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A FURTHER LOOK AT REINFORCEMENT RATE AND RESURGENCE

UNA MIRADA MÁS PROFUNDA A LA TASA DE REFORZAMIENTO Y EL RESURGIMIENTO

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Abstract

Resurgence is the recurrence of a previously reinforced and then extinguished response when a more recently reinforced response is extinguished. The purpose of the present experiments was to examine the relation between alternative reinforcement rates and resurgence with pigeons. Each experiment consisted of a three-phase procedure and each phase of three experiments was a two-component multiple schedule, except for Experiments 2a and 2b, which employed single schedules. In each experiment, the target response was reinforced according to a variable–interval (VI) schedule in the Acquisition phase. In the Elimination phase, the target response was eliminated using either extinction or a differential–reinforcement–of–other–behavior (DRO) schedule and the alternative response was reinforced according to a VI schedule. The rate of alternative reinforcement differed between components, but the number of reinforcers per hour (and thus the reinforcement ratio) was 60 and 180 in the Lean and Rich

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components, respectively. In the Resurgence phase, all reinforcers were withheld and resurgence was compared between components. Across all experiments, results were inconsistent. In some instances there was greater resurgence in the Rich component, but the opposite was observed in others. These results do not offer evidence supporting the prediction of behavioral momentum and related models of resurgence.

Keywords: resurgence, extinction, alternative reinforcement, behavioral momentum, multiple schedule, pigeons

Resumen

El resurgimiento es la recurrencia de una respuesta previamente reforzada y luego extinguida cuando una respuesta más recientemente reforzada es extinguida. El propósito de los presentes experimentos fue examinar la relación entre las tasas de reforzamiento alternativo y el resurgimiento en palomas. Cada experimento consistió de un procedimiento de tres fases y cada fase de tres experimentos fue un programa múltiple de dos componentes, excepto para los Experimentos 2a y 2b, en los que se emplearon programas simples. En cada experimento, se reforzó la respuesta blanco conforme a un programa de intervalo variable (IV) en la fase de Adquisición. En la fase de Eliminación, la respuesta blanco se eliminó usando ya sea extinción o un programa de reforzamiento diferencial de otras conductas (RDO) y la respuesta alternativa se reforzó conforme a un programa IV. La tasa de reforzamiento alternativo difirió entre componentes, pero el número de reforzadores por hora (y por lo tanto la proporción de reforzamiento) fue de 60 y 180 en los componentes pobres y densos, respectivamente. En la fase de Resurgimiento, todos los reforzadores fueron descontinuados y se comparó el resurgimiento entre componentes. A través de todos los experimentos, los resultados fueron inconsistentes. En algunas instancias hubo un mayor resurgimiento en el componente denso, pero se observó lo contrario en otras. Estos resultados no ofrecen evidencia que apoye la predicción del momento conductual y los modelos de resurgimiento relacionados.

Palabras clave: resurgimiento, extinción, reforzamiento alternativo, momento conductual, programa múltiple, palomas

Resurgence is the recurrence of a previously reinforced and subsequently extinguished response when a more recently reinforced response is extinguished (Epstein, 1983, 1985). In a typical laboratory study, resurgence is examined by using a three-phase procedure (e.g., Carey, 1951; Leitenberg, Rawson, & Bath, 1970; Lieving & Lattal, 2003). In the Acquisition phase, a target response is reinforced. In the Elimination phase, the target response is eliminated and an alternative response is reinforced. In the Resurgence phase, the alternative response also is eliminated. An increase in the rate or probability of the target response in the third phase relative to that observed in the Elimination phase defines resurgence.

Variables that affect resurgence may be associated with each of the three phases. With respect to the effects of variables in the Elimination phase on resurgence, conflicting results have been reported. For example, Leitenberg, Rawson, and Mulick (1975) reported that higher alternative reinforcement rates produced greater resurgence. In their study, key pecking of pigeons was reinforced on a variable–interval (VI) 120–s schedule in the Acquisition phase. In the subsequent Elimination phase, an alternative lever-press response was reinforced according to a VI 30–s schedule in one (Rich) group and a VI 240–s schedule in another (Lean) group. The Rich group showed more rapid extinction of the target response in the Elimination phase and greater resurgence of the target response in the Resurgence phase.

Leitenberg et al.'s (1975) findings suggest that the reinforcement rate in the Elimination phase is an important variable that should be accounted for by models of resurgence. For example, Shahan and Sweeney (2011) updated the model proposed by Podlesnik and Shahan (2010; see also Podlesnik & Shahan, 2009) to account for rapid extinction and greater resurgence under higher rates of alternative reinforcement. The model identifies two roles for alternative reinforcement during the Elimination phase. One is that alternative reinforcement itself has a disruptive effect on the target response. This assumption makes it possible to explain more rapid extinction of the target response under higher rates of alternative reinforcement. The other one is that alternative reinforcement contributes to the overall strength of the target response. This second assumption plays a critical role in explaining greater resurgence under higher rates of alternative reinforcement. Podlesnik and Shahan (2009) showed that the Pavlovian stimulus–reinforcer relation, widely considered to be the mechanism of resistance to change, also could determine the magnitude of resurgence, at least in relative terms (i.e., where the proportion of baseline response rate is used as the measure of resurgence). In their study, target responses in both the Rich and Lean components were reinforced on VI 120–s schedules in the Acquisition phase. In addition, response–independent reinforcers delivered according to a variable–time (VT) 20–s schedule were added in the Rich component (i.e., conjoint VI 120–s VT 20–s schedules were in effect in the Rich component). In the Resurgence phase, resurgence in the Rich component was greater than that in the Lean component, despite the lower response rates in that component during the Acquisition phase. They concluded that the Pavlovian stimulus–reinforcer relation determined the magnitude of resurgence on a relative scale (see also Podlesnik & Shahan, 2010). Note that an important aspect of the Pavlovian stimulus–reinforcer relation is that the source of reinforcement does not matter. In other words, all reinforcers obtained in that context contribute to the response strength. It follows from this behavioral momentum perspective that the rate of alternative reinforcement in the Elimination phase affects the strength of target response and hence resurgence.

Other models for resurgence also assign a role to the rate of alternative reinforcement in resurgence, but with assumptions other than those of behavioral momentum theory (e.g., the response–prevention hypothesis; Leitenberg et al. 1975; Rawson, Leitenberg, Mulick, & Lefebvre, 1977; see also Cleland, Foster, & Temple, 2000).

Several more recent studies, however, have reported results inconsistent with those of Leitenberg et al. (1975) and with the prediction of these models. Winterbauer and Bouton (2010), for example, failed to show differential resurgence when a random-interval (RI) 10–s and a RI 30–s reinforcement schedules were in effect in the their Rich and Lean groups, respectively, during the Elimination phase. Cançado and Lattal (2013) also examined the same issue by using within–subject comparisons and did not find differential resurgence when several different values of a differential–reinforcement–of–other–behavior (DRO) schedule were in effect in the Elimination phase.

Taken together, models for resurgence incorporate the effects of the alternative reinforcement and predict greater resurgence under higher alternative reinforcement rates, but the aforementioned two recent studies have reported results at odds with these predictions. Cançado and Lattal's experiments used DRO schedules rather than the VI schedules used by others to arrange differential rates of reinforcement of the alternative response, which may contribute to their results in comparison to Leitenberg et al. and Shahan and colleagues (2009, 2011). Winterbauer and Bouton (2010) used a group design with relatively few training sessions in comparison to the other experiments cited above. The purpose of the present experiments was to further examine the effect of alternative reinforcement on resurgence in a two–component multiple schedule in which differential alternative reinforcement rates and/or different reinforcement schedule were in effect in the Elimination phase.

Experiment 1

In this experiment resurgence was compared in a two–component multiple schedule in which either higher or lower alternative reinforcement rates were in effect for eliminating the target response in the Elimination phase. The different reinforcement rates were arranged in Experiments 1a and 1b by using fixed or variable DRO schedules, respectively, in a systematic replication of Cançado and Lattal (2013).

Method

Subjects. Four pigeons (*Columba livia*) were maintained at about 80% of their free–feeding weights. They were housed individually with a 12:12 h light/dark cycle (lights on 08:00 a.m.) and had free access to water and grit in the home cage. All subjects had previous experiences with various experimental procedures.

Apparatus. Four operant chambers, 32 cm long, 25 cm wide, and 33 cm high were used. Each chamber had three response keys on the front wall 26 cm above the grid floor. Each key was 3 cm in diameter and placed 6 cm apart from each other (center to center) and could be transilluminated with lights of different colors. A minimum force of approximately 0.15 N was required to operate the keys. Reinforcement was 3–s access to mixed grains delivered by a food hopper located below the center key. During reinforcement, the hopper was illuminated with white light. A house light on the rear wall provided general illumination. Each chamber was housed in a sound-attenuating box with a ventilation fan. White noise presented in the box masked extraneous noise. Event scheduling and data recording were controlled by a computer using Visual Basic 2005 Express Edition software.

Procedure. Pigeons initially were trained to key peck on a VI schedule. During this training, one of the three keys —left, center, or right— was white and the location of the color was randomly assigned for successive reinforcements. Each session lasted for 30 min. The mean VI values were gradually increased from 5 to 30 s across the five sessions. Each interval was sampled without replacement from 12 intervals generated using the Fleshler and Hoffman (1962) progression. Following this training, pigeons were exposed to the following procedures.

In both Experiments 1a and 1b, a two-component multiple schedule arranged on the center key was in effect across all phases. Both components were 180–s in duration and separated by a 60–s intercomponent interval (ICI), during which a blackout was in effect. Each of the two components strictly alternated and occurred five times during a session. Daily sessions occurred 7 days a week at approximately the same time each day. Each pigeon first was exposed to Experiment 1a and then to Experiment 1b. The schedule and the number of sessions in each phase are shown in Table 1.

In the Acquisition phase, a VI 30-s schedule was in effect in both components for a minimum of 20 sessions in Experiment 1a and 15 sessions in Experiment 1b. This phase was terminated when the following stability criterion was met: The mean response rates in each component from the final six sessions were divided into two blocks consisting of the three sessions. When each of the two sub–means of each component differed from the overall mean by less than 10%, the next phase was implemented.

In the Elimination phase, a DRO 20–s and 60–s schedules were in effect in what will be labeled hereafter the Rich and Lean components, respectively. Thus, reinforcers were delivered only when a response had not been emitted for a period of time and each response restarted the DRO timer in that component. The difference between Experiments 1a and 1b in this phase was whether the DRO value was constant or varied: In Experiment 1a, each DRO value was sampled without replacement from 12 intervals (Fleshler & Hoffman, 1962) so that each interreinforcer interval (IRI) was varied within a session (hereafter called VDRO). In contrast, constant DRO values

Table 1

The schedules of target and alternative responses in each phase of all Experiments.

	Rich Component		Lean Component	
Phase	Target	Alternative	Target	Alternative
Experiment 1a				
Acquisition	VI 30-s	-	VI 30-s	-
Elimination	EXT	VDRO 20-s	EXT	VDRO 60-s
Resurgence	EXT	EXT	EXT	EXT
Experiment 1b				
Acquisition	VI 30-s	-	VI 30-s	-
Elimination	EXT	FDRO 20-s	EXT	FDRO 60-s
Resurgence	EXT	EXT	EXT	EXT
Experiment 2a				
Acquisition	VI 30-s	-	VI 30-s	-
Elimination	EXT	VI 20-s	EXT	VI 60-s
Resurgence	EXT	EXT	EXT	EXT
Experiment 2b				
Acquisition	VI 30-s	-	-	-
Elimination	EXT	VI 20-s	-	-
Resurgence	EXT	EXT	-	-
Experiment 2c				
Acquisition	-	-	VI 30-s	-
Elimination	-	-	EXT	VI 60-s
Resurgence	-	-	EXT	EXT
Experiment 3				
Acquisition	VI 30-s	-	VI 30-s	-
Elimination	VDRO 30-s	VI 60-s	EXT	VI 60-s
Resurgence	EXT	EXT	EXT	EXT

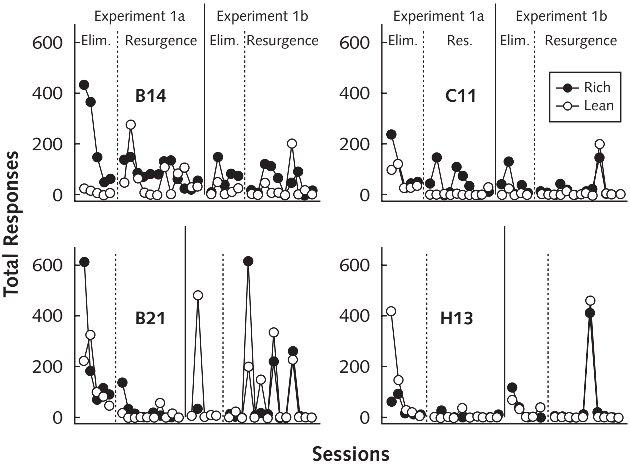

Figure 1. Total number of target responses over the last 5 sessions of the Elimination phase and the all sessions of the Resurgence phase in Experiment 1a and 1b. Dashed and solid vertical lines in each graph separate the Elimination and Resurgence phases, and the Experiments 1a and 1b, respectively.

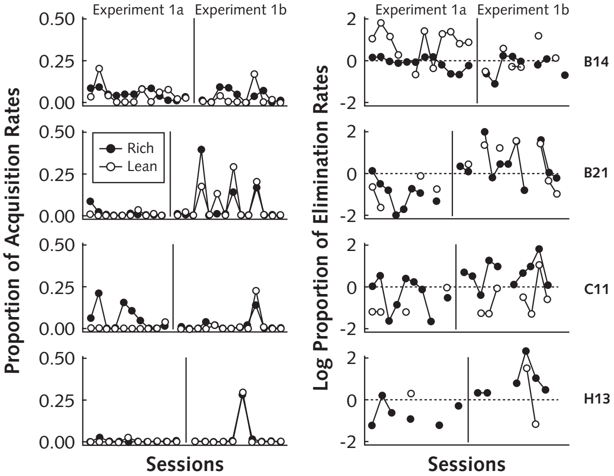

Figure 2. Proportion of the Acquisition response rates (left panel) and log proportion of the Elimination (right panel) response rates during the Resurgence phase. Solid vertical lines in each graph separate the Experiments 1a and 1b. Proportion of the Acquisition rates was calculated by dividing the response rates in each session of the Resurgence phase by mean response rates during the last 6 sessions in the Acquisition phase. Log proportion of the Elimination rates was the logarithm of values calculated by dividing the response rates in each session of the Resurgence phase by mean response during the last 3 sessions in the Elimination phase. Each point above the horizontal dashed line in the right panel represents the resurgence.

were used in Experiment 1b (hereafter called FDRO). In both DRO schedules, any response during a given IRI reset the IRI to the value of the IRI in effect. In Experiments 1a and 1b, the minimum number of sessions in this phase was 10 sessions and were terminated when the following two stability criteria were met: The target response rates decreased below 10% of baseline rates for 3 consecutive sessions in both components.

The Resurgence phase was the same in both Experiments 1a and 1b such that all reinforcers were withheld. That is, extinction was in effect in both components. This phase lasted for at least 10 sessions and was terminated when both the target and alternative response rates decreased below 10% of baseline rates (i.e., Acquisition phase response rates of the target response and Elimination phase response rates of the alternative response) for 3 consecutive sessions in both components.

Results and Discussion

Figure 1 shows the total number of target responses in the Rich and Lean component during the last 5 sessions of the Elimination phase and all Resurgence phase sessions. Figure 2 shows these data as proportion and log proportion of the target response rates during the stable sessions of the immediately preceding Training (left panel) or Elimination (right panel) phase, respectively. The patterns of resurgence between components were different for each pigeon in both Experiments 1a and 1b. In Experiment 1a, Pigeons B21 and C11 showed somewhat greater resurgence in the Rich component. For Pigeon B14, the larger amount of resurgence occurred in the Lean component of the second session. Although there seemed to be little difference in resurgence between components as shown in Figure 1 and the left panel of Figure 2, target responding in the Lean component more frequently reappeared across sessions than did responding in the Rich component, relative to response rates in the preceding Elimination phase (see the right panel of Figure 2). For Pigeon H13, there was no systematic difference in resurgence between the Rich and Lean components.

In Experiment 1b, greater resurgence occurred in Pigeons B21 and H13 than in Experiment 1a. For Pigeon H13, there was little difference in resurgence between components. For Pigeon B21, resurgence was greater in the Rich component in the fourth session, but the opposite results was found in the sixth and eighth sessions. It may be notable that the rate of target responding in the Acquisition phase of B21 was higher in the Lean component (see Table 2). Some experiments have reported that higher rates of target responding in the Acquisition phase produced greater resurgence (da Silva, Maxwell, & Lattal, 2008; Winterbauer, Lucke, & Bouton, 2013, Experiment 1). Thus, it was possible that the higher rate of target response in the Lean component during the Acquisition phase, rather than alternative reinforcement rates, contributed

Table 2

Mean response rates and reinforcement rates (standard deviations in parenthesis) over the last 6 sessions in the Rich and Lean components of the Acquisition and Elimination phase and the total number of sessions across Experiments

		Responses per Minute								Reinforcers per Minute								Num. of Sessions		
		Acquisition Phase				Elimination Phase				Acquisition Phase				Elimination Phase						
Experiments	Pigeons	Rich		Lean		Rich		Lean		Rich		Lean		Rich		Lean		Acq.	Elim.	Res.
[a]Exp. 1a	B14	108.75	(13.00)	91.50	(5.99)	-	-	-	-	1.94	(0.10)	1.99	(0.09)	2.20	(0.13)	0.86	(0.22)	15	16	10
	B21	108.41	(11.34)	122.87	(10.09)	-	-	-	-	1.91	(0.06)	1.91	(0.12)	1.33	(0.31)	0.43	(0.21)	33	26	10
	C11	46.69	(17.21)	52.07	(15.76)	-	-	-	-	1.73	(0.27)	1.73	(0.41)	2.17	(0.41)	0.76	(0.07)	21	30	11
	H13	72.08	(7.64)	91.18	(7.13)	-	-	-	-	1.87	(0.11)	1.96	(0.09)	2.56	(0.00)	0.84	(0.26)	21	17	18
[a]Exp. 1b	B14	86.93	(7.68)	81.07	(8.74)	-	-	-	-	1.94	(0.17)	1.90	(0.12)	2.45	(0.21)	0.86	(0.08)	15	15	10
	B21	76.32	(9.88)	104.55	(15.88)	-	-	-	-	1.88	(0.06)	1.82	(0.13)	2.81	(0.09)	0.95	(0.04)	16	14	14
	C11	58.18	(6.32)	69.67	(6.30)	-	-	-	-	1.90	(0.07)	1.97	(0.17)	2.64	(0.22)	0.95	(0.04)	19	12	13
	H13	95.86	(2.90)	105.28	(8.22)	-	-	-	-	1.94	(0.11)	1.91	(0.14)	2.93	(0.05)	0.91	(0.13)	19	10	10
Exp. 2a	A01	47.36	(9.01)	60.28	(12.24)	103.49	(4.82)	73.51	(3.28)	1.94	(0.08)	1.94	(0.15)	2.97	(0.10)	0.98	(0.14)	33	22	10
	A02	48.00	(7.62)	44.14	(7.98)	49.49	(7.27)	42.40	(8.13)	1.79	(0.19)	1.89	(0.22)	2.86	(0.09)	1.00	(0.11)	30	21	10
	A03	84.25	(17.67)	68.80	(8.72)	121.24	(5.38)	115.84	(7.15)	1.99	(0.08)	1.98	(0.09)	2.86	(0.12)	1.00	(0.08)	34	21	10
	A04	54.44	(2.08)	62.29	(5.53)	58.87	(5.26)	52.33	(5.14)	1.86	(0.08)	1.94	(0.16)	2.87	(0.09)	0.93	(0.08)	41	16	10
Exp. 2b	A01	83.23	(6.42)	-	-	67.32	(9.04)	-	-	1.94	(0.09)	-	-	2.86	(0.10)	-	-	17	15	10
	A02	56.51	(3.49)	-	-	49.27	(2.36)	-	-	1.88	(0.05)	-	-	2.88	(0.04)	-	-	15	15	12
	A03	93.60	(4.98)	-	-	75.13	(6.43)	-	-	1.94	(0.04)	-	-	2.89	(0.08)	-	-	15	15	11
	A04	51.68	(5.95)	-	-	49.08	(3.83)	-	-	1.94	(0.06)	-	-	2.87	(0.05)	-	-	15	15	11
Exp. 2c	A01	-	-	52.22	(5.09)	-	-	48.21	(9.75)	-	-	1.94	(0.07)	-	-	0.96	(0.06)	16	16	16
	A02	-	-	53.00	(3.67)	-	-	39.50	(6.53)	-	-	1.91	(0.06)	-	-	0.97	(0.06)	15	31	10
	A03	-	-	74.80	(3.02)	-	-	70.06	(12.05)	-	-	1.95	(0.05)	-	-	0.98	(0.06)	15	15	10
	A04	-	-	57.96	(4.49)	-	-	51.41	(5.11)	-	-	1.91	(0.09)	-	-	0.95	(0.03)	16	16	10
bExp. 3	A11	53.21	(1.57)	53.27	(2.78)	51.92	(3.14)	42.23	(7.08)	1.84	(0.04)	1.87	(0.11)	2.06	(0.55)	0.91	(0.09)	33	16	12
	B01	32.05	(6.76)	34.49	(8.58)	29.51	(1.83)	29.90	(8.51)	1.63	(0.33)	1.64	(0.35)	2.53	(0.13)	0.76	(0.19)	21	28	10
	C23	83.83	(12.89)	87.60	(7.35)	89.66	(16.48)	72.35	(16.22)	1.94	(0.13)	1.90	(0.12)	2.83	(0.15)	1.09	(0.10)	33	17	10
	D11	80.11	(5.50)	76.40	(15.10)	98.52	(12.51)	80.53	(14.23)	1.93	(0.12)	1.87	(0.16)	2.67	(0.15)	1.05	(0.08)	21	15	11
bExp. 3 replication	A11	64.74	(7.27)	63.78	(6.62)	45.24	(3.73)	56.01	(4.05)	1.89	(0.05)	1.91	(0.12)	2.66	(0.36)	0.94	(0.08)	20	16	10
	D11	80.84	(14.38)	80.63	(12.30)	79.82	(9.10)	72.23	(6.28)	1.94	(0.11)	1.87	(0.10)	2.63	(0.15)	0.98	(0.00)	30	23	10

Note. Acq. = Acquisition phase; Elim. = Elimination phase; Res. = Resurgence phase.

[a]Mean reinforcement rates in the Elimination phase are the means of the last 3 sessions because the scope of the stability criterion in this phase is limited to this range. [b]Mean reinforcement rates in the Rich component of the Elimination phase are calculated by dividing all reinforcers obtained from both keys by the total component duration.

to the amount of resurgence. For Pigeons B14 and C11, resurgence occurred in neither component. There was no obvious difference in resurgence between Experiments 1a and 1b suggesting that whether the DRO value in the Elimination phase was variable (VDRO) or fixed (FDRO) did not affect the amount of target responses, a finding consistent with the results reported by Doughty, da Silva, and Lattal (2007).

Taken together, although there were some instances of greater resurgence in the Rich component, there were other instances where resurgence was greater in the Lean component or where there were no differences in resurgence between the Rich and Lean components. It also is notable that there was little to no resurgence on several occasions. One possible reason for this result was the use of a DRO schedule for eliminating the target response. Although Doughty et al. (2007) suggested that more resurgence might occur when a DRO schedule is used, the results of other studies suggest this may not be the case (e.g., Cançado & Lattal, 2013; Mulick, Leitenberg, & Rawson, 1976). In addition, Pacitti and Smith (1977) suggested the possibility that the topography of alternative responding in the Elimination phase also may affect the amount of resurgence (cf. Doughty et al., 2007). These procedural differences between the present experiment and prior ones investigating reinforcement rate and resurgence may have contributed to the general absence of a systematic effect of these two variables. The next two experiments (2 and 3) therefore used VI reinforcement of key pecking in the Alternative reinforcement phase of the experiment, rather than DRO, to further examine the relation between alternative reinforcement rates and the amount of resurgence.

Experiment 2

In Experiment 2, resurgence was compared when the alternative response in each component was the same topography as the target response, but was reinforced on different-valued VI schedules.

Method

Subjects and Apparatus. Four pigeons (*Columba livia*), different from those used in Experiment 1, were maintained at about 80% of their free-feeding weights. They were housed individually with a 12:12 h light/dark cycle (lights on 08:00 a.m.) and had free access to water and grit in the home cage. All had previous experience with various experimental procedures. The apparatus was the same as in Experiment 1.

Procedure. After pretraining, the pigeons were exposed to the following three phases. Daily sessions consisted of a two–component multiple schedule across all phases. The details of the multiple schedule in Experiment 2a and the stability criteria for changing between phases were as described for Experiment 1. Each phase terminated when the minimum number of sessions was conducted and the stability criteria were met. The schedules and the number of sessions in each phase are shown in Table 1.

Experiment 2a

Experiment 2a consisted of a two–component multiple schedule across all phases. In the Acquisition phase, target responses to either the left or right side key were reinforced on a VI 30–s schedule in both components. This phase lasted for a minimum of 30 sessions. In the Elimination phase, the target responses to either side key were extinguished in both components, while alternative responses to the center key were reinforced on VI 20–s and VI 60–s schedules in the Rich and Lean components, respectively. A 3–s changeover delay (COD) was in effect between responses on the key that was operative in the previous Acquisition phase and reinforced responses on the key in effect during the Elimination phase. This phase lasted for a minimum of 15 sessions and was terminated when both target and alternative responses met the stability criteria. In the Resurgence phase, all reinforcers were withheld in both components. This latter phase lasted for at least 10 sessions.

Experiments 2b and 2c

In contrast to the multiple schedule used in Experiment 2a, Experiments 2b and 2c consisted of a single schedule of reinforcement in each of the three phases of the experiment. This was done in an attempt to determine whether schedule interactions between components might have contributed to the results of Experiments 1 and 2a. The schedules in Experiments 2b and 2c are shown in Table 1 and corresponded to those in effect in the Rich and Lean components, respectively, of Experiment 2a. Each session started after a 30–s blackout and ended after 30–min. In both conditions, the minimum number of sessions in the Acquisition phase was 15. Other aspects of each phase were as described for Experiment 1a. The order of Experiments 2b and 2c differed across pigeons: A01 and A03 were exposed to Experiment 2c at first and then 2b; for A02 and A04, the order was reversed.

Results and Discussion

Figure 3 shows the number of target responses in the Rich and Lean component during the last 5 sessions of the Elimination phase and all sessions of the Resurgence phase in Experiment 2. Figure 4 shows the Figure 3 data for each session in the resur-

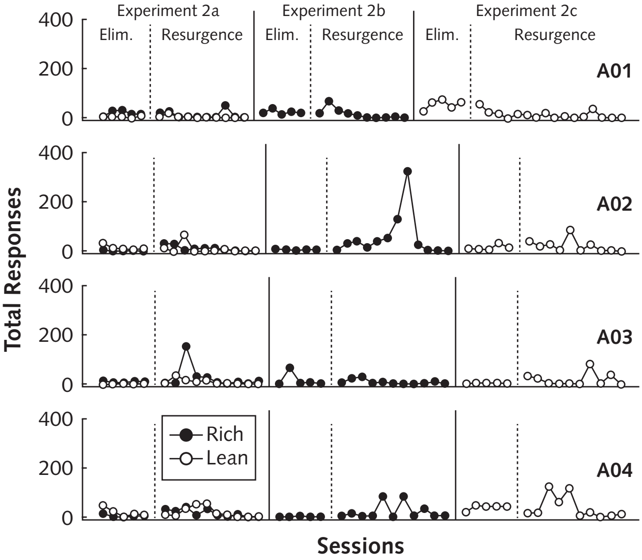

Figure 3. Total number of target responses over the last 5 sessions of the Elimination phase and the all sessions of the Resurgence phase in Experiments 2. Dashed and solid vertical lines in each graph separate the Elimination and Resurgence phases, and the Experiments 2a, 2b, and 2c, respectively.

gence conditions as a proportion of the mean response rate during the last six Acquisition phase sessions (left graphs) or the last three Elimination phase sessions (right graphs). As with Experiment 1, the patterns of resurgence as indexed by any of the measures shown in these figures were different for each pigeon.

In Experiment 2a, Pigeon A03 showed greater absolute and relative resurgence (by either index) in the Rich component. As shown in the right panel of Figure 4, A02 showed resurgence during many sessions of the Resurgence phase, but there was little difference in the magnitude of resurgence between components when measured in either absolute or relative terms. The other pigeons showed little to no resurgence and no systematic difference in resurgence between components. For Pigeon A03, it should be noted that there was a big difference in the rates of target responses between the Rich and Lean component of the Acquisition phase, while reinforcement rates were almost equal (see Table 2). As noted above, da Silva et al. (2008) showed that resurgence was greater when the rates of target responding were higher, at least in absolute terms (see also Winterbauer et al., 2013, Experiment 1). Thus, it is unclear how the higher target response rates during the Acquisition phase and the higher alternative reinforcement rates during the Elimination phase each contributed to the greater resurgence in Pigeon A03.

In Experiments 2b and 2c, differential resurgence did not occur in Pigeons A01 and A03. For Pigeon A02, the amount of resurgence measured in either absolute or relative terms as noted above was larger in Experiment 2b than 2c. For Pigeon A04, differential resurgence did not occur in both absolute and relative terms. However, the increase in target responses from the stable sessions during the Elimination phase was somewhat greater in Experiment 2b (the Rich component), as shown in the right panel of Figure 4.

In sum, differential resurgence as a function of the different rates of alternative reinforcement in the Elimination phase did not occur systematically in Experiment 2. The exceptions were A03 in Experiment 2a and A02 in Experiments 2b and 2c: These pigeons in the noted conditions showed greater resurgence when the rates of alternative reinforcement were higher.

In Experiment 2, the effect of alternative reinforcement rates on resurgence was examined by manipulating the VI value between the Rich and Lean components.

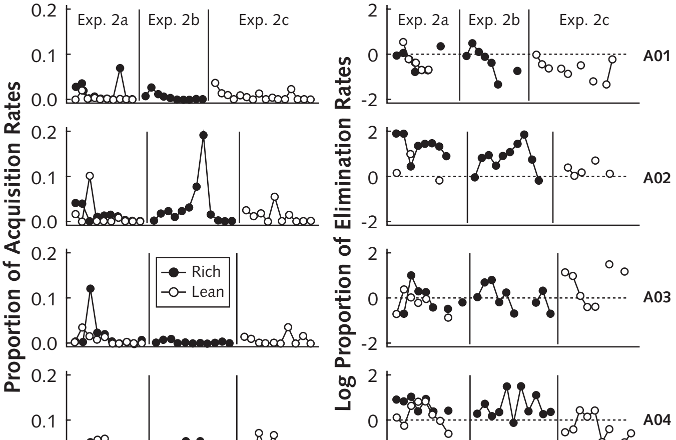

Figure 4. Proportion of the Acquisition (left panel) and the Elimination (right panel) response rates during the Resurgence phase. Solid vertical lines in each graph separate the Experiments 2a, 2b, and 2c. Proportion of the Acquisition rates was calculated by dividing the response rates in each session of the Resurgence phase by mean response rates during the last 6 sessions in the Acquisition phase. Log proportion of the Elimination rates was the logarithm of values calculated by dividing the response rates in each session of the Resurgence phase by mean response during the last 3 sessions in the Elimination phase. Each point above the horizontal dashed line in the right panel represents the resurgence.

However, the higher reinforcement rate typically also produced higher response rates, so that the two variables are confounded, thereby obscuring the contributions of either variable to differential resurgence. In fact, both the rates of alternative responding and reinforcement differed between components in the Elimination phase in almost all instances of Experiment 2 (see Table 2). Thus, the higher rate of alternative response, not only the alternative reinforcement rate, was another variable that might contribute to the differential resurgence found between Experiments 2b and 2c shown by Pigeon A02 and in Experiment 2a shown by A03. Other studies concerning the effect of alternative reinforcement rates also have not separated these two variables (e.g., Leitenberg et al., 1975; Winterbauer & Bouton, 2010). Experiment 3 addressed this problem to further examine the effect of alternative reinforcement rates on resurgence.

Experiment 3

In Experiment 3, resurgence was compared when alternative responses were reinforced on VI 60–s schedules in both components of a multiple schedule, but additional reinforcers also were delivered independently of the alternative response according to a DRO schedule in the Rich component.

Method

Subjects and Apparatus. Four pigeons (*Columba livia*), different from those used in any of the preceding experiments, were maintained at about 80% of their free–feeding weights. They were housed individually with a 12:12 h light/dark cycle (lights on 08:00 a.m.) and had free access to water and grit in the home cage. All subjects had previous experiences with various experimental procedures. The apparatus was the same as in Experiment 1.

Procedure. After pretraining, the pigeons were exposed to the following three phases. Daily sessions consisted of a two–component multiple schedule across all phases. The details of the multiple schedule and the stability criteria were as described for Experiment 1a. Each phase terminated when the minimum number of sessions was conducted and the stability criteria were met. Note that the response keys used in Experiment 3 differed for each pigeon: For Pigeons A11, C23, and D11, the center and left keys served as target and alternative responses, respectively, in the Rich and Lean components. For Pigeon B01, the left and right keys served as target responses in the Rich and Lean components, respectively, and the center key served as alternative responses in both components. The schedule and the number of sessions in each phase are shown in Table 1.

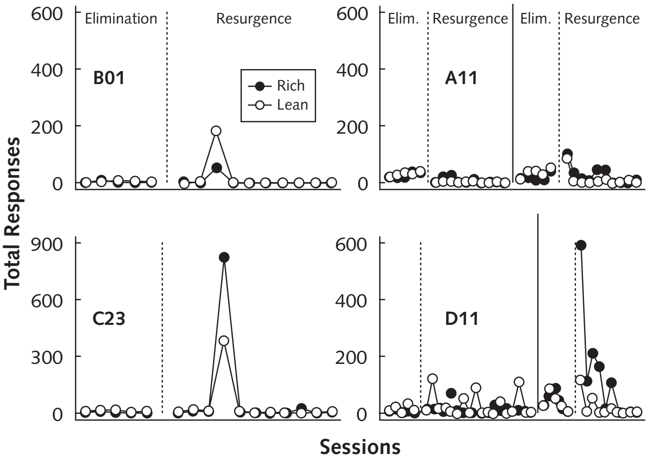

Figure 5. Total number of target responses over the last 5 sessions of the Elimination phase and the all sessions of the Resurgence phase in Experiment 3. Dashed vertical lines in each graph separate the Elimination and Resurgence phases. Solid vertical lines in the two right graphs separate the first and second exposure to the procedure of Experiment 3. Note the different y-axis scale.

In the Acquisition phase, target responses were reinforced on a VI 30–s schedule in both components. This phase lasted for a minimum of 20 sessions. In the Elimination phase, alternative responses were reinforced on a VI 60–s schedule in both components, and target responses to the center key were eliminated by a VDRO 30–s schedule in the Rich component and by extinction in the Lean component. This phase lasted for a minimum of 15 sessions. In the Resurgence phase, all reinforcers were withheld for at least 10 sessions. The sequence of phases was repeated for A11 and D11.

Results and Discussion

Figure 5 shows the number of target responses in the Rich and Lean component during the last 5 sessions of the Elimination phase and all sessions of the Resurgence phase in Experiment 3. Figure 6 shows the Figure 5 data for each session in the resurgence conditions as a proportion of the mean response rate during the last 6 Acquisition phase sessions (left graphs) or during the last 3 Elimination phase sessions (right graphs). As in Experiments 1 and 2, the patterns of resurgence as indexed by any of the measures shown in these figures were different for each pigeon.

For Pigeons C23 and, especially, the second exposure of D11, differences in resurgence favored the Rich component. Pigeon B01, however, showed greater resurgence in the Lean component in both absolute and relative terms. Resurgence for Pigeon D11,

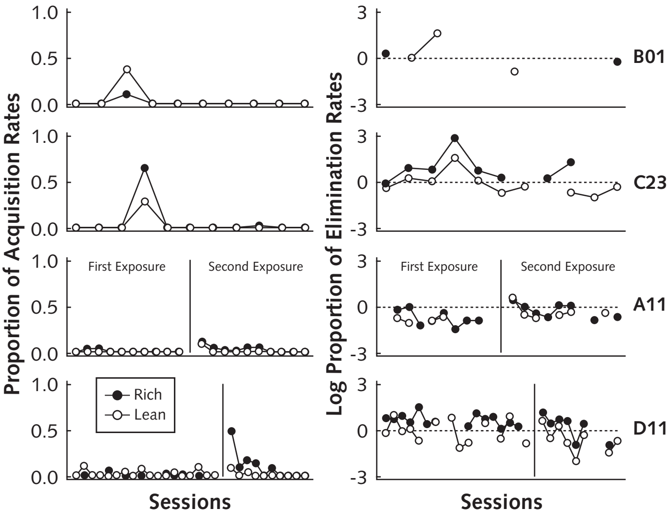

Figure 6. Proportion of the Acquisition (left panel) and the Elimination (right panel) response rates during the Resurgence phase. Solid vertical lines in the lower two graphs separate the first and second exposure to Experiment 3. Proportion of the Acquisition rates was calculated by dividing the response rates in each session of the Resurgence phase by mean response rates during the last 6 sessions in the Acquisition phase. Log proportion of the Elimination rates was the logarithm of values calculated by dividing the response rates in each session of the Resurgence phase by mean response during the last 3 sessions in the Elimination phase. Each point above the horizontal dashed line in the right panel represents the resurgence.

however, was not different across the Rich and Lean components during the first resurgence test. Pigeon A11 did not show differential resurgence across either the first or second exposures.

Both the response and reinforcement rates of target responding were almost equal between components, so that either the alternative response or reinforcement rates could be the determinant of the differential resurgence. For each pigeon, reinforcement rates in the two components during the Elimination phase were systematically different, although the reinforcement rates in the Rich component were relatively smaller than those programmed. Response–independent reinforcers, or reinforcers delivered independently of the alternative response according to a DRO schedule were expected to reduce alternative response rates in the Rich component. The mean alternative response rates, however, were higher in the Rich than in the Lean component for 4 out of 6 instances (see Table 2). It was possible that the relatively small number of sessions in the Elimination phase might have contributed to the failure of this expected effect to occur. In fact, some of the data supported this possibility. Pigeon B01, for example, experienced 28 sessions in the Elimination phase and showed no difference in the alternative response rates.

Taken together, in some conditions with some pigeons, there was greater resurgence in the Rich component, while in others there was little difference in resurgence between the two components. However, the procedures of the present study again did not equate alternative response rates between components, so that it remains an open question as to whether the higher rates of alternative responses or reinforcers are responsible for the amount of resurgence.

General Discussion

The present experiments examined the relation between the rates of alternative reinforcement and resurgence. In Experiment 1, DRO schedules were in effect in both the Rich and Lean components during the Elimination phase. Alternative reinforcement rates in two components of this phase were consistently different although obtained rates were relatively smaller than those programmed in both components. In some conditions with some pigeons, there was greater resurgence in the Rich component while in others showed the opposite results. Thus, there was no systematic relation between alternative reinforcement rates and resurgence. In addition, a systematic difference in resurgence was not found between Experiments 1a and 1b. This latter result replicates the finding of Doughty et al. (2007) that variable (VDRO) and fixed (FDRO) DROs have similar effects on the resurgence of target responses. In Experiment 2, unlike Experiment 1, the alternative response in each component was the same topography as the target response, but was reinforced according to different-valued VI schedules. As with Experiment 1, differential resurgence was not observed as a function of the different reinforcement rates arranged in the Elimination phase (cf. Cançado & Lattal, 2013; Winterbauer & Bouton, 2010). In Experiment 3, alternative responses were reinforced on VI 60–s in both the Rich and Lean components in the Elimination phase. In the Rich component, additional reinforcers were delivered independently of the alternative response according to a DRO schedule. As noted above, Shahan and Sweeney's (2011) model predicts that all reinforcers obtained in that component during the Elimination phase affects the magnitude of resurgence (see also Podlesnik & Shahan, 2009, 2010). Thus, it was predicted based on that model that greater resurgence would be found in the Rich component, where the additional response-independent reinforcers delivered. There was, however, greater resurgence in the Rich component in only two out of six instances, at least in relative terms.

Of most importance was the findings that more resurgence did not occur systematically under higher rates of reinforcement in the Elimination phase across all of the present experiments: Although some pigeons showed greater resurgence in the Rich component, others showed the opposite results or little to no resurgence in either components. Thus, results of the present experiment do not offer systematic evidence supporting the prediction of behavioral momentum and other models for resurgence.

Although the effects of differential reinforcement rates in the Acquisition and Elimination phases on resurgence were mixed, there were some instances where the predicted relation held. Those instances of greater resurgence in the Rich component across the three present experiments seem to be consistent with the findings of Leitenberg et al. (1975) and the prediction of some models for resurgence (e.g., Leitenberg et al. 1975; Shahan & Sweeney, 2011; see also Cleland et al., 2000). However, another potential contributing variable to the observed resurgence should be considered before concluding that only alternative reinforcement rates account for these results. In most instances in which the aforementioned relation was observed between resurgence and reinforcement rates in the Elimination phase, response rates in that phase also frequently were higher than in the corresponding lower–reinforcement rate component. For example, although A02 showed greater resurgence in Experiment 2b than 2c, both alternative reinforcement and response rates were also higher in Experiment 2b. Thus, the contributions of alternative response and reinforcement rates in the Elimination phase to resurgence remains unclear. Experiment 3 addressed this problem in such a way that response-independent reinforcers delivered in the Rich component were arranged specifically to prevent an increase in response rate in that component. It has been reported that response–independent reinforcers decrease the response rate (e.g., Rachlin & Baum, 1972), while also increasing response strength (e.g., Nevin, Tota, Torquato, & Shull, 1990). Hence, it was expected that additional reinforcers by a DRO schedule would decrease the rate of responding while increasing the alternative reinforcement rate in the Rich component. However, the attempt to equate alternative response rates between components again failed (see Table 2; four out of six instances showed higher response rate in the Rich component), perhaps partly because of the small number of sessions in the Elimination phase. Thus, as with previous studies (e.g., Leitenberg et al., 1975; Winterbauer & Bouton, 2010), it still remains unclear whether the higher rates of alternative responses or reinforcers are responsible for the amount of resurgence. This point should be examined more precisely in future research. Note that a DRO schedule was in effect in both components during the Elimination phase of Experiment 1 and no particular alternative response rate was recorded. The alternative response rate therefore does not become the issue as long as a DRO schedule is used for eliminating the target response in the Elimination phase and alternative responses with particular topography are not recorded. However, it should also be noted that increasing reinforcement rate by adding the DRO schedule still may increase some unmeasured dimension of behavior much as if it were changing response rate.

Procedural differences between resurgence experiments continue to be a potential source of different outcomes of the sorts discussed in these experiments. As noted above, inconsistent results have been reported with respect to the effects of variables in the

Elimination phase on resurgence. Some studies reported that higher alternative reinforcement rates produced greater resurgence (e.g., Leitenberg et al., 1975) or the topography of alternative response also affected the amount of resurgence (e.g., Doughty et al., 2007; Pacitti & Smith, 1977). Other studies, however, reported opposite findings (e.g., Cançado & Lattal, 2013; Mulick et al., 1976; Winterbauer & Bouton, 2010). Several variables may contribute to these discrepancies. For example, they might stem from differences between within and between–subject assessments of resurgence in that different numbers of sessions may be involved in each phase in these two types of assessments (cf, e.g., Leitenberg et al., 1975; Winterbauer & Bouton, 2010, to Cancado & Lattal, 2013). The measure of resurgence also may contribute to the interpretation of the results. For example, the presence of resurgence may depend on whether it is measured in absolute (e.g., response rates) or relative terms (e.g., proportion of baseline) (da Silva et al., 2008; see also Podlesnik & Shahan, 2009, for a discussion of this issue), or whether mean data across the subjects or individual data for each subject are used. Using stringent stability criteria seems necessary in assessing resurgence, because the effects usually are small and transient. For example, in Experiment 1a, although Pigeon B14 seemed to show the same amount of resurgence as shown in Figure 1 and the left panel of Figure 2, the recovery of the target response from the immediately preceding Elimination phase was greater in the Lean component (see the right panel of Figure 2). This difference might have been reconciled if the target responses in both component had more completely extinguished under a more strict stability criterion than that used in the Elimination phase of the present study. Thus, the conflicting results relating to the variables in the Elimination phase has these important implications for study on resurgence itself. This is the important and inevitable problem left for future research in exploring the common determinant of resurgence.

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