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LA PERSISTENCIA DE LAS EJECUCIONES BAJO PROGRAMAS DE RAZÓN FIJA Y DE REFORZAMIENTO DIFERENCIAL DE TASAS BAJAS

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Abstract

The effects of fixed-ratio (FR) and differential-reinforcement-of-low-rate (DRL) schedule histories on behavioral persistence were studied in three experiments with pigeons. After exposure to a multiple FR DRL schedule (baseline), either one of two prefeeding amounts were effected under the same schedule (test condition of Experiment 1), under extinction (test condition of Experiment 2), and under fixed-interval (FI) schedules (test condition of Experiment 3). FR response rates generally were less persistent than DRL response rates in Experiments 1 and 2, with the opposite occurring in Experiment 3. Regardless of the test schedules, FR response rates decreased and were less persistent under the large than under the small prefeeding amount. Rates under

DRL schedules, however, were maintained when the test schedule was the same as in baseline (Experiment 1), and increased when the baseline schedule changed to an FI (Experiment 3), regardless of the prefeeding amount. Only when extinction was in effect during the test (Experiment 2) were the effects of prefeeding amounts on DRL rates observed consistently, such that these rates decreased with the larger prefeeding amount. These results suggest that the contingencies on response rates and patterns established by the baseline schedule affect the persistence of operant behavior to different prefeeding amounts and to changes in the test schedule.

Keywords: behavioral persistence; reinforcement schedules; prefeeding; key peck; pigeons.

Resumen

Se estudiaron los efectos de historia en programas de reforzamiento de razón fija (RF) y de reforzamiento diferencial de tasas bajas (RDB) sobre la persistencia conductual en tres experimentos en los que se emplearon palomas como sujetos. Se expuso a las palomas a un programa múltiple RF RDB (línea base) y posteriormente se determinaron los efectos de entregar una de dos cantidades de alimento pre-sesión sobre la ejecución en este mismo programa de reforzamiento (condición de prueba del Experimento 1), en extinción (condición de prueba del Experimento 2) y en programas de intervalo fijo (IF; condición de prueba del Experimento 3). Las tasas de respuesta bajo el programa de RF fueron menos persistentes que aquellas mantenidas por el programa de RDB en los Experimentos 1 y 2, y lo opuesto ocurrió en el Experimento 3. Independientemente de los programas de prueba, las tasas de respuesta bajo el programa de RF fueron más bajas y menos persistentes cuando se entregó una cantidad mayor de comida pre-sesión que cuando se entregó una cantidad menor. Las tasas de respuesta bajo los programas de RDB se mantuvieron cuando el programa de prueba fue el mismo que en la línea base (Experimento 1) y aumentaron cuando el programa de la línea base se cambió por un IF (Experimento 3), independientemente de la cantidad de comida pre-sesión. Sólo cuando la extinción estuvo en efecto durante la prueba (Experimento 2) se observaron consistentemente los efectos de las cantidades de comida pre-sesión sobre las tasas de respuesta bajo el DRB, de tal forma que estas tasas disminuyeron a mayor cantidad de comida pre-sesión. Estos resultados sugieren que las contingencias en las tasas de respuesta y los patrones establecidos durante el programa de línea base afectan la persistencia de la conducta operante a las diferentes cantidades de comida pre-sesión y a los cambios en el programa de prueba.

Palabras clave: persistencia conductual, programas de reforzamiento, alimentación pre-sesión, presiones de tecla, palomas

Behavioral persistence can be defined as the degree of behavioral change that accompanies a change in contingencies of reinforcement. In resistance-to-change studies, persistence most often has been evaluated by exposing the subjects, during a baseline, to variable-interval (VI) schedules in each component of a multiple schedule of reinforcement (for other procedures, see Cohen, 1998; Nevin & Grace, 2000a). The VIs in each component might differ with respect to reinforcement rate (Nevin, 1974), delay (Grace, Schwendiman, & Nevin, 1998; Nevin, 1974) or magnitude (Harper, 1996; Nevin, 1974). In the test, a disrupting operation – for example, prefeeding (Nevin, Smith, & Roberts, 1987, Experiment 1), response-independent food during intercomponent intervals (ICIs; Nevin, 1974, Experiment 3), or extinction (Nevin, 1974; Nevin, Tota, Torquato, & Shull, 1990) – is effected and persistence is evaluated by comparing the degree of change in responding in each multiple-schedule component relative to baseline responding in that component. When VI schedules operate in both components, persistence tends to vary directly with baseline reinforcement rate (e.g., Nevin, 1974) and magnitude (e.g., Harper & McLean, 1992), and inversely with delay (e.g., Bell, 1999).

Other resistance-to-change studies have used different contingencies on response rates and patterns to program reinforcement in each component of the multiple schedule. The typical finding of such studies is that, all else being equal (e.g., reinforcement rates, delays and magnitude), component schedules controlling higher response rates also produce behavior that is less persistent than component schedules controlling lower response rates. Comparisons involved tandem VI differential-reinforcement-of-low-rate (DRL) and tandem VI differential-reinforcement-of-high-rate (DRH) schedules (Nevin, 1974, Experiment 5); tandem VI fixed-ratio (FR) and tandem VI DRL schedules (Lattal, 1998); VR and VI schedules (Nevin, Grace, Holland, & McLean, 2001), and VR and DRL schedules (Doughty et al., 2005, Experiment 1).

Characteristics of the disrupting operations also influence behavioral persistence. Based on previous studies (e.g., Nevin, 1974; Nevin, 1992b; Nevin et al., 1983; Nevin et al., 1990; Shettleworth & Nevin, 1965), Nevin (1992a) suggested that greater magnitudes of the disrupting operation (e.g., increasing amounts of prefeeding) lead to greater reductions in responding. Moreover, disrupting operations such as increases in satiation and extinction seem to have additive effects on persistence. Nevin and Grace (2000b), for example, used either a variable time (VT) schedule during the ICI, extinction, or a VT during the ICI plus extinction as disruptors after a multiple VI VI schedule was in effect in baseline, and found ordinarily additive effects of such disruptors. That is, the sum of the relative persistence to VT and to extinction was similar to the persistence to VT plus extinction (i.e., when these operations were implemented together). Nevin et al. (2001) replicated these results using a multiple VI VR schedule. The individual and combined effects of disrupting operations as a function of other baseline contingencies that produce high or low response rates, however, remain unknown. De-

termining these effects is important to establish the generality of the findings that, regardless of baseline response rates, increasing the magnitude of the disrupting operations decreases persistence, and combined disrupting operations affect behavior additively.

The primary purpose of the present study was to extend the analysis of the effects of different baseline schedules that generate high and low response rates on behavioral persistence to an FR and a DRL schedule. The effects of these schedules have been studied with different dependent measures (e.g., absolute response rates, cf. Weiner, 1964, 1965, 1969; distribution of responses throughout the interreinforcer intervals, cf. LeFrancois & Metzger, 1993). To our knowledge, however, the behavioral persistence engendered by these schedules, measured as response rates relative to baseline, has been studied solely by Lattal (1989), but he used a multiple tandem VI FR tandem VI DRL schedule. Programming the VI in tandem with the FR and DRL schedules allows for equating reinforcement rates between components. However, adding such a schedule also makes the contingencies more similar between components - for example, establishing a similar aperiodicity to reinforcer deliveries in the FR and DRL schedules, and imposing an interval contingency that is similar in both schedule components. In the present study, to investigate the effects of the specific FR and DRL contingencies (as opposed to other interval-based, combined, contingencies) on behavioral persistence, the interreinforcer intervals between the components were yoked (cf. Freeman & Lattal, 1992).

The second purpose of the present study was to evaluate persistence under different and combined disrupting operations, after exposure to FR and DRL schedules in the baseline. Specifically, in Experiment 1, we asked whether greater disrupting operations lead to greater reductions in responding when the baseline schedules are FR and DRL, as they do when these schedules are VI and VR (cf. Nevin, 1992a). In Experiment 2, we investigated whether prefeeding and extinction have additive effects with FR and DRL baseline schedules, as they do with VI and VR schedules (cf. Nevin & Grace, 2000b; Nevin, Grace, et al., 2001). In Experiment 3, we evaluated the persistence of behavior previously maintained by FR and DRL schedules to disruption by prefeeding when the schedule changed to an FI (with the same interreinforcer intervals [IRI] as in baseline, cf. Freeman & Lattal, 1992). In summary, the present study aimed to extend previous research by evaluating the degree of behavioral persistence as a function of FR and DRL reinforcement-schedule histories, and the nature, magnitude, and interactions of the disrupting operations.

Experiment 1

In this experiment, the persistence of responding maintained by FR and DRL schedules under different magnitudes of prefeeding was investigated.

Method

Subjects. Six mixed-breed, experimentally-naïve pigeons were maintained at approximately 80% of their free-feeding weights (except during sessions with prefeeding, as described in the Procedure). Pigeons were housed individually, with free access to water, in a room with a 12hr: 12 hr light:dark cycle.

Apparatus. One operant chamber (29.5 cm wide by 35 cm long by 25 cm high) located in a sound- and light-attenuating enclosure was used. The front wall was an aluminum work panel with four response keys (2-cm in diameter) horizontally aligned, spaced evenly apart, and located 25 cm from the floor. Only the two centermost keys were used (hereafter, the *right* and *left* keys). Each key was operated by a force of at least 0.14 N and could be transilluminated red or white. When raised, a hopper located behind a 5 cm by 5 cm aperture on the midline of the work panel, with its lower edge 6 cm from the floor, was illuminated with a white light and provided 3-s access to mixed grain (reinforcers). A white houselight, located near the ceiling at the rear wall, provided general illumination except during reinforcer deliveries (when the keylight also was off). A computer equipped with MED-PC ® interface and software controlled conditions and recorded data.

Procedure

Training and Baseline. After keypeck response shaping, pecking was acclimated to a multiple FR 18 DRL 5-s schedule. The FR was in effect on the right [red] key, and the DRL on the left [white] key. After two such sessions, the FR value of the multiple FR 18 DRL 5-s schedule was altered to equate reinforcement rates between components (cf. Freeman & Lattal, 1992). The maximum reinforcement-rate difference allowed between components was 2 reinforcers per minute, during 5 consecutive sessions. The final FR value was 10, for Pigeons R1 and R5; 12, for Pigeon R3; 15, for Pigeons R2 and R4; and 20, for Pigeon R6. Thirty minutes after each daily session, each pigeon received enough mixed-grain to maintain 80% of its free feeding weight.

All sessions started with the houselight and keylights off for 90 s, after which the 180-s multiple-schedule components alternated strictly, always starting with the FR component and ending after five presentations of each component. Components were separated by 90-s ICIs during which the chamber was dark.

Once response rates in each component were considered stable on visual inspection, the Average Maximum Food Consumed (AMFC) by each pigeon was measured. During this measurement, experimental sessions were not conducted. The maximum food consumed by each pigeon was measured (when each was at 80% of its free-

feeding weight and after 23.5 hr of food deprivation) by providing access to 60 g of grain (the same grain delivered as reinforcers during sessions) in the home cage and recording the total amount consumed in 30 min. After each measurement day, each pigeon received 5 g of pigeon food (which did not contain the grain delivered as reinforcers) per day until 80% of the pigeon's free-feeding weight was recovered. For each pigeon, the AMFC was set as equal to the average amount of food consumed during five measurement days.

After AMFC measurement and return to 80% of the pigeons' free feeding weight, the baseline condition was in effect. During baseline, each pigeon was reexposed to daily sessions of the multiple FR DRL schedule (with the same values described previously) until there were no ascending or descending trends in response rates in each schedule component for five consecutive sessions, as visually assessed. In this and the following (test) condition, to increase the probability of control of behavior by the experimental events, post-session feedings were discontinued (i.e., all food was consumed during experimental sessions).

Test. The procedure in this condition was as in baseline except that, before each of five successive sessions, different amounts of grain were provided to the pigeons. Pigeons R1, R4 and R6 (hereafter, the 20% pigeons) received 20% of their AMFC, and Pigeons R2, R3 and R5 (hereafter, the 100% pigeons) received 100% of their AMFC. Consumption took approximately 5 min for the 20% pigeons and 30 min for the 100% pigeons. To ensure that sessions started approximately 30 min after consumption, mixed-grain first was made available 35 min and 60 min before sessions for the 20% pigeons and the 100% pigeons, respectively. Sessions were conducted on alternate days for the 20% pigeons, and after recovery of 80% of free-feeding weights (which took approximately 3-5 days), for the 100% pigeons. On days when sessions were not conducted, each pigeon received 5 g of pigeon food in its home cage.

Results and Discussion

Table 1 (upper portion) shows the number of sessions in the baseline and test conditions, for each pigeon. Also shown is the average reinforcement rate in each schedule component during the last five sessions of the baseline condition and during all five sessions of the test condition. During baseline, reinforcement rates were similar between components for Pigeons R1, R3, R4 and R6 (for these pigeons, the difference in reinforcement rates between components was within the 2 reinforcers-per-minute criterion established during training) but were higher in the FR component for Pigeons R2 and R5. During the test, reinforcement rates were similar between components for all pigeons.

Table 1

Average Reinforcement (Sᴿ) Rates (in Reinforcers per Min, with Range in Parenthesis) in Each Multiple-Schedule Component During the Last Five Sessions of the Baseline and all Sessions of the Test Conditions (Except Extinction, in Experiment 2), Number of Sessions in Each Condition, and the Percentage of the Average Maximum Food Consumed (AMFC) Given to Each Pigeon Before Test Sessions in each Experiment. For Experiment 2, Mean Difference Between "FR" and "DRL" Response Rates During the First Five Sessions of Each Test Condition Also Are Shown.

EXPERIMENT 1

Condition		R1	R2	R3	R4	R5	R6
Baseline	Sᴿ Rate FR	5.0 (4.3-5.3)	6.2 (6.0-6.3)	7.0 (6.9-7.3)	5.1 (4.5-6.0)	6.4 (6.2-6.5)	6.2 (6.0-6.3)
	Sᴿ Rate DRL	4.4 (3.9-5.0)	2.8 (2.1-3.1)	5.3 (4.9-5.9)	5.8 (5.5-6.0)	4.1 (2.8-5.3)	5.7 (5.6-5.7)
	Sessions	13	10	16	10	16	27
Test	AMFC	20%	100%	100%	20%	100%	20%
	Sᴿ Rate FR	5.5 (5.2-6.0)	1.7 (0.3-3.7)	3.7 (2.9-3.8)	5.1 (4.8-5.3)	4.5 (3.7-5.2)	6.5 (6.3-6.7)
	Sᴿ Rate DRL	4.0 (3.5-4.2)	3.7 (3.3-4.1)	4.3 (3.7-5.1)	6.0 (5.9-6.1)	4.4 (3.5-4.6)	5.5 (5.3-5.7)
	Sessions	5	5	5	5	5	5

(Continued)

EXPERIMENT 2

Condition		R1	R2	R3	R4	R5	R6
Baseline 1	S^R Rate FR	5.8 (5.3-6.2)	6.0 (5.8-6.3)	7.6 (7.5-7.9)	4.9 (4.5-5.3)	5.6 (4.7-6.3)	5.5 (5.3-5.7)
	S^R Rate DRL	3.3 (3.0-3.7)	3.1 (2.6-3.8)	4.9 (4.4-5.3)	5.5 (4.9-6.7)	5.1 (4.7-5.3)	5.5 (5.1-5.9)
	Sessions	6	5	5	9	6	5
Test 1	AMFC	20%	100%	100%	100%	20%	20%
	Sessions	19	8	7	17	7	17
Baseline 2	S^R Rate FR	5.4 (4.6-5.9)	5.7 (5.3-6.0)	6.1 (5.8-6.4)	--	--	--
	S^R Rate DRL	2.3 (1.9-2.6)	3.4 (2.7-4.1)	5.6 (5.1-5.9)	--	--	--
	Sessions	13	25	32	--	--	--
Test 2	AMFC	100%	20%	20%	--	--	--
	Sessions	6	18	15	--	--	--

(Continued)

EXPERIMENT 3

Condition		R1	R2	R3	R4	R5	R6
Baseline 1	S^R Rate FR	5.6 (5.5-5.7)	6.0 (5.9-6.1)	7.6 (7.3-7.7)	4.5 (3.7-5.3)	5.7 (5.5-5.9)	6.5 (6.3-6.7)
	S^R Rate DRL	4.6 (4.4-4.9)	3.2 (2.7-3.7)	5.2 (4.8-5.7)	6.0 (5.5-6.3)	3.1 (2.4-3.7)	5.3 (4.8-5.7)
	Sessions	12	10	11	16	14	11
Test 1	AMFC	20%	100%	100%	20%	100%	20%
	S^R Rate "FR"	3.7 (3.7-3.9)	2.5 (1.1-3.2)	4.6 (3.8-4.9)	3.9 (3.8-4.0)	2.8 (1.9-3.3)	4.3 (4.2-4.4)
	S^R Rate "DRL"	3.7 (3.1-3.9)	2.9 (2.1-3.3)	4.6 (4.1-5.0)	3.9 (3.6-4.0)	2.9 (2.1-3.3)	4.3 (3.8-4.4)
	Mean Difference	49.95	10.96	61.12	35.14	19.38	10.02
	Sessions	38	12	28	14	13	39

EXPERIMENT 3

Condition	R1	R2	R3	R4	R5	R6
Baseline 2						
S^R Rate "FR"	5.7 (5.3-6.1)	5.6 (4.9-5.9)	7.3 (6.8-7.5)	5.5 (5.0-5.9)	5.1 (4.3-6.0)	5.9 (5.6-6.3)
S^R Rate "DRL"	2.0 (0.9-2.6)	3.3 (3.0-3.8)	5.2 (4.4-5.7)	6.0 (5.7-6.3)	4.7 (4.3-4.9)	5.3 (4.7-5.8)
Sessions	18	6	6	9	20	7
Test 2						
AMFC	100%	20%	20%	100%	20%	100%
S^R Rate FR	3.4 (3.1-3.6)	3.3 (3.3)	4.9 (4.9-5.0)	3.6 (3.1-3.9)	3.3 (3.2-3.3)	4.1 (3.5-4.3)
S^R Rate DRL	3.6 (3.5-3.7)	3.3 (3.2-3.3)	4.9 (4.9-5.0)	3.9 (3.7-4.0)	2.8 (2.5-3.0)	4.2 (4.0-4.4)
Mean Difference	16.26	19.34	26.12	2.88	47.16	91.5
Sessions	5	5	5	5	5	5

(Continued)

EXPERIMENT 3

Condition		R1	R2	R3	R4	R5	R6
Baseline 3	S^R Rate FR	6.4 (5.8-6.8)	5.9 (5.7-6.1)	7.6 (7.4-7.7)	5.6 (5.3-5.9)	4.9 (4.3-5.1)	--
	S^R Rate DRL	3.6 (2.8-4.0)	1.9 (1.4-2.7)	5.2 (4.6-5.6)	5.3 (4.6-5.8)	5.4 (5.2-5.6)	--
	Sessions	30	30	30	30	30	--
Test 3	AMFC	20%	100%	100%	20%	100%	--
	S^R Rate "FR"	4.2 (3.7-5.9)	3.3 (3.2-3.3)	4.3 (2.7-4.9)	4.0 (4.0)	2.5 (2.0-3.0)	--
	S^R Rate "DRL"	4.0 (3.5-5.6)	3.3 (3.2-3.3)	4.8 (4.4-4.9)	3.8 (3.2-4.0)	2.6 (1.8-2.9)	--
	Mean Difference	62.6	1.1	1.84	45.78	19.76	--
	Sessions	5	7	5	5	5	--

Figure 1 shows that, during baseline, response rates were higher in the FR than in the DRL component for each pigeon. During the test, delivering 20% of the AMFC did not affect response rates substantially in either component, and delivering 100% of the AMFC decreased response rates only in the FR component. Figure 2 shows that changes in log-proportions of baseline response rates did not occur for the 20% pigeons, with the exception of a transitory increase in DRL-response rates (sessions 3 and 4) for Pigeon R1. For the 100% pigeons, response rates decreased more in the FR than in the DRL component, although the difference for R5 was less than for the other two pigeons. These results replicate previous findings that behavior maintained by reinforcement schedules that control higher response rates also engender behavior that is less persistent (e.g., Doughty et al., 2005; Lattal, 1989; Nevin, 1974, Exp. 5; Nevin, Grace, et al., 2001).
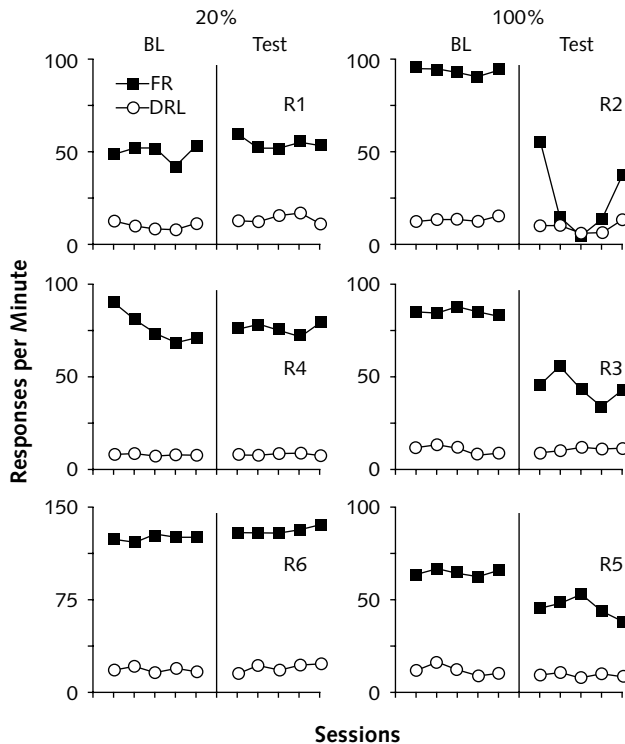

Figure 1. Responses per min for each 20% (left) and 100% (right) pigeon during the last five sessions of the baseline (BL) and during each session of the test in Experiment 1. Circles and squares show responses per min in the FR and DRL multiple-schedule components, respectively. Note the different Y-axis scale for Pigeon R6.
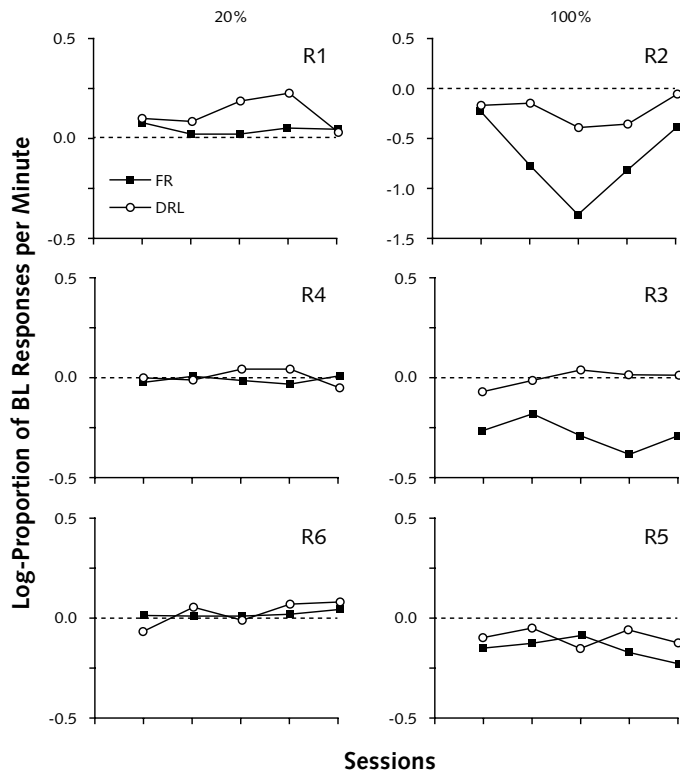
Figure 2. Log-proportion of baseline response rate for each 20% (left) and 100% (right) pigeon during each session of the test in Experiment 1. Data points are the logarithm of the response rate in each session of the test divided by the average response rate of the last five sessions of the baseline. Circles and squares show responding in the FR and DRL multiple-schedule components, respectively. Note the different Y-axis scale for Pigeon R2.

The effects of the reinforcement schedules and of the prefeeding amounts on behavioral persistence are summarized in Figure 3. Each data point is the average log-proportion of baseline response rates in one schedule component for all pigeons exposed to the 20% or 100% AMFC during all test sessions. Response rates decreased consistently from baseline only at the 100% prefeeding amount and when the FR schedule was in effect, extending previous findings that greater prefeeding amounts lead to greater reductions in VI response rates (cf. Nevin, 1992a) to responding maintained by FR schedules. In addition, the data shown in Figure 3 refine the relation between prefeeding amount and response rate, insofar as response rates decreased more consistently across pigeons (as indicated by the error bars) in the FR than in the DRL schedule with the greater prefeeding amount.
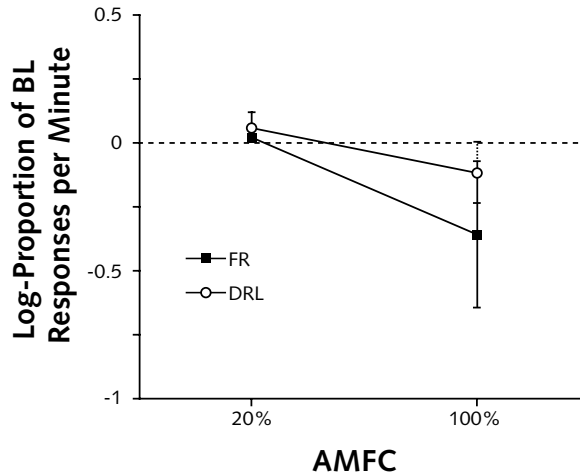
Figure 3. Log-proportion of baseline response rates as a function of AMFC in Experiment 1. Data points are averages of responding of all pigeons exposed to the 20% or 100% AMFC during all test sessions. Circles and squares show responding in the FR and DRL multiple-schedule components, respectively. DRL and FR error bars are dashed and solid, respectively, and show ± 1 standard deviation.

Experiment 2

Experiment 2 assessed the combined effects on persistence of prefeeding and extinction after FR and DRL schedules were in effect during baseline. This experiment thus tested the generality of the results of Nevin, Grace, et al. (2001), who found an additive effect of satiation and extinction on responding maintained by VI and VR schedules. In addition, as in Experiment 1, behavioral persistence in Experiment 2 was investigated by using a within-subject rather than a between-subjects design.

Method

Subjects and Apparatus. The pigeons and the apparatus were as in Experiment 1.

Procedure. Pigeons R1, R2 and R3 were exposed to two cycles of baseline and test conditions. Pigeons R4, R5 and R6 were exposed only once to each condition.

Baseline. The procedure and stability criteria in this condition were as in Experiment 1. In each baseline, the final FR value was 10 for Pigeon R1; 15 for Pigeon R2; 12 (first baseline) and 15 (second baseline) for Pigeon R3; 15 for Pigeon R4; and 10 for Pigeons R5 and R6.

Test. During the test sessions, no reinforcers were provided (i.e., extinction was in effect). Otherwise, these sessions and the prefeeding procedure were conducted as in Experiment 1 (i.e., pigeons received 100% or 20% of the AMFC, respectively, 60 min and 35 min before sessions). Sessions were conducted on alternate days when pigeons received 20% of the AMFC, and after recovery of 80% of the free-feeding weight when pigeons received 100% of the AMFC. In the first test, Pigeons R1, R4 and R6 received 20% of the AMFC, and Pigeons R2, R3, and R5 received 100% of the AMFC. The prefeeding amount delivered to Pigeons R1, R2 and R3 was reversed in the second test session. Each test session lasted until response rates were 0.5 responses per min or less in each schedule component for one session, or until 18 sessions were conducted.

Results and Discussion

The middle portion of Table 1 shows reinforcement rates in each schedule component during each baseline and test condition of Experiment 2. Baseline reinforcement rates were similar between components, except for Pigeons R1 and R2 (first and second baseline conditions), and Pigeon R3 (first baseline condition), for which reinforcement rate was higher in the FR than in the DRL component.

Figures 4 and 5 show, respectively, response rates and log-proportion of baseline response rates. For each pigeon, response rates were higher in the FR than in the DRL component in each baseline. During each test condition, in both components, response rates reached zero or near-zero in fewer sessions when the pigeon received 100% rather than 20% of the AMFC (Figure 4). Except for Pigeon R3 (first test), greater reductions in responding relative to baseline occurred in the presence of the stimulus previously correlated with the FR (hereafter, the "FR") than in the presence of the stimulus previously correlated with the DRL (hereafter, the "DRL") component (Figure 5). Thus, FR rates were less persistent in extinction than DRL rates, particularly under the largest (i.e., 100% of AMFC) prefeeding amount. These results replicate and extend those of the present Experiment 1 and of previous studies (e.g., Lattal, 1989), suggesting that DRL schedules maintain behavior that is more persistent under extinction than FR schedules. As in Experiment 1, the differential persistence observed in this experiment was not related systematically to baseline reinforcement-rate differences between components, because when reinforcement rates differed, they were higher in the FR component. In fact, the lower persistence of FR than DRL responding was the opposite of what would be expected based on the results of previous experiments where there was reported a direct relation between reinforcement rates and persistence (e.g., Nevin, 1974; Nevin et al., 1990; Nevin & Grace, 2000).

Figure 6 shows, for Experiments 1 and 2, the relation between prefeeding amount, baseline, and test schedules. Data are the log-proportion of baseline response rates
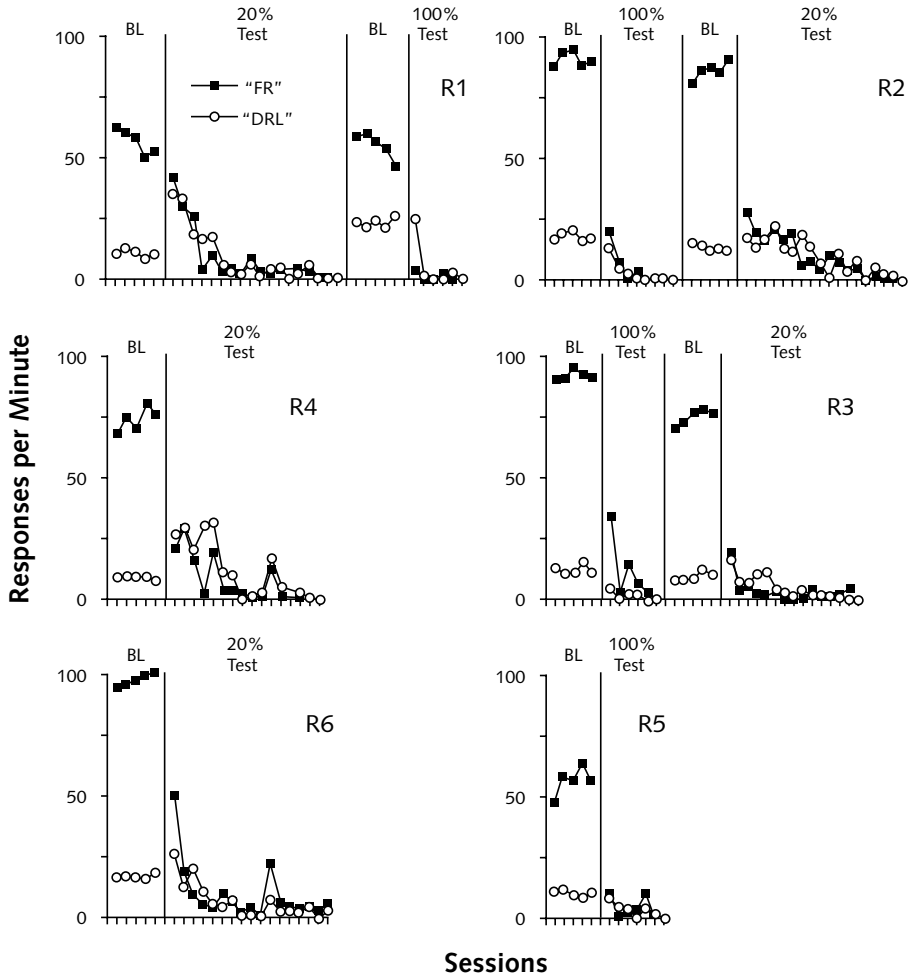
Figure 4. Responses per min during the last five sessions of each baseline condition and during each session of the tests conditions (20% and 100% of AMFC) for each pigeon in Experiment 2. In each baseline, circles and squares show responses per min in the FR and DRL multiple-schedule components, respectively. Circles and squares show, in each session of the test conditions, responses per min in the components correlated with the FR ("FR") and DRL ("DRL") schedules in the immediately preceding baseline condition, respectively. Note the different Y-axis scale for Pigeon R6.

averaged for all pigeons across the first five sessions of each test. The data allow the comparison of the effects of prefeeding when the test schedules were maintained (Experiment 1) with the effects of prefeeding when the test schedule changed to extinction (Experiment 2). When the FR schedule was in effect during baseline (upper graph),
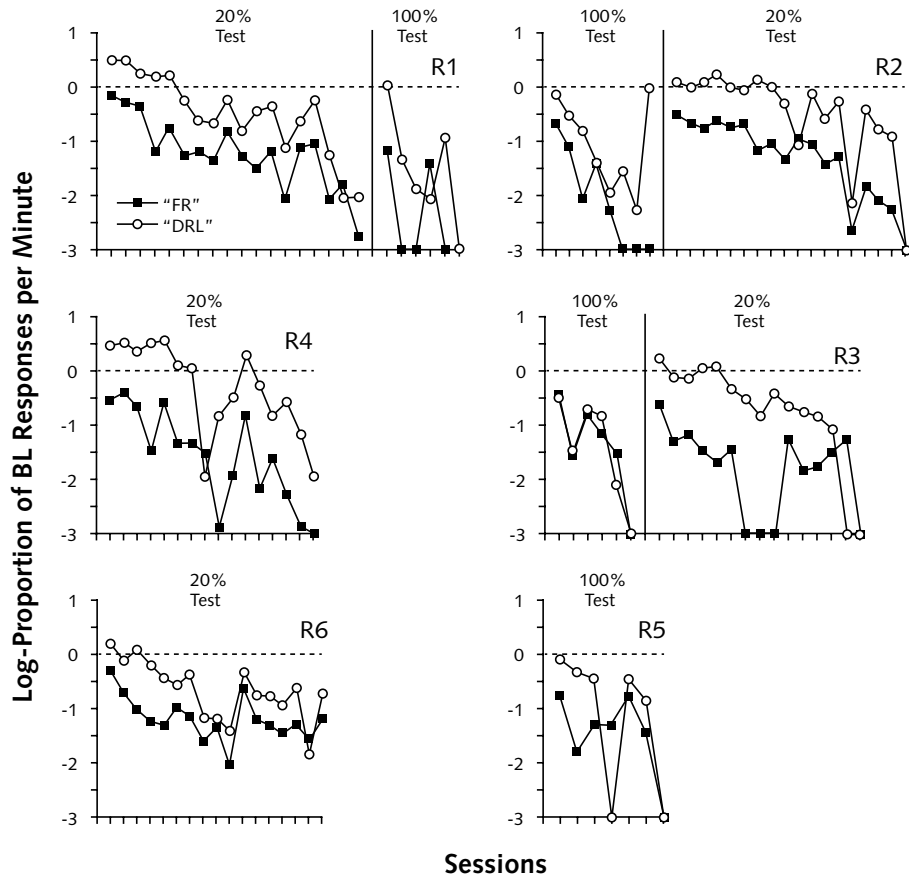
Figure 5. Log-proportion of baseline response rate during each session of the test conditions for each pigeon in Experiment 2. Left and right graphs show data for pigeons exposed to the 20-100 % AMFC test conditions and to the 100-20% AMFC test conditions. Other details as in Figure 2.

response rates decreased more relative to baseline when 100% rather than 20% of AMFC was in effect, especially when extinction was programmed during the test. Also, the lines in the upper graph are parallel, suggesting that prefeeding amounts and extinction had additive effects on decreasing "FR" rates relative to baseline. The "DRL" rates (bottom graph), however, decreased substantially only when extinction was in effect during the test and when the prefeeding amount was 100%. Additionally, the lines in the bottom graph are not parallel, indicating an interaction between prefeeding amount and extinction, that is, the effects of prefeeding on "DRL" rates depended on extinction being in effect during the test.
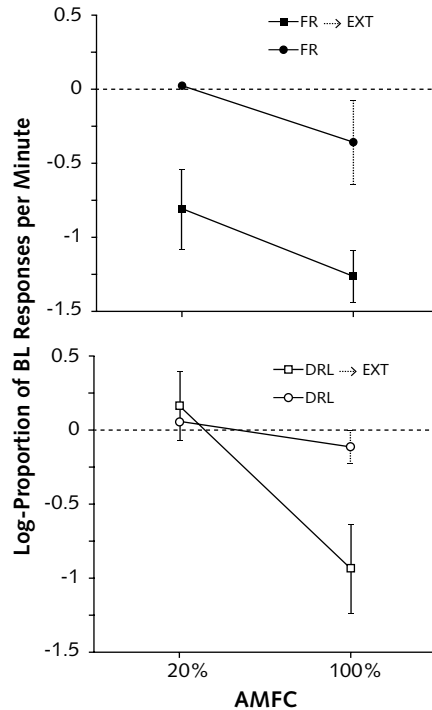
Figure 6. Log-proportion of baseline response rate as a function of AMFC and test schedules, in Experiments 1 and 2. Closed circles and squares (upper graph) show, respectively, responding in the FR schedule (test of Experiment 1) and in EXT in the presence of the stimulus previously correlated with the FR schedule (test of Experiment 2). Open circles and squares (lower graph) show, respectively, responding in the DRL schedule (test of Experiment 1) and in EXT in the presence of the stimulus previously correlated with the DRL schedule (test of Experiment 2). Data are averaged across the first five sessions of the test conditions. Error bars for data from Experiments 1 and 2 are dashed and solid, respectively. Other details as in Figure 3.

The additive and interactive effects of prefeeding amount and extinction after a history of, respectively, FR and DRL schedules, extend and qualify the results of previous studies. For example, Nevin and Grace (2000b) found that response-independent food during the ICI had additive effects to extinction in the test when the baseline schedule was a multiple VI VI (see also Nevin, Grace, et al., 2001, for similar results when a multiple VI VR was the baseline schedule). The results of these previous studies, and those of the present experiment, indicate that prefeeding amounts and extinction have additive effects after VI-, VR-, and FR-schedule histories, but not after a DRL-schedule history. This establishes a limit to the validity of the additive effect of extinction and prefeeding to behavior maintained by the former reinforcement schedules.

Experiment 3

Behavioral persistence commonly has been assessed by using prefeeding (e.g., Nevin et al., 1990), response-independent food during the ICI (e.g., Lattal, 1989), or extinction (e.g., Nevin, McLean & Grace, 2001). In the present experiment, the persistence of FR and DRL responding under different prefeeding amounts was studied by changing the reinforcement schedule in the test to an FI. An FI was used as the test schedule because it allows variations in response rates to occur during the IRI while reinforcement rates are equated between baseline and test conditions (cf. Freeman & Lattal, 1992).

Method

Subjects and Apparatus. The pigeons and the apparatus were the same as in Experiments 1 and 2.

Procedure. Each pigeon was exposed to three cycles of baseline and test conditions (except for Pigeon R6, which was exposed to two such cycles).

Baseline. The procedure and the stability criteria were as described in the baseline of Experiment 1. The final FR value in each baseline was 10 for Pigeons R1 and R5, 15 for Pigeon R2, 12 for Pigeon R3, 10 (first baseline) and 15 (second and third baselines) for Pigeon R4, and 20 (first baseline) and 10 (second baseline) for Pigeon R6.

Test. A multiple FI FI schedule was in effect. Otherwise, the procedure was as described in the test condition of Experiment 1. For each pigeon, the FI values were established by selecting, from among the last 10 sessions of the immediately preceding baseline, five sessions with the most similar IRIs between the FR and DRL schedule components. The value of the FI was set equal to the average IRIs in each component during these five sessions. The FI value in each test condition was 12 s, for Pigeon R1; 14 s, for Pigeon R2; 9 s, for Pigeon R3; 11 s, for Pigeon R4; 14 s, for Pigeon R5; and 10 s, for Pigeon R6.

Prefeeding was conducted as in Experiment 1. Across tests, Pigeons R1, R4, and R6 received 20%, 100%, and 20% of the AMFC (but Pigeon R6 was not exposed to the last, 20% test), and Pigeons R2, R3, and R5 received 100%, 20% and 100% of the AMFC. The first test ended after 10 sessions during which a maximum difference of 10 responses per min between multiple-schedule components occurred. The second and third tests lasted for five sessions each (except for Pigeon R2, for which the third test lasted for seven sessions).

Results and Discussion

The lower portion of Table 1 shows reinforcement rates during each baseline and test condition of Experiment 3. Reinforcement rates were higher in the FR component for Pigeon R1 in the second and third baseline, for Pigeons R2 and R3 in all baselines, and for Pigeon R5 in the first baseline. During the other conditions and for the other pigeons, reinforcement rates were similar between components.

Figure 7 shows that, for each pigeon, response rates in each baseline were higher in the FR than in the DRL component. During the first test, "DRL" and "FR" response rates eventually converged to similar values. During the second and third tests, of the seven cases in which response rates converged between components (Pigeons R1, R2, R3, R4 and R6, in the second test, and Pigeons R2 and R3, in the third test), five cases were at the largest (i.e., 100% of the AMFC) prefeeding amount (Pigeons R1, R4 and R6, in the second test, and Pigeons R2 and R3, in the third test). Table 1 shows that, for each pigeon, the mean difference between "FR" and "DRL" response rates during the first five sessions of each test was smaller (indicating similar response rates between components) under the largest prefeeding amount (100% of the AMFC), except for Pigeon R3 in the first test.
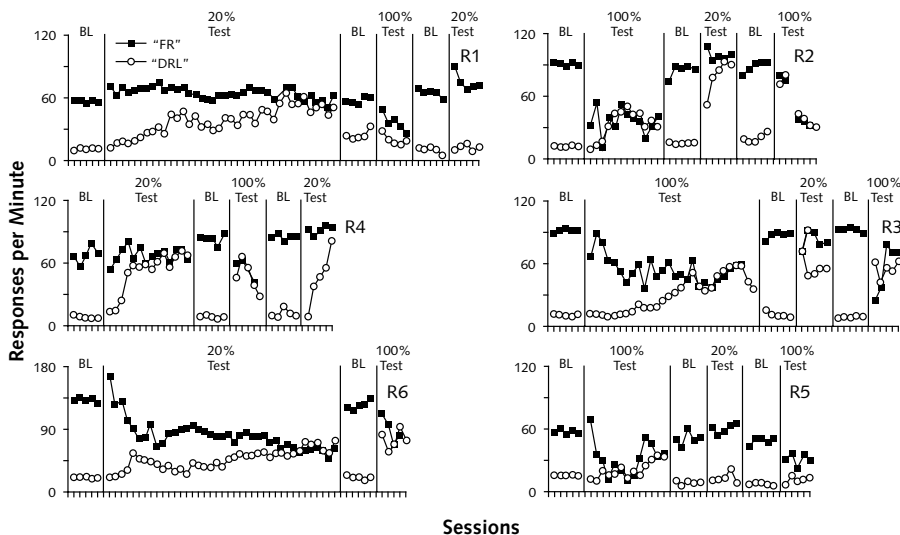

Figure 7. Responses per min during the last five sessions of each baseline condition and during each session of the test conditions (20% and 100% of AMFC) for each pigeon in Experiment 3. Note the different Y-axis scale for Pigeon R6. For Pigeon R2 (third test condition) a break in each function represents missing data. Other details as in Figure 4.

Figure 8 indicates that "FR" response rates decreased consistently relative to baseline only under the largest preefeeding amount, that is, the 100% of the AMFC (except for the response-rate decrease found under both 20% and 100% of the AMFC for Pigeon R6). "DRL" response rates increased, for each pigeon, under both prefeeding amounts (except for Pigeon R1 in the second and third tests). That is, response rates maintained by the DRL schedule in baseline generally were less persistent when the schedules were changed to FI than were response rates previously maintained by the FR schedule. These results cannot be attributed solely to differences in reinforcement rates, because responding was less persistent after DRL exposure even when the obtained reinforcement rates were similar between components (e.g., Pigeon R1, in the first test, and Pigeons R4 and R6, in all tests). The results, however, do not replicate those of previous studies in which higher response rates were less persistent than lower response rates (e.g., Lattal, 1989; Experiments 1 and 2 of the present study). The results are, however, consistent with the fact that FR-schedule performance shares more commonalities with FI schedules than with DRL schedules (cf. Freeman & Lattal, 1992). On the one hand, FR and FI schedules share the characteristic break-and-run patterns (e.g., Schneider, 1969; Wanchisen, Tatham & Mooney, 1989) and similar pausing, when IRIs between the two schedules are yoked to one another (cf. Killeen, 1969). Responding under DRL schedules, on the other hand, typically is characterized
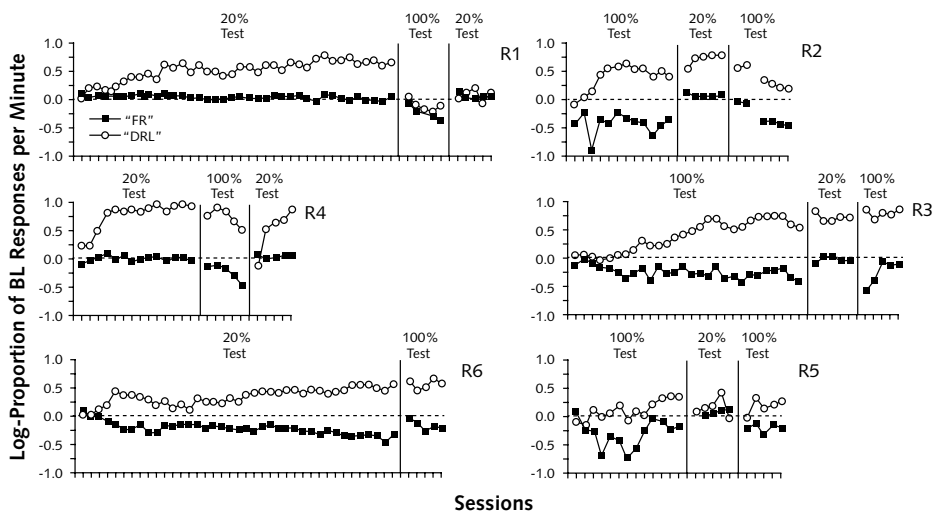

Figure 8. Log-proportion of baseline response rate during each session of the test conditions for each pigeon in Experiment 3. Left and right graphs show data for pigeons exposed to the 20-100-20% AMFC test conditions and to the 100-20-100% AMFC test conditions, respectively. Other details as in Figure 2.

by a bimodal distribution of interresponse times (IRT), with one mode at short, and another mode at longer IRTs (cf. Kramer & Riling, 1970). In addition, although reinforcers in FR and FI schedules tend to be periodically delivered, DRL reinforcers tend to be less periodic because of the sequential dependencies typically found in these schedules: reinforced and unreinforced IRTs tend to follow, respectively, reinforced and unreinforced IRTs (e.g., Farmer & Schoenfeld, 1964; Kelleher, Fry, & Cook, 1959; Malott & Cumming, 1964), which results in variable IRIs. The similarities between FR and FI schedules and dissimilarities between DRL and FI schedules may account for the differential persistence found in the present experiment. That is, the greater such similarities, the less responding may change from one to the other schedule.
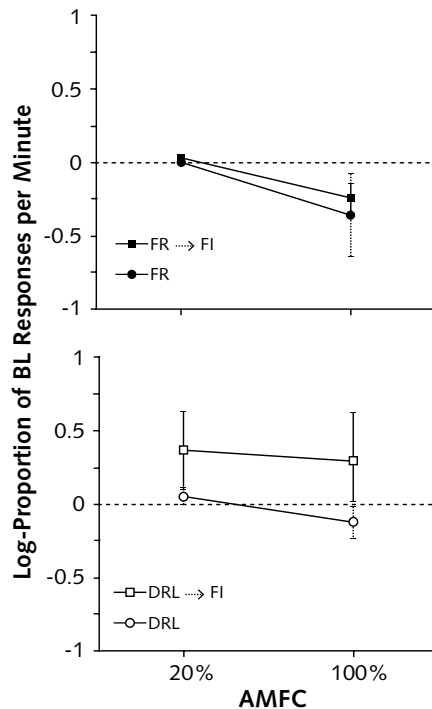

Figure 9. Log-proportion of baseline response rate as a function of AMFC and test schedules, in Experiments 1 and 3. Closed circles and squares (upper graph) show, respectively, responding in the FR schedule (test of Experiment 1) and in the FI schedule in the presence of the stimulus previously correlated with the FR schedule (test of Experiment 3). Open circles and squares (lower graph) show, respectively, responding in the DRL schedule (test of Experiment 1) and in the FI schedule in the presence of the stimulus previously correlated with the DRL schedule (test of Experiment 3). Data are averaged across the first five sessions of the test conditions. Error bars for data from Experiments 1 and 2 are dashed and solid, respectively. Other details are as described for Figure 3.

Changes in response rates as a function of the baseline and test schedules and of the prefeeding amount were analyzed further in Figure 9. This figure shows, for Experiments 1 and 3, the relation between these variables as the log-proportion of baseline-response rates (averaged for all pigeons across the first five sessions of each test). It thus allows comparison of the effects of prefeeding when the test schedules were maintained (Experiment 1) with the effects of prefeeding when the test schedule changed to an FI (Experiment 3). Delivering 20% of the AMFC did not affect "FR" rates consistently regardless of whether the test schedule was an FR (Experiment 1) or an FI (Experiment 3), while delivering 100% of the AMFC decreased "FR" rates under both FR and FI test schedules in Experiments 1 and 3, respectively. Thus, there was only a main effect of the AMFC amount when the baseline schedule was an FR. In contrast, "DRL" rates did not change substantially when the test schedule was a DRL (Experiment 1), but increased consistently relative to baseline when it was an FI (Experiment 3), under both prefeeding amounts. That is, when the baseline schedule was a DRL, there was only a main effect of the test schedule.

In summary, the data in Figure 9 show that, in Experiments 1 and 3, "FR" rates only decreased relative to baseline at the largest prefeeding amount, and that "DRL" rates increased consistently only when the test schedule was an FI. As in Experiment 2, when the schedule changes from baseline to the test, increasing prefeeding amounts may not always lead to greater reductions in response rates (cf. Nevin, 1992a).

General Discussion

In the present experiments, behavioral persistence was a function of the baseline reinforcement schedule. When this schedule was an FR, greater response rate decreases occurred under larger prefeeding amounts (cf. Nevin, 2002), regardless of whether baseline and test schedules were equal (Experiment 1) or different (Experiments 2 and 3). When the baseline schedule was a DRL, however, maintenance or changes in response rates during the test under each prefeeding amount depended on the test schedule. That is, when the test schedule was a DRL (Experiment 1) and an FI (Experiment 3), "DRL" rates did not change substantially and increased relative to baseline, respectively, under both prefeeding amounts. Only when extinction was in effect during the test (Experiment 2) were the effects of prefeeding amounts on DRL rates observed consistently, such that these rates decreased with the larger prefeeding amount.

In Experiments 1 and 2, FR response rates were less persistent than DRL response rates. This result is consistent with previous findings suggesting that, all else being equal, contingencies that establish lower response rates also establish behavior that is more persistent (e.g., Blackman, 1968a, 1968b; Doughty et. al., 2005; Lattal, 1989; Lattal, Reilly & Kohn, 1998; Nevin, 1974, Experiment 5; Nevin, Grace, et al., 2001).

According to Lattal (1989), this effect should not be attributed to response rates *per se,* but to the interaction between the disrupting operation and the ratio or interval (e.g., DRL) requirement in each multiple-schedule component. For example, the greater requirement of the number of responses per reinforcer under ratio- than under interval-based schedules may entail that responding under the former schedules is more susceptible to disruption. Nevin, Grace, et al. (2001) used a similar argument when discussing their findings of higher response rates being less persistent, and suggested an account based on behavioral economics. That is, the greater number of responses per reinforcer (i.e., the unit price; e.g., Hursh, 1984) when response rates are higher but reinforcer rates are similar between the components of a multiple schedule may create a more elastic demand, or alternatively, decrease behavioral persistence (p. 70).

In Experiment 3, however, "DRL" rates were less persistent than "FR" rates when the test schedule was an FI. This suggests that the reinforcement schedule during the test, and how it compares with the reinforcement schedule during baseline, might affect behavioral persistence. On the one hand, because IRIs are periodic and response patterns are similar in FR and FI schedules (e.g., Wanchisen et al., 1989), and this is not the case with DRL schedules (e.g., Farmer & Schoenfeld, 1964), behavior might be expected to take longer to contact the change from FR to FI than the change from DRL to FI (i.e., behavior should be maintained for longer, as it was in the present Experiment 3, in the "FR" schedule). On the other hand, the increase in the "DRL" response rates during the test in Experiment 3 was unexpected, because increasing the satiation of the reinforcer normally decreases response rates (e.g., Nevin, 2002). DRL and FI schedules are similar in that they both involve an interval contingency, but they differ because DRL schedules place a requirement on IRTs that FI schedules do not. That is, under DRL schedules, reinforcement occurs only when the IRT meets or exceeds the minimum IRI; under FI schedules, however, reinforcement depends solely on the occurrence of one response after the IRI elapses. In changing from a DRL to an FI during the test in Experiment 3, the removal of such an IRT requirement may be responsible for the increase in the "DRL" rates. This interpretation is consistent with the results of other studies that found increases in response rates during transitions from DRL to FI schedules (e.g., Freeman & Lattal, 1992). In Experiment 2, however, changing from FR and DRL schedules to extinction meant that responding previously maintained by these schedules never was reinforced, and response rates decreased in all but one case – "DRL" rates, at the 20% AMFC. In that case, the prefeeding amount may not have been enough to decrease response rates in the first five test sessions (such rates did reach zero or near-zero values, eventually).

The procedure and the changes observed in responding controlled by FR and DRL schedules in baseline when these schedules were replaced by FIs in the test are sim-

ilar to those of behavioral history studies that used these same schedules in the base-line and test (e.g., Freeman & Lattal, 1992; Urbain, Poling, Millam, & Thompson, 1978; Weiner, 1964, 1965, 1969). It can be argued, thus, that the present Experiment 3 can be qualified as a behavioral history study. In fact, in a broad sense, all persis-tence studies can be qualified as studies about the effects of behavioral history (cf. Sidman's [1960] definition of studies that investigate reinforcement history, for ex-ample). Resistance-to-change studies, however, usually are more limited procedur-ally, traditionally involving satiation and/or extinction during the test. This limitation rests on the interest in the theoretical construct of response strength (e.g., Nevin & Wacker, 2013), and on the argument that response rates relative to baseline can be adequately interpreted as a measure of response strength only when the disruptor is applied equally to behavior in each component (e.g., Nevin & Grace, 2000a). When FI schedules replace FR and DRL schedules in behavioral history studies, the term "resistance to change" usually is not used because the "disruptor" is not applied equally to both components. That is, the FI contingency interacts differentially with the baseline-schedule contingencies, and thus an adequate measure of resistance to change independently of the disruptor could not be obtained. However, it also seems arguable that using extinction as a disrupting operation presents the same problem because removing reinforcers also may have effects that are not equal between com-ponents. For example, the decrease in reinforcement rate from a mult VI VI to extinc-tion is larger in the component with the greater rate of reinforcement (cf. Nevin, McLean, & Grace, 2001), an effect that may facilitate contact with the withdrawal of reinforcers in that component. Thus, because both extinction and an FI schedule may not apply equally to the different baselines, one may not be taken as less appropriate than the other as a disruptor in a resistance-to-change test. There is, however, a quan-titative approach to isolating the reinforcer-devaluing from the discriminative effect of the disrupting operation (e.g., Nevin, McLean, et al., 2001). This approach has not been extended to the use of FI schedules as the disrupters, perhaps because the main interest of resistance-to-change studies is to evaluate the strength of responding as a function of baseline variables, independently of the disrupting operation. If one is interested in behavioral persistence more broadly, however, considering persistence as independent of the type of change implemented may be an oxymoron. Persistence should be analyzed as it occurs in the world, that is, involving at least two conditions and being affected by those conditions and by the way they combine and interact. In this sense, the research area in which a particular study is included matters less than whether it sheds light on a behavioral phenomenon, and the research on persistence should continue to include a wide range of baseline and testing conditions.

Differential persistence in the present experiments was observed regardless of eventual reinforcement-rate differences between multiple-schedule components dur-

ing baseline conditions (in general, when such differences occurred, higher reinforce-
ment rates were obtained in the FR than in the DRL component in Experiments 1 and
2; in Experiment 3, reinforcement rate differences did not vary systematically with
behavioral persistence, which generally was lower in the DRL than in the FR sched-
ule). Despite the extensive evidence of a direct relation between baseline reinforce-
ment rates and persistence (see Nevin & Grace, 2000a), the finding that exposure to
different baseline contingencies on response rates and patterns can affect persistence
independently of reinforcement-rate differences is not without precedence. In addi-
tion to the studies by Doughty et al. (2005), Lattal (1989), Nevin (1974) and Nevin,
Grace, et al. (2001), for example, in the studies by Doughty and Lattal (2001), and by
Arantes, Berg, Le and Grace (2012), varying response sequences was more resistant
to prefeeding and to response-independent food than repeating such sequences, even
though both response patterns were maintained by similar reinforcement rates in
baseline. Souza, Abreu-Rodrigues and Baumann (2010) also reported that varying
response sequences was more resistant to extinction than repeating response sequenc-
es, despite the higher reinforcement rates obtained under the repetition contingency
(see also Abreu-Rodrigues, Hanna, Cruz, Matos & Delabrida, 2004, and the present
Experiments 1 and 2). Thus, and as noted by different authors (e.g., Craig, Nevin, &
Odum, 2014; Nevin, Grace, et al., 2001; Nevin & Wacker, 2013), it seems that Pav-
lovian relations (i.e., stimulus-stimulus relations) are not the sole determinant of be-
havioral persistence.

In summary, the present results further the understanding of the combined effects
of different disrupting operations when different reinforcement schedules are in effect
during baseline. While the effects of prefeeding and extinction were additive when
responding was previously maintained by an FR schedule, they were not so when the
baseline arranged reinforcers according to a DRL schedule (in this case, increasing
the prefeeding amount only decreased responding when extinction was in effect dur-
ing the test). Furthermore, changing the schedule to an FI did not disrupt "FR" respond-
ing beyond the effects of prefeeding alone, while this change increased "DRL" rates
similarly under both prefeeding amounts. Thus, disrupting operations seem to not
always have equal, additive effects: Whether and how disruption will occur depends
on the specific combination of past and current contingencies.

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