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*EXPERIENCE WITH DYNAMIC REINFORCEMENT RATES DECREASES
RESISTANCE TO EXTINCTION*

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The ability of organisms to detect reinforcer-rate changes in choice preparations is positively related to two factors: the magnitude of the change in rate and the frequency with which rates change. Gallistel (2012) suggested similar rate-detection processes are responsible for decreases in responding during operant extinction. Although effects of magnitude of change in reinforcer rate on resistance to extinction are well known (e.g., the partial-reinforcement-extinction effect), effects of frequency of changes in rate prior to extinction are unknown. Thus, the present experiments examined whether frequency of changes in baseline reinforcer rates impacts resistance to extinction. Pigeons pecked keys for variable-interval food under conditions where reinforcer rates were stable and where they changed within and between sessions. Overall reinforcer rates between conditions were controlled. In Experiment 1, resistance to extinction was lower following exposure to dynamic reinforcement schedules than to static schedules. Experiment 2 showed that resistance to pre-session feeding, a disruptor that should not involve change-detection processes, was unaffected by baseline-schedule dynamics. These findings are consistent with the suggestion that change detection contributes to extinction. We discuss implications of change-detection processes for extinction of simple and discriminated operant behavior and relate these processes to the behavioral-momentum based approach to understanding extinction.

Key words: extinction, change detection, dynamic reinforcement schedules, key pecking, pigeons

Operant extinction entails suspending reinforcement for a targeted response (see Lattal, St. Peter, & Escobar, 2013, for review). As a consequence, behavior tends to decrease in frequency with continued exposure to extinction contingencies. The extent to which responding persists in the face of extinction may be termed ‘resistance to extinction’, and clarifying those factors that contribute to resistance to extinction is of both theoretical and practical importance. For example, changes in behavior during extinction often are used as a metric of response strength engendered by baseline conditioning situations (see, e.g., Nevin, 1974; Nevin & Grace, 2000) and as a method for examining how organisms adapt to environmental stochasticity

(Gallistel, 2012). Further, because behavioral interventions often incorporate extinction components for behavior that is targeted for elimination (see Petscher & Bailey, 2008), a thorough analysis of resistance-to-extinction mechanisms could have implications for understanding various treatment dynamics.

Several factors are known to impact resistance to extinction of operant behavior. One such factor that reliably has been shown to impact rate of extinction is the schedule of reinforcement that maintained responding prior to introduction of extinction contingencies. For example, the partial-reinforcement extinction effect (PREE) refers to the common finding that partial reinforcement of a response produces behavior that is more persistent during extinction than continuous reinforcement of a response (Nevin & Grace, 2005; Mackintosh, 1974). Several authors have suggested the PREE results from differential generalization decrement produced by transitioning from periods of continuous or partial reinforcement during baseline to nonreinforcement during extinction (Catania, 1973; Nevin & Grace, 2000; Rescorla & Skucy, 1969). According to this hypothesis, nonreinforcement conditions are more similar to partial-reinforcement than to continuous-reinforcement conditions. Thus, disruption of

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responding should be greater following a transition to extinction from continuous reinforcement than from partial reinforcement.

Gallistel (2012) offered a conceptual account of generalization-decrement effects on extinction performance based on statistical decision making and change detection (see also Gallistel & Gibbon, 2000, for a similar approach). In this account, behavior during extinction can be explained in part by assuming an organism gathers information about the temporal distribution of reinforcers in its environment. In extinction, the organism compares currently experienced intervals in the absence of reinforcement to previously experienced interreinforcer intervals (IRIs). When a currently experienced interval in extinction sufficiently exceeds those IRIs experienced during baseline, the organism may detect a change in reinforcer rates. Decreases in response rates during extinction reflect an innate policy of response allocation that is governed by perceived reinforcer rates (see also Gallistel et al., 2007; Gallistel, Mark, King, & Latham, 2001).

According to this perspective, when reinforcers are delivered relatively frequently prior to extinction, as in the case of a continuously reinforced response, the organism should expect relatively short intervals between reinforcers. Conversely, when baseline reinforcers are delivered relatively infrequently, as in the case of partial reinforcement, the organism should expect relatively long intervals. Thus, Gallistel's (2012) approach suggests a positive relation between magnitudes of generalization decrement and baseline reinforcer rates as follows. As extinction progresses, time without reinforcement increases. This increasingly long interval analytically is more similar to a collection of long IRIs than to a collection of short IRIs. Thus, it should be more difficult for an organism to detect a transition to extinction contingencies following low-rate reinforcement than following high-rate reinforcement. Qualitatively, then, this approach provides a feasible mechanism through which generalization decrement may exert its effects on responding during extinction.

Aside from the size of the change in reinforcer rates between baseline and extinction conditions, other variables have been shown to impact organisms' abilities to detect changes in reward availability. For example, in

choice situations, the rapidity with which organisms adapt to changes in relative reinforcer rates is positively related to the frequency with which those reinforcer rates change. If, for example, a change in relative reinforcer rates occurs following prolonged exposure to stable relative rates, responding adapts to these changes gradually (see Gallistel et al., 2001; see also Mazur, 1995; 1996). If, however, relative reinforcer rates change frequently, reallocation of responding with respect to prevailing relative reinforcer rates occurs quickly following each change, often within a few visit cycles between response alternatives (Baum & Davison, 2004; Davison & Baum, 2000; Gallistel et al., 2001).

To describe these findings in the choice literature, Gallistel and colleagues (2001) applied the same conceptual analysis that Gallistel (2012) applied to extinction performance. These authors asserted organisms' ability to detect and adapt to changes in relative rates of reinforcement is a composite function of two factors. First, as discussed above, larger changes in relative rates should be easier to detect. Second, change detection should be positively related to the rapidity with which changes in relative reinforcer rates occur in the environment. That is, if changes in relative rates occur frequently, organisms should detect and adapt to those changes more quickly than if changes occur infrequently.

Based on the putative commonality of change-detection processes between extinction and choice preparations detailed above, it is reasonable to believe factors that affect detection of changes in choice situations also should impact detection in operant-extinction situations. More specifically, if rapidly changing relative reinforcer rates facilitate change detection in choice, rapidly changing baseline reinforcer rates also should facilitate change detection during extinction. Consequently, one might expect experience with dynamic or changing, relative to static or unchanging, baseline reinforcer rates to hasten extinction of operant behavior. The present Experiment 1 aimed to address this empirical question. Pigeons pecked keys for variable-interval (VI) food under conditions where mean IRIs were the same from session to session and where mean IRIs changed both between and within sessions. After each of these conditions,

persistence of responding in extinction was measured. Importantly, reinforcer rates were controlled between conditions, allowing for isolation of reinforcer-rate effects from effects of rate dynamics on resistance to extinction.

Experiment 1

Method

Design. A within-subjects ABCBAB design was used in this experiment. In phases labeled 'A' subjects responded under a Dynamic-VI schedule in which reinforcer rates changed both between and within sessions. The 'C' phase was a Static-VI schedule in which the VI value for each subject was individually determined by averaging the reinforcer rates each subject obtained during the last eight sessions of the first Dynamic-VI condition. 'B' phases were extinction tests. The dependent variable was resistance to extinction as measured by proportion-of-baseline response rates.

Subjects. Eight experimentally naïve homing pigeons (Double T Farm, Glenwood, IA) served. Each pigeon was housed separately in a colony room with a 12:12 hr light/dark cycle (lights on at 7:00 am) and had free access to water in its home cage. Sessions were conducted daily at approximately the same point during the light cycle. Pigeons were maintained at 80% of their free-feeding weights (± 15 g) by the use of supplementary postsession feedings when necessary. Reacquisition of key pecking during the Static-VI baseline condition was problematic for Pigeon 4277. This subject was maintained at the lower end of its 80% range (± 15 g) for all conditions thereafter. Animal housing and care were conducted in accordance with the regulations of Utah State University's Institutional Animal Care and Use Committee.

Apparatus. Four sound-attenuating operant chambers for pigeons (dimensions approximately 29 cm long, 26 cm deep, and 29 cm high; Coulbourn Instruments, Whitehall, PA) were used. These chambers were constructed of clear plastic and brushed aluminum, and each had an aluminum work panel on the front wall. Each aluminum work panel had two opaque plastic response keys measuring 2.5 cm in diameter and located 16 cm from the floor of the chamber and 2 cm from either of the side walls. Only the right key was used

during this experiment and was transilluminated white during pretraining and either orange or blue during experimental conditions. A 28-v house light located in the center of the work panel and 23 cm from the floor of the chamber provided general illumination. Both the house light and the right key light were lighted at all times except during reinforcer deliveries and blackout periods. A food aperture measuring 6 cm wide by 5 cm high was located in the center of the work panel 5 cm from the floor of the chamber. A 28-v lamp illuminated this aperture during reinforcer deliveries, which consisted of 1.5 s of access to Purina Pigeon Checkers delivered by a solenoid-operated food hopper. White noise was present at all times to mask extraneous sound. All sessions were controlled by MedPC software (Med Associates, St. Albans, VT) run on a PC computer.

Procedure. During all phases of the experiment, sessions began with a 60-s blackout period to allow the pigeons to acclimate to the operant chambers. All VI schedules consisted of 10 intervals and were constructed using the constant-probability algorithm introduced by Fleshler and Hoffman (1962).

Pretraining. Magazine training and key-peck autoshaping (Brown & Jenkins, 1968) first were conducted. After autoshaping, pigeons earned food under a fixed-ratio (FR) 1 schedule. Across sessions, reinforcer rates were thinned until pigeons reliably pecked to earn food on a VI 60-s schedule. All sessions of pretraining terminated after 40 reinforcer deliveries or 40 min, excluding time for reinforcement, whichever occurred first.

Dynamic-VI conditions. In these conditions, responding was reinforced according to a VI schedule in which the VI value changed both between and within sessions. Sessions began with illumination of the house light and the right key (either orange or blue, counterbalanced across pigeons). The VI values used for the Dynamic VI were 30, 70, 110, and 150 s and within-session changes to the VI schedule occurred 5, 15, or 25 min into a session. If an IRI lapsed and a schedule change occurred before the pigeon collected the available reinforcer, that reinforcer was cancelled and the new schedule commenced immediately. Each subject experienced every possible combination of prechange schedule, postchange schedule, and change point across sessions (i.e., a

total of 36 schedule/change-point combinations were experienced across 36 sessions per condition). Four-session blocks of schedules were constructed such that each of the four possible schedules was experienced for the same amount of time in each block (see Table 1 for an exhaustive list of blocked sessions). This blocked arrangement was used to simplify determination of the reinforcer rates used in the Static VI condition (see below). The specific order of the schedules in each block and the order in which the pigeons experienced the blocks of sessions were randomized, but the subjects experienced the same progression of blocks during the first and second Dynamic-VI conditions to allow direct between-condition comparisons of extinction performance. Sessions lasted 30 min, excluding time for reinforcement.

For Pigeon 4277, responding decreased inexplicably during the last block of the first Dynamic-VI condition. Accordingly, the first block of sessions this pigeon experienced was reintroduced prior to extinction testing. The second Dynamic-VI condition for this pigeon was truncated to 36 sessions by removing the first block of sessions from its progression.

Static-VI condition. In the Static-VI condition, responding was reinforced according to a single VI schedule. Sessions began with illumination of the house light and the right key (either orange or blue, whichever stimulus was not used during the Dynamic-VI condition). The VI value for each subject was individually determined by equating it to the mean reinforcer rates obtained by that subject in the last

eight sessions of the preceding Dynamic-VI condition. These values were rounded to the nearest 1,000th of a whole s (see Table 2 for a list of these values). The Static-VI condition included 36 sessions. Again, sessions terminated after 30 min, excluding time for reinforcement.

Extinction testing. Resistance to extinction was assessed for each subject following completion of each Dynamic-VI and Static-VI condition. The key-light color used in extinction was identical to that used in the preceding baseline condition. Responding, however, had no programmed consequences. These phases lasted for five 30-min sessions.

Results

Baseline reinforcer rates. Mean reinforcer rates from the last eight sessions of the first Dynamic-VI, Static-VI, and second Dynamic-VI baseline conditions were 52.97 (*SEM* = 3.30), 50.25 (*SEM* = 0.44), and 53.56 (*SEM* = 3.43) reinforcers per hr, respectively. Despite variability of reinforcer rates within and between sessions in Dynamic-VI baseline conditions, there were never instances where pigeons earned zero reinforcers per session. For each pigeon, obtained reinforcer rates were lower in the Static-VI baseline condition than in either Dynamic-VI baseline conditions because programmed reinforcer rates for the Static-VI condition were yoked to obtained rates from the first Dynamic-VI condition. Under interval schedules of reinforcement, unless subjects earn reinforcers as soon as they are made

Table 1
Schedules and Change Points for Blocks of Sessions Within the Dynamic-VI Conditions

Block	Change Point (Mins)	Pre-Change VI (s)	Post-Change VI (s)	Block	Change Point (Mins)	Pre-Change VI (s)	Post-Change VI (s)	Block	Change Point (Mins)	Pre-Change VI (s)	Post-Change VI (s)
1	5	30	70	4	5	70	110	7	15	30	150
	5	70	30		5	110	70		15	150	30
	15	110	150		25	30	150		25	70	110
	15	150	110		25	150	30		25	110	70
2	5	30	110	5	5	70	150	8	15	30	110
	5	110	30		5	150	70		15	110	30
	15	70	150		25	30	110		25	70	150
	15	150	70		25	110	30		25	150	70
3	5	30	150	6	5	110	150	9	15	30	70
	5	150	30		5	150	110		15	70	30
	15	70	110		25	30	70		25	110	150
	15	110	70		25	70	30		25	150	110

Table 2
Static-VI Values for Experiment 1

Subject	Static VI (s)
4275	64.865
4276	67.290
4274	72.362
1499	67.290
4278	66.977
4188	68.246
4189	66.977
4277	70.244

available, obtained reinforcer rates necessarily underestimate programmed rates. These differences, however, were small. A one-way, repeated-measures analysis of variance (ANOVA) was used to examine differences in obtained reinforcer rates between conditions. The main effect was not significant, $F(1.05, 66.10) = 0.82$, $p = \text{NS}$.

Baseline response rates. Mean response rates from the last eight sessions of the first Dynamic-VI, Static-VI, and second Dynamic-VI baseline conditions were 70.93 ($SEM = 4.07$), 59.54 ($SEM = 2.25$), and 60.92 ($SEM = 2.14$) responses per min, respectively. A one-way, repeated-measures ANOVA was used to examine differences in response rates between conditions. The main effect was significant, $F(1.47, 92.73) = 7.74$, $p < .01$. Bonferroni-corrected pairwise comparisons based on estimated marginal means revealed response rates from the first Dynamic-VI baseline condition were significantly higher than rates in both the Static-VI and second Dynamic-VI conditions. Response rates did not differ, however, between the latter two conditions.

Extinction. Mean (plus SEM) responses per min during the last eight sessions of each baseline condition and responses per min for each session of extinction are shown in the top panel of Figure 1. Proportion-of-baseline response rates across sessions of extinction testing are displayed in the bottom panel of this figure (see Supplementary Fig. 1 for proportion-of-baseline response rates across sessions of extinction for individual pigeons). These rates were calculated for each subject by dividing response rates during each session of extinction by the mean rate of responding for that subject from the last eight sessions of the preceding baseline condition.¹

Fig. 1. Top panel: Mean (plus SEM) responses per min during the last eight sessions of baseline and each session of extinction testing for each condition of Experiment 1. Bottom panel: Mean (plus SEM) proportion-of-baseline response rates across sessions of extinction for each condition of Experiment 1.

For six of eight pigeons, proportion-of-baseline response rates were highest in the Static-VI condition during the first session of extinction. Further, proportion-of-baseline response rates were highest in the Static-VI condition in a total of 23 of 40 (8 pigeons $\times$ 5 sessions of extinction) comparisons.

¹Because baseline reinforcer rates varied widely across sessions of both Dynamic-VI conditions, it is reasonable to believe that response rates might have varied during these conditions as well. Thus, large variations in response rates across sessions of baseline could have rendered proportion-of-baseline response rates unstable, depending on the number of sessions used to calculate these rates. This, however, was not the case. To demonstrate this, proportion-of-baseline rates were calculated for each condition using mean response rates from the last eight, four, two, and one session(s) of baseline for each pigeon. Three separate 4×6 (Method $\times$ Session) repeated measure ANOVA then were conducted, one for each condition. In no case was the main effect of Method (for the first Dynamic-VI, Static-VI, and second Dynamic-VI conditions, respectively: $F(3, 21) = 1.09$, $p = \text{NS}$; $F(1.03, 7.22) = 0.48$, $p = \text{NS}$; and $F(1.58, 11.02) = 0.35$, $p = \text{NS}$) or the Method $\times$ Session interaction ($F(15, 105) = 1.31$, $p = \text{NS}$; $F(15, 105) = 0.65$, $p = \text{NS}$; and $F(15, 105) = 0.42$, $p = \text{NS}$) significant.

When comparing extinction performance from the Static-VI condition to the first and second Dynamic-VI conditions individually, proportion-of-baseline response rates were higher in the Static-VI condition for 27 of 40 and 29 of 40 comparisons, respectively. On average, proportion-of-baseline response rates were higher in the Static-VI condition than in either Dynamic-VI condition for all sessions. A 3 X 6 (Condition X Day) repeated-measures ANOVA revealed a significant main effect of Condition, $F(2, 14) = 7.89, p < .01$, a significant main effect of Day, $F(5, 35) = 248.09, p < .001$, and a significant Condition X Day interaction, $F(10, 70) = 2.40, p < .05$. Bonferroni-corrected pairwise comparisons based on estimated marginal means for Condition revealed that resistance to extinction following the Static-VI condition was greater than resistance to extinction following both Dynamic-VI conditions, but resistance to extinction following the first and second Dynamic-VI conditions did not differ.

Relating extinction to other training variables. Some evidence suggests that resistance to extinction in multiple schedules is a function only of recently experienced baseline reinforcer rates (cf., Craig, Cunningham, & Shahan, 2015). Because the Dynamic-VI baseline conditions arranged reinforcer rates that were regular across blocks of sessions but varied widely across sessions, Pearson product-moment correlation analyses were conducted to determine if relative resistance to extinction between the Dynamic- and Static-VI conditions was related to the relative reinforcer rates each pigeon experienced during the final session (where between-subject variability in rate was maximal in Dynamic-VI conditions), and the last eight sessions, of these conditions. Here, relative resistance to extinction was defined as the log ratio of mean proportion-of-baseline response rates from all sessions of Dynamic-VI and Static-VI extinction (cf., Grace & Nevin, 1997). Relative resistance to extinction was calculated separately for the first and second Dynamic-VI conditions. These values are plotted against log relative reinforcer rates (Dynamic/Static) in Figure 2.

The left panel of Figure 2 shows relative resistance to extinction plotted against log relative reinforcer rates from the last session of each baseline condition (Dynamic/Static), and the right panel shows relative resistance to

extinction plotted against log relative reinforcer rates using mean rates from the last eight sessions of each condition (Dynamic/Static). Data points falling below the horizontal dashed line represent subjects for whom resistance to extinction was lower in the Dynamic-VI condition than in the Static-VI condition, and points that fall to the left of the vertical dashed line represent subjects for whom reinforcer rates were lower in the Dynamic-VI condition. In neither case was relative resistance to extinction significantly correlated with log relative reinforcer rates [for the left panel, $r(22) = .05, p = \text{NS}$; for the right panel, $r(22) = .35, p = \text{NS}$].

Response rates tended to be higher during the first Dynamic-VI baseline than in the other baseline conditions. Because, under some circumstances, baseline response rates have been shown to affect resistance to extinction (Lattal, 1989; Nevin, Grace, Holland, & McLean, 2001), Pearson product-moment correlation analyses were conducted to examine the extent to which relative resistance to extinction between both Dynamic-VI and the Static-VI conditions was related to log relative baseline response rates from these conditions. Relative resistance to extinction was defined here as above. These values were plotted as a function of log relative response rates from the last eight sessions of baseline (Dynamic/Static). Log relative response rates were calculated separately for the first and second Dynamic-VI conditions. These data are shown in Figure 3. Data points falling below the horizontal dashed line represent subjects for whom resistance to extinction was lower in the Dynamic-VI condition than in the Static-VI condition, and points that fall to the left of the vertical dashed line represent subjects for whom response rates were lower in the Dynamic-VI condition. No significant relation was present between log relative baseline response rates and relative resistance to extinction, $r(6) = .12, p = \text{NS}$.

Discussion

The data from Experiment 1 suggest that previous experience with dynamic reinforcer rates produces behavior that is less persistent in the face of extinction than does experience with static reinforcer rates. These effects were independent of the slight differences in

Fig. 2. Relative resistance to extinction (Dynamic/Static) for each subject, plotted as a function of log relative reinforcer rates (Dynamic/Static) for Experiment 1. Log relative resistance to extinction and reinforcer rates are displayed for both Dynamic-VI condition (D1/S and D2/S). The left panel shows log relative reinforcer rates from the last session of each baseline condition, and the right panel shows log relative reinforcer rates using mean rates from the last eight sessions of each condition. Dashed lines represent the point at which resistance to extinction (horizontal) or reinforcer rates (vertical) were equal between conditions.

Fig. 3. Log relative resistance to extinction (Dynamic/Static) plotted as a function of log relative response rates (Dynamic/Static) for Experiment 1. Log relative resistance to extinction and response rates are displayed for both Dynamic-VI condition (D1/S and D2/S). Dashed lines represent the point at which resistance to extinction (horizontal) or response rates (vertical) were equal between conditions.

baseline reinforcer rates just prior to extinction (Fig. 2) and baseline response rates generated by these reinforcement schedules (Fig. 3). This finding is consistent with Gallistel's (2012) conceptual analysis of generalization-decrement effects on operant extinction. As noted previously, from this

perspective experience with rapidly changing reinforcer rates (like those experienced under the Dynamic-VI baseline conditions) should facilitate detection of changes in reinforcer rates relative to experience with static reinforcer rates (see also Gallistel et al., 2001). Though these data provide tentative support for Gallistel's position, it remains unclear to what extent reinforcer-rate dynamics affected generalization decrement, *per se*. That is, experience with dynamic reinforcer rates during baseline could have had other, ancillary effects on behavior that produced less persistence than experience with static baseline reinforcer rates.

One widely used approach to understanding factors that affect operant extinction is offered by behavioral momentum theory (Nevin, Mandell, & Atak, 1983). Momentum theory suggests that resistance to change of behavior generally is affected by two opposing forces: disrupting factors that suppress responding and response-strengthening factors that promote persistence of responding (see Craig, Nevin, & Odum, 2014; Nevin & Grace, 2000). Importantly for present purposes, momentum theory offers a formalized, quantitative account of extinction performance that allows for post-hoc isolation of generalization-decrement effects from other factors known to affect extinction.

The augmented model of extinction based on behavioral momentum theory is as follows (see Nevin & Grace, 2000):

$$\log\left(\frac{B_t}{B_o}\right) = \frac{-t(c + dr)}{r^b} \quad (1)$$

The left side of Equation 1 is log-transformed proportion-of-baseline response rates at time t in extinction. The right side of the equation represents those factors that affect behavior during extinction and can be broken into two more general terms. The numerator captures those factors that produce disruption during extinction. Here, t is time in extinction, measured in sessions. The c parameter is the disruptive impact of suspending the response-reinforcer contingency, and dr collectively represents generalization decrement, where r is the change in reinforcer rates between baseline and extinction (in reinforcers omitted per hr) and d is a scaling factor. The free parameters c and d typically assume values of 1 and 0.001, respectively, when Equation 2 is fitted to obtained extinction data. The denominator represents a mass-like quality of behavior (commonly "behavioral mass") engendered by reinforcer deliveries that contributes to response persistence. Here, r is baseline reinforcer rates, in reinforcers delivered per hr, and b is a sensitivity parameter that is free to vary and typically assumes a value of 0.5 when Equation 1 is fitted to obtained resistance-to-extinction data using least-squares regression (see Nevin, 1992a).

When zero-rate responding occurs within a session (as was the case for several pigeons in Experiment 1), log-transformed proportion-of-baseline response rates are undefined. The model still can be fitted to obtained data under such circumstances by allowing both the left and right sides of Equation 1 to serve as the exponent of 10. This manipulation eliminates log transformation of proportion-of-baseline response rates on the left side of the equation. This equation appears as follows:

$$\frac{B_t}{B_o} = 10^{\frac{-t(c + dr)}{r^b}} \quad (2)$$

Here, all parameters are as they were in Equation 2.

To determine what behaviorally relevant factors were affected by baseline reinforcer-rate dynamics in the present experiment, Equation 2 was fitted to obtained proportion-of-baseline response rates for each subject, and to aggregated group proportion-of-baseline rates, across sessions of extinction following each condition. Fits were conducted separately for each condition using Microsoft Excel Solver, a nonlinear curve-fitting program. Free-parameter values (c , d , and b), reinforcer-rate parameters (r), and R^2 values for each fit may be found in Table 3, under the column heading "All Free."

As may be seen from the table, values of c (for the first Dynamic-VI, Static-VI, and second Dynamic-VI conditions, respectively, range: 0.98-1.00, 0.95-1.00, and 0.98-1.00) and b (range: 0.5-0.68, 0.41-0.68, and 0.48-0.68) were relatively constant across conditions. These values were similar to those values typically obtained from fits of Equation 2 to extinction data from multiple-schedule preparations (i.e., $c = 1$, $b = 0.5$; see Nevin & Grace, 2000). Values of d , however, varied systematically between conditions. More specifically, for six of eight subjects, values of d were higher for fits to extinction functions from the first and second Dynamic-VI conditions (respectively, range: 0-0.067 and 0.001-0.068) than for the Static-VI condition (range: 0-0.008). Values of d for the Dynamic-VI conditions, but not for the Static-VI condition, were substantially higher than those typically reported (i.e., $d = 0.001$).

To further evaluate the extent to which differences in persistence during extinction could be explained by systematic variations in d values alone, Equation 2 was fitted to obtained data a second time. In these fits, however, the c and b parameters were fixed at values of 1 and 0.5, respectively. Values of d and R^2 may be found in Table 3 under the column heading " d Free." As with the first round of model fits detailed above, where all free parameters were allowed to vary, values of d in the present fits tended to be higher for fits to extinction functions from the first and second Dynamic-VI conditions (respectively, range: 0-0.025 and 0-0.32) than for the Static-VI condition (range: 0-0.009). For five of eight subjects, d values from both Dynamic-VI conditions were higher than values from the Static-VI condition. Further, including two

Table 3
Parameter Values from Fits of Equation 2 to Extinction Data from Experiment 1

Subject	Condition	All Free					<i>d Free*</i>	
		<i>c</i>	<i>d</i>	<i>b</i>	<i>r</i>	<i>R</i> ²	<i>d</i>	<i>R</i> ²
4275	Dynamic 1	1	0.056	0.68	55.5	0.97	0.018	0.97
	Static	1	0.005	0.51	51.25	0.97	0.004	0.97
	Dynamic 2	1	0.041	0.63	52.5	0.97	0.017	0.97
4276	Dynamic 1	1	0	0.51	53.5	0.98	0	0.98
	Static	0.95	0.001	0.68	50.75	0.99	0	0.90
	Dynamic 2	0.99	0.001	0.53	55	0.96	0	0.96
4274	Dynamic 1	1	0.067	0.67	49.75	0.99	0.025	0.99
	Static	1	0.008	0.5	46.5	0.99	0.009	0.99
	Dynamic 2	1	0.028	0.6	54	0.99	0.012	0.99
1499	Dynamic 1	1	0	0.5	53.5	0.89	0	0.89
	Static	0.97	0	0.6	51.5	0.89	0	0.83
	Dynamic 2	1	0.061	0.61	52.5	0.97	0.320	0.97
4278	Dynamic 1	0.98	0.002	0.56	53.75	0.99	0	0.99
	Static	0.98	0	0.56	50.75	0.99	0	0.97
	Dynamic 2	0.98	0.004	0.58	53.25	0.99	0	0.98
4188	Dynamic 1	1	0.024	0.59	52.75	0.98	0.011	0.98
	Static	1	0.001	0.41	51	0.88	0.009	0.88
	Dynamic 2	1	0.068	0.68	54.25	0.99	0.024	0.99
4189	Dynamic 1	1	0.05	0.67	53.75	0.99	0.016	0.99
	Static	1	0.004	0.51	52.25	0.95	0.003	0.95
	Dynamic 2	1	0.035	0.62	53.25	0.99	0.014	0.99
4277	Dynamic 1	1	0.01	0.52	51.25	0.98	0.008	0.98
	Static	0.99	0.002	0.52	48	0.96	0	0.96
	Dynamic 2	1	0.011	0.48	53.75	0.88	0.013	0.88
Group	Dynamic 1	1	0.01	0.53	52.97	0.99	0.007	0.99
	Static	1	0	0.51	50.25	0.99	0	0.99
	Dynamic 2	1	0.008	0.48	53.56	0.99	0.011	0.99

Note. Values of *c* and *b* were rounded to the nearest 100th of a whole number. Values of *d* were rounded to the nearest 1,000th.

*Values of *c* and *b* were fixed at 1 and 0.5, respectively.

additional free parameters (i.e., *c* and *b*) in the initial round of model fits resulted in higher variance accounted for in only 4 of 27 fits.

In summary, fits of Equation 2 to the present extinction data demonstrated systematic variation between Dynamic-VI and Static-VI conditions only in the *d* term meant to capture detrimental effects on responding of generalization decrement. Indeed, the second round of model fits, where only *d* was allowed to vary between fits, accounted for virtually the same amount of variance in the extinction data as did fits where *c*, *b*, and *d* all were allowed to vary. These fits provide support for the thesis that experience with dynamic, relative to static, baseline reinforcer rates produced greater generalization decrement between baseline and extinction conditions, thus hastening the extinction process. Experiment 2 was conducted to further test if the

effects reported here were due, in fact, to generalization decrement.

Experiment 2

Other disruptors of operant behavior, such as pre-session feeding for hungry animals (Nevin, 1974; see also Craig, Nevin, & Odum, 2014, for review) often are used, and momentum theory offers quantitative accounts of resistance to change in the face of these disruptors as well (Nevin & Grace, 2000; Nevin & Shahan, 2011). When pre-session feeding is used as a disruptor, momentum theory asserts:

$$\log\left(\frac{B_x}{B_o}\right) = \frac{-kx}{r^b} \quad (3)$$

That is, persistence of responding in the face of pre-session feeding is directly related to the magnitude of the disruptor (i.e., the

amount pre-fed, x , multiplied by a scaling parameter, k) and inversely related to behavioral mass (r^b), a finding that has been empirically supported (see Nevin, 1992a; 2002). From this perspective, because there is no change in reinforcer availability during tests for resistance to pre-session feeding, generalization decrement *does not* contribute to disruption of responding. If dynamic baseline reinforcer rates produce greater generalization decrement than static rates (see Table 3) and generalization decrement plays no part in disruption of responding by pre-session feeding (see Eq. 3), then experience with dynamic, relative to static, schedules of reinforcement during baseline should have no impact on resistance to pre-session feeding. Experiment 2 tested this prediction.

Method

Design. A within-subjects ABCB design was used in this experiment. In the phase labeled 'A' subjects responded under a Dynamic-VI schedule in which reinforcer rates changed both between and within sessions (note that a second exposure to the Dynamic-VI condition was not used in this experiment because no significant effect of repeated testing was found in Experiment 1). The 'C' phase was a Static-VI schedule. Here, the VI value for each subject was individually determined by averaging the reinforcer rates each subject obtained during the last eight sessions of the Dynamic-VI condition. 'B' phases were pre-session feeding sessions. The dependent variable of this experiment was resistance to pre-feeding as measured by proportion-of-baseline response rates.

Subjects. The same pigeons that were used in Experiment 1 served in Experiment 2. Animal care and housing were conducted as in Experiment 1.

Apparatus. The same operant chambers used in Experiment 1 were used in Experiment 2. Dynamic and Static schedules, however, were signaled by either blue or white key lights.

Procedure. During all phases of the experiment, sessions began with a 60-s blackout period to allow the pigeons to acclimate to the operant chambers.

Dynamic-VI condition. Sessions began with illumination of the house light and the right

key (either blue or white, counterbalanced across pigeons). The same progression of pre-change schedules, postchange schedules, and change points that were used in the second Dynamic-VI condition of Experiment 1 were used in Experiment 2. This condition lasted for thirty-six 30-min sessions, excluding time for reinforcement.

Static-VI condition. Sessions in this condition began with illumination of the house light and the right key (either blue or white, whichever stimulus was not used during the Dynamic-VI condition). As in Experiment 1, the VI value for each subject was individually determined by equating it to the mean reinforcer rates obtained by that subject in the last eight sessions of the preceding Dynamic-VI condition. These values were rounded to the nearest 1,000th of a whole s (see Table 4 for a list of these values). The Static-VI condition included 36 sessions. Again, sessions terminated after 30 min, excluding time for reinforcement.

For pigeon 4188, responding decreased inexplicably during Session 31 of this condition. Three additional sessions of Static-VI training were conducted for this subject to obtain stable response rates during the last eight sessions of this condition.

Pre-session feeding. Following completion of each baseline condition, two 30-min sessions of pre-session feeding were conducted. The key-light color used during pre-feeding was the same as during the preceding baseline condition, and in both sessions following both conditions, reinforcer rates were held constant. These rates were calculated in the same way as reinforcer rates for the Static-VI condition (see above). During the first session of pre-session feeding, each pigeons was given 12% of its 80% free-feeding body weight worth of pigeon chow 1 hr before sessions. During the

Table 4
Static-VI Values for Experiment 2

Subject	Static VI (s)
4275	67.925
4276	66.667
4274	69.565
1499	64.286
4278	66.359
4188	67.925
4189	64.865
4277	65.455

second session of pre-session feeding, each pigeon received 14% of its 80% free-feeding body weight worth of pigeon chow 1 hr before sessions.

Results

Baseline reinforcer rates. Mean reinforcer rates from the last eight sessions of the Dynamic- and Static-VI baseline conditions were 54.06 ($SEM = 3.41$) and 51.28 ($SEM = 0.47$) reinforcers per hr, respectively. Note that, in the Dynamic-VI baseline condition, there were never instances where pigeons earned zero reinforcers per session. For each pigeon, obtained reinforcer rates were lower in the Static-VI baseline condition than in the Dynamic-VI baseline condition because, as in Experiment 1, programmed reinforcer rates for the Static-VI condition were yoked to obtained rates from the Dynamic-VI condition. Again however, these differences were not significant, $t(63) = 0.79$, $p = NS$.

Baseline response rates. Mean response rates from the last eight sessions of the Dynamic- and Static-VI baseline conditions were 61.37 ($SEM = 1.60$) and 52.72 ($SEM = 2.44$) per min, respectively. Baseline response rates differed significantly between conditions, $t(63) = 3.17$, $p < .01$.

Prefeeding. Mean (plus SEM) responses per min during the last eight sessions of both baseline conditions and responses per min for both sessions of prefeeding, aggregated across subjects, are shown in the top panel of Figure 4. Proportion-of-baseline response rates across sessions of prefeeding are displayed in the bottom panel of this figure (see Supplementary Fig. 2 for proportion-of-baseline response rates across sessions of prefeeding for individual pigeons). These rates were calculated for each subject by dividing response rates during each session of prefeeding by the mean rate of responding for that subject from the last eight sessions of the preceding baseline condition.

Proportion-of-baseline response rates tended to decrease as the amount of food provided to the pigeons prior to sessions increased. Further, these rates were higher in the Dynamic-VI condition for seven of eight pigeons when they were provided with 12% of their criterion body weight worth of chow before session, though these differences

tended to be small. When 14% was provided, proportion-of-baseline response rates were greater in the Dynamic-VI condition for half of the pigeons. A 2 X 3 (Condition X Amount) repeated-measures ANOVA revealed a significant main effect of Amount, $F(2, 14) = 35.44$, $p < .01$; neither the main effect of Condition nor the Condition X Amount interaction was significant (respectively: $F[1, 7] = 1.03$, $p = NS$; and $F[2, 14] = 1.71$, $p = NS$).²

To determine the extent to which the present data support the null hypothesis that baseline-schedule dynamics do not impact persistence of pigeons' key pecking in the face of pre-session feeding, a Bayes factor was calculated for the main effect of Condition. To calculate this factor, mean proportion-of-baseline response rates during both sessions of pre-session feeding were calculated for each pigeon separately for both conditions. Difference scores then were generated for each pigeon by subtracting mean proportion-of-baseline response rates from the Static-VI condition from those scores in the Dynamic-VI condition. The t value from a one-sample t -test conducted on these data, $t(7) = 0.34$, $p = NS$, then was used to calculate a Jeffrey-Zellner-Siow Bayes factor based on the method offered by Rouder, Speckman, Sun, Morey, & Iverson (2009). The resulting Bayes factor was 2.83, indicating anecdotal support for the null hypothesis (Jeffreys, 1961).

²Because only two sessions of pre-session feeding were conducted, it is worth noting the differing effects of baseline reinforcer-rate dynamics on resistance to change between Experiments 1 and 2 cannot easily be attributed to different durations of testing conditions. Not only were between-condition differences in resistance to extinction most visually apparent during the first two sessions of testing in Experiment 1 (see Fig. 1), but these differences also were statistically significant. A 3 X 3 (Condition X Session) repeated-measures ANOVA conducted on extinction data from the first two sessions of testing in Experiment 1 revealed a significant main effect of Condition, $F(2, 14) = 7.59$, $p < .01$, a significant main effect of Day $F(1.19, 8.33) = 132.25$, $p < .001$, and a significant Condition X Session interaction $F(2.27, 15.89) = 3.57$, $p < .05$. Bonferroni-corrected pairwise comparisons based on estimated marginal means for the main effect of Condition again revealed persistence was significantly higher in the Static-VI condition than in the first or second Dynamic-VI conditions. Persistence in the latter conditions, however, did not differ.

Fig. 4. Top panel: Mean (plus SEM) responses per min during the last eight sessions of baseline and both sessions of prefeeding for both conditions of Experiment 2. Bottom panel: Mean (plus SEM) proportion-of-baseline response rates across sessions of prefeeding for both conditions of Experiment 2.

Discussion

The purpose of Experiment 2 was to examine whether reinforcer-rate dynamics experienced during baseline impacted resistance of pigeons’ key pecking to presession feeding. If dynamic, relative to static, baseline reinforcer rates facilitate detrimental effects on responding of generalization decrement, perhaps through change-detection processes (Gallistel, 2012; Gallistel et al., 2001), one would anticipate no difference in resistance to presession feeding of behavior maintained by these contingencies, because generalization decrement does not contribute to disruption by presession feeding.

In most cases, persistence in the face of presession feeding was not systematically related to baseline reinforcer-rate dynamics; that is, persistence was higher in one condition at one pre-fed amount but higher in the other condition at the other pre-fed amount (see Supplementary Fig. 2). Though some pigeons did demonstrate systematically higher persistence in one condition than in the other, between-subject comparisons suggest these differences

were not reliably found in either condition. Further, when data were aggregated across pre-fed amounts, Bayesian analyses provided some support for the null hypothesis that baseline reinforcer-rate dynamics did not impact persistence of responding in the face of presession feeding.

As previously mentioned, behavioral momentum theory offers a formalized account of resistance to change during presession feeding. Since disruptors of equal magnitude were applied to ongoing behavior following Dynamic- and Static-VI conditions, any differences in the impact of these disruptors on behavior should be captured by the scaling parameter, k , in the numerator of Equation 3. To examine parametric effects of static versus dynamic baseline reinforcer rates on resistance to prefeeding, the following equation was fitted to obtained presession feeding data:

$$\frac{B_x}{B_o} = 10^{\frac{-kx}{r^b}} \tag{4}$$

Note this equation is the exponentiated version of Equation 3 and that it was used instead of Equation 3 because zero-rate proportion-of-baseline responding occurred for several pigeons during sessions of presession feeding. Separate fits were conducted for persistence data from the Dynamic-VI and Static-VI conditions for each subject and for data aggregated across subjects using Microsoft Excel Solver. Free-parameter values (k and b), reinforcer-rate parameters (r), and R^2 values for each fit may be found in Table 5.

In the case of most pigeons, values of b were similar between conditions (from the Dynamic- and Static-VI conditions, respectively, ranges: 0.58-1.31 and 0.45-0.89). This finding is consistent with that of Experiment 1, where values of b were reasonably consistent between Dynamic- and Static-VI conditions. Values of k , which scale the disruptive impact of presession feeding amount on responding, were not systematically higher in one condition than in the other: These values were lower in the Dynamic-VI condition for four subjects, lower in the Static-VI condition for three subjects, and the same in both conditions for one subject. Thus, data from Experiments 1 and 2, together, suggest effects of baseline-schedule dynamics on response

Table 5

Parameter Values from Fits of Equation 4 to Pre-session Feeding Data from Experiment 2

Subject	Condition	<i>k</i>	<i>b</i>	<i>r</i>	<i>R</i> ²
4275	Dynamic	0.39	0.7	53	0.18
	Static	0.41	0.7	50.25	0.42
4276	Dynamic	0.16	1.31	54	0.96
	Static	0.44	0.87	52.25	0.85
4274	Dynamic	0.46	0.59	52.8	0.99
	Static	0.44	0.61	49.5	0.99
1499	Dynamic	0.43	0.63	56	0.68
	Static	0.41	0.68	50.25	0.97
4278	Dynamic	0.42	0.68	54.25	0.98
	Static	0.42	0.89	52	0.96
4188	Dynamic	0.46	0.58	55.5	0.98
	Static	0.51	0.47	50.25	0.98
4189	Dynamic	0.37	0.79	53	0.91
	Static	0.53	0.45	52.25	0.99
4277	Dynamic	0.4	0.73	55	0.85
	Static	0.39	0.73	53.5	0.99
Group	Dynamic	0.39	0.71	53	0.89
	Static	0.42	0.67	50.39	0.96

Note. Values of *b* and *k* were rounded to the nearest 100th of a whole number.

persistence are restricted to situations where persistence is measured through extinction. Further, these effects appear to be mediated through generalization decrement.

General Discussion

Extinction of responding following suspension of reinforcement is a multifaceted behavioral phenomenon that may be affected by several variables (see Lattal & Lattal, 2012). The present experiments focused on one such variable, generalization decrement, which is thought to capture disruption of responding based on degree of dissimilarity in reinforcer availability between baseline and extinction conditions (see Nevin, McLean, & Grace, 2001; Rescorla & Skucy, 1969). More specifically, based on Gallistel's (2012) argument that extinction of operant behavior results from detecting changes to zero-rate reinforcement during extinction (see also Baum, 2012, for a similar argument), these experiments examined the relation between generalization decrement during extinction, a disruptive factor presumably related to detection of changes in reinforcer rates, and variables that have been demonstrated to affect detection of changes in reinforcer rates.

Data from several empirical reports suggest that, in choice situations, the ability of organisms to detect changes in reinforcer availability is a function of at least two variables: the size of the change in reinforcer rates and the frequency with which changes occur in the environment (see, e.g., Baum & Davison, 2004; Davison & Baum, 2000; Gallistel et al., 2001; Mazur, 1995; 1996). The first of these variables has been shown to affect extinction performance (Cohen, 1996; 1998; Mackintosh, 1974; Shull & Grimes, 2006), providing tentative support for the connection between generalization-decrement effects on, and detection of changes in reinforcer rates during, extinction. The purpose of the present experiments was to assess effects of the second of these variables on extinction performance.

To this end, Experiment 1 demonstrated that rapidly changing baseline reinforcer rates produced behavior that was less persistent than relatively static baseline reinforcer rates. Follow-up analyses using the quantitative framework of behavioral momentum theory revealed these effects were well characterized by the theory—dynamic baseline schedules produced greater generalization decrement than did static baseline schedules. Experiment 2 provided further support for this hypothesis. When pre-session feeding, a manipulation that should not evoke generalization decrement as a source of disruption, was applied instead of extinction, persistence was unrelated to baseline reinforcer-rate dynamics.

Gallistel (2012) suggested that change detection could serve as an overarching explanatory mechanism for operant extinction. Though the present data suggest generalization-decrement effects on extinction are driven, at least in part, by detection of changes in reinforcer rates, it is important to note this approach cannot offer a unified theory of extinction in that it cannot straightforwardly account for all factors shown to impact resistance to extinction. One such circumstance where the qualitative predictions of Gallistel's conceptual analysis seem to fail is that the relation between baseline reinforcer rates and resistance to extinction depends on the method used to study these effects. Though a negative relation between reinforcer rates and resistance routinely is found in single schedules of reinforcement (Cohen, 1996; 1998; Mackintosh, 1974; Shull & Grimes, 2006), the

opposite relation is found when two or more reinforcement schedules are presented together in a multiple schedule (Nevin, 1974; 1992a; 2002; 2012b). That is, when discriminated operant behavior is considered, resistance to extinction tends to be positively, not negatively, related to baseline reinforcer rates.

Behavioral momentum theory is predicated on the positive relation between baseline reinforcer rates and resistance to change in multiple schedules (see Nevin & Grace, 2000, for discussion). According to the theory, reinforcer deliveries within a discriminative-stimulus situation engender a mass-like quality of behavior (r^b in the denominators of Eqs. 1-4) that produces persistence when disruptors like extinction are applied. In the case of extinction, though higher rates of reinforcement produce greater disruptive impacts of generalization decrement than do lower rates, the contribution of these rates to behavioral mass is great enough to overcome the added disruption (unless exceedingly high reinforcer rates, like those produced by continuous reinforcement of responding, are used; Nevin & Grace, 2005). Momentum theory, though, also is limited in terms of capturing several facets of operant extinction (see Craig, Nevin, & Odum, 2014, for detailed discussion) including the negative relation between baseline reinforcer rates and resistance to extinction often observed when single reinforcement schedules are used.

In light of these limitations, Shull and Grimes (2006) suggested generalization decrement might play different roles in single and multiple schedules. This assertion was based, in part, on single-schedule resistance-to-extinction data from rats that experienced several different baseline reinforcer rates arranged by VI schedules (range: 3.75-240 reinforcers per hr). As one would expect based on previous investigations of resistance to change in single schedules (e.g., Cohen, Riley, & Weigle, 1993; Cohen, 1996), persistence was negatively related to baseline reinforcer rates under these conditions. Further, when Equation 1 was fitted to these data, d values (mean from individual subjects = 0.23) were substantially higher than those typically reported in multiple schedules (i.e., 0.001).

Based on these findings, Shull and Grimes (2006) argued that generalization decrement

reflects disruption produced by the change in overall reinforcer rates between baseline and extinction conditions. In multiple schedules, these overall baseline reinforcer rates might reflect reinforcer rates averaged between schedule components. Thus, since this term would be the same between components, generalization decrement would have little if any differential impact on response persistence. In single schedules, generalization-decrement effects are specifically and positively related to the reinforcer rate experienced prior to extinction testing, thus generating differential disruption of responding based on baseline reinforcer rates. Since both single- and multiple-schedule extinction entails suspending reinforcement, however, it is theoretically unclear why generalization decrement would provide relatively little disruption in multiple schedules (i.e., $d \approx 0.001$) and a large amount of disruption (i.e., $d \approx 0.23$) in single schedules. Further, it should be noted that c values were small in their model fits ($c = 0$ in most cases), suggesting negligible impacts on responding of suspending the response-reinforcer contingency in single schedules. It is not intuitive to presuppose this source of disruption operates only in multiple schedules. Though these assumptions allow the momentum-based model of extinction to describe persistence data from single schedules, they are based on post hoc results from fits of a model typically used to describe multiple-schedule performance. Thus, this interpretation of the differential dependency of resistance to extinction on baseline reinforcer rates generated by single and multiple schedules is not without challenges.

Gallistel (2012) attempted to reconcile differences between resistance to extinction in single and multiple schedules with his statistical decision-making approach by including an additional assumption to the theory. This assumption states that, in extinction it is in the interest of the organism to continue to sample from response options in the case that reinforcer availability is reinstated. Further, sampling rate should be roughly proportional to previously experienced reinforcer rates. Thus, despite the enhanced detectability of transitions to extinction following relatively high reinforcer rates, differential persistence might reflect the organism's differential "checking" whether the state of reinforcer availability has

changed. As Nevin (2012a) described, however, this interpretation necessarily is either incorrect or incomplete because it is unclear why differential sampling in extinction should occur between single and multiple schedules. That is, if relatively high reinforcer rates produce relatively high rates of checking in general, one would anticipate a positive relation between resistance to extinction and baseline reinforcer rates regardless of the schedule arrangement.

Thus, neither Gallistel's (2012) analysis of extinction performance nor the quantitative theory of extinction offered by behavioral momentum theory appear to present complete descriptions of the behavior processes involved in extinction. Though these theoretical accounts of extinction performance have different conceptual underpinnings, one could argue that change-detection and momentum-based response-strengthening processes *both* contribute to extinction and that the interplay between these processes differs depending on the preparation in which extinction is assessed. That is, detectability of changes in reinforcer rates might predominantly govern resistance to extinction in single schedules while response-strengthening processes predominantly govern resistance to extinction in multiple schedules. Combining these separate theories of extinction performance is attractive in that it reconciles the discrepant findings produced when extinction is assessed in single- versus multiple-schedule contexts. If both of these proposed facets of operant extinction contribute to extinction performance, however, it is unknown how they interact and why one schedule context should evoke one process more than (or instead of) the other.

Our conjecture is that multiple schedules of reinforcement present more complicated sources of information to organisms than do single schedules. Further, behavioral-momentum effects during extinction in multiple schedules might be the manifestation of the organism using this information in equally complicated and perhaps unexpected ways to navigate changing reinforcement contingencies. In multiple schedules, response persistence depends not only on reinforcer rates within a component but also on overall reinforcer rates across components (see Nevin, 1992b). Thus, the sources of

information provided by reinforcer rates within multiple-schedule components likely are not considered as entirely separate sources of information by the organism. Instead, reinforcer rates in either component might contribute mutual information to the organism's *overall* assessment of reinforcer availability. If, for example, the organism detects that reinforcer presentations have ceased in one component during extinction, the strength of the evidence that presentations have ceased in the other component might not need to be as strong for the organism to conclude that extinction is in effect globally. Returning to Gallistel's (2012) argument, the organism might then sample frequently in the rich-schedule context because it also serves as a relatively rich source of information about the global state of reinforcer availability.

Data from the current experiments are not sufficient to discriminate between these theoretical possibilities. These results do, however, suggest that detection of changes in reinforcer rates contributes to operant extinction (or at least to generalization-decrement effects on extinction performance). Thus, detection of changes in reinforcer rates might provide an underlying mechanism for generalization-decrement effects on extinction performance. Further, these data suggest that the ability of organisms to detect changes in reinforcer rates can be experimentally manipulated by presenting periods during which reinforcer rates change rapidly (cf., Gallistel et al., 2001). Further work will be necessary to determine precisely how organisms navigate the temporal dynamics of reinforcer availability inherent in operant extinction.

References

- Baum, W. M. (2012). Extinction as discrimination: The molar view. *Behavioural Processes*, 90, 101–110.
- Baum, W. M., & Davison, M. (2004). Choice in variable environments: Visit patterns in the dynamics of choice. *Journal of the Experimental Analysis of Behavior*, 81, 85–127.
- Brown, P., & Jenkins, H. M. (1968). Auto-shaping of the pigeon's key peck. *Journal of the Experimental Analysis of Behavior*, 11, 1–8.
- Catania, A. C. (1973). The nature of learning. In J. A. Nevin & G. S. Reynolds (Eds.), *The study of behavior* (pp. 30–68). Glenview, IL: Scott Foresman.
- Cohen, S. L. (1996). Behavioral momentum of typing behavior in college students. *Journal of Behavior Analysis and Therapy*, 1, 36–54.

- Cohen, S. L. (1998). Behavioral momentum: The effects of the temporal separation of rates of reinforcement. *Journal of the Experimental Analysis of Behavior*, 69, 29–47.
- Cohen, S. L., Riley, D. S., & Weigle, P. A. (1993). Tests of behavior momentum in simple and multiple schedules with rats and pigeons. *Journal of the Experimental Analysis of Behavior*, 60, 255–291.
- Craig, A. R., Cunningham, P. J., & Shahan, T. A. (2015). Behavioral momentum and accumulation of mass in multiple schedules. *Journal of the Experimental Analysis of Behavior*, 103, 437–449.
- Craig, A. R., Nevin, J. A., & Odum, A. L. (2014). Behavioral momentum and resistance to change. In F. K. McSweeney, & E. S. Murphy (Eds.), *The Wiley-Blackwell handbook of operant and classical conditioning* (pp. 249–274). Oxford, UK: Wiley-Blackwell.
- Davison, M., & Baum, W. M. (2000). Choice in variable environments: Every reinforcer counts. *Journal of the Experimental Analysis of Behavior*, 74, 1–24.
- Fleshler, M., & Hoffman, H. S. (1962). A progression for generating variable-interval schedules. *Journal of the Experimental Analysis of Behavior*, 5, 529–530.
- Gallistel, C. R. (2012). Extinction from a rationalist perspective. *Behavioural Processes*, 90, 66–80.
- Gallistel, C. R., & Gibbon, J. (2000). Time, rate, and conditioning. *Psychological Review*, 107, 289–344.
- Gallistel, C. R., King, A. P., Gottlieb, D., Balci, F., Papachristos, E. B. ... & Carbone, K. S. (2007). Is matching innate? *Journal of the Experimental Analysis of Behavior*, 87, 161–199.
- Gallistel, C. R., Mark, T. A., King, A. P., & Latham, P. E. (2001). The rat approximates an ideal detector of changes in rates of reward: Implications for the law of effect. *Journal of Experimental Psychology: Animal Behavioural Processes*, 27, 354–372.
- Grace, R. C., & Nevin, J. A. (1997). On the relation between preference and resistance to change. *Journal of the Experimental Analysis of Behavior*, 67, 43–65.
- Jeffreys, H. (1961). *Theory of probability* (3rd ed.). Oxford, UK: Oxford University Press.
- Lattal, K. A. (1989). Contingencies on response rate and resistance to change. *Learning and Motivation*, 20, 191–203.
- Lattal, K. A., St. Peter, C., & Escobar, R. (2013). Operant extinction: Elimination and generation of behavior. In G. J. Madden, W. V. Dube, T. D. Hackenberg, G. P. Hanley, & K. A. Lattal (Eds.), *APA handbook of behavior analysis, Vol. 2: Translating principles into practice* (pp. 77–107). Washington, D.C.: American Psychological Association.
- Lattal, K. M., & Lattal, K. A. (2012). Facets of Pavlovian and operant extinction. *Behavioural Processes*, 90, 1–8.
- Mackintosh, N. J. (1974). *The psychology of animal learning*. London, UK: Academic Press.
- Mazur, J. E. (1995). Development of preference and spontaneous recovery in choice behavior with concurrent variable-interval schedules. *Animal Learning & Behavior*, 23, 93–103.
- Mazur, J. E. (1996). Past experience, recency, and spontaneous recovery in choice behavior. *Animal Learning & Behavior*, 24, 1–10.
- Nevin, J. A. (1974). Response strength in multiple schedules. *Journal of the Experimental Analysis of Behavior*, 21, 389–408.
- Nevin, J. A. (1992a). An integrative model for the study of behavioral momentum. *Journal of the Experimental Analysis of Behavior*, 57, 301–316.
- Nevin, J. A. (1992b). Behavioral contrast and behavioral momentum. *Journal of Experimental Psychology: Animal Behavior Processes*, 18, 126–133.
- Nevin, J. A. (2002). Measuring behavioral momentum. *Behavioural Processes*, 57, 198–287.
- Nevin, J. A. (2012a). Behavior theory and information theory: Some parallels. *Behavioural Processes*, 90, 84–86.
- Nevin, J. A. (2012b). Resistance to extinction and behavioral momentum. *Behavioural Processes*, 90, 89–97.
- Nevin, J. A., & Grace, R. C. (2000). Behavioral momentum and the law of effect. *Behavioral and Brain Sciences*, 23, 73–130.
- Nevin, J. A., & Grace, R. C. (2005). Resistance to extinction in the steady state and in transition. *Journal of Experimental Psychology: Animal Behavior Processes*, 31, 199–212.
- Nevin, J. A., Grace, R. C., Holland, S., & McLean, A. P. (2001). Variable-ratio versus variable-interval schedules: Response rate, resistance to change, and preference. *Journal of the Experimental Analysis of Behavior*, 76, 43–74.
- Nevin, J. A., Mandell, C., & Atak, J. R. (1983). The analysis of behavioral momentum. *Journal of the Experimental Analysis of Behavior*, 39, 49–59.
- Nevin, J. A., McLean, A. P., & Grace, R. C. (2001). Resistance to extinction: Contingency termination and generalization decrement. *Animal Learning & Behavior*, 29, 176–191.
- Nevin, J. A., & Shahan, T. A. (2011). Behavioral momentum theory: Equations and applications. *Journal of Applied Behavior Analysis*, 44, 877–895.
- Petscher, E. S., & Bailey, J. S. (2008). Comparing main and collateral effects of extinction and differential reinforcement of alternative behavior. *Behavior Modification*, 32, 468–488.
- Rescorla, R. A., & Skucy, J. C. (1969). Effect of response-independent reinforcers during extinction. *Journal of Comparative and Physiological Psychology*, 67, 381–389.
- Rouder, J. N., Speckman, P. L., Sun, D., Morey, R. D., & Iverson, G. (2009). Bayesian *t* tests for accepting and rejecting the null hypothesis. *Psychonomic Bulletin & Review*, 16, 225–237.
- Shull, R. L., & Grimes, J. A. (2006). Resistance to extinction following variable-interval reinforcement: Reinforcer rate and amount. *Journal of the Experimental Analysis of Behavior*, 85, 23–39.

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Supporting Information

Additional Supporting Information may be found in the online version of this article at the publisher's web-site.