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FIXED-RATIO PAUSING: JOINT EFFECTS OF PAST REINFORCER MAGNITUDE AND STIMULI CORRELATED WITH UPCOMING MAGNITUDE

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Pigeons responded on fixed-ratio schedules ending in small or large reinforcers (grain presentations of different duration) interspersed within each session. In mixed-schedule conditions, the response key was lit with a single color throughout the session, and pausing was directly related to the past reinforcer (longer pauses after large reinforcers than after small ones). In multiple-schedule conditions, different colors accompanied the ratios ending in small and large reinforcers, and pausing was affected by the upcoming reinforcer as well as the past one. Pauses were shorter before large reinforcers than before small ones, but they continued to be longer after large reinforcers than after small ones. The influence of the past reinforcer was modulated by the magnitude of the upcoming reinforcer; in the presence of the stimulus before the small reinforcer, the effect of the past reinforcer was enhanced relative to its effect in the stimulus before the large reinforcer. These results show that pausing between ratios is jointly determined by two competing factors: past conditions of reinforcement and stimuli correlated with upcoming conditions.

Key words: preratio pause, postreinforcement pause, reinforcer magnitude, fixed-ratio schedules, stimulus control, inhibitory aftereffects of reinforcement, contrast, key peck, pigeons

When behavior maintained by free operant schedules is interrupted by the delivery of a reinforcer, the pause in responding often extends beyond the period required to consume the reinforcer. Such pausing is especially pronounced on fixed-ratio (FR) and fixed-interval (FI) schedules, as well as on combinations thereof in the form of tandem, chained, and conjunctive schedules (e.g., see reviews by Harzem & Harzem, 1981; Shull, 1979; Zeiler, 1977). Although not studied as often, pausing also occurs on other schedules, including variable-interval (VI) and variable-ratio (VR) schedules (e.g., Blakely & Schlinger, 1988; Harzem, Lowe, & Priddle-Higson, 1978; Priddle-Higson, Lowe, & Harzem, 1976; Schlinger, Blakely, & Kaczor, 1990). Thus, as Priddle-Higson et al. (1976) put it, there is reason to believe that pausing is "an almost universal phenomenon" (p. 347).

Nevertheless, research still has not resolved the basic question of whether pausing is controlled by the conditions of reinforcement that have just passed or by stimuli correlated with the upcoming conditions. Emphasis on the upcoming conditions is exemplified by Shull's (1979) observation that pausing before the start of a ratio or interval can be viewed as an index of the strength of the terminal behavior maintained by the schedule. Presumably, stimuli correlated with onset of the schedule exert discriminative control over the strength of responding and, as a consequence, the latency to respond. Such an account supports Griffiths and Thompson's (1973) suggestion that functional control of pausing on FR schedules is aptly conveyed by calling it *preratio* pausing. Moreover, this account predicts that manipulations to enhance response strength, such as increasing the frequency or magnitude of reinforcement, should reduce pausing. Supporting data come from research with FR, FI, and VR schedules (e.g., Blakely & Schlinger, 1988; Crossman, 1971; Felton & Lyon, 1966; Griffiths & Thompson, 1973; Inman & Cheney, 1974; Killeen, 1969; Lowe & Harzem, 1977; Powell, 1968, 1969; Rider & Kametani, 1984; Schlinger et al., 1990). For example, Powell (1969) studied reinforcement frequency by manipulating FR size; as frequency was increased (by lowering the FR), pausing was reduced. In addition, at each FR Powell alternated sessions with

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a small reinforcer (2.5-s access to grain) and sessions with a large reinforcer (4-s access). Pauses were shorter in the sessions with the large reinforcer, especially at higher FRs. Overall, then, pauses were briefest under the most favorable schedule conditions, that is, those with the largest and most frequent reinforcers.

A different account was offered by Harzem and Harzem (1981), who pointed to control by the past reinforcer. They proposed that pausing is an unconditioned inhibitory aftereffect of reinforcement, an effect that increases with the magnitude of the reinforcer (see also Staddon, 1974). According to this view, pausing should be longer after large reinforcers than after small ones, and the term *postreinforcement* pausing (cf. Ferster & Skinner, 1957) seems appropriate. Again, considerable support is available from research with both ratio and interval schedules (e.g., Davey, Harzem, & Lowe, 1975; Harzem, Lowe, & Davey, 1975; Hatten & Shull, 1983; Jensen & Fallon, 1973; Lowe, Davey, & Harzem, 1974; Priddle-Higson et al., 1976; Staddon, 1970). For example, Lowe et al. (1974) trained rats on FR schedules using a 30% concentration of sweetened condensed milk as the reinforcer. After responding stabilized, they conducted test sessions in which the reinforcer concentration varied unpredictably from 10% to 70% across blocks of ratios. As the concentration was raised, pauses increased; in other words, the rats paused longer as the conditions of reinforcement became more favorable.

Thus, the research to date has yielded contradictory results. One set of findings indicates that the relation between pausing and reinforcer magnitude is inverse (e.g., Powell, 1969), whereas the other indicates that the relation is direct (e.g., Lowe et al., 1974). Noting this discrepancy, Perone, Perone, and Baron (1987) proposed that pause duration is a product of two competing factors: inhibitory aftereffects of the past reinforcer and excitatory control by stimuli correlated with the upcoming reinforcer. Contradictory results may reflect procedural differences affecting the degree to which these two factors can contribute to experimental outcomes. A critical point is whether the procedure allows stimulus control to develop over the behavior leading to the different reinforcer magnitudes. In Powell's (1969) study, colored lights were correlated with the small and large reinforcers. Differences in discriminative control by these stimuli may have given rise to the inverse relation observed between magnitude and pausing, with relatively short pauses in the presence of the stimulus signaling the large reinforcer and long pauses in the stimulus signaling the small reinforcer. Indeed, of the previously cited studies, all of those reporting an inverse magnitude-pause relation included stimuli to signal the magnitudes (Blakely & Schlinger, 1988; Inman & Cheney, 1974; Powell, 1969; Schlinger et al., 1990). By comparison, in Lowe et al.'s (1974) study the different magnitudes were presented at random, from one ratio to the next, in the absence of correlated stimuli. The prevention of stimulus control in their procedure may have allowed exclusive expression of inhibitory aftereffects, so that the magnitude-pause relation was direct. Again, in line with Perone et al.'s (1987) account, all of the previously cited studies reporting direct relations omitted signals (Davey et al., 1975; Harzem et al., 1975; Hatten & Shull, 1983; Jensen & Fallon, 1973; Lowe et al., 1974; Priddle-Higson et al., 1976; Staddon, 1970).

The present research measured FR pausing as a function of past and upcoming reinforcers of varying magnitudes in the presence and absence of discriminative stimuli correlated with those magnitudes. When such stimuli are absent, only the past reinforcer should have a discernible influence on pausing. When stimuli are present, however, both the past and upcoming reinforcers have the potential to influence responding. Therefore, the current research was designed to distinguish the effect of the past reinforcer from that of the upcoming reinforcer.

The pauses of interest on FR schedules occur after the delivery of one reinforcer and before the start of responding on the next ratio (i.e., in the transition from one schedule component to the next). Our procedure involved transitions of four types, categorized according to the magnitudes of the past and upcoming reinforcers. Within each session, half of the ratios ended with a "small" reinforcer and half with a "large" reinforcer. These two outcomes alternated in an irregular pattern that changed from session to session. The pattern was arranged so that the magnitude of any given reinforcer had no relation to the magnitude of the next reinforcer. In each session, the transitions between ratios were divided equally among the four types, which may be described as follows: a ratio with a small reinforcer followed by another with a small reinforcer (small-small), a ratio with a small reinforcer followed by one with a large reinforcer (small-large), a ratio with a large reinforcer followed by a ratio with a small reinforcer (large-small), and a ratio with a large reinforcer followed by another with a large reinforcer (large-large). This factorial manipulation of the past and upcoming reinforcer magnitudes allowed assessment of the overall effect of the past reinforcer (small-small pauses and small-large pauses combined vs. large-small pauses and large-large pauses combined) and the overall effect of the upcoming reinforcer (small-small and large-small vs. small-large and large-large), as well as the interaction between the past and upcoming reinforcers (comparisons across all four types).

METHOD

Subjects

Four male White Carneau pigeons, all with experience on a variety of schedules, were maintained at 80% (±2%) of their free-feeding weights by grain deliveries during the experimental sessions and supplemental feedings at least 30 min afterwards. Water and health grit were freely available in the home cage, which was kept in a temperature-controlled room with a 12:12 hr light/dark cycle.

Apparatus

Sessions were conducted in sound-attenuating chambers 37 cm high, 30 cm wide, and 32 cm deep. Three response keys, about 2 cm in diameter, were arranged in a row on the front panel 24 cm from the floor and 9 cm apart, center to center. The keys could be illuminated from behind by 28-V bulbs (No. 1819) covered with colored caps. Pecks on the center key, the only one used, were reinforced with grain made available through a rectangular opening (5 cm by 6 cm) located about 11 cm below the center key. A 28-V houselight, located in the lower left corner of the front panel, was illuminated during sessions. The response key also was illuminated during the sessions, except when food was delivered, at which time the grain aperture was illuminated instead. Noise from a ventilation fan on the side of the chamber helped mask extraneous sounds. Control and recording operations were accomplished with microcomputers (Tandy, TRS-80 Model 4) connected to the chambers by a commercial interface (Alpha Products, Interfacer 80) and electromechanical components, using software described elsewhere (Perone, 1985).

General Procedure

Sessions were conducted at least 5 days per week, and each lasted until 41 reinforcers were delivered. The schedule requirement was raised from FR 1 to FR 80 during 30 to 48 sessions of preliminary training; thereafter it remained at FR 80. Pauses and run times were recorded on a ratio-by-ratio basis in 30ths of a second. Pauses were measured from the end of the reinforcement cycle until the first peck; run times were measured from the first peck to the last.

Within each session, about half of the ratios ended with a reinforcer designated "small," and the rest ended with a reinforcer designated "large." In Phase 1, the durations of both the small and large reinforcers were varied across conditions; in Phase 2, the small reinforcer was held constant and only the large reinforcer was varied.

Both phases were divided into sets of conditions with mixed schedules and multiple schedules. In the mixed-schedule conditions, the response key was lit with a single color throughout the session (yellow for Bird 3611, white for the others). In the multiple-schedule conditions, different key colors accompanied the ratios ending in small and large reinforcers. Birds 5112 and 3526, who were first studied with the mixed schedules, began the experiment proper immediately upon reaching FR 80 at the end of preliminary training. Birds 3280 and 3611, who were first studied with the multiple schedules, participated in a series of preliminary multiple schedules with FR 80 schedules leading to equal reinforcers in both components. The key colors in the two components were varied across blocks of sessions until a pair of colors was found in which performance differences were minimal. After 44 to 55 sessions, blue and yellow were selected

Table 1

Phase 1: Mixed- and multiple-schedule conditions and running response rates (pecks per minute) as a function of the upcoming and past reinforcer magnitudes (feeder durations in seconds). Entries are medians and interquartile ranges (in parentheses) for the last 10 sessions of each condition; each measure is based on rates from 100 ratios. Conditions are shown in order of exposure, along with the number of sessions in each.

		Magnitude (s)			Before small reinforcer		Before large reinforcer	
Bird	Schedule	Small	Large	Sessions	After small	After large	After small	After large
5112	Mixed	4	4	33	223 (204-234)	218 (205-238)	219 (202-233)	219 (202-232)
		2	6	40	165 (145-185)	158 (143-173)	160 (140-176)	164 (146-181)
		1	7	51	154 (134-178)	156 (140-172)	149 (132-173)	160 (137-179)
		0.5	7.5	50	164 (140-187)	174 (157-198)	158 (142-180)	181 (154-201)
3526	Mixed	4	4	27	276 (244-326)	277 (255-318)	269 (228-308)	282 (244-342)
		2	6	35	322 (288-355)	332 (301-352)	314 (284-348)	322 (297-352)
		1	7	25	324 (285-348)	324 (287-348)	325 (288-353)	332 (304-356)
		0.5	7.5	25[a]	286 (258-304)	292 (269-311)	292 (264-312)	287 (269-305)
3280	Multiple	4	4	38	273 (254-288)	281 (265-298)	245 (210-261)	233 (210-250)
		2	6	29	275 (251-298)	290 (258-308)	238 (223-251)	245 (230-260)
		1	7	31	192 (169-223)	167 (137-209)	246 (232-256)	244 (232-258)
	Mixed	2	6	21	267 (248-288)	265 (247-281)	270 (254-289)	266 (246-283)
		1	7	15	283 (262-304)	271 (254-283)	281 (265-297)	264 (242-278)
		0.5	7.5	10	268 (248-288)	246 (224-265)	274 (256-292)	235 (216-256)
		4	4	11	266 (247-282)	250 (233-270)	260 (241-280)	258 (243-275)
3611	Multiple	3	3	36	169 (146-181)	163 (148-178)	154 (134-168)	155 (136-169)
		1.5	4.5	50	142 (116-160)	122 (90-145)	142 (130-152)	143 (130-154)
	Mixed	1.5	4.5	50	135 (114-149)	133 (108-144)	134 (110-148)	131 (111-143)
		0.75	5.25	10	133 (105-147)	124 (105-137)	132 (114-149)	122 (109-137)
		3	3	31	126 (108-142)	126 (110-138)	134 (110-143)	125 (104-137)

[a] Condition ended prematurely because the subject became ill. See text for details.

for Bird 3280 and blue and white for Bird 3611.

Phase 1

Table 1 lists the conditions in Phase 1 and the number of sessions in each. In the baseline conditions, the small and large reinforcers were both 4 s (3 s for Bird 3611, who gained too much weight with 4-s reinforcers). Then, across successive conditions, the small reinforcer was reduced by half and the difference was added to the large reinforcer, a procedure that held constant the bird's total access to grain per session. These manipulations were continued until the effects on pausing were clear. All 4 birds were studied with the mixed schedules, and 2 (Birds 3280 and 3611) were studied with the multiple schedules.

The order in which the small and large reinforcers were presented within a session was determined by one of 40 different sequences, each constructed by generating a random series of 41 reinforcers (20 small and 21 large, or 21 small and 20 large) and then evaluating the series against several criteria. The 41 ratios per session provided the opportunity to measure pausing in 40 transitions between ratios, with each transition falling into one of four categories based on the past and upcoming reinforcer magnitudes (small-small, small-large, large-small, large-large). For a sequence to be acceptable, the order of small and large reinforcers had to be such that each type of transition would occur exactly 10 times per session, and no more than four small reinforcers or four large reinforcers would occur in succession. A total of 40 sequences meeting these criteria were assembled into two sets of 20. One set included sequences with 20 small reinforcers and 21 large reinforcers, with the first being a large one. Sequences in the other set had 21 small reinforcers and 20 large reinforcers, with the first being a small one. At the beginning of every other session, one of the sets was selected at random; the other set was used in the next session. Once a set had been selected, a sequence was drawn at random for that day's session.

Conditions were changed when pausing was stable over the most recent 10 sessions, or after a maximum of 50 sessions. The stability criteria were applied separately to the session medians calculated for (a) pauses after small reinforcers, (b) pauses after large reinforcers, (c) pauses before ratios leading to small reinforcers, and (d) pauses before ratios leading to large reinforcers. These measures were chosen to ensure that performances were stable whether considered in terms of postreinforcement pauses, as in (a) and (b), or preratio pauses, as in (c) and (d). For conditions to be changed, all four measures had to lack increasing or decreasing trends, and the difference between the mean of the first five medians and mean of the last five medians (over the last 10 sessions) had to be within 10% of the grand mean or within 1 s.

One exception to the stability criteria was made for Bird 3526, who became ill after Session 25 of his final condition. When the stability criteria were applied to the last 10 sessions before his illness, all measures were stable except for the pauses after the small reinforcer, which showed a decreasing trend.

Phase 2

In Phase 2, Birds 5112 and 3280 were studied further with a different system of manipulating reinforcer magnitude. The small reinforcer was held constant at 4 s and the large reinforcer was increased, across conditions, from 4 s to 12 s or 20 s. Because this allowed total access to grain to vary, the sessions were shortened from 41 to 21 ratios to prevent satiation and excessive weight gain.

To arrange the order of small and large reinforcers, two sets of 20 sequences were constructed and used in the same way as in Phase 1, except for a few modifications necessitated by the shortened sessions. The sequences in one set had 10 small reinforcers and 11 large ones and began with a large reinforcer; the sequences in the other set had 11 small reinforcers and 10 large ones and began with a small reinforcer. Each of the four types of transitions between ratios occurred five times, and no more than three small reinforcers or three large reinforcers occurred in succession.

Table 2 presents the magnitude of the reinforcers within and across conditions of Phase 2, as well as the number of sessions in each condition and the colors used as discriminative stimuli. Both mixed and multiple schedules were studied with each bird. The

Table 2

Phase 2: Mixed- and multiple-schedule conditions and running response rates (pecks per minute) as a function of the upcoming and past reinforcer magnitudes (feeder durations in seconds). Entries are medians and interquartile ranges (in parentheses) for the last 10 sessions of each condition; each measure is based on rates from 50 ratios. Conditions are shown in order of exposure, along with the number of sessions in each.

		Magnitude (s)		Key color			Before small reinforcer		Before large reinforcer	
Bird	Schedule	Small	Large	Small	Large	Sessions	After small	After large	After small	After large
5112	Mixed	4	4	White	White	25	198 (176–236)	204 (176–224)	204 (177–229)	206 (185–230)
		4	12	White	White	50	189 (161–209)	173 (155–195)	172 (149–193)	174 (161–206)
		4	20	White	White	26	207 (179–237)	212 (191–231)	206 (178–220)	203 (189–227)
	Multiple	4	20	Yellow	Green	26	149 (139–166)	150 (128–164)	168 (155–179)	168 (149–181)
		4	20	Green	Yellow	50	126 (110–140)	134 (113–147)	125 (115–137)	121 (110–130)
3280	Mixed	4	4	White	White	28	219 (194–249)	227 (199–251)	231 (203–248)	228 (209–251)
		4	12	White	White	50	202 (179–215)	192 (175–212)	203 (184–229)	191 (170–209)
	Multiple	4	12	Yellow	Blue	44	184 (170–200)	158 (140–178)	237 (213–255)	215 (200–238)
		4	12	Blue	Yellow	22	212 (182–233)	201 (170–220)	249 (221–269)	251 (230–273)

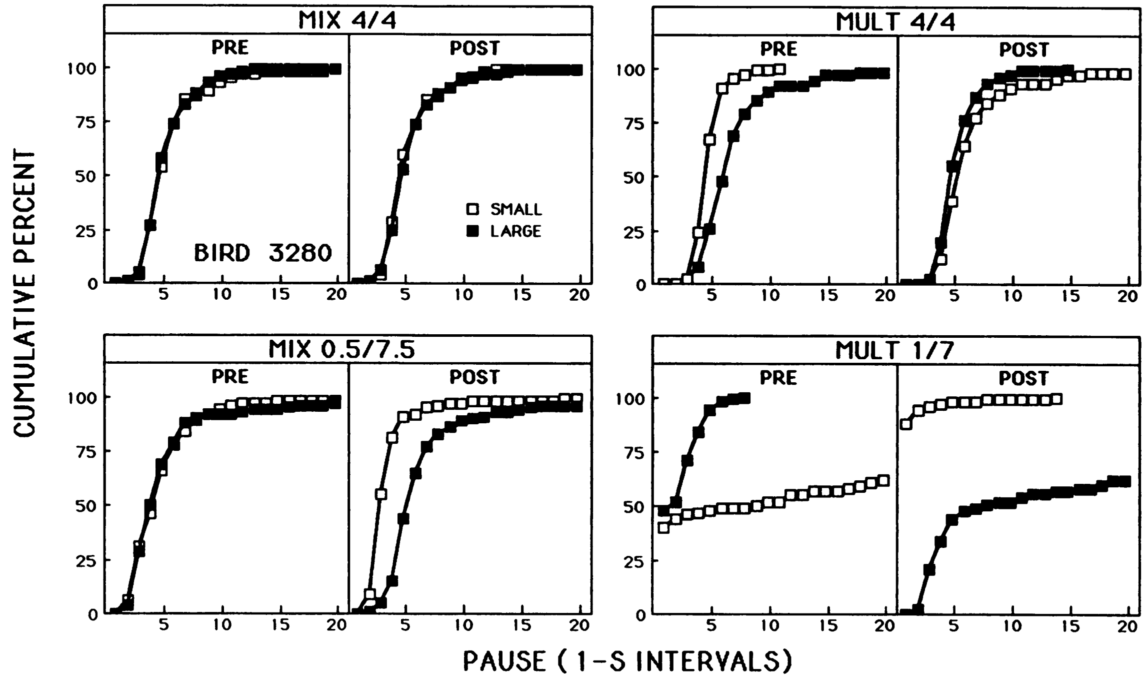

Fig. 1. Phase 1: Relative cumulative frequency distributions of pauses, in 1-s class intervals, for Bird 3280. The pauses are from the last 10 sessions of four selected conditions and are shown separately as a function of the magnitude of the upcoming reinforcer (Pre) and the past reinforcer (Post). The condition labels include the durations (in seconds) of the small and large reinforcers.

stimuli for Bird 3280 were the same as in Phase 1. The stimuli were chosen arbitrarily for Bird 5112, who lacked prior experience on multiple schedules. After pausing was stable in the first multiple-schedule condition, the stimuli were reversed so that the color previously correlated with a small upcoming reinforcer was correlated with a large upcoming reinforcer, and vice versa.

Conditions were changed when pausing was stable over the last 10 sessions, or after a maximum of 50 sessions. The stability criteria were the same as in Phase 1, except the maximum difference between the means of the first five and last five median pauses was increased to 15% of the grand mean.

RESULTS

Phase 1

Figure 1 illustrates the overall effects of the past and upcoming reinforcers on pausing under the mixed and multiple schedules in Phase 1. All of the data are from Bird 3280 (1 of the 2 subjects studied in both schedule conditions) but they are representative of the other subjects' performances. The figure shows the relative cumulative frequency distributions of pauses in the baseline conditions where the reinforcers designated "small" and "large" were equal (labeled *Mix 4/4* and *Mult 4/4*) and in the conditions with the most extreme differences between the reinforcers (*Mix 0.5/7.5* and *Mult 1/7*). For each of these conditions, the 400 pauses from the last 10 sessions were analyzed twice, once as preratio pauses and once as postreinforcement pauses. In the panels labeled *Pre,* the pauses are shown as a function of the upcoming reinforcer; that is, one distribution represents the 200 pauses that preceded a ratio leading to the small reinforcer and the other represents the 200 pauses that preceded a ratio leading to the large reinforcer. In the panels labeled *Post,* the data are reorganized to show distributions of the 200 pauses that followed the small reinforcer and the 200 that followed the large one.

The distributions from the mixed-schedule conditions are shown on the left of Figure

1. In the Mix 4/4 condition, there were no differences in the pause distributions as a function of the upcoming or past reinforcers (compare the open and closed symbols in the Pre and Post panels). In the Mix 0.5/7.5 condition, the pause distributions did not differ as a function of the upcoming reinforcer (Pre), but they did separate as a function of the past (Post). The distribution of pauses after the large reinforcer shifted slightly—but clearly—toward longer pauses relative to the distribution after the small reinforcer. Thus, under mixed-schedule conditions pausing was unrelated to the magnitude of the upcoming reinforcer but was directly related to the magnitude of the past reinforcer.

The right panels of Figure 1 show the distributions from the multiple-schedule conditions. In the Mult 4/4 condition, there was a difference as a function of the upcoming reinforcer even though the small and large reinforcers were equal; this presumably reflects a bias introduced by the different colors signaling the reinforcers. (To avoid capitalizing on this bias, the color controlling the shorter pausing was correlated with the small reinforcer in subsequent conditions.) In the Mult 1/7 condition, there were sizable effects of both the upcoming and past reinforcers, and these effects were in opposite directions. As shown in the Pre panel, pauses before the small reinforcer tended to be much longer than pauses before the large one; in other words, pausing was under discriminative control of the stimuli correlated with the upcoming reinforcers. By comparison, the Post panel shows that when the data are categorized according to the past reinforcer, pauses after the small reinforcer tended to be much shorter than pauses after the large one.

Figures 2 and 3 present a more comprehensive picture of the results in Phase 1. Every condition is shown for every subject, and pausing is analyzed not as a simple function of either the past or upcoming reinforcer, but rather as a joint function of both. Each distribution is based on 100 pauses over the last 10 sessions of the condition; thus, the four distributions per condition account for all 400 pauses during the terminal sessions.

The data from the mixed-schedule conditions of Phase 1 are shown in Figure 2. The general pattern of results corroborates the simpler analysis shown in Figure 1. The upcoming reinforcer had no effect, but pausing was directly related to the past reinforcer, with longer pauses after large reinforcers than after small ones. This effect tended to become greater and more reliable as the difference

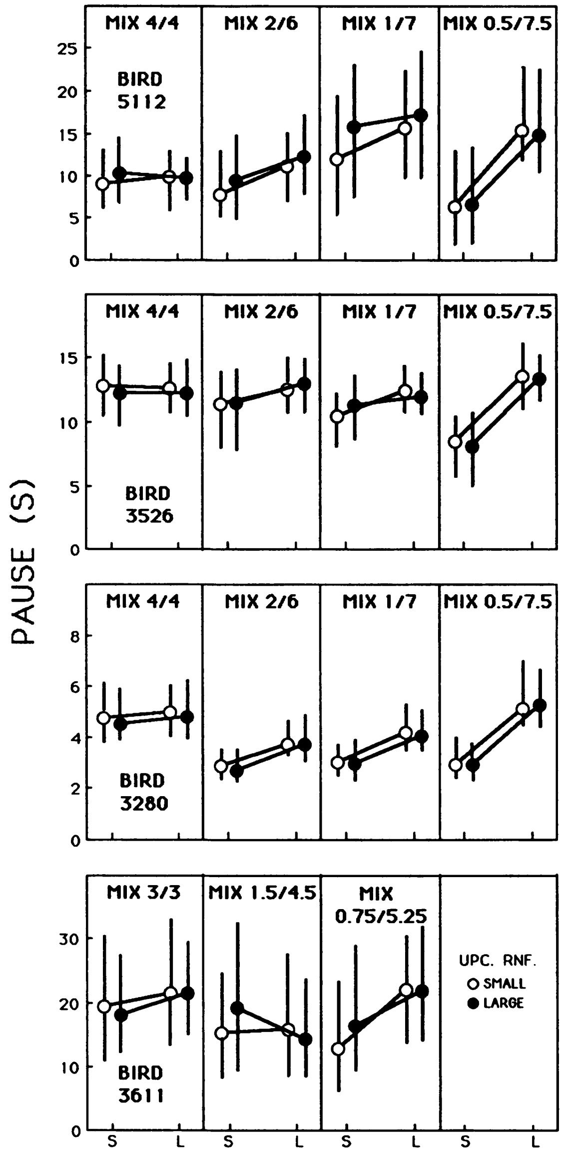

Fig. 2. Phase 1: Pause duration as a function of past and upcoming reinforcer magnitude in the mixed-schedule conditions for each of the 4 birds. The symbols and vertical lines represent the medians and interquartile ranges (25th to 75th percentiles) of the distributions of pauses over the last 10 sessions of each condition.

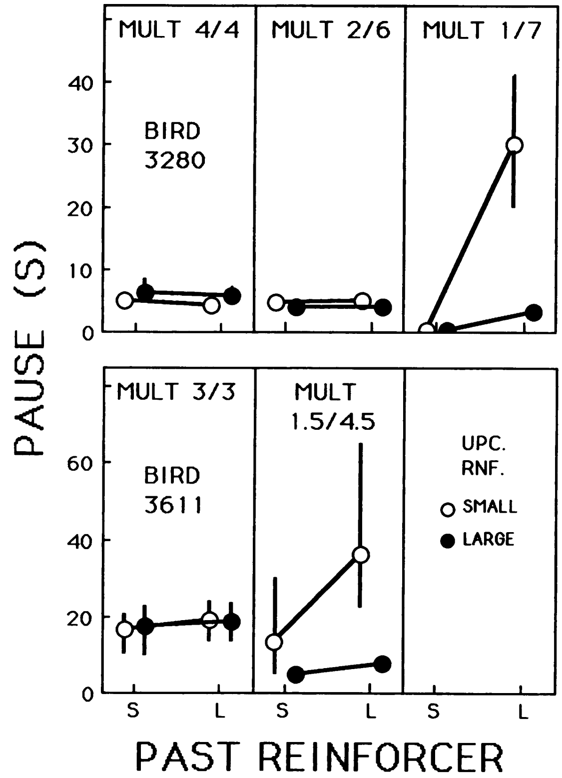

Fig. 3. Phase 1: Pause duration as a function of past and upcoming reinforcer magnitude in the multiple-schedule conditions for Birds 3280 and 3611. Details as in Figure 2.

between the large and small reinforcers was made more extreme.

Figure 3 shows the results from the multiple-schedule conditions of Phase 1; additional information about the absolute and relative effects of reinforcer magnitude is presented in the upper half of Table 3. The effects of the past and upcoming reinforcers were not apparent until the last condition for each bird. There, the overall effects were just as in Figure 1: Pauses were longer in the presence of the stimulus before the small reinforcer than in the stimulus before the large one, and pauses were longer after the large reinforcer than after the small one. In addition, however, Figure 3 and Table 3 show that there was an interaction between the past and upcoming reinforcers, in that the effect of the past reinforcer depended on the magnitude of the upcoming reinforcer. In the presence of the stimulus before the small reinforcer, pauses after the large reinforcer were considerably longer than those after the small reinforcer. The median difference was 30 s for Bird 3280 and 22.75 s for Bird 3611, representing increases of 17,647% and 169%, respectively (see the Mult 1/7 and Mult 1.5/4.5 conditions in Table 3). In the stimulus before the large reinforcer (Figure 3), the difference in pausing after the large and small reinforcers was only about 3 s for both birds, representing increases of 1,706% for Bird 3280 and 69% for Bird 3611. Thus, the effect of the past reinforcer was substantially greater in the presence of the stimulus before the small reinforcer than in the stimulus before the large reinforcer, whether expressed in absolute terms (about a 7- to 10-fold difference across the two stimuli) or relative terms (about a 2.5- to 10-fold difference).

Table 1 presents the median running response rates (and interquartile ranges) during the last 10 sessions of each condition in Phase 1, expressed as a function of the upcoming and past reinforcer magnitudes. No consistent differences can be seen in either the mixed- or multiple-schedule conditions.

Phase 2

Figure 4 shows cumulative frequency distributions of pauses under the conditions of Phase 2 with the most extreme difference between the small and large reinforcers. For each bird, the data are from the 200 pauses over the last 10 sessions of the final mixed-schedule condition and the first multiple-schedule condition. The overall effects of the upcoming and past reinforcers were similar to those in Phase 1. In the mixed-schedule conditions, the distributions did not differ as a function of the upcoming reinforcer (Pre), but distributions after the large reinforcer were displaced toward longer pauses relative to those after the small reinforcer (Post). In the case of Bird 5112, however, the difference was minimal. In the multiple-schedule conditions, the upcoming and past reinforcers had opposite effects, as in Phase 1. The distributions before the large reinforcer were displaced toward shorter pauses relative to the distributions before the small reinforcer (Pre). The distributions after the large reinforcer were displaced toward longer pauses (Post).

Figure 5 shows the medians (and interquartile ranges) of the pause distributions

Table 3

Absolute and relative effects of the past reinforcer as a function of the upcoming reinforcer during the last 10 sessions of the multiple-schedule conditions of Phases 1 and 2. Shown are the reinforcer magnitudes (in seconds), median pauses (in seconds), absolute differences between the after-large and after-small medians, and the difference between the after-large and after-small medians expressed as a percentage of the after-small median.

	Magnitude (s)		Before small reinforcer				Before large reinforcer			
Bird	Small	Large	After small	After large	Absolute difference	Percentage difference	After small	After large	Absolute difference	Percentage difference
Phase 1										
3280	4	4	4.86	4.33	−0.53	−11	6.25	5.72	−0.53	−8
	2	6	4.63	4.93	0.30	6	3.89	4.04	0.15	4
	1	7	0.17	30.17	30.00	17,647	0.18	3.25	3.07	1,706
3611	3	3	16.75	19.17	2.42	14	17.50	18.56	1.06	6
	1.5	4.5	13.50	36.25	22.75	169	4.68	7.92	3.24	69
Phase 2										
5112	4	20	13.50	20.25	6.75	50	1.79	4.38	2.59	145
	4	20	6.50	36.50	30.00	462	1.69	6.88	5.19	307
3280	4	12	5.38	18.50	13.12	244	2.50	3.56	1.06	42
	4	12	3.67	6.50	2.83	77	2.47	3.40	0.93	38

from the last 10 sessions of the mixed-schedule conditions in Phase 2. In the Mix 4/12 condition, Bird 3280 showed clear effects of the past reinforcer but Bird 5112 did not. When the latter subject was studied under a more extreme condition (Mix 4/20), the distributions separated but the difference was small (cf. Figure 4).

Parallel results from the multiple-schedule conditions of Phase 2 are shown in Figure 6, with information about the absolute and relative effects of reinforcer magnitude presented in the lower half of Table 3. Again, the results are in line with those of Phase 1. In both the initial condition and the reversal, longer pauses occurred before the small reinforcer and after the large reinforcer. The previously described interaction between the past and upcoming reinforcers was replicated in both conditions for Bird 3280, but in only the second for Bird 5112. Because the sole difference across the conditions was the reversal of the stimuli correlated with the reinforcer magnitudes, it seems likely that bias introduced by the stimuli themselves obscured the interaction in Bird 5112's first condition. The problem may be attributed to the arbitrary selection of the stimuli for Bird 5112, which, in retrospect, was unfortunate. With Bird 3280, however, extensive pretesting had been conducted to find stimuli that minimized bias, and the interaction was maintained across the stimulus reversal.

Table 2 presents the median running response rates (and interquartile ranges) during the last 10 sessions of each condition in Phase 2, expressed as a function of the upcoming and past reinforcer magnitudes. The only consistent effect appeared in the multiple schedule conditions for Bird 3280. This subject pecked at lower rates before the small reinforcer than before the large one, a difference that was maintained across the stimulus reversal.

DISCUSSION

Previous investigators have reported contradictory effects of reinforcer magnitude on pausing, with some finding a direct relation and others an inverse relation. The present research sought to resolve the issue by showing that both sets of findings are correct, but that each is limited to demonstrating control by one of two competing factors. These factors define the interface during which pauses occur: in the period after a reinforcer has been delivered, and in the presence of stimulus conditions that accompany the schedule leading to the next reinforcer. To dissociate the effects

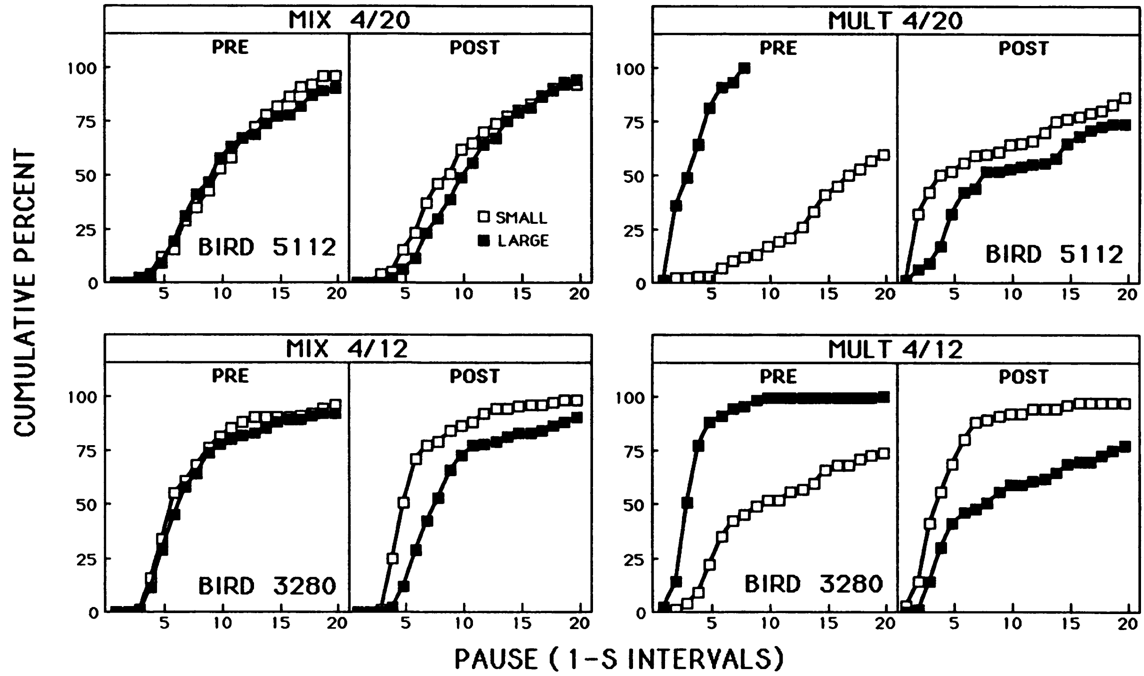

Fig. 4. Phase 2: Relative cumulative frequency distributions of pauses for Birds 5112 and 3280. Details as in Figure 1.

of these variables, we organized the data two ways, according to the past and upcoming reinforcer magnitudes. In so doing, we were successful in replicating both sets of previous findings. First, in line with research and theory on inhibitory aftereffects of reinforcement (Harzem & Harzem, 1981), pause duration was directly related to the magnitude of the past reinforcer. Second, when ratios leading to small and large reinforcers were distinguished by multiple-schedule stimuli that allowed for differences in stimulus control, pausing was inversely related to the magnitude of the upcoming reinforcer (cf. Shull, 1979).

The multiple-schedule conditions provided further evidence of competing control by the past and upcoming reinforcers. In the presence of a stimulus signaling a small reinforcer, the effect of the past reinforcer was dramatic, with pauses after the large reinforcer greatly exceeding pauses after the small one. By comparison, when the stimulus signaled a large reinforcer, the effect of the past reinforcer was considerably smaller, in both absolute and relative terms (Figures 3, 6; Table 3). One interpretation, derived from Perone et al.'s (1987) two-factor account, is in terms of an interaction between the response-inhibiting effect of the past reinforcer and the excitatory effect of stimuli signaling the upcoming reinforcer. When excitatory stimulus control was weak (i.e., when the stimulus signaled a small reinforcer), the past reinforcer was left to have the dominant effect, which was measured, of course, as longer pauses. But when excitatory control was strong (i.e., when the stimulus signaled a large reinforcer), it opposed the effect of the past reinforcer, and pauses were shorter.

Inhibitory aftereffects were observed on both mixed and multiple schedules, but the multiple schedules provided the more sensitive preparation for detecting them. Consider the Phase 1 data from Birds 3280 and 3611, who were studied with both schedules (cf. Figures 2 and 3). For Bird 3280, the difference in median pauses after the small and large reinforcers was only about 1 s in the Mix 1/7 condition. In the Mult 1/7 condition, however, the difference was 30 s in the presence of the stimulus signaling the small upcoming reinforcer and about 3 s in the stimulus signaling the large reinforcer. Bird 3611 showed no systematic difference in median pauses as a function of the past reinforcer in the Mix 1.5/4.5 condition (a clear difference did emerge

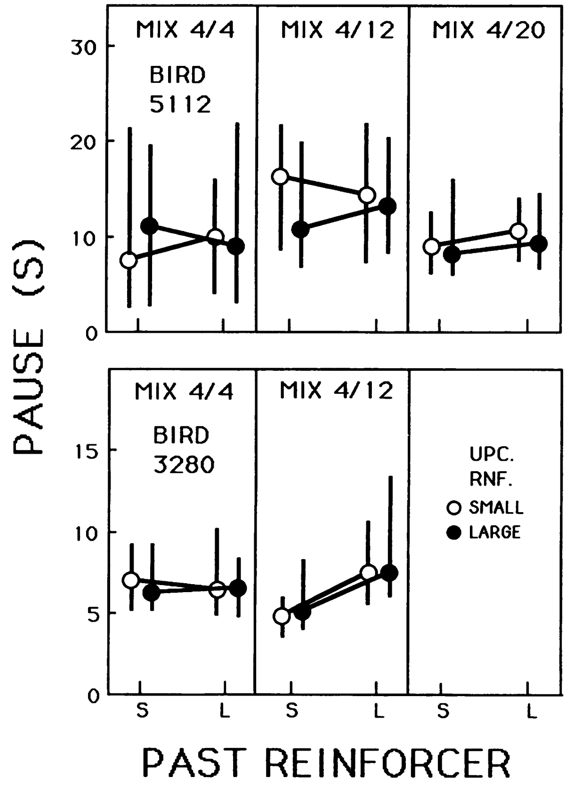

Fig. 5. Phase 2: Pause duration as a function of past and upcoming reinforcer magnitude in the mixed-schedule conditions for Birds 5112 and 3280. Details as in Figure 2.

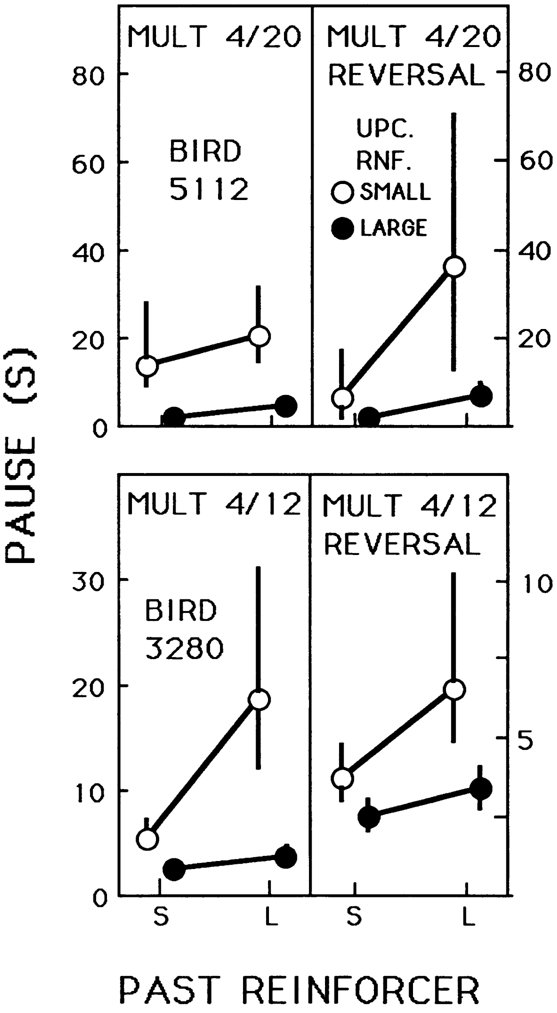

Fig. 6. Phase 2: Pause duration as a function of past and upcoming reinforcer magnitude in the multiple-schedule conditions for Birds 5112 and 3280. Details as in Figure 2.

in the Mix 0.75/5.25 condition). But in the Mult 1.5/4.5 condition, the difference was over 20 s in the presence of the signal for the small reinforcer and about 3 s in the signal for the large reinforcer. Similar patterns can be seen in the Phase 2 data of Birds 5112 and 3280 (cf. Figures 5 and 6). These findings can be explained in terms of the previously described interaction between inhibitory aftereffects and excitatory stimulus control. By arranging components in which excitatory control was weakened, the multiple schedules allowed the aftereffects to be uncovered. In the mixed schedules, the excitatory control was constant and thus tended to obscure the aftereffects somewhat.

Previous investigations have not explicitly considered the possibility of joint control, and therefore the procedures have been designed to isolate the effects of one factor or the other. Consider two studies of pausing on VR schedules that led to opposite conclusions. Priddle-Higson et al. (1976) measured pausing in relation to past reinforcers that varied in magnitude across the components of a mixed schedule; given the absence of discriminative stimuli and the measurement of aftereffects, it is not surprising that they reported a direct relation between magnitude and pausing. By comparison, Blakely and Schlinger (1988) measured pausing in relation to upcoming reinforcers that varied in magnitude across the components of a multiple schedule; given the presence of discriminative stimuli and the measurement of preratio pauses, it is not surprising that they reported an inverse relation. Blakely and Schlinger went on to suggest that the discrepancy was due to Priddle-Higson et al.'s manipulation of milk concentration rather than food access to define the levels of reinforcer magnitude (a suggestion contradicted by clear evidence of inhibitory aftereffects as a function of food access—see Hatten & Shull, 1983; Staddon, 1970). By the present account, the critical differences involved the opportunity for stimulus control (presence or absence of magnitude signals) and the strategy for measuring pauses (in relation to past or upcoming reinforcers).

We are aware of three studies concerned specifically with the possibility of joint control of pausing by past and upcoming conditions of reinforcement. The conclusions presented by the authors of these studies differ from those offered here; nevertheless, we believe their results can be interpreted as consistent with our own. First, Inman and Cheney (1974) manipulated both reinforcer magnitude (water volumes given to thirsty rabbits) and FR size across randomly alternating components of a multiple schedule. They reported that there were no effects of the past reinforcer or ratio. The only documentation of this, however, is in the form of sample cumulative records; the main figures show only the effects of the upcoming conditions (as expected, pausing was inversely related to upcoming magnitude and directly related to the upcoming ratio size). Furthermore, the sessions in the magnitude experiment lasted for only 15 ratios; such short sessions would tend to minimize the number of transitions from one magnitude to the next and, as a possible result, the opportunity for interactions of the sort observed in the present experiment.

In the second study, Mintz, Mourer, and Gofseyeff (1967) programmed multiple schedules with different FR sizes in the components and reported an interaction that may be seen as parallel to the one reported here: In the presence of the stimulus signaling a small ratio there was no effect of the past ratio size, but in the stimulus signaling a large ratio the median pauses were longer after the small ratio than after the large one. The parallel with the present results can be seen by recognizing that small ratios arrange relatively high reinforcement densities (perhaps functionally similar to large magnitudes) and large ratios arrange low densities (small magnitudes). Recast this way, Mintz et al. found that in the presence of the stimulus signaling high-density reinforcement there was no effect of the past density, but in the stimulus signaling low-density reinforcement, pauses were longer after the high density than after the low density. Unfortunately, Mintz et al.'s procedure used a fixed pattern of components (two short FRs followed by two long FRs). Thus, as Inman and Cheney (1974) noted, it is possible that the apparent interaction was actually an anticipatory effect: Although pausing in the transition between ratios n and $n + 1$ could involve an interaction between these ratios, it could also reflect discrimination of the size of ratio $n + 2$.

The third and most relevant study was by Griffiths and Thompson (1973), who studied FR size in mixed and multiple schedules with randomly alternating components and reported data in the form of relative pause distributions in the four transitions between the small and large ratios. No differences can be discerned in their graph of the mixed-schedule data (Griffiths & Thompson, 1973, Figure 2). In the multiple-schedule conditions, however, the past and upcoming ratios interacted in the same way reported by Mintz et al. (Griffiths & Thompson, 1973, Figure 3). Indeed, in the critical transition after the small ratio and before the large one (i.e., after high-density reinforcement and before low-density reinforcement), the shift in the pause distribution is striking, with a substantial increase in the longest class interval (representing pauses ≥30 s). Interestingly, although Griffiths and Thompson acknowledged the great change in this transition, they did not discuss the interaction it represented between the past and upcoming ratios. They concluded that the pausing was "largely a function of the relative size of the upcoming ratio" (p. 233).

Although the present results are consistent with an account of pausing in terms of a competition between unconditioned inhibitory aftereffects of reinforcement and excitatory stimulus control (Perone et al., 1987), the results do not require interpretation in such terms. Consider the specification by Harzem and Harzem's (1981) theory that the inhibitory aftereffects are *unconditioned.* In other words, the effects cannot be attributed to discriminative properties that the reinforcer may acquire, as, for example, when the reinforcer at the end of an FI functions as a negative discriminative stimulus by virtue of its association with a period in which further responding will not be reinforced (i.e., the beginning of the next interval). In the present research, the sequence of ratios ending in small and large reinforcers was designed specifically to prevent discrimination of the upcoming reinforcer magnitude on the basis of the past. Nevertheless, the possibility remains that reinforcer delivery functioned as a discriminative stimulus through a mechanism described by Hatten and Shull (1983; see also Gibbon, 1977, pp. 297–298). Although the magnitude of the just-delivered reinforcer bore no relation to the absolute magnitude of the next reinforcer, it was correlated with a local change from the overall magnitude. For example, in the Mix 1/7 condition the average magnitude was 4 s. Delivery of the small reinforcer signaled an improvement in the conditions of reinforcement (from 1 s to 4 s) and thus set the occasion for prompt responding. By comparison, delivery of the large reinforcer signaled a worsening in the reinforcement conditions (from 7 s to 4 s) and set the occasion for long pauses before responding.

As noted previously, the most striking results were in the multiple-schedule conditions, where the effects of the past reinforcer were found to vary as a function of the stimulus signaling the upcoming reinforcer. Such an interaction between multiple-schedule components could be properly described as a contrast effect, and it may be illuminating to consider the present findings in this light. Williams (1981, 1983) argued that the contrast observed in steady-state behavior may be ascribed to the schedule component that regularly follows the one in which responding is elevated or suppressed (the "following-schedule effect"). In the present experiment, however, the irregular alternation of the components prevented such effects. It appears that the contrast we observed is of a different sort than that described by Williams, although it is premature to conclude that it is generated by way of different mechanisms.

The results also may be compared to those obtained in studies of incentive contrast, particularly the type known as "simultaneous negative contrast" (Ludvigson & Gay, 1966, 1967; Matsumoto, 1969; see also reviews by Flaherty, 1982, and Mackintosh, 1974, chapter 7). These studies bear close similarity to the present one, both in procedure and results. Rats were given trials in two different-colored alleys (black vs. white) baited with different magnitudes of reinforcement. Across groups, the magnitudes correlated with the alleys were small and large (e.g., 1 vs. 25 food pellets), both small, or both large. Trials in the two alleys alternated randomly, and the key datum was the latency to leave a gray start box before running to the food at the other end of the alley. When the alley color signaled that the upcoming reinforcer was large, the group mean latencies tended to be short regardless of the magnitude of other reinforcer. By comparison, when the color signaled that the upcoming reinforcer was small, latencies were directly related to the magnitude of the other reinforcer. This pattern, produced by piecing together group means from various conditions, is strikingly similar to that seen in the individual subject data of the present study.

But there are two important differences. First, note that in describing the pattern in the group studies, reference is made to the "other reinforcer" rather than to the "past reinforcer." This is because the available data are not categorized according to the actual transitions in reinforcer magnitudes, but only according to the overall context of reinforcement. For example, it is possible to identify the latencies on "large trials" in a condition in which large trials and small trials alternated, but it is not possible to identify the latencies on the specific large trials that followed small trials. Second, even if such specific data were available, it seems unlikely that any differences observed as a function of the past reinforcer could be attributed to an unconditioned inhibitory aftereffect, because the trials were separated by intervals of 4 to 20 min—certainly long enough for aftereffects to dissipate (cf. Harzem & Harzem, 1981). Thus, the fact that the two magnitudes had an interactive effect on latencies in these discrete-trial experiments raises the possibility that the molar context of reinforcement somehow contributes to the interactive effects on pausing we observed in the free operant situation. In light of Hatten and Shull's (1983) proposal, described above, it seems likely that the context modulates the effects produced by local shifts in the conditions of reinforcement.

REFERENCES

Blakely, E., & Schlinger, H. (1988). Determinants of pausing under variable-ratio schedules: Reinforcer magnitude, ratio size, and schedule configuration.

Journal of the Experimental Analysis of Behavior, **50,** 65–73.

Crossman, E. K. (1971). The effects of fixed-ratio size in multiple and mixed fixed-ratio schedules. *The Psychological Record,* **21,** 535–544.

Davey, G. C. L., Harzem, P., & Lowe, C. F. (1975). The aftereffects of reinforcement magnitude and stimulus intensity. *The Psychological Record,* **25,** 217–223.

Felton, M., & Lyon, D. O. (1966). The post-reinforcement pause. *Journal of the Experimental Analysis of Behavior,* **9,** 131–134.

Ferster, C. B., & Skinner, B. F. (1957). *Schedules of reinforcement.* New York: Appleton-Century-Crofts.

Flaherty, C. F. (1982). Incentive contrast: A review of behavioral changes following shifts in reward. *Animal Learning & Behavior,* **10,** 409–440.

Gibbon, J. (1977). Scalar expectancy theory and Weber's Law in animal timing. *Psychological Review,* **84,** 279–325.

Griffiths, R. R., & Thompson, T. (1973). The post-reinforcement pause: A misnomer. *The Psychological Record,* **23,** 229–235.

Harzem, P., & Harzem, A. L. (1981). Discrimination, inhibition, and simultaneous association of stimulus properties: A theoretical analysis of reinforcement. In P. Harzem & M. D. Zeiler (Eds.), *Advances in analysis of behaviour: Vol. 2. Predictability, correlation, and contiguity* (pp. 81–124). New York: Wiley.

Harzem, P., Lowe, C. F., & Davey, G. C. L. (1975). After-effects of reinforcement magnitude: Dependence on context. *Quarterly Journal of Experimental Psychology,* **27,** 579–584.

Harzem, P., Lowe, C. F., & Priddle-Higson, P. J. (1978). Inhibiting function of reinforcement: Magnitude effects on variable-interval schedules. *Journal of the Experimental Analysis of Behavior,* **30,** 1–10.

Hatten, J. L., & Shull, R. L. (1983). Pausing on fixed-interval schedules: Effects of the prior feeder duration. *Behaviour Analysis Letters,* **3,** 101–111.

Inman, D. P., & Cheney, C. D. (1974). Functional variables in fixed ratio pausing with rabbits. *The Psychological Record,* **24,** 193–202.

Jensen, C., & Fallon, D. (1973). Behavioral aftereffects of reinforcement and its omission as a function of reinforcement magnitude. *Journal of the Experimental Analysis of Behavior,* **19,** 459–468.

Killeen, P. (1969). Reinforcement frequency and contingency as factors in fixed-ratio behavior. *Journal of the Experimental Analysis of Behavior,* **12,** 391–395.

Lowe, C. F., Davey, G. C. L., & Harzem, P. (1974). Effects of reinforcement magnitude on interval and ratio schedules. *Journal of the Experimental Analysis of Behavior,* **22,** 553–560.

Lowe, C. F., & Harzem, P. (1977). Species differences in temporal control of behavior. *Journal of the Experimental Analysis of Behavior,* **28,** 189–201.

Ludvigson, H. W., & Gay, R. A. (1967). An investigation of conditions determining contrast effects in differential reward conditioning. *Journal of Experimental Psychology,* **75,** 37–42.

Ludvigson, H. W., & Gay, S. E. (1966). Differential reward conditioning: S− contrast as a function of the magnitude of S+. *Psychonomic Science,* **5,** 289–290.

Mackintosh, N. J. (1974). *The psychology of animal learning.* London: Academic Press.

Matsumoto, R. T. (1969). Relative reward effects in differential conditioning. *Journal of Comparative and Physiological Psychology,* **68,** 589–592.

Mintz, D. E., Mourer, D. J., & Gofseyeff, M. (1967). Sequential effects in fixed-ratio postreinforcement pause duration. *Psychonomic Science,* **9,** 387–388.

Perone, M. (1985). A software system for real-time laboratory use of TRS-80 microcomputers. *Behavior Research Methods, Instruments, & Computers,* **17,** 119–121.

Perone, M., Perone, C. L., & Baron, A. (1987). Inhibition by reinforcement: Effects of reinforcer magnitude and timeout on fixed-ratio pausing. *The Psychological Record,* **37,** 227–238.

Powell, R. W. (1968). The effect of small sequential changes in fixed-ratio size upon the post-reinforcement pause. *Journal of the Experimental Analysis of Behavior,* **11,** 589–593.

Powell, R. W. (1969). The effect of reinforcement magnitude upon responding under fixed-ratio schedules. *Journal of the Experimental Analysis of Behavior,* **12,** 605–608.

Priddle-Higson, P. J., Lowe, C. F., & Harzem, P. (1976). Aftereffects of reinforcement on variable-ratio schedules. *Journal of the Experimental Analysis of Behavior,* **25,** 347–354.

Rider, D. P., & Kametani, N. N. (1984). Interreinforcement time, work time, and the postreinforcement pause. *Journal of the Experimental Analysis of Behavior,* **42,** 305–319.

Schlinger, H., Blakely, E., & Kaczor, T. (1990). Pausing under variable-ratio schedules: Interaction of reinforcer magnitude, variable-ratio size, and lowest ratio. *Journal of the Experimental Analysis of Behavior,* **53,** 133–139.

Shull, R. L. (1979). The postreinforcement pause: Some implications for the correlational law of effect. In M. D. Zeiler & P. Harzem (Eds.), *Advances in analysis of behaviour: Vol. 1. Reinforcement and the organization of behaviour* (pp. 193–221). New York: Wiley.

Staddon, J. E. R. (1970). Effect of reinforcement duration on fixed-interval responding. *Journal of the Experimental Analysis of Behavior,* **13,** 9–11.

Staddon, J. E. R. (1974). Temporal control, attention, and memory. *Psychological Review,* **81,** 375–391.

Williams, B. A. (1981). The following schedule of reinforcement as a fundamental determinant of steady state contrast in multiple schedules. *Journal of the Experimental Analysis of Behavior,* **35,** 293–310.

Williams, B. A. (1983). Another look at contrast in multiple schedules. *Journal of the Experimental Analysis of Behavior,* **39,** 345–384.

Zeiler, M. D. (1977). Schedules of reinforcement: The controlling variables. In W. K. Honig & J. E. R. Staddon (Eds.), *Handbook of operant behavior* (pp. 201–232). Englewood Cliffs, NJ: Prentice-Hall.

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