link conditions: (a) delay from onset of the terminal-link stimulus until trial outcome, (b) overall temporal spacing between trial outcomes, and (c) temporal spacing between choice (i.e., initial-link) opportunities.

Table 4

Results and signal conditions from Experiment 3.

Bird	TL/ITI	Signal condition	C.P.	TL responses (peck/min)			Obt % rf		Session
				100% S+	50% S+	50% S−	50%	Overall	
13	50/0	sig	.96	0.09	0.67	0.12	47.62	85.05	39
	10/0	sig	1.00	0.14	0.00	0.00	25.00	99.46	15
	50/0	sig	.46	0.00	0.99	0.32	50.85	73.27	69
	10/40	sig	.99	0.62	9.00	12.00	66.67	99.82	18
	50/0	sig	.45	0.00	0.60	0.41	52.26	74.30	65
	10/0	sig	.89	1.04	5.38	1.49	47.22	94.13	20
	50/0	sig	.44	0.02	0.64	0.31	48.23	70.97	20
	10/40	sig	.98	1.04	7.50	1.50	60.00	98.54	15
14	50/0	sig	.08	0.29	1.16	0.38	51.92	55.55	52
	10/0	sig	.70	0.08	1.02	0.22	54.59	84.06	21
	50/0	sig	.13	0.13	1.11	0.45	52.03	58.01	35
	10/40	sig	.99	1.60	18.00	0.00	50.00	99.82	15
	50/0	sig	.19	0.23	0.80	1.49	49.61	59.36	65
	10/0	sig	1.00	0.87	—	—	0.00	100.00	15
	50/0	sig	.46	0.26	0.78	0.60	52.75	75.36	26
	10/40	sig	1.00	2.64	—	—	0.00	100.00	15
15	50/0	sig	.92	0.75	9.77	2.55	31.11	94.63	65
	10/0	sig	.98	0.48	6.00	0.00	54.47	99.09	15
	50/0	sig	.77	0.24	1.11	0.45	51.94	88.85	31
	10/40	sig	.87	2.07	19.90	9.95	50.60	93.70	18
	50/0	sig	.59	0.38	1.38	0.90	54.54	81.11	34
	10/0	sig	.91	0.10	6.10	1.75	61.82	96.67	20
	50/0	sig	.35	0.18	1.10	0.62	48.12	66.11	26
	10/40	sig	.94	1.54	16.50	6.43	54.05	97.29	16
16	50/0	sig	.36	0.00	0.06	0.03	52.68	69.54	92
	10/0	sig	.07	0.00	2.04	0.20	52.10	54.81	46
	50/0	sig	.33	0.02	0.05	0.03	49.73	66.18	39
	10/40	sig	.56	0.08	1.01	1.03	53.17	79.28	20
	50/0	sig	.26	0.00	0.01	0.00	50.00	62.84	20
	10/0	sig	.07	0.11	2.05	0.03	52.31	55.39	15
	50/0	sig	.06	0.00	0.01	0.01	52.16	55.28	15
	10/40	sig	.12	0.00	8.76	0.02	57.71	56.95	24

Note: TL = terminal link, ITI = intertrial interval, sig = signaled, unsig = unsignaled, C.P. = choice proportion, 100% S+ = stimulus signaling food on reliable side, 50% S+ = stimulus signaling food on unreliable side, 50% S− = stimulus signaling blackout on unreliable side, Obt % rf = obtained percentage of reinforcement. Dashes indicate that particular terminal-link stimulus was not entered.

Any of these temporal differences might underlie the preference differences observed in Experiments 1 and 2. Experiment 3 was designed to differentiate among these three possibilities. An intertrial interval (ITI) was added to the concurrent-chains procedure to equate short and long terminal-link conditions on the latter two temporal factors. Thus, the effect of the delay from terminal-link onset to outcome was isolated as the terminal-link durations were varied.

Method

Subjects

Three naive White King pigeons and 1 experienced Silver King pigeon served as subjects. The experienced bird had prior exposure to concurrent-chains procedures but not to percentage-reinforcement manipulations.

Procedure

The birds were exposed to three conditions, each of which employed a signaled percentage-reinforcement concurrent-chains procedure. In one condition, denoted as 50/0, the duration of the terminal link was 50 s and outcomes were followed by a 0-s ITI. In a second condition, denoted as 10/0, the duration of the terminal link was 10 s and outcomes were again followed by a 0-s ITI. In the third condition, denoted as 10/40, the duration of the terminal link was 10 s and outcomes were followed by a 40-s ITI. All response keys, the

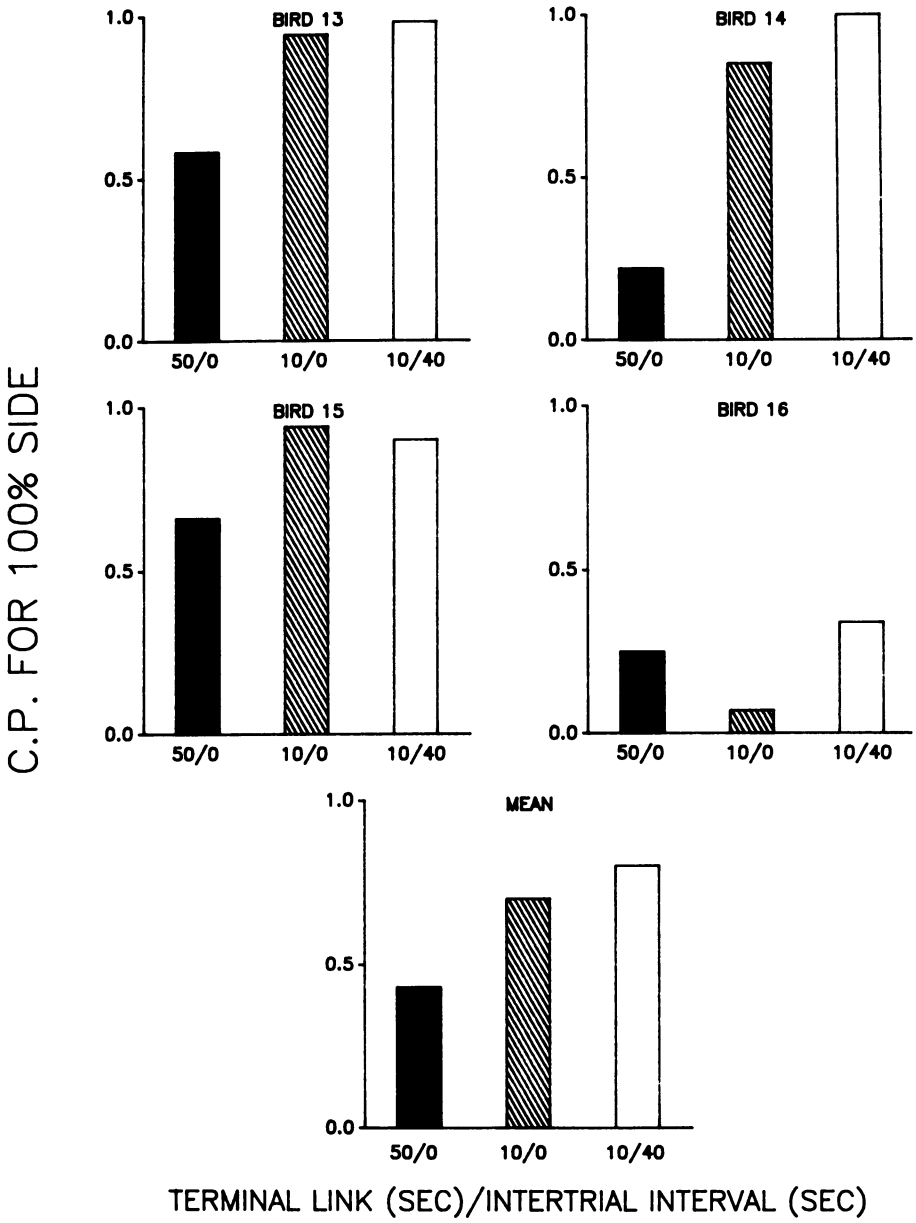

Fig. 6. Choice proportion (C.P.) for the 100% reinforcement side for the three conditions tested in Experiment 3.

houselight, and the magazine light were darkened during the intertrial interval. All birds received the same order of conditions, which consisted of the 50/0 condition alternating with the 10/0 and the 10/40 conditions (see Table 4). In this experiment the right chain provided 100% reinforcement and the left chain provided 50% reinforcement. The stimulus conditions associated with each component of these chains are presented in Table 1. All other aspects of the procedure are the same as in previous experiments.

Results

Choice proportions for the 100% side under the three conditions are presented in Figure 6. These values are the average of the four exposures to condition 50/0 and of the two exposures to conditions 10/0 and 10/40. The mean values plotted in the bottom panel of

Figure 6 reveal a marked reduction in preference for the 100% side in the condition that employed the longer terminal link (i.e., the 50/0 condition) relative to preference for the 100% side in the conditions that employed shorter terminal links (i.e., the 10/0 and 10/40 conditions). Although there was considerable variability in absolute choice proportions between birds, 3 of the 4 birds demonstrated a stronger preference for the 100% side under both of the 10-s terminal-link conditions (i.e., 10/0 and 10/40) than under the 50/0 condition. In addition, preference for reliable reinforcement tended to be more similar between the 10/40 and 10/0 conditions than between the 10/40 and 50/0 conditions, even though these two conditions were equalized for the overall temporal spacing between outcomes and the temporal spacing between choice (i.e., initial-link) opportunities. Bird 16 responded primarily to the 50% side under all three conditions.

Detailed results for each condition, in order of exposure, are shown in Table 4. It should be noted that choice proportions were quite labile in the 50/0 condition. Birds 13, 15, and 16 each showed a systematic decrease in choice proportions for the 100% alternative across their four exposures to the 50/0 condition. In contrast, Bird 14 showed a systematic increase in choice proportions in these four determinations.

Discussion

In general, the results from Experiment 3 suggest that the temporal delay from the onset of the terminal link to the outcome is the important factor in the reduction in preference for the 100% alternative observed with increases in terminal-link duration. Overall temporal spacing between outcomes and temporal spacing between choice opportunities do not appear to play a critical role in this phenomenon.

GENERAL DISCUSSION

The present series of experiments demonstrates that, for most pigeons, preference for a reliable alternative attenuates when outcomes are delayed in a signaled percentage-reinforcement concurrent-chains procedure. At short delays (i.e., 5-s or 10-s terminal links), most pigeons (i.e., 12 of the 16 tested) displayed extreme preference for the 100% reinforcement alternative. Preference for the reliable alternative declined (in some cases to below .5) as the outcome delay increased to 30 s or longer. This attenuation of preference was much stronger when the outcomes on the unreliable alternative were signaled than when they were unsignaled. Furthermore, control of this preference attenuation appeared to be a function of the delay from the onset of the terminal-link stimulus to the presentation of the outcome, rather than the overall temporal spacing of outcomes or the spacing of opportunities to choose.

Four of the 16 pigeons tested did not conform to certain aspects of this general description. Bird 3 in Experiment 1, Birds 5 and 12 in Experiment 2, and Bird 16 in Experiment 3 all displayed a very strong tendency to choose the unreliable alternative in the signaled percentage-reinforcement procedure, and their choice behavior was not affected systematically by the duration of the terminal links. This strong tendency to choose the unreliable side did not, however, seem to reflect a simple side bias, because a strong tendency to choose the reliable side occurred when 3 of these subjects (Birds 3, 5 and 12) were tested with an unsignaled procedure. Why 25% of the birds showed a different pattern than the remaining birds is unclear.

In Experiment 3, considerable within-subject variability also was apparent in the choice proportions obtained in the condition employing a signaled procedure and long terminal-link delays, suggesting that these conditions generate quite labile choice behavior. It is interesting to note that the number of sessions required to satisfy the stability criteria also provides an indication of the lability generated by these conditions. For example, across the three experiments there were eight instances in which more than 50 sessions were required to satisfy the stability criteria; all of these instances came from conditions in which a signaled procedure was used and the terminal-link delay was 30 s or longer. In several of these cases, choice proportions fluctuated in a cyclical fashion over blocks of sessions; that is, the choice proportions showed an increasing trend for several sessions followed by a decreasing trend for several sessions.

In spite of the considerable variability both between and within subjects, the present re-

sults clearly indicate that pigeons often will display a suboptimal tendency to choose the unreliable alternative in a signaled concurrent-chains percentage-reinforcement procedure in which the initial links entail FR 1 schedules and the terminal links are 30 s or longer. Under these conditions, a considerable portion of the pigeons' choices (about 55% on average) are to the unreliable alternative, a finding consistent with Kendall's (1974, 1985) work.

Although there may be several frameworks in which the present results can be viewed, they fit nicely with the functional conditioned-reinforcement framework proposed by Dunn and Spetch (1990). Dunn and Spetch suggested that when FR 1 schedules are used in a concurrent-chains procedure, the onset of the terminal-link stimulus on the 100% side may not function as a conditioned reinforcer because it does not signal a reduction in delay to reinforcement over that already signaled by a peck to the initial-link stimulus on that side. In contrast, the onset of the terminal-link stimulus that signals food on a 50% alternative would signal a substantial reduction in delay over that signaled by the initial-link peck. Thus, conditioned reinforcement effects should favor the 50% alternative in signaled procedures. On the other hand, primary reinforcement would always favor the 100% alternative.

The effects of terminal-link duration reported here are consistent with the assumption made by Dunn and Spetch (1990) that initial-link responses are influenced by both conditioned reinforcement and delayed primary reinforcement. In signaled procedures, primary reinforcement effects (which always favor the 100% side) should exert more control over responding when terminal-link delays are relatively short. The longer the delay to primary reinforcement, the greater the tendency should be to choose the 50% alternative, which affords immediate conditioned reinforcement. The reduction in preference for reliable reinforcement with increases in terminal-link duration reported in Experiments 1 and 2, together with the evidence from Experiment 3 suggesting that this effect was due specifically to the delay from terminal-link onset to outcome, is consistent with these notions.

Regardless of the specific underlying mechanism, a tendency to choose unreliable reinforcement over reliable reinforcement when reinforcement magnitudes are equal seems clearly maladaptive because it reduces the overall rate of reinforcement that can be obtained. Thus, it seems quite inconsistent with a molar optimal foraging perspective. Although some foraging models predict that animals should be risk prone under conditions of negative energy budget (e.g., Caraco, 1983), this tendency to choose the risky (i.e., unreliable) alternative should apply only under conditions in which the maximum magnitude of a food outcome is greater on the unreliable alternative than on the reliable one. That is, when choice of the reliable outcome would eventually lead to starvation, a tendency to choose a less reliable but potentially larger outcome should emerge because it provides a chance to avoid starvation. However, in the present task the unreliable outcome was not larger than the reliable one, so choice of the unreliable alternative would never offer even a temporary gain over that offered by choice of the reliable alternative. Thus, a risk-sensitive foraging perspective does not appear to provide an explanation for the pigeons' tendency to choose the unreliable alternative in the present task.

Although counterintuitive, the reduced preference for reliable alternatives observed in the present experiments appears to parallel some effects from other procedures in which pigeons are exposed to signaled percentage reinforcement. One of these is the single-chain procedure, in which the rate or latency to respond during an initial link provides an indication of the conditioned reinforcing value of entry into a terminal link. When outcomes are signaled by the terminal-link stimuli, pigeons show enhanced initial-link responding in a 50% reinforcement chain compared to a 100% reinforcement chain (Branch, 1977; Kendall, 1975; Wilton & Clements, 1971). This enhanced responding with 50% reinforcement does not occur with an unsignaled procedure.

Another preparation that has yielded results analogous to those obtained here is the serial autoshaping procedure. In this procedure two elements of a compound conditioned stimulus (CS) are presented successively prior to food presentation. In a number of experiments, it has been reported that pigeons will make more pecks to the first stimulus of the compound if the value of the second stimulus varies across

trials. For example, in Condition AB^+A^0 of a study by Collins, Young, Davies, and Pearce (1983), the first stimulus (A) was followed on 50% of the trials by a second stimulus (B), which was followed by food. On the remaining trials, A was followed by nothing. In a comparison condition (AB^+), Stimulus A was always followed by Stimulus B, which was then followed by food. Stimulus A was therefore only partially paired with food in Condition AB^+A^0 but was always paired with food in Condition AB^+. In spite of the less frequent pairing with food, pigeons pecked Stimulus A at a higher rate in Condition AB^+A^0 than in Condition AB^+. This finding, which appears to be very reliable (Collins & Pearce, 1985) has been interpreted in terms of orienting responses that are thought to be inversely related to the predictive accuracy of a CS (see Collins & Pearce, 1985; Pearce & Hall, 1980). More orienting responses would occur to the A stimulus when it is only sometimes followed by the CS for food than when it is always followed by the CS for food.

Although the procedures and terminology are quite different, these results obtained with serial autoshaping are similar to those obtained under signaled percentage-reinforcement conditions. In the long terminal-link conditions of our experiments, pigeons made slightly more pecks on average to the initial-link stimulus that was only sometimes followed by a stimulus that signaled food (the S^+ terminal-link stimulus on the 50% side) than they did to the initial-link stimulus that was always followed by a stimulus that signaled food (the terminal link on the 100% side). Thus, a high number of pecks occurred to the initial-link stimulus that had the lowest predictive accuracy. This similarity between the results reported here and those obtained in serial autoshaping studies suggests that a common mechanism might be operating.

Although a definitive interpretation of the suboptimal choice behavior reported here must await further experimentation, it is clear that one cannot make a simple statement about pigeons' tendency to choose alternatives that provide uncertain outcomes. Hamm and Shettleworth (1987), in their paper on pigeons' choice between variable and constant amounts of food, concluded that "response to risk is not independent of the kind of risk to which an animal is exposed" (p. 380). Our results further suggest that pigeons' response to outcome uncertainty is not independent of schedule parameters or signal conditions.

REFERENCES

Ainslie, G. W. (1974). Impulse control in pigeons. *Journal of the Experimental Analysis of Behavior,* **21,** 485–489.

Autor, S. M. (1969). The strength of conditioned reinforcers as a function of frequency and probability of reinforcement. In D. P. Hendry (Ed.), *Conditioned reinforcement* (pp. 127–162). Homewood, IL: Dorsey Press.

Branch, M. N. (1977). Signalled and unsignalled percentage reinforcement of performance under a chained schedule. *Journal of the Experimental Analysis of Behavior,* **27,** 71–83.

Caraco, T. (1983). White-crowned sparrows (*Zonotrichia leucophrys*): Foraging preferences in a risky environment. *Behavioral Ecology and Sociobiology,* **12,** 63–69.

Collins, L., & Pearce, J. M. (1985). Predictive accuracy and the effects of partial reinforcement on serial autoshaping. *Journal of Experimental Psychology: Animal Behavior Processes,* **11,** 548–564.

Collins, L., Young, D. B., Davies, K., & Pearce, J. M. (1983). The influence of partial reinforcement on serial autoshaping with pigeons. *Quarterly Journal of Experimental Psychology,* **35B,** 275–290.

Dunn, R., & Spetch, M. L. (1990). Choice with uncertain outcomes: Conditioned reinforcement effects. *Journal of the Experimental Analysis of Behavior,* **53,** 201–218.

Fantino, E. (1966). Immediate reward followed by extinction vs. later reward without extinction. *Psychonomic Science,* **6,** 233–234.

Fantino, E. (1969). Choice and rate of reinforcement. *Journal of the Experimental Analysis of Behavior,* **12,** 723–730.

Fantino, E. (1977). Conditioned reinforcement: Choice and information. In W. K. Honig & J. E. R. Staddon (Eds.), *Handbook of operant behavior* (pp. 313–339). Englewood Cliffs, NJ: Prentice-Hall.

Fantino, E. (1981). Contiguity, response strength, and the delay-reduction hypothesis. In P. Harzem & M. D. Zeiler (Eds.), *Advances in analysis of behaviour: Vol. 2. Predictability, correlation, and contiguity* (pp. 169–201). Chichester, England: Wiley.

Fantino, E., Dunn, R., & Meck, W. (1979). Percentage reinforcement and choice. *Journal of the Experimental Analysis of Behavior,* **32,** 335–340.

Hamm, S. L., & Shettleworth, S. J. (1987). Risk aversion in pigeons. *Journal of Experimental Psychology: Animal Behavior Processes,* **13,** 376–383.

Kendall, S. B. (1974). Preference for intermittent reinforcement. *Journal of the Experimental Analysis of Behavior,* **21,** 463–473.

Kendall, S. B. (1975). Enhancement of conditioned reinforcement by uncertainty. *Journal of the Experimental Analysis of Behavior,* **24,** 311–314.

Kendall, S. B. (1985). A further study of choice and percentage reinforcement. *Behavioural Processes,* **10,** 399-413.

Menlove, R. L., Inden, H. M., & Madden, E. G. (1979). Preference for fixed over variable access to food. *Animal Learning & Behavior,* **7,** 499-503.

Moore, J. (1976). Choice and percentage reinforcement in pigeons. *Animal Learning & Behavior,* **4,** 441-450.

Navarick, D. J., & Fantino, E. (1976). Self-control and general models of choice. *Journal of Experimental Psychology: Animal Behavior Processes,* **2,** 75-87.

Pearce, J. M., & Hall, G. (1980). A model for Pavlovian learning: Variations in the effectiveness of conditioned but not of unconditioned stimuli. *Psychological Review,* **87,** 532-552.

Schneider, J. W. (1968). Effects of percentage reinforcement on choice in a concurrent chain schedule. *Psychonomic Science,* **12,** 211-212.

Spetch, M. L., & Dunn, R. (1987). Choice between reliable and unreliable outcomes: Mixed percentage-reinforcement in concurrent chains. *Journal of the Experimental Analysis of Behavior,* **47,** 57-72.

Wilton, R. N., & Clements, R. O. (1971). Observing responses and informative stimuli. *Journal of the Experimental Analysis of Behavior,* **15,** 199-204.

Received September 18, 1989
Final acceptance November 17, 1989