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A Parametric Analysis of Resurgence: Toward a Synthetic View of Behavioral Momentum Theory and Context-change Hypothesis

慶應義塾大学大学院社会学研究科
心理学専攻

藤巻　峻

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fujimaki1026@gmail.com

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1	11	Liev~~e~~ing	Lieving
2	2, 16, 17	relationship	relation
3	6, 11	a greater	greater
4	10	rates were	rates are
4	20	a more	more
4	21	a greater	greater
5	1	relationship	relation
6	3	in the	using
6	7	VI	the VI
6	14	was not observed	not
7	5	from	of
7	8	on	of
7	14	the higher	higher
7	14	a greater	greater
8	3, 4	a greater	greater
8	4	a higher	higher
8	7	extinguished	disappeared
8	15	then the	then a
8	22	the resurgece	resurgence
9	1	behavior	target response
9	2, 8	a greater	greater
9	3	it	such resurgence
9	5	were conducted	occurred
9	6	respondse	response
10	6	non-contingent	response-independent
11	6	, and	;
11	7	the Phase 2	Phase 2
11	17	a greater	greater
12	19, 21, 22	a greater	greater
13	8	the weak	weak
13	13	the target	reinforcement of the target
13	13	extinguished	discontinued
13	20	with an	but in
14	3	should predict	predicts
14	6	it	the context-change hypothesis
14	7	BMT model	(2011) BMT model
14	8	relationship	relation
14	11	broader	broad
16	3	Context-change	the Context-change
16	7	had	have
16	7	we	I
16	9	reinforcements	reinforcers
17	1	The other	Other
17	2	manner	effect
17	3	in both VI 30-s and	following either VI 30-s or
17	15	They found that	The
18	1	with resurgence	with at least some
18	3	produces	produce
18	11	context-change	the context-change
18	13	occur	occurrs
18	17	from	of
19	1	the positive	a positive
19	5–8	Somewhat surprising is that the only studies were reported by Podlesnik and Shahan (2009, 2010) that demonstrated systematic relation between resurgence and reinforcement rate for the target response	Somewhat surprising is that the only studies that demonstrated a systematic relation between resurgence and reinforcement rate for the target response were reported by Podlesnik and Shahan (2009, 2010).
19	15	explain	account for
19	17	the synthetic	a synthetic
20	5	These figures are reproduced	Reproduced
21	18	relationship	relation
21	22	variant	variable
22	2	conducting the parametric	conducting such a paremtric
22	9	the discrete-trial	discrete-trial
22	12	the discrete-trial	a discrete-trial
22	17	magnitude	probability
38	11	of Phase 3 in Experiment 1-3	of Phase 3
41	12	while in others	while others
46	7	have	has
46	10	the procedure	a procedure
46	12	may be	is
46	14–15	the reinforcement	reinforcement
46	15	the response rate	response rate
46	17	free-operant procedure	free-operant procedure (e.g., da Silva et al.)
46	17–18	the frequency of response	response rate
46	18	in discrete-trial	in a discrete-trial
46	18	due to	with this
48	10, 12, 13	sec	-s
48	16	on RR 4	on a RR 4
49	12	on RR 4	on a RR 4
50	4, 5	sec	-s

51	4	of alternative	of the alternative
52	1–2	in the discrete-trial	in a discrete-trial
53	3	.25 to ,50 and their	.25 in Experiment 1 to .50 and its
53	10	on RR 2	on a RR 2
53	11	Stability	The stability
54	2	inter-dependent	interdependent
55	10	question is	question was
56	13	Stability	The stability
56	17	Three Rats showed	Three rats (B02, B05, and B06) showed
56	21	approximated to	approimated
58	2	only the slight	only a slight
58	3	between conditions	between the two experiments
58	3, 5, 11	B05	B03
58	4	a greater	greater
58	4	each condition	each condition than Experiment 2-1
58	4	the magnitude did not differ	the magnitudes in the two experiments were similar
59	1	except for	the exception being
59	2	Rat B01	Rat B02
59	4	Other 3 rats	The other
59	6	these patterns	they
59	10	conditions	experiments
59	10	response ratio	the response ratio
59	11	cease	change
59	14	support that	support the suggestion
59	16	affect	affects
59	19	the discrete-trial	a discrete-trial
60	4	is	was
60	7	all expeiments	Experiment 2
60	10	strongly	more strongly
60	12	2-3a	2-3b
60	15-16	the greater	a greater
60	18	the systematic	a systematic
60	21	except for	being the exception
60	22	It	This
61	2	response inversely	response is inversely
61	4	shows	show
61	5	to conduct	for conducting
61	5	affecting	that might affect
61	6	the paremetric analysis	a parametric analysis
62	5	typical	the typical
62	6	so that	which is
62	18	to typical	to the typical
62	18	for human	for a human
62	20	it was tested whether resurgence can be obtained with rats in the within-session procedure introduced by Cook and Lattal (2014)	whether resurgence can be obtained with rats in the within-session procedure introduced by Cook and Lattal (2014) was examined.
63	3	month	months
63	13	40 min	40-min
63	20	Experimental sessions lasted for 30 days	Thirty experimental sessions were conducted
64	6	but	they
64	10	the latter	in subsequent
64	11	moderate	a moderate
64	12	last block	last 10-session block
64	13	process	processes
64	17	all responses is	all responses during the resurgence phase of each session
64	18	dominantly distributed	dominant
64	19	by the increase	by an increase
65	2	weak	weaker
69	3	Cook and Lattal (2013)	Cook and Lattal (2014)
69	10	on control lever	on the control lever
69	14	showed remarkable	showed a remarkable
69	15-16	Rats A26 and A27	Rats B09 and B10
70	1	the greater	greater
70	11	effect of independent	effect of the independent
70	16	prevent from attenuating	prevent attenuation of
70	17-18	for more effectively reflecting the effects of rates and magnitude of reinforcement	to ensure sufficient exposure to the reinforcement rates or magnitude
70	22	are	were
71	18	should provide	provide
71	21	should predict	predicts
72	5–6	should predicts the	predicts a
72	7	was	is
72	16	Apparatus	The apparatus
72	20	four experimental conditions	four conditions
73	2	sec	-s
73	4	only a	only the
73	7	trials at least	trials for at least
73	9	reinforced on	reinforcerd with a
73	11	target response of rats	rats' target response
73	11	studies simultaneously	studies have simultaneously
73	12	extinction of target	extinction of the target
73	12, 14	of alternative	of the alternative
73	15	Phase 2 served	Phase 2 would serve
73	16	for the alternative	responding on that

73	20–21	on assigned probability	on the assigned probability
73	21–22	presented throught	presented but did not produce reinforcer
74	2	sessions of extinction	sessions of the extinction
74	3	10 responses at least	10 for at least
74	7	Reinforcer	The reinforcer
75	2	across 3 phases	across the 3 phases
75	6	readily	quickly
75	10	can be inferred	seems reasonable to infer
75	16	and after which	after which
75	18–19	the different patterns	different patterns
75	19–20	the target	the resurged target
76	1	4th	the 4th
76	3	was sometimes observed	has been observed
76	4	in the previpus	in previous
76	9	different pattern	a different pattern
76	10	though the linear	though a linear
76	12	prediction by the	prediction of the
80	6	for each cage	in each cage
80	9	balanced	counterbalanced
80	7	Apparatus	The apparatus
81	15	support for	support
81	16	but not for	but not
85	8	under the	under an
85	17	four rats	the four rats
85	17	show sigmoid-like	show the sigmoid-like
85	19	should predict	predict
85	20	is observed	should be observed
85	20	with lower	with a lower
87	6	and the reinforcer	and reinforcer
87	13	the number of reinforcers per session	reinforcer magnitude
87	16	the total number of reinforcers delivered in each session	reinforcer magnitude per reinfrocement
88	7	Apparatus	The apparatus
91	4–5	that the reinforcer	that reinforcer
94	12	at 3 across	at 3 pellets
94	20	Rats B16	B16
95	2	2nd	second
95	3	for the retracted lever and pressed it	reached into the recess and pressed the retracted lever
95	17	both the BMT and	either the BMT or
99	3–4	the increase	an increase
99	7	inverted	an inverted
99	8–9	sigmoid-like curve of	a sigmoid like resurgence function
99	12	model is not	model was not
99	13	hypothesis	hypothesis either
99	17	it assumes	it is assumed

99	20	argued later in General Discussion	discussed in the General Discussion section below
100	6–7	to three-phase procedure	to a three-phase resurgence procedure
100	7	weaken	weakened
100	8	sufficiently reflecting the effect of reinforcement rate to resurgence	to ensure sufficient exposure to the reinforcement rates
100	16	for each cage	in each cage
100	18	Apparatus	The apparatus
100	21	exposed to training on	exposed to
100	22	are	were
101	1, 7, 13	sec	-s
101	1	across the 5	across 5
101	1	is	was
101	5	and	followed by
101	6	phases with 15-min	2 15-min phases
101	7	after the 30-s	after a 30-s
101	9	chambers	the chambers
101	15	A 40-min	Each 40-min
101	15	session devided	session was devided
101	17	minutes	min
103	16	rat showed	rat also showed
103	16	resurgence also in	resurgence in
103	17	showed the similar	showed a similar
103	17–18	other rats	other two rats
103	20	Response rates	Mean response rates
103	21	were averaged and are	are
104	1	programmed one	programmed rate
104	1	condition	conditions
104	5	It should be noted that these	These
104	6	in VI 30-s	in the VI 30-s
104	7	that	, which also
104	11	further experiment	a further experiment
104	15	showed positive	showed a positive
104	16	condition, indicating that this relation	condition, therefore this relation
104	18	over limited range	over a limited range
104	18	The present	On the one hand, the present
104	19	which could predict	which predicts
104	22	responsding	responding
108	8	Apparatus	The apparatus
108	12	on VI 30-s	on a VI 30-s
108	12–13	while value of VI schedule for	while the value of the VI schedule reinforcing
108	19	response	responding
109	3	on the VI	on a VI
109	5	of for	of
109	6	decreased	decrease

109	7	in VI 60-s	in the VI 60-s
109	11	the grater	a greater
113	3	magnitude	magnitudes
113	4	was observed in	was observed with
113	5	is linear	is a linear
113	6	magnitude of resurgence was	magnitudes of resurgence were
113	7	(i.e., VI 15-s)	(i.e., the VI 15-s)
113	13	provided the evidence	provided evidence
113	14	occur	occurs
113	15	only the slight	only a slight
113	16	not	no
113	17	grater	greatest
113	18	showed the remarkable	showed a remarkable
113	20	higher reinforcement conditions	higher reinforcement (i.e., the VI 15-s and VI 30-s) conditions
114	4	and context-change hypothesis	and the context-change hypothesis
115	5	magnitude	magnitudes
115	10	Given that the	Given that
115	12	the reinforcer magnitude	reinforcer magnitude
115	17–18	From behavioral-momentum	From a behavioral-momentum
115	19	BMT model should expect	BMT model predicts
115	20	if the reinforcer magnitude	if reinforcer magnitude
115	21–22	should predict	predicts
116	8	Apparatus	The apparatus
116	9	balanced	counterbalanced
116	14	8 pellets	8 pellets per reinforcement cycle
119	7	showed linear	showed a linear
119	12	prevented from the magnitude of resurgence being attenuated	may have attenuated differntial
119	14	the reinforcer magnitude	that reinforcer
123	8	Apparatus	The apparatus
123	21	it was similar to Experiment 7-1 that the acquisition and extinction processes of the target and alternative responses across three phases	the results were similar to those of Experiment 7-1
124	2–3	between the reinforcer	between reinforcer
124	3	Rat A13 showed inverted	Rat A13's reponding showed an
124	4	condition	conditions
124	5	difference	differences among these conditions
124	8	Ovbviously, systematic relation	Ovbviously, a systematic relation
127	4	was successfully	were successfully
127	4–5	though somewhat lower than the	though the rates of obtained reinforcers were somewhat than their
127	16–17	it must be clearly defined what spect of environment defines "context"	what aspects of an environment defines "context" must be defined
128	2–3	that the reinforcement for	that reinforcement associated with
128	4	reinforcement for	reinforcement of
128	11	Shahan and Sweeney's (2011)	Shahan and Sweeney's
128	15	resurgence occurs	resurgence will occur
128	19	it results in the occurrence of resurgence	it is this context change that results in resurgence
128	19	Since	Because
128	19–20	numerical measures evaluating	quantitative measures of
129	7	which of the BMT model and	whether the BMT model or
129	8	relationship	relation
129	8	provide	provides
129	9, 21	We	I
129	10–11	through three experiments using multiple schedule	through the three experiments in this document using a multiple schedule
129	13	as reported in several studies	consistent with several earlier studies
129	21	in the individual subject	within a single subject
130	1	Therefore it is another purpose	Therefore another purpose
130	1	study to develop	study was to develop
130	3	proudced the substantial	produced substantial
130	8	Target Reinforcement	Target-Response Reinforcement
130	18	increasing of	increasing
130	22	parametric	the parametric
130	22	and 7-2	and 7-1
131	1	target reinforcement	target-response reinforcement
131	3	Alternative Reinforcement	Alternative-response Reinforcement
131	8	a greater	greater
131	13	indicate that there is no systematic relationship	indicated no systematic relation
131	17	reinforcment magnitude	reinforcer magnitude
131	17	reinforcement frequency	reinforcer frequency
132	2	no systematic	unsystematic
132	11	programmed reinforcers per session	programmed reinforcers delivered per session
134	7	supports for	supports
134	8	not for	not
134	8	should support	support
134	11	alterntive	alternative
134	12	no systematic was	no systematic relation was
134	21	delivered for	delivered within
135	1–2	produced the context change	produced a context change
135	5	not total number	not the total number
135	19	at which resurgence occur	at which it occurs
136	7	value is	values are
136	17	they are adbongoning	they have abandoned
137	5	the good model	a good model
137	7	to our knowledge	to my kowledge
140	18	U.S.A., 77,	77,
144	14	mag- nitude	magnitude

Figure 27　修正版

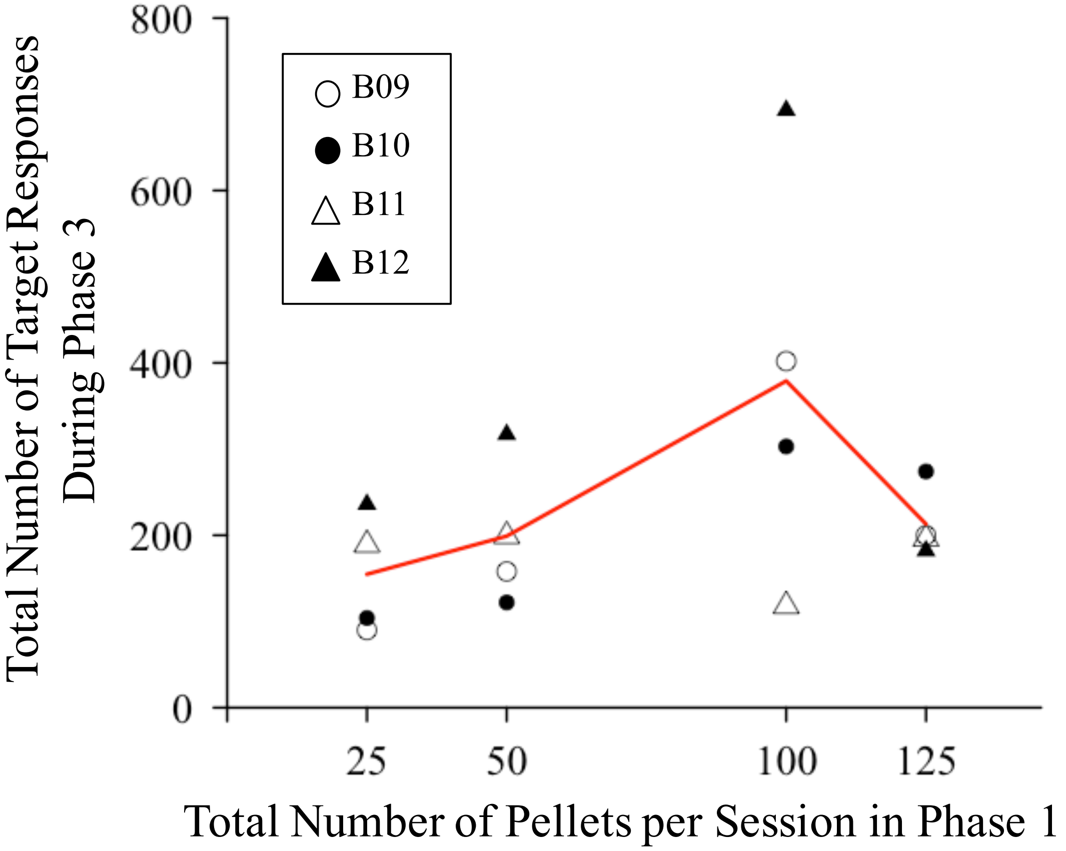

Figure 27. Total number of target responses during Phase 3 for each condition. The red line shows mean total number of the target responses across all rats in each condition.

Figure 34　修正版

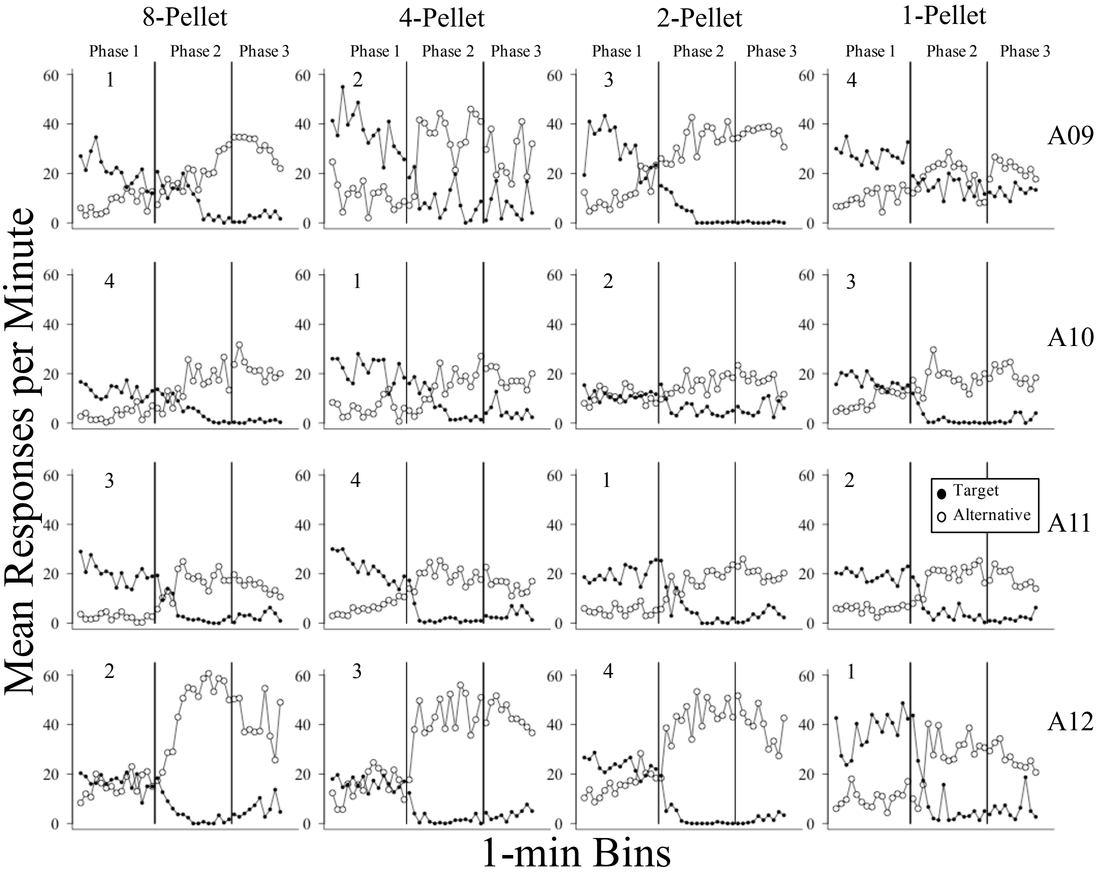

Figure 34. Mean rates of the target and alternative responses across 3 phases of each condition. The vertical lines separate successive phases. The numbers in each panel refer to the order of conditions to which the rat was exposed.

1. INTRODUCTION

Resurgence is the recurrence of a previously reinforced and then extinguished behavior when a more recently reinforced behavior is placed on extinction (Cleland, Foster, & Temple, 2000; Epstein, 1983; 1985). General procedure for studying resurgence includes three phases. In Phase 1, a target behavior is reinforced; in Phase 2, the target behavior is eliminated and an alternative behavior is reinforced; in Phase 3, the alternative behavior is also eliminated. An increase in the target behavior in the third phase defines resurgence. Resurgence has been demonstrated across species, including rats (e.g., Leitenberg, Rawson, & Bath, 1970; Reed & Morgan, 2006; Winterbauer & Bouton, 2012), pigeons (e.g., Epstein & Skinner, 1980; Leitenberg, Rawson, & Mulick, 1975; Lieveing & Lattal, 2003), hens (Cleland et al., 2000), White-Leghorn chicks (Moriyama, Kazama, Obata, & Nakamura, 2015), Siamese fighting fish (da Silva, Cançado, & Lattal, 2014), squirrel monkey (Mulick, Leitenberg, & Rawson, 1976), and humans (e.g., Bruzek, Thompson, & Peters, 2009; Doughty, Cash, Finch, Holloway, & Wallington, 2010; Lieving, Hagopian, Long, & O'Connor, 2004; Reed & Clark, 2011; Volkert, Lerman, Call, & Trosclair-Lasserre, 2009; Wilson & Hayes, 1996). More than 60 years have passed since Carey (1951) first reported the experimental analysis of resurgence, but more attention has been focused on the phenomenon in recent years. This is largely due to the important implications of resurgence for applied settings and clinical treatments (see Lit & Mace, 2015; Pritchard, Hoerger, Mace, Penny, & Harris, 2014; St. Peter, 2015). However, it also should be emphasized that the behavioral mechanisms underlying resurgence are still not understood fully. This is despite increased studies, in the last 15 years, investigating the relationship between resurgence and the following independent variables. Some of them include pattern (e.g., Cançado & Lattal, 2011) and response rate (e.g., da Silva, Maxwell, & Lattal, 2008; Reed & Morgan, 2007; Winterbauer & Bouton, 2010) of the target response; reinforcement rates of the target (e.g., Podlesnik & Shahan, 2009, 2010) and alternative responses (e.g., Leitenberg et al., 1975); reinforcement schedule (e.g., Bouton & Schepers, 2014; Leitenberg et al., 1975; Winterbauer & Bouton, 2010), distribution (Schepers & Bouton, 2015), and topography (Doughty, da Silva, & Lattal, 2007) of the alternative response; response-elimination techniques for the target (Bouton & Schepers, 2014; Doughty et al., 2007; Kestner, Redner, Watkins, & Poling, 2015) and alternative responses (e.g., Jarmolowicz & Lattal, 2014; Lieving & Lattal, 2003; Podlesnik & Kelley, 2014); length of Phases 1 and 2 (e.g., Lieving & Lattal, 2003; Winterbauer, Lucke, & Bouton, 2013). These studies clearly show that variables in each of the three phases affect the magnitude and pattern of resurgence. Of these variables, much attention has been, and is still being, paid to the relationship between reinforcement rates and the magnitude of resurgence. In the following section, studies on the relationship between resurgence and the reinforcement rates of target and alternative responses are reviewed.

1.1 Effects of Reinforcement Rate for the Target Response on Resurgence

da Silva et al. (2008) first investigated the relation between resurgence and the target reinforcement rates by using a concurrent schedule. In their first experiment, all pigeons showed more resurgence in the Rich key, where variable-interval (VI) 1-min and VI 6-min schedules were assigned to Rich and Lean keys, respectively. It is worth noting that a greater resurgence was observed only in absolute terms (i.e., responses per min), but not in relative terms (i.e., proportion of baseline). They further examined the effects of target reinforcement rates by arranging differential reinforcement rates on the Rich and Lean keys while equating the responses rates on these keys. However, differential resurgence was not found in either relative or absolute terms.

In contrast, Podlesnik and Shahan (2009) reported a greater resurgence under the higher reinforcement rates for the target response. In this study, pigeons were exposed to a two-component multiple schedule across three phases. In the first phase, the target response on the center key was reinforced on a VI 120-s schedule, in both Rich and Lean components. In addition, response-independent reinforcers, delivered according to a variable-time (VT) 20-s schedule, were added to the Rich component (i.e., a conjoint VI 120-s VT 20-s schedule was in effect in the Rich component). In Phase 3, resurgence in the Rich component was greater than that in the Lean component, despite (or because of) the lower response rates in the Rich component during Phase 1. They concluded that the Pavlovian stimulus-reinforcer relation determined the magnitude of resurgence on a relative scale (see also Podlesnik & Shahan, 2010). They also tried to account for the inconsistent results reported by da Silva et al. (2008) in terms of behavioral momentum theory. In da Silva et al.'s experiment, the magnitude of resurgence did not differ even though differential rates of reinforcement were assigned to the Rich and Lean keys in the concurrent schedule. Behavioral momentum theory suggests that the overall stimulus–reinforcer relation determines the response strength, and resurgence. 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. This means that responses on the Rich and Lean keys share the same stimulus-reinforcer relation in the concurrent schedule. It is therefore expected that the same level of resurgence can be obtained in the concurrent schedule even if differential reinforcement rates were arranged. Together, reinforcement rates for the target response could affect the magnitude of resurgence, but the effect depends on the stimulus context and the measures (i.e., which absolute or relative terms are used; for review, see Cançado, Abreu-Rodrigues, & Aló, 2016).

1.2 Effects of Reinforcement Rate for the Alternative Response on Resurgence

Leitenberg et al. (1975) first reported that higher alternative reinforcement rates produced greater resurgence. In their study, key pecking of pigeons was reinforced on a VI 120-s schedule in the first phase. In the subsequent phase, an alternative response was reinforced according to a VI 30-s schedule in a Rich group and a VI 240-s schedule in a Lean group. The Rich group showed a more rapid extinction of the target response in Phase 2 and a greater resurgence of the target response in Phase 3 (see Figure 1 from Leitenberg et al.'s (1975) Figure 3). This finding has been challenged by some studies that showed no systematic relationship between resurgence and the alternative reinforcement rates. For example, Winterbauer and Bouton (2010) failed to show differential resurgence when a random-interval (RI) 10-s and a RI 30-s reinforcement schedules were in effect in their Rich and Lean groups, respectively, during Phase 2. 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 Phase 2.

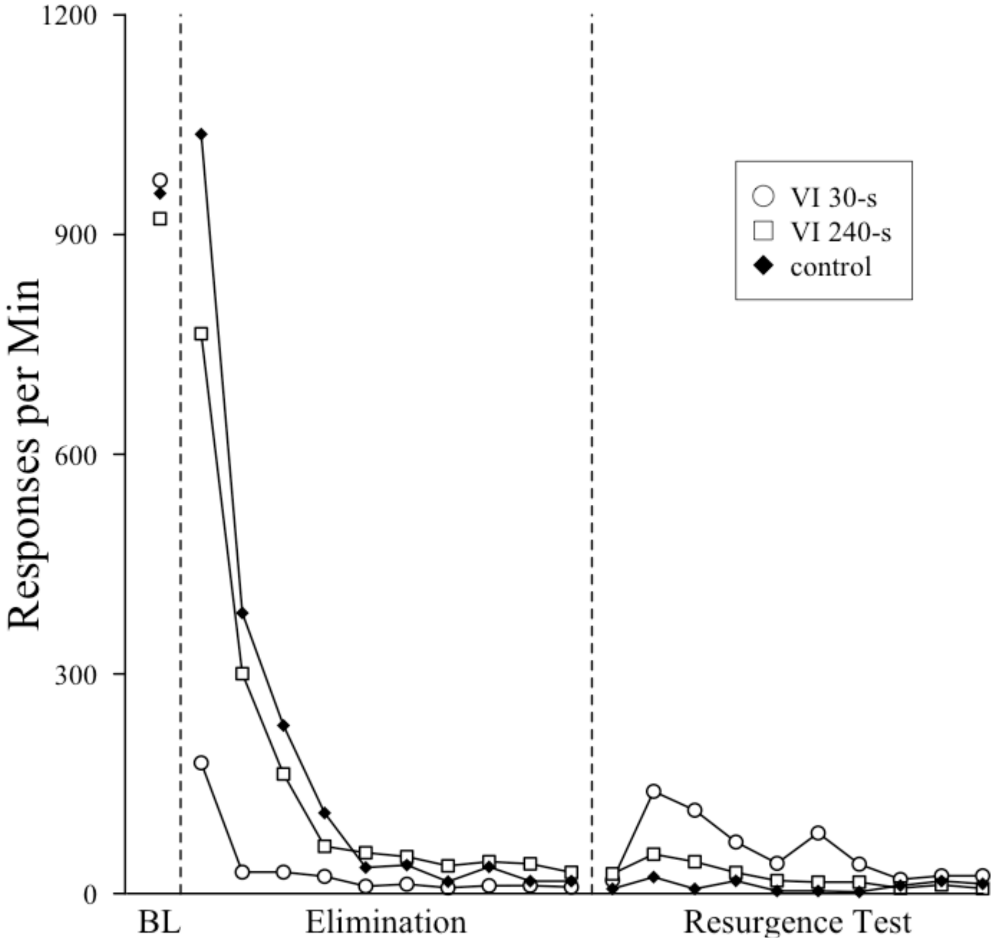

Figure 1. Rates of target responses across 3 phases for each condition of Leitenberg et al.'s (1975) Experiment 3. This figure is reproduced from Leitenberg et al. (1975) with permission from the publisher.

On the other hand, more recent studies have provided evidence supporting the findings of Leitenberg et al. (1975). For example, Sweeney and Shahan (2013) observed the greater resurgence under higher rates of alternative reinforcement in the between-subject comparisons. They compared the magnitude of resurgence under three conditions with different rates of alternative reinforcement. In Phase 2, alternative lever pressing of rats was reinforced on a VI 10-s and a VI 100-s schedule in the Rich and Lean groups, respectively. In a Thinning group, VI value for the alternative response was 10-s on the first day and increased by 10-s per day for the next 9 days. The alternative response was not reinforced in a Control group. As a result, resurgence was observed only in the Rich group. Bouton and Trask (2016) also found significant resurgence under the higher rates of alternative reinforcement in between-subject comparison. In Phase 2, alternative responses for each rat in the four groups were reinforced on a VI 30-s, VI 60-s, VI 90-s, or VI 120-s schedules. Resurgence was observed only in groups VI 30-s and VI 60-s, and was not observed in the other groups over the phase (see Figure 2; see also Cançado, Abreu-Rodrigues, & Aló, 2015; Craig & Shahan, 2016; Craig, Nall, Madden, & Shahan, 2016; but cf. Schepers & Bouton, 2015, Exp. 3).

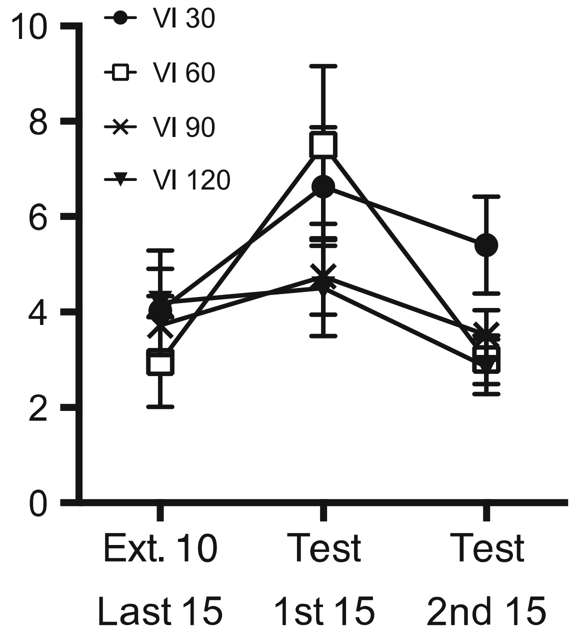

Figure 2. Means and standard errors of target response rates for each group during the last 15 minutes of the last session in Phase 2 and the first and last 15 minutes in Phase 3 of Bouton and Trask's (2016) Experiment 1. This figure is reproduced from Bouton and Trask (2016), with permission from the publisher.

1.3 Theories of Resurgence

There are at least three theories on resurgence; the response-prevention hypothesis (e.g., Leitenberg et al., 1975; Rawson et al., 1977), behavioral-momentum-theory-based model (hereafter BMT model; Shahan & Sweeney, 2011; see also Podlesnik & Shahan, 2009, 2010), and contextual-change hypothesis (e.g., Bouton, Winterbauer, & Todd, 2012; Winterbauer & Bouton, 2010). A common feature of these models is the prediction of effects of alternative reinforcement on resurgence reported by Leitenberg et al. (1975). All models were created to provide a reasonable explanation for a greater resurgence under the higher rates of alternative reinforcement. In the following sections, these three models are briefly reviewed.

1.3.1 Response-prevention (Prevention-of-extinction) Hypothesis

Leitenberg and his colleagues proposed a response-prevention (or prevention-of-extinction) hypothesis to explain why resurgence occurs and why a greater resurgence is observed under a higher alternative reinforcement (e.g., Lietenberg et al., 1975; Rawson et al., 1977; see also Cleland et al., 2001). This hypothesis focuses on the extinction processes of the target response when the alternative reinforcement is introduced in Phase 2. In general, the target response is more rapidly extinguished in the presence of an alternative source of reinforcement (see e.g., Figure 1). According to the response-prevention hypothesis, the source of the alternative reinforcement should prevent the target response from being extinguished and lead to its recurrence when the alternative reinforcement is removed in Phase 3. However, some studies demonstrated that resurgence could occur even when the target response was extinguished separately from the reinforcement of the alternative response. Lieving and Lattal (2003), for example, examined resurgence in a 4-phase procedure. In their Phase 2, the target response was extinguished for the 10 sessions, and then the treadle-pressing response was introduced and reinforced for the next 5 or 30 sessions in Phase 3. Thus, the target response was sufficiently exposed to the extinction contingency without prevention by the alternative reinforcement. Nevertheless, all pigeons showed robust resurgence in Phase 4 where all reinforcers were withheld (see also Epstein, 1983; Winterbauer & Bouton, 2011). These results clearly reject the response-prevention hypothesis.

However, these results only rejected the assumption of the response-prevention hypothesis that the resurgence is results from the reappearance of an insufficiently extinguished behavior. It does not seem to reject the assumption of the response-prevention hypothesis of a greater resurgence under the higher rates of the alternative reinforcement, because it was observed only in the 3-phase procedure in which both the extinction of the target response and acquisition of the alternative one were conducted in Phase 2. In such a case, it is possible that insufficient extinction of the target respondse led to the greater magnitude of resurgence (see, e.g., Craig et al., 2016; Leitenberg et al., 1975; Sweeney & Shahan, 2013). Furthermore, there has been no evidence that a greater resurgence under the higher rates of alternative reinforcement could occur in the 4-phase procedure that Lieving and Lattal (2003) used. In that sense, it is fair to say that the response-prevention hypothesis cannot be dismissed completely.

1.3.2 Quantitative Model Based on Behavioral Momentum Theory

A second account of resurgence is a behavioral-momentum-based model derived from the augmented model of extinction provided by Nevin and Grace (2000). This augmented model assumes that responding in a stimulus context associated with higher rates of reinforcement is relatively more resistant to the disruptive effects of extinction. This is characterized by:

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

where B_t is response rate at time t in extinction, B_o is asymptotic baseline response rate, c is the disruptive effect of terminating the contingency between responding and reinforcement, d scales the disruptive impact of the removal of reinforcers (i.e., generalization decrement), r is reinforcement rate in the presence of the stimulus in the baseline, and b is the parameter of sensitivity to reinforcement rate. Note that this model separates the two aspects of the extinction schedule. First, reinforcers are no longer contingent on the response (i.e., parameter c). This assumption makes it possible to explain the decrease in the response rate under the non-contingent reinforcement schedule (e.g., Rescorla & Skucy 1969). Secondly, removal of reinforcers changes the overall stimulus context. This second assumption is sometimes called the *generalization decrement* (i.e., parameter d) and seems to be compatible with the notion of context-change (see Section 1.3.3). One approach to predict the relapse phenomena based on Equation 1 is to assume that the effects of the disruptor in the numerator are decreased by the introduction of relapse operations. Podlesnik and Shahan (2009) incorporated this assumption in Equation 1 as follows:

$$\log\left(\frac{B_t}{B_o}\right) = \frac{-t(mc + mdr)}{r^b} \tag{2}$$

where parameter m scales the reduction of disruptive effects by contingency suspension (i.e., c) and generalization decrement (i.e., dr), and the other terms are as Equation 1. During extinction, parameter m equals 1.0 and thus, Equation 2 provides the same prediction as Equation 1. After the introduction of the relapse operation, parameter m takes a value less than 1.0, so that the magnitude of the disruptor in the numerator is reduced and Equation 2 predicts the increase of the extinguished response (see Podlesnik and Shahan (2009, 2010) for further details of this model). However, this model cannot predict benchmark results by Leitenberg et al. (1975), rapid extinction and greater resurgence under higher rates of alternative reinforcement. In order to account for this result, Shahan and Sweeney (2011) updated Equation 2 as follows:

$$\log\left(\frac{B_t}{B_o}\right) = \frac{-t(kR_a + c + dr)}{(r + R_a)^b} \tag{3}$$

where the added variables R_a is the rate of the alternative reinforcement introduced during Phase 2, and k scales the disruptive impact of that alternative reinforcement on the target behavior, and all other terms are as in Equation 1. Equation 3 identifies two roles for alternative reinforcement during the Phase 2. One is that the 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. This is represented in Equation 3 by adding the effects of the alternative reinforcement on disruptive effects of extinction in the numerator (i.e., kR_a). The other one is that the alternative reinforcement contributes to the overall strength of the target response. As noted above, the important aspect of the Pavlovian stimulus–reinforcer relation is that the source of the reinforcement does not matter, suggesting that all reinforcers obtained in Phase 2 contribute to the response strength, and thus resurgence. This second assumption plays a critical role in explaining a greater resurgence under higher rates of alternative reinforcement, and is represented by the added value R_a to the denominator of Equation 3. It should be noted that the values R_a in the denominator and the numerator changes in different ways when the alternative reinforcement is discontinued in Phase 3. In the numerator, R_a decreased to zero in Phase 3 to represent the removal of the additive disruptive effects by the alternative reinforcement on the target behavior and it lead to the occurrence of resurgence. By contrast, R_a in the denominator is carried over to Phase 3 to represent the strengthening effects of the history of the alternative reinforcement during Phase 2 (see Shahan & Sweeney, 2011, for further detail). As a result of these extensions, Equation 3 can predict the more rapid extinction and greater resurgence under higher rates of alternative reinforcement (see Craig, Nevin, & Odum, 2014; Nevin & Shahan, 2011, for reviews). However, the predictions of this model have been challenged by several studies, especially by Bouton and his colleague's findings as noted in the following section.

1.3.3 Context-change Hypothesis

A third explanation of resurgence is the context-change hypothesis proposed by Bouton and his colleagues (e.g., Bouton & Trask, 2016; Schepers & Bouton, 2015; Winterbauer & Bouton, 2010). This hypothesis assumes that resurgence can be viewed as ABC renewal where the target response is reinforced in Context A, then extinguished in Context B, and finally recurs when Context C is introduced. On this view, when alternative reinforcers are withheld in resurgence testing, their removal produces a change in context and the target response therefore recur. In other words, this account emphasizes the discriminative properties of the reinforcer in resurgence. Based on this assumption, a greater resurgence under the higher alternative reinforcement rates is explained as follows: when Phase 3, with rich reinforcement changes into resurgence testing, the removal of alternative reinforcers produces a greater change of the context relative to the lean reinforcement condition, resulting in a greater resurgence. It also explains the weak resurgence in a thinning schedule, on the assumption that there is an increased generalization between the contexts of Phases 2 and 3. Winterbauer and Bouton (2012), for example, introduced the alternative reinforcement with higher rates at first, but gradually thinned the rates of reinforcement towards the end of Phase 2. When all reinforcers were removed in Phase 3, little to no resurgence was observed (see also Schepers & Bouton, 2015; Sweeney & Shahan, 2013; Winterbauer & Bouton, 2012). According to the contextual view, the thinning procedure attenuated the abruptness of the contextual change between Phases 2 and 3, and resulted in the weak resurgence. Although this finding could be predicted by both the context-change hypothesis and the BMT model, the latter could not predict the results of "reverse thinning" by Schepers and Bouton (2015; see also Bouton & Schepers, 2014). In their second experiment, the target response of rats was reinforced on a VI 30-s schedule in Phase 1. In the subsequent phase, the target response was extinguished for all groups, and the alternative response was reinforced in different ways. In the VI 10-s group, the alternative response was reinforced on a VI 10-s schedule for all sessions of Phase 2. In the Reversed-thinning group, a VI 1200-s was introduced in the first session, and the VI value became richer by a factor of four over the first four sessions (i.e., the VI value was changed from 1200-s to 300-s, 75-s, and 19.5-s over the 4 days). During the last four sessions, the alternative response was reinforced on a VI 10-s schedule. The Thinning group received the same schedules with an opposite order such that a VI 10-s schedule was in effect for the first four sessions, and the VI value became leaner for the next four sessions. During Phase 3, only the VI 10-s, and, to a lesser degree, the Reverse-thinning groups showed a significant increase in the target response. Since the BMT model provides the prediction using mean rates of the alternative reinforcement during the final few sessions of Phase 2, it should predict the same levels of resurgence. By contrast, the context-change hypothesis explains the results of reverse thinning by assuming that lean rates of reinforcement, during the first few sessions of Phase 2, did not completely transfer to the resurgence test. Thus, it could provide a more comprehensive explanation than Shahan and Sweeney's BMT model for the relationshipp between resurgence and alternative reinforcement in Phase 2 (see also Bouton & Trask, 2016).

Perhaps the most troublesome aspect of this hypothesis is that the definition of the context is too broader. A variety of stimuli could play the role of context. For instance, apparatus, room, place, or location can constitute the exteroceptive context, and drug state, hormonal state, mood state, deprivation state, recent events, expectation of events, or passage of time can constitute the interoceptive context (e.g., Bouton, 2000, 2002). In the case of resurgence, the delivery and removal of reinforcers would play the role of context. Lattal and Wacker (2015) pointed out the difficulty of contextual accounts as follows:

> "One of the challenges facing investigators studying renewal has been that of defining context in a noncircular manner. For example, if one institutes a nominal ABC renewal procedure, but fails to obtain renewal in the C condition, does one conclude that such renewal does not occur or that the C condition did not really constitute a context change? If the

> latter, then a C condition exists only if renewal occurs, making renewal both the definition and the cause of the recurrence."

Thus, if resurgence does not occur in a given situation, the contextual view might suggest that the context between Phases 2 and 3 did not sufficiently change, and vice versa. The contextual account of reversal thinning results noted above also seems to be the same as this instance. Evidently, these explanations are a circular argument. As Craig et al. (2016) pointed out, the flexibility of the contextual account makes it difficult to determine whether any given result is consistent with the predictions of this hypothesis (see also McConnell & Miller, 2014), and the prediction provided by this view is always qualitative. Critically, this model does not seem to give a reasonable account of the effects of reinforcement rates for the target response on resurgence. Despite these limitations, the contextual view may be attractive in the sense that it provides an integrative framework for understanding other forms of relapse (e.g., renewal, reinstatement, spontaneous recovery) in a parsimonious manner. Even so, the contextual change hypothesis and its account should be formalized more clearly (for related discussion, see Craig & Shahan, 2016; Craig et al, 2016; Shahan & Craig, in press).

1.4 Differential Roles of Reinforcement for the Target and Alternative Responses in Resurgence: Proposal for a Synthetic View of Behavioral Momentum Theory and Context-change Hypothesis

Both the BMT and the context-change hypothesis may assume that reinforcement rates for the alternative response affect the *magnitude* of resurgence. Furthermore, the BMT model should assume that the reinforcement of the target and alternative responses had similar effects on resurgence. However, we would like to propose another possibility—a synthetic view of the BMT and the context-change hypothesis. Here, reinforcements for the target and the alternative response affect differential aspects of resurgence. The former affects the magnitude of resurgence, and the latter affects the occurrence of resurgence. In addition, the former and latter seem compatible with the BMT model and the context-change hypothesis respectively. In order to show evidence of these assumptions, let us reconsider the previous findings described in Sections 1.1 and 1.2.

As noted in Section 1.2, conflicting results have been reported with respect to the effects of alternative reinforcement on resurgence. Some studies showed a positive relation between resurgence and the rates of alternative reinforcement. The common feature of these studies is that there was a significant difference between the resurgence of the Rich and Lean conditions only when resurgence occurred in the Rich condition, but not in the Lean one. For example, in Sweeney and Shahan's (2013) experiment, resurgence occurred only in the Rich condition (see Figure 3), and they concluded that the higher alternative reinforcement rates produced the greater resurgence.

The other studies also drew the same conclusion based on this kind of "all-or-nothing" manner (see Figure 4 from Craig et al.'s (2016) results and Figure 1 from Leitenberg et al.'s (1975) results). As note in Section 1.2, although Bouton and Trask (2016) observed resurgence in both VI 30-s and VI 60-s conditions, there was no significant difference in the magnitude of resurgence between these conditions (see Figure 2; see also Winterbauer & Bouton, 2010).

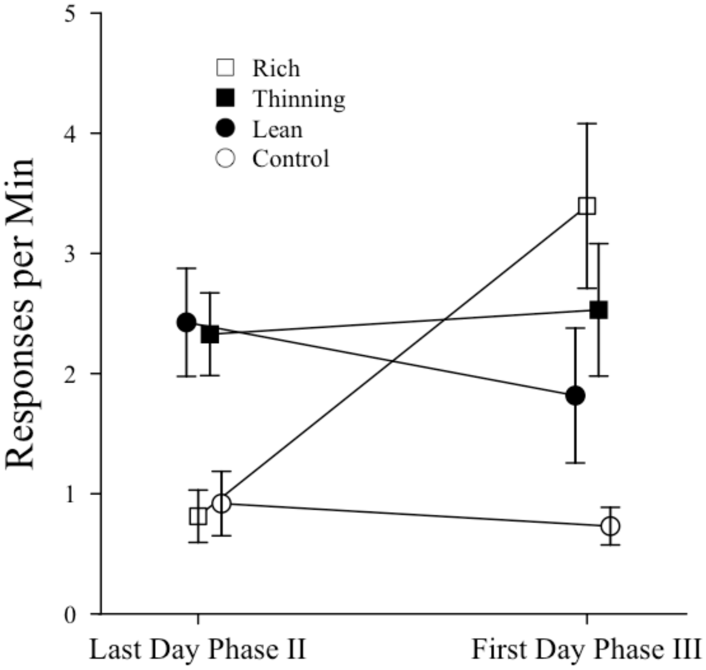

Figure 3. Means and standard errors of target response rate for each group on the last day of Phase 2 and the first day of Phase 3 in Sweeney and Shahan (2013). This figure is reproduced from Sweeney & Shahan (2013), with permission from the publisher.

Cançado et al.'s (2015) results further supports this view. They parametrically manipulated alternative reinforcement rates and investigated their effects on resurgence by measuring both the magnitude of resurgence and the number of sessions in which it occurred. They found that the magnitude of resurgence did not differ consistently across subjects but the total number of sessions with resurgence increased as a function of alternative reinforcement rates. These findings seem to suggest that the rates of alternative reinforcement might affect the occurrence of resurgence and produces qualitative, but not quantitative, differences in resurgence (i.e., whether resurgence occurs or not). In other words, the “threshold” for inducing resurgence might be determined by the alternative reinforcement. In addition, this idea seems to be consistent with the context-change hypothesis of resurgence. Given that there are no numerical measures for evaluating the extent to which the context changes as a function of manipulation for producing contextual change, the change in context must be judged in the all-or-nothing manner. If this reasoning is acceptable and if resurgence is produced by the same mechanism underlying ABC renewal, context-change hypothesis should predict that the rates of alternative reinforcement determine whether or not resurgence occur.

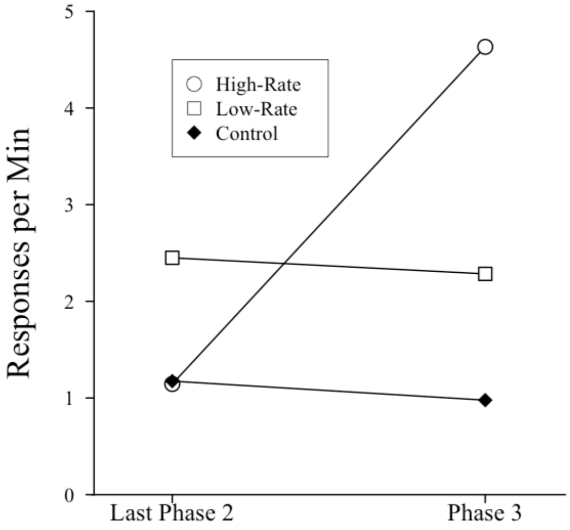

Figure 4. Mean rates of target responses during the last session of Phase 2 and Phase 3 for each group in Craig et al. (2016). This figure is reproduced from Craig et al. (2016), with permission from the publisher.

Podlesnik and Shahan (2009, 2010) reported the positive relation between the magnitude of resurgence and the rates of target reinforcement. More importantly, both studies showed quantitative, but not qualitative, differences in resurgence between the Rich and Lean conditions. In other words, resurgence was observed in both the Rich and Lean conditions, but at different magnitudes (see Figure 5). Somewhat surprising is that the only studies were reported by Podlesnik and Shahan (2009, 2010) which demonstrated the systematic relation between resurgence and the reinforcement rate for the target response. Further evidence is therefore necessary and if future studies manipulate the target reinforcement rates parametrically and shows the systematic relation, then that relation could be well predicted by the framework of behavioral momentum theory. To summarize, previous studies seem to support the possibility raised here that the reinforcement for the target and alternative responses have differential effects on resurgence. With respect to the effect of reinforcement rates on the target response, behavioral momentum theory could provide a reasonable prediction. The context-change hypothesis, on the other hand, could explain the effects of alternative reinforcement on resurgence. If these hypotheses raised here are proven correct, the synthetic view of these theories can become an integrative model for predicting the relation between resurgence and reinforcement rates.

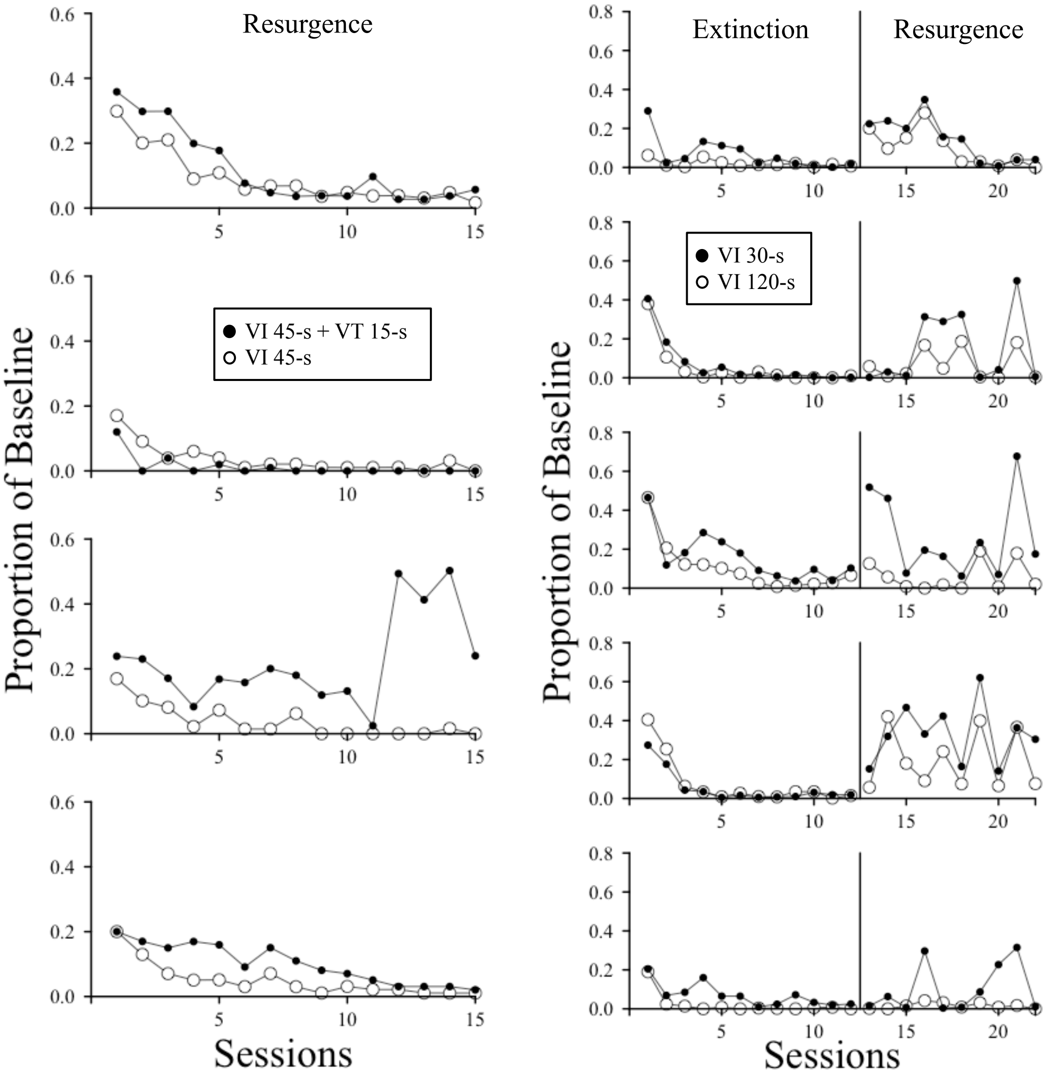

Figure 5. Proportion of baseline response rates of extinction and resurgence conditions in experiments with rats (left panel) and pigeons (right panel) arranging different rates of reinforcement during baseline. These figures are reproduced from Podlesnik and Shahan (2010), with permission from the publisher.

1.5 Purpose of the Present Study

The general purpose of the present study was to investigate the hypothesis of the synthetic view of resurgence that reinforcements for the target and alternative responses have different effects on resurgence. This view predicts that reinforcement for the target response produces quantitative differences (i.e., the magnitude of resurgence) and reinforcement for the alternative response produces qualitative differences in resurgence (i.e., occurrence of resurgence). In other words, it assumes that the magnitude and occurrence of resurgence is governed by the same mechanism as resistance to change and ABC renewal, respectively.

In Experiment 1, the effect of alternative reinforcement rates on resurgence was examined by using a multiple schedule at first. As reported by Cançado and Lattal (2013), it was expected that the relation between resurgence and rates of alternative reinforcement would be unsystematic. For testing the hypothesis proposed here further, it is necessary to conduct a parametric analysis because there are just two studies examining the effects of the target reinforcement and results are mixed with respect to the effects of alternative reinforcement. Even though the number of studies on resurgence has greatly increased in the last 15 years, only Cançado et al. (2015) have reported a parametric analysis of the relationship between resurgence and independent variables. The lack of parametric experiments is due to several obstacles. First, a typical resurgence study takes at least months or longer so that it takes long time if the independent variables are parametrically manipulated. In addition to this, resurgence sometimes does not occur and is highly variant in both individual subjects and between subjects, and thus consistent results within and across subjects are not likely to be obtained. This may be the biggest obstacle faced when conducting the parametric analysis. One solution to this problem is to repeatedly conduct experiments under the same conditions and average the performance. However, this is not a realistic method because it will take much longer time to conduct the experiment. A more realistic solution is to establish new procedures where resurgence can be robustly observed for each testing and/or resurgence tests can be conducted over a shorter period. Experiments 2 and 3 are designed to test the utility of two procedures that are expected to meet these conditions: the discrete-trial and within-session procedures are tested in Experiments 2 and 3, respectively. In Experiments 4 and 5, the probability and reinforcer magnitude for either the target or alternative response were parametrically manipulated and their effects on resurgence were examined using the discrete-trial procedure. In Experiments 6 and 7, the effects of the rates and reinforcer magnitude were examined in a similar manner as in Experiments 4 and 5 using the within-session procedure. Figure 6 shows the predictions of the synthetic view of behavioral momentum and context-change account. This view provides the following predictions: the magnitude of resurgence increases as a linear function of rates, magnitude, and reinforcer magnitude for the target response. Baum (1993) indicated that although response rates under the variable-ratio (VR) and VI schedules of reinforcement increased as a function of reinforcement rates, the response rates decreased under extremely high reinforcement rates. In addition, Nevin and Grace (2000) suggested that this decrement could also occur in resistance to extinction in terms of behavioral momentum theory. It is therefore expected that the magnitude of resurgence would also decrease under the extremely high rates of reinforcement, if resistance to change and resurgence share the same behavioral mechanism. Indeed, Shahan and Sweeney's (2011) model can produce the inverted U-shape function of resurgence. On the other hand, the magnitude of resurgence increases as a *non-linear* (e.g., sigmoid) function of rate and amount of reinforcement for the alternative response. If this prediction is correct, results from Experiment 4 to 7 are expected to fit the prediction shown in Figure 6.

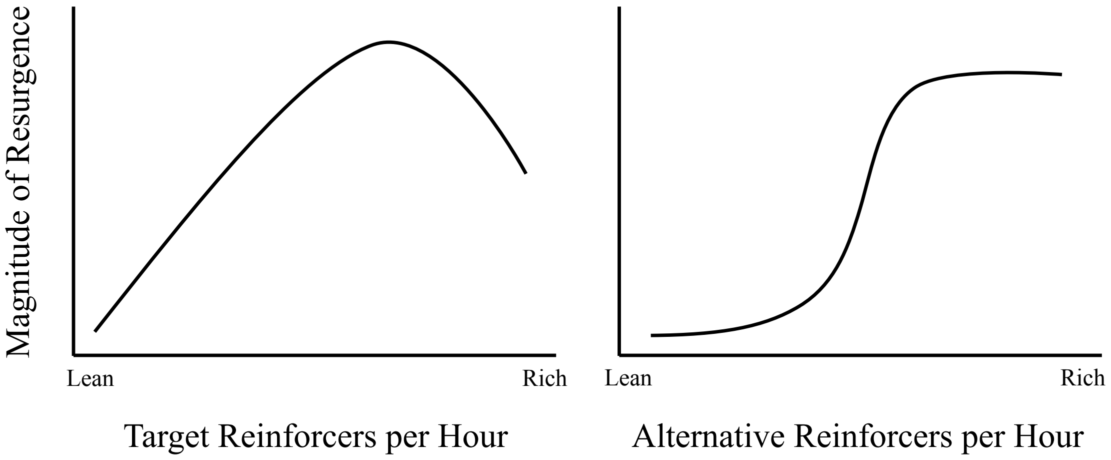

Figure 6. Prediction of the synthetic view of resurgence. The left and right panels show the magnitudes of resurgence as a function of rate, probability, or amount of reinforcement for the target and alternative reinforcement, respectively.

2. EXPERIMENTS

2.1 A Further Look at Reinforcement Rate and Resurgence

Experiment 1

Alternative Reinforcement Rate and Resurgence in a Multiple Schedule

As noted, models for resurgence incorporate the effects of the alternative reinforcement and predict greater resurgence under higher alternative reinforcement rates, but the aforementioned some studies have reported results at odds with these predictions. The purpose of Experiment 1 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 Phase 2.

Experiment 1-1

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 Phase 2. The different reinforcement rates were arranged in Experiments 1-1a and 1-1b 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 1-1a and 1-1b, 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 Phase 1, a VI 30-s schedule was in effect in both components for a minimum of 20 sessions in Experiment 1-1a and 15 sessions in Experiment 1-1b. 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.

Table 1. The schedules of target and alternative responses in each phase of all Experiments.

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

The Resurgence phase was the same in both Experiments 1-1a and 1-1b 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 7 shows the total number of target responses in the Rich and Lean component during the last 5 sessions of Phase 2 and all Resurgence phase sessions. Figure 8 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 1-1a and 1-1b. In Experiment 1-1a, 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 7 and the left panel of Figure 8, 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 8). For Pigeon H13, there was no systematic difference in resurgence between the Rich and Lean components.

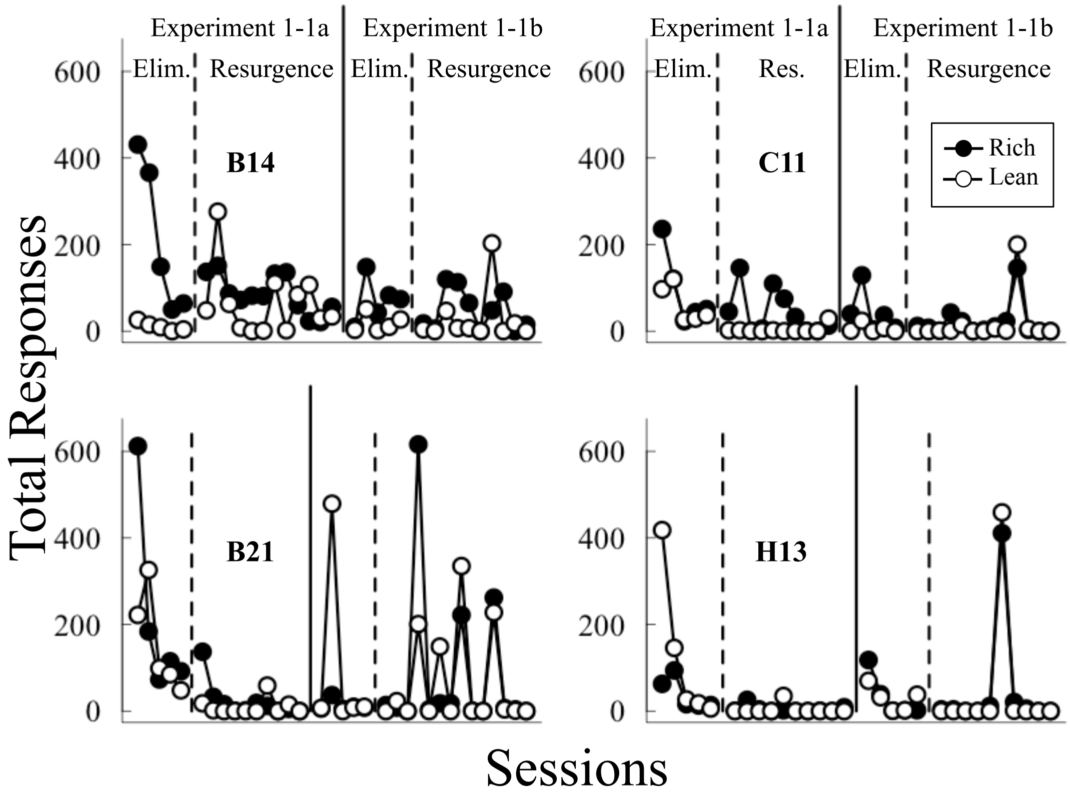

Figure 7. Total number of target responses over the last 5 sessions of Phase 2 and the all sessions of Phase 3 in Experiment 1-1a and 1-1b. Dashed and solid vertical lines in each graph separate the Elimination and Resurgence phases, and the Experiments 1-1a and 1-1b, respectively.

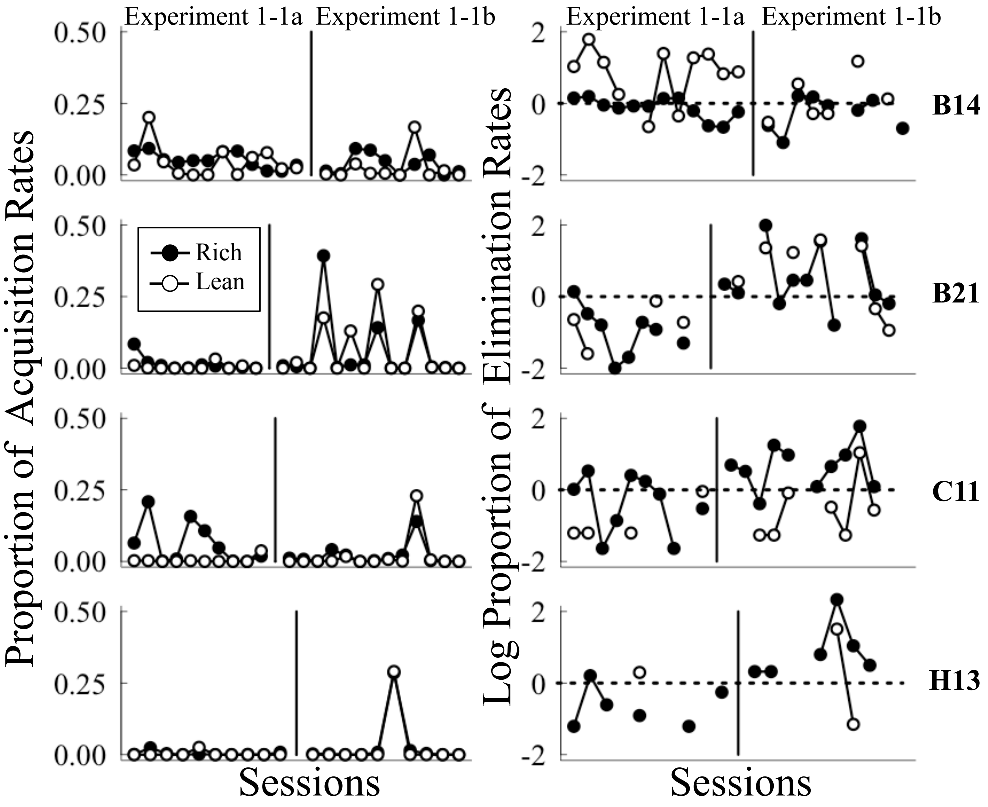

Figure 8. Proportion of the Acquisition response rates (left panel) and log proportion of the Elimination (right panel) response rates during Phase 3. Solid vertical lines in each graph separate the Experiments 1-1a and 1-1b. Proportion of the Acquisition rates was calculated by dividing the response rates in each session of Phase 3 by mean response rates during the last 6 sessions in Phase 1. Log proportion of the Elimination rates was the logarithm of values calculated by dividing the response rates in each session of Phase 3 by mean response during the last 3 sessions in Phase 2. Each point above the horizontal dashed line in the right panel represents the resurgence.

In Experiment 1-1b, greater resurgence occurred in Pigeons B21 and H13 than in Experiment 1-1a. 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 Phase 1 of B21 was higher in the

Lean component (see Table 2). Some experiments have reported that higher rates of target responding in Phase 1 produced greater resurgence (da Silva et al., 2008; Winterbauer et al., 2013, Experiment 1). Thus, it was possible that the higher rate of target response in the Lean component during Phase 1, rather than alternative reinforcement rates, contributed to the amount of resurgence. For Pigeons B14 and C11, resurgence occurred in neither component. There was no obvious difference in resurgence between Experiments 1-1a and 1-1b suggesting that whether the DRO value in Phase 2 was variable (VDRO) or fixed (FDRO) did not affect the amount of target responses, a finding consistent with the results reported by Doughty et al. (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 et al., 1976). In addition, Pacitti and Smith (1977) suggested the possibility that the topography of alternative responding in Phase 2 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 (1-2 and 1-3) 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 1-2

In Experiment 1-2, 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 1-2a and the stability criteria for changing between phases were as described for Experiment 1-1. 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 1-2a Experiment 1-2a consisted of a two-component multiple schedule across all phases. In Phase 1, 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 Phase 2, 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 Phase 2. This phase lasted for a minimum of 15 sessions and was terminated when both target and alternative responses met the stability criteria. In Phase 3, all reinforcers were withheld in both components. This latter phase lasted for at least 10 sessions.

Experiments 1-2b and 1-2c. In contrast to the multiple schedule used in Experiment 1-2a, Experiments 1-2b and 1-2c 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 1-1 and 1-2a. The schedules in Experiments 1-2b and 1-2c are shown in Table 1 and corresponded to those in effect in the Rich and Lean components, respectively, of Experiment 1-2a. Each session started after a 30-s blackout and ended after 30-min. In both conditions, the minimum number of sessions in Phase 1 was 15. Other aspects of each phase were as described for Experiment 1-1a. The order of Experiments 1-2b and 1-2c differed across pigeons: A01 and A03 were exposed to Experiment 1-2c at first and then 1-2b; for A02 and A04, the order was reversed.

Results and Discussion

Figure 9 shows the number of target responses in the Rich and Lean component during the last 5 sessions of Phase 2 and all sessions of Phase 3 in Experiment 1-2. Figure 10 shows the Figure 9 data for each session in the resurgence 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 1-1, the patterns of resurgence as indexed by any of the measures shown in these figures were different for each pigeon.

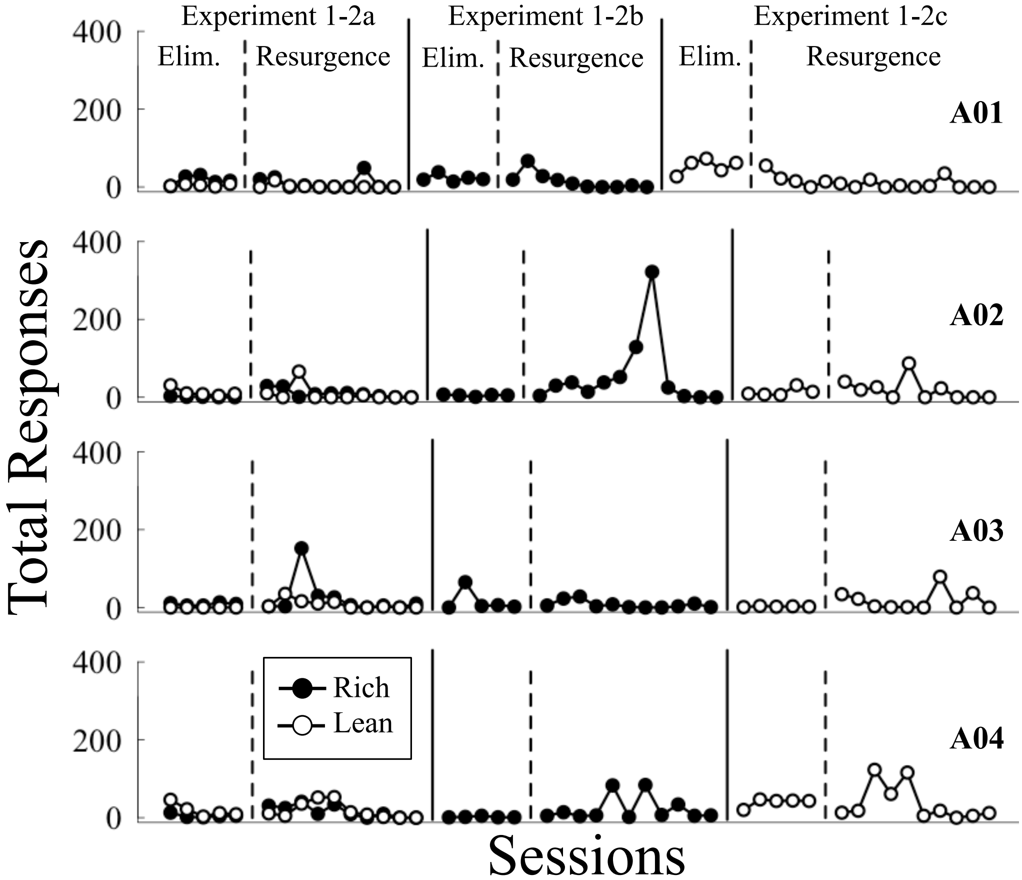

Figure 9. Total number of target responses over the last 5 sessions of Phase 2 and the all sessions of Phase 3 in Experiments 1-2. Dashed and solid vertical lines in each graph separate the Elimination and Resurgence phases, and the Experiments 1-2a, 1-2b, and 1-2c, respectively.

In Experiment 1-2a, Pigeon A03 showed greater absolute and relative resurgence (by either index) in the Rich component. As shown in the right panel of Figure 10, A02 showed resurgence during many sessions of Phase 3, 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 Phase 1, 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 Phase 1 and the higher alternative reinforcement rates during Phase 2 each contributed to the greater resurgence in Pigeon A03.

In Experiments 1-2b and 1-2c, 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 1-2b than 1-2c. 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 Phase 2 was somewhat greater in Experiment 1-2b (the Rich component), as shown in the right panel of Figure 10.

In sum, differential resurgence as a function of the different rates of alternative reinforcement in Phase 2 did not occur systematically in Experiment 1-2. The exceptions were A03 in Experiment 1-2a and A02 in Experiments 1-2b and 1-2c: These pigeons in the noted conditions showed greater resurgence when the rates of alternative reinforcement were higher.

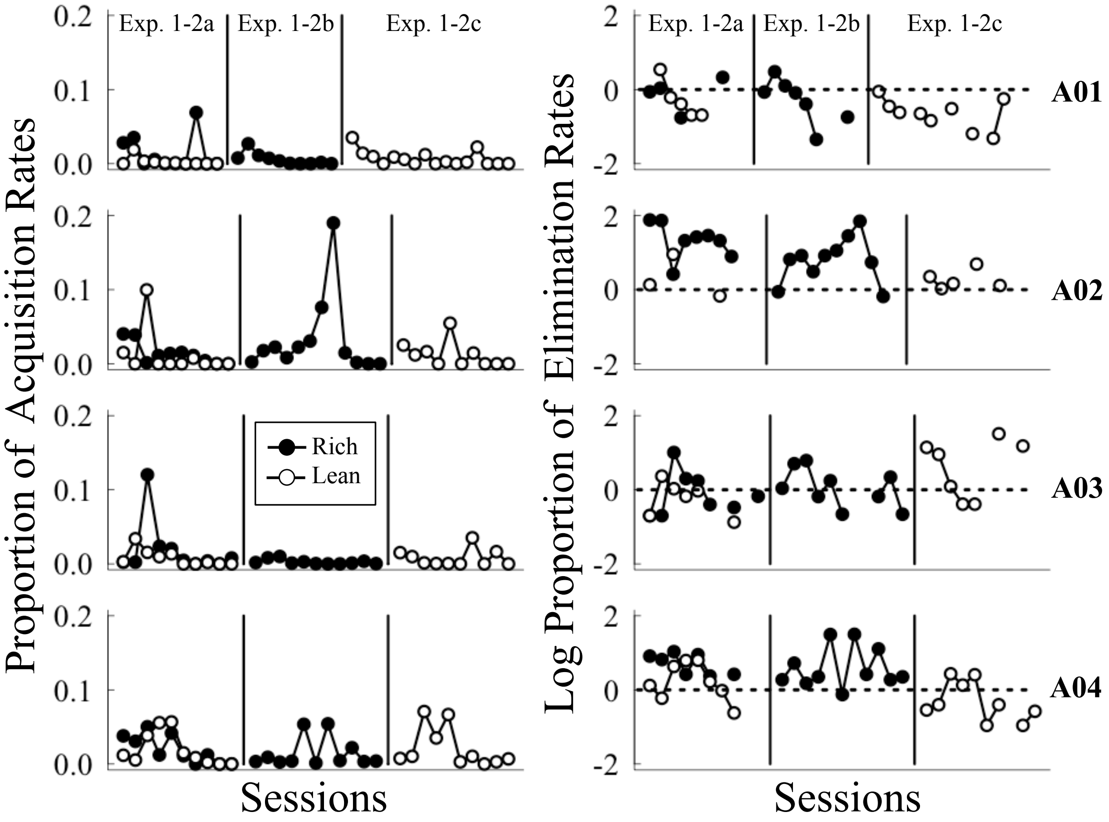

Figure 10. Proportion of the Acquisition (left panel) and the Elimination (right panel) response rates during Phase 3. Solid vertical lines in each graph separate the Experiments 1-2a, 1-2b, and 1-2c. Proportion of the Acquisition rates was calculated by dividing the response rates in each session of Phase 3 by mean response rates during the last 6 sessions in Phase 1. Log proportion of the Elimination rates was the logarithm of values calculated by dividing the response rates in each session of Phase 3 by mean response during the last 3 sessions in Phase 2. Each point above the horizontal dashed line in the right panel represents the resurgence.

In Experiment 1-2, the effect of alternative reinforcement rates on resurgence was examined by manipulating the VI value between the Rich and Lean components. 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 Phase 2 in almost all instances of Experiment 1-2 (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 1-2b and 1-2c shown by Pigeon A02 and in Experiment 1-2a 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 1-3 addressed this problem to further examine the effect of alternative reinforcement rates on resurgence.

Experiment 1-3

In Experiment 1-3, 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 1-1.

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 1-1a. 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 1-3 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.

In Phase 1, target responses were reinforced on a VI 30-s schedule in both components. This phase lasted for a minimum of 20 sessions. In Phase 2, 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 Phase 3, all reinforcers were withheld for at least 10 sessions. The sequence of phases was repeated for A11 and D11.

Results and Discussion

Figure 11 shows the number of target responses in the Rich and Lean component during the last 5 sessions of Phase 2 and all sessions of Phase 3 in Experiment 1-3. Figure 12 shows the Figure 10 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 1-1 and 1-2, 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. Resurgence for Pigeon D11 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.

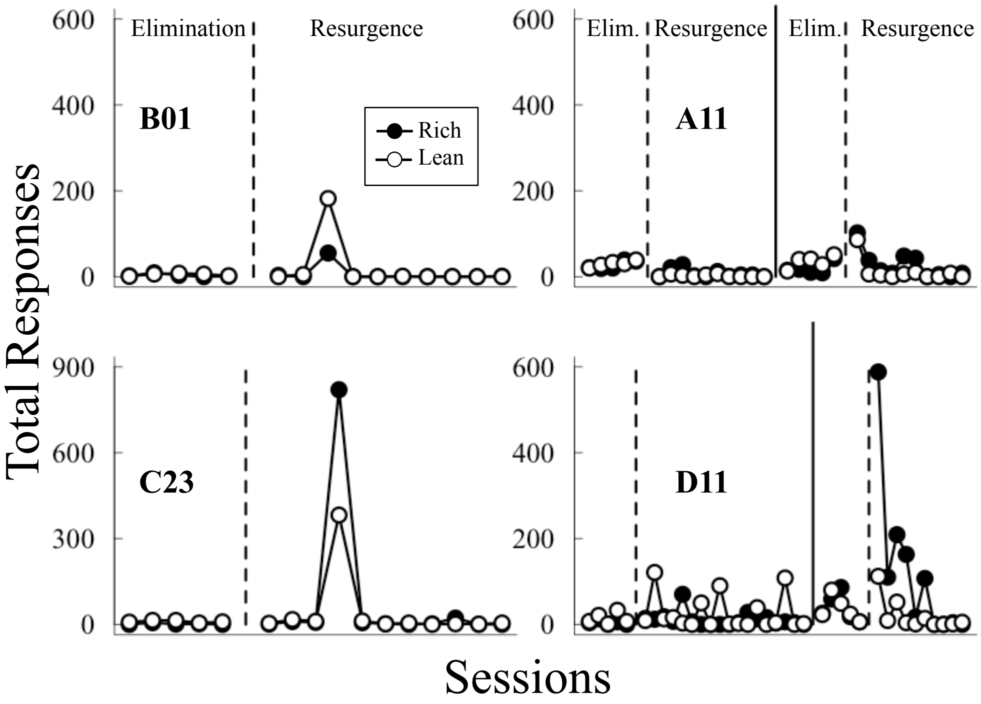

Figure 11. Total number of target responses over the last 5 sessions of Phase 2 and the all sessions of Phase 3 in Experiment 1-3. Dashed vertical lines in each graph separate the Elimination and Resurgence phases. Solid vertical lines in the two right graphs separate the first and second exposure to the procedure of Experiment 1-3. Note the different y-axis scale.

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 Phase 2 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 Phase 2 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 Phase 2 and showed no difference in the alternative response rates.

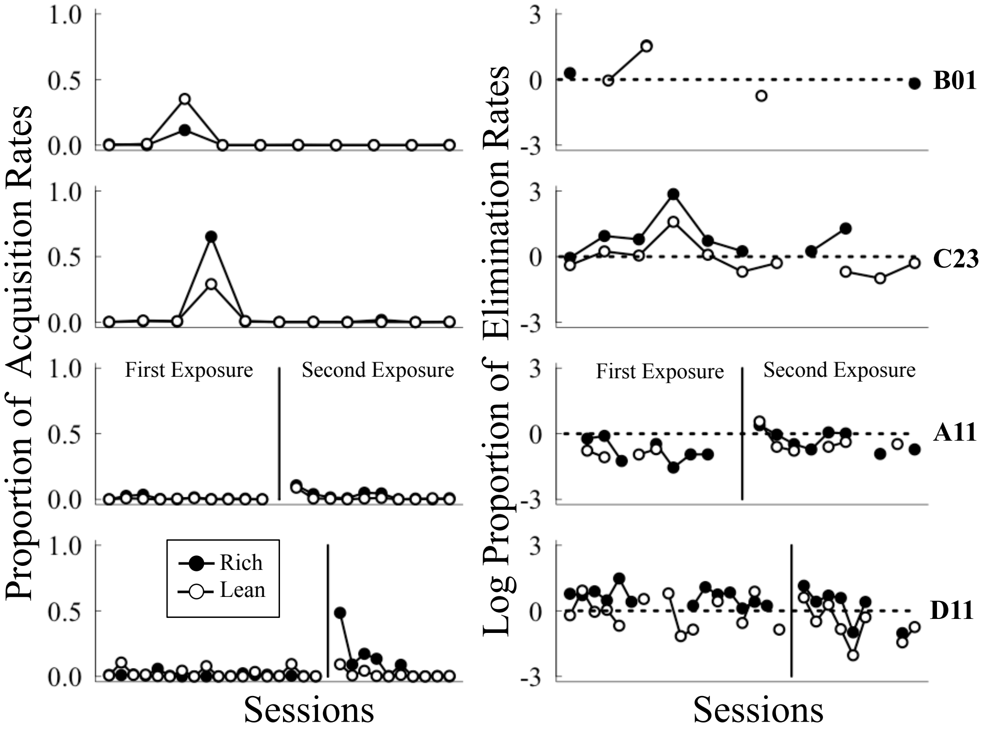

Figure 12. Proportion of the Acquisition (left panel) and the Elimination (right panel) response rates during Phase 3. Solid vertical lines in the lower two graphs separate the first and second exposure to Experiment 1-3. Proportion of the Acquisition rates was calculated by dividing the response rates in each session of Phase 3 by mean response rates during the last 6 sessions in Phase 1. Log proportion of the Elimination rates was the logarithm of values calculated by dividing the response rates in each session of Phase 3 by mean response during the last 3 sessions in Phase 2. Each point above the horizontal dashed line in the right panel represents the resurgence.

In some conditions with some pigeons, there was greater resurgence in the Rich component, while in others there was little difference in resurgence. 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 magnitude of resurgence.

General Discussion

The present experiments examined the relation between the rates of alternative reinforcement and resurgence. In Experiment 1-1, DRO schedules were in effect in both the Rich and Lean components during Phase 2. 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 1-1a and 1-1b. 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 1-2, unlike Experiment 1-1, 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 1-1, differential resurgence was not observed as a function of the different reinforcement rates arranged in Phase 2 (cf. Cançado & Lattal, 2013; Winterbauer & Bouton, 2010). In Experiment 1-3, alternative responses were reinforced on VI 60-s in both the Rich and Lean components in Phase 2. In the Rich component, additional reinforcers were delivered independently of the alternative response according to a DRO schedule. As noted above, Sweeney and Shahan's (2011) model predicts that all reinforcers obtained in that component during Phase 2 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.

Of most importance was the findings that more resurgence did not occur systematically under higher rates of reinforcement in Phase 2 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 Phase 2, 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 1-2b than 1-2c, both alternative reinforcement and response rates were also higher in Experiment 1-2b. Thus, the contributions of alternative response and reinforcement rates in Phase 2 to resurgence remains unclear. Experiment 1-3 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 Phase 2. 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.

In summary, consistent differential resurgence could not be observed throughout the series of experiments. Perhaps a more serious problem is that there was little to no resurgence in some conditions with some pigeons. Although multiple schedule have often used when comparing resurgence with different conditions, some studies reported the failure of producing resurgence (e.g., Cançado & Lattal, 2013; Cançado et al., 2015; Mulick et al., 1976). These findings and the present one seem to emphasize the necessity of developing the procedure that produces resurgence more robustly for conducting the parametric analysis. This issue is addressed in Experiments 2 and 3.

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. 1-1a	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. 1-1b	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. 1-2a	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. 1-2b	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. 1-2c	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
[b]Exp. 1-3	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
[b]Exp. 1-3 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.

2.2 Development of New Procedures for Studying Resurgence

Experiment 2

Resurgence in a Discrete-trial Procedure[1]

The results of Experiment 1 did not offer evidence of the positive relation between resurgence and the alternative reinforcement rate. Perhaps, a more serious problem is that there was little to no resurgence in some conditions with some pigeons. Although multiple schedule have often used when comparing the effect of reinforcement rates on resurgence, some studies reported the failure of producing resurgence (e.g., Cançado & Lattal, 2013; Cançado et al., 2015; Mulick et al., 1976). These findings and the Experiment 1 seem to emphasize the necessity of developing the procedure that consistently produces greater resurgence. One candidate that can meet this requirement may be a discrete-trial procedure. The discrete-trial procedure considered here is such that only a single response can be emitted per trial. Putting a restriction on the number of responses per trial makes it possible to assess the relation between resurgence and the reinforcement frequency, independently of the influence of the response rate. In general, rate of response as well as reinforcement is affected when manipulating the reinforcement frequency in the free-operant procedure. In contrast, the frequency of response is not an issue in the discrete-trial procedure due to this restriction. Thus, the discrete-trial procedure proposed here might pave a way toward a parametric analysis of resurgence. Experiment 2 tested this possibility through 3 experiments.

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[1] Experiments 2-1 and 2-2 were reported in an undergraduate thesis by Natsumi Goto. Reprinted with the permission of the author.

Experiment 2-1

Method

Subjects. Six experimentally naive male *Wistar* rats were maintained at 80% of their free-feeding weights throughout the experiment. They were approximately 4 months old at the start of the experiment and were housed individually with free access to water in a temperature-controlled room on a 12:12 light-dark cycle (lights on 8:00 pm). One rat (B04) died before the completion of shaping, so only five rats were used in the present series of experiments.

Apparatus. Five identical operant chambers were used. Each chamber was approximately 32 cm long, 25 cm wide and 25 cm high, and was housed in a sound-attenuating box with a ventilation fan. The sidewalls and ceiling of each chamber were Plexiglas, and the front and back walls were aluminum. Two retractable levers were located on the front wall centered 16 cm apart and 6.7 cm above the grid floor. A force of approximately 0.25 N was required to operate each lever. A 2.8-W lamp was located 8 cm above each lever. A pellet dispenser delivered 45-mg pellets into a food cup that was located between the two levers, 5 cm above the floor. A houselight mounted at the top and center of the rear wall provided general illumination. A white noise in the room and a ventilation fan in each chamber masked extraneous sounds. All event scheduling and data recording were controlled by a PC using MED-PC IV software, located outside the experiment room.

Procedure. After the hand shaping of the lever pressing response, all rats were exposed to the following three-phase procedure. Details of each phase for all conditions of Experiment 2 are shown in Table 3. Across all phases, sessions ended after 200 trials and occurred 6 or 7 days a week at approximately the same time each day. At the start of each trial, the two levers were extended into the chamber, and the lever lights and the houselight were lit. A single response on either lever terminated the trial and a reinforcer was delivered according to a random-ratio (RR) schedule of reinforcement. Assignment of the left or right lever to the target lever or alternative lever was balanced across all subjects and experiments (see Table 4).

An intertrial interval (ITI) separated each trial during which all lights were turned off and the levers retracted. The ITI duration of each trial was varied in such a way that the trial duration was constant at 10-sec: if the response occurred within 10-sec after the trial onset, the ITI duration of that trial was calculated by subtracting the latency from 10. For example, if the response occurred the 3-sec after the trial onset, the next trial started after the 7-sec ITI. On the other hand, if the response occurred more than 10-sec after the trial onset, the next trial always started immediately after the blackout during which both levers were retracted.

In Phase 1, a single response on any lever was reinforced on RR 4 schedule (i.e., reinforcer was presented on 25% of the trials). During the first 10 sessions, two probability generators were assigned to each lever and independently determined the reinforcer availability. However, two rats showed exclusive preference for one particular lever, so that from the 11th session, reinforcers were scheduled in a similar manner of Stubbs and Pliskoff (1969), such that one probability generator sampled every trial and assigned the reinforcer to either lever with the probability of .5. Once reinforcement was scheduled, it remained available until delivered in the subsequent trials. This first phase lasted for a minimum of 20 sessions. The mean number of responses on each lever during the last 5 sessions was assessed by the two-tailed binomial test, and the next phase began when there was no significant difference in the number of responses between levers.

Table 3. Experimental Designs for Each Experiment.
Probabilities of reinforcement are shown in parenthesis.

Experiments		Target lever	Alternative lever
Exp. 2-1	Phase 1	RR 4 (0.25)	RR 4 (0.25)
	Phase 2	EXT	RR 4 (0.25)
	Phase 3	EXT	EXT
Exp. 2-2	Phase 1	RR 2 (0.50)	RR 2 (0.50)
	Phase 2	EXT	RR 2 (0.50)
	Phase 3	EXT	EXT
Exp. 2-3a	Phase 1	RR 4 (0.25)	RR 4 (0.25)
	Phase 2	EXT	RR 2 (0.50)
	Phase 3	EXT	EXT
Exp. 2-3b	Phase 1	RR 2 (0.50)	RR 2 (0.50)
	Phase 2	EXT	RR 4 (0.25)
	Phase 3	EXT	EXT

In Phase 2, the response on the lever that served as the target response was extinguished, while the response on the other side, which served as the alternative response, produced the reinforcer on RR 4 schedule. This phase lasted for at least 10 sessions and the resurgence test began when the number of target responses decreased below 10% of the baseline level for at least 3 consecutive sessions. The baseline level of target response was calculated by the mean number of responses during the last five sessions of Phase 1.

In Phase 3, reinforcement for the alternative lever was discontinued. Thus, all reinforcers were withheld in this phase to examine the increase of the target response. It should be noted that each trial in this phase ended 10-sec after the trial onset if no response occurred within 10-sec. Phase 3 lasted for a minimum of 10 sessions and also until both the number of target and alternative responses decreased below 10% of their baseline levels for at least 3 consecutive sessions or until after a maximum of 30 sessions, whichever came first. The baseline levels were calculated by the mean number of these responses during the last 5 sessions of phase 1.

Results and Discussion

Figure 13 shows the numbers of the target and alternative responses across all phases. During the first 10 sessions of Phase 1, two rats (B05 and B06) showed exclusive preference for one of the two levers and the other rats showed inconsistent response. However, the implementation of Stubbs and Pliskoff (1969) procedure produced almost an equal number of responses between levers, except for Rat B05 that showed a somewhat larger number of responses in one particular lever. In Phase 2, the target response almost ceased within the first few sessions for all rats, while the alternative response sharply increased and was gradually stable in the later sessions.

In Phase 3, all rats showed resurgence of the target response. The greatest level of resurgence was observed within the first few sessions and the number of target responses gradually decreased as the session progressed. This monotonic-decrease pattern of resurgence is similar to that of previous studies conducted in the free-operant procedure (e.g., Leitenberg et al., 1970; Lieving & Lattal, 2003). It should be noted that Rats B02 and B03 showed long-lasting resurgence compared to the typical results of resurgence experiments. In addition, these rats and Rat B05 showed greater resistance to change of alternative response in Phase 3. It is unknown what aspects of the present study produced these features.

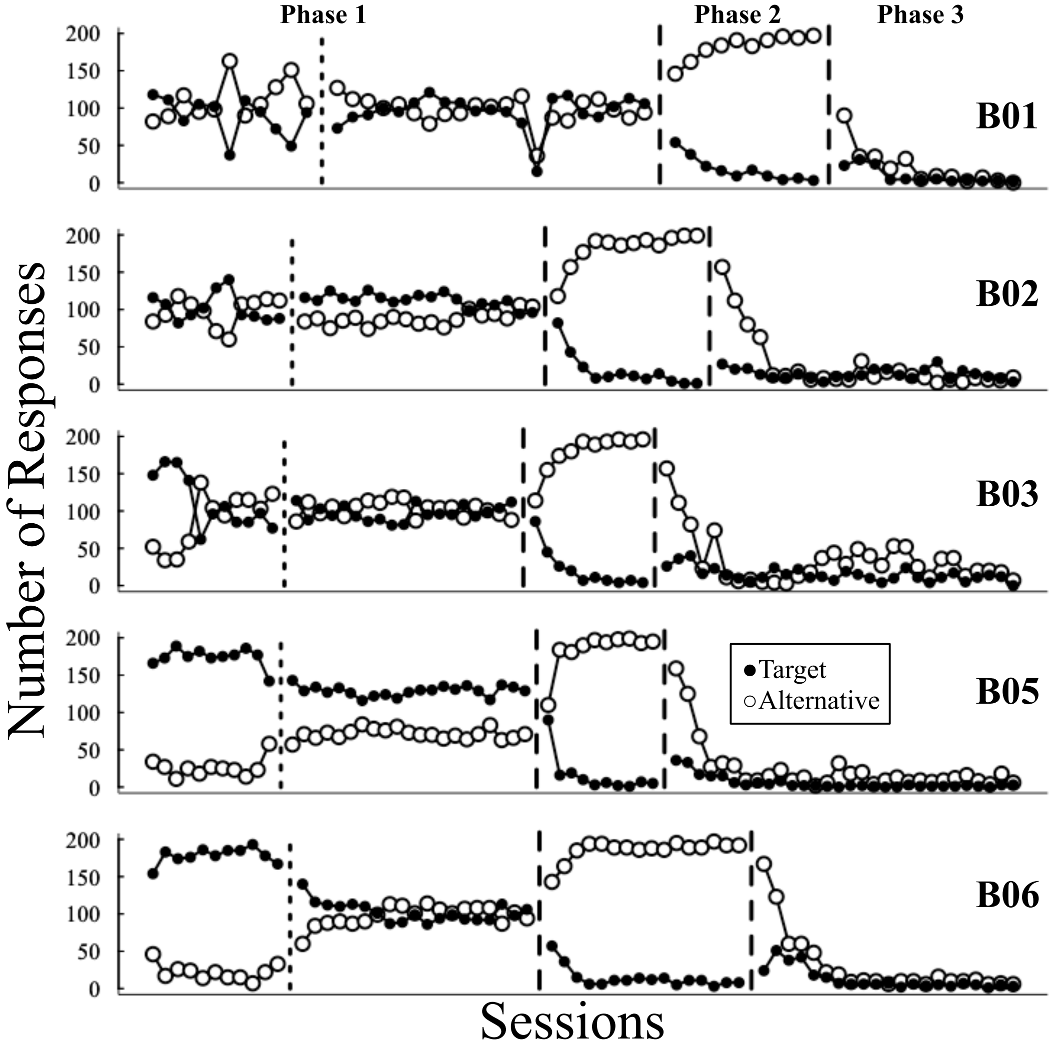

Figure 13. The number of responses on the target and alternative levers across 3 phases of Experiment 2-1. The dotted vertical lines separate the introduction of Stubbs and Pliskoff's assignment of reinforcements and the dashed vertical lines separate successive phases.

The results of Experiment 2-1 demonstrate that resurgence can be observed in the discrete-trial procedure, and that the pattern of resurgence was similar to that observed in the free-operant procedure. Many studies have reported that the magnitude of resurgence is affected by many factors such as reinforcement rates, response rates, and so on. It remains an open question whether or not resurgence observed in the present discrete-trial procedure was also affected by these variables. Experiment 2-2 therefore examined the effect of probability of reinforcement on resurgence.

Table 4 Position of the target and the alternative levers and mean obtained probability of reinforcement during the last five sessions of Phases 1 (target) and 2 (alternative). Standard deviations are shown in parenthesis.

		Position of the lever		Mean obtained prob. of rft.	
Exp.	Subjects	Target	Alternative	Target	Alternative
Exp. 2-1	B01	Right	Left	.219 (.018)	.250 (.002)
	B02	Right	Left	.205 (.021)	.250 (.002)
	B03	Left	Right	.203 (.025)	.250 (.002)
	B05	Left	Right	.154 (.010)	.250 (.003)
	B06	Left	Right	.217 (.021)	.250 (.002)
Exp. 2-2	B01	Left	Right	.393 (.025)	.501 (.002)
	B02	Left	Right	.363 (.014)	.500 (.000)
	B03	Right	Left	.407 (.027)	.499 (.002)
	B05	Right	Left	.395 (.018)	.499 (.001)
	B06	Right	Left	.360 (.020)	.502 (.001)
Exp. 2-3a	B01	Right	Left	.150 (.004)	.501 (.001)
	B02	Left	Right	.234 (.012)	.499 (.002)
	B03	Right	Left	.215 (.016)	.501 (.002)
	B05	Left	Right	.206 (.017)	.499 (.001)
	B06	Left	Right	.238 (.034)	.499 (.002)
Exp. 2-3b	B01	Right	Left	.428 (.021)	.251 (.003)
	B02	Right	Left	.392 (.020)	.251 (.002)
	B03	Left	Right	.386 (.048)	.248 (.001)
	B05	Right	Left	.436 (.021)	.251 (.002)
	B06	Right	Left	.375 (.023)	.249 (.001)

Experiment 2-2

In Experiment 2-2, the probability of reinforcement in Phases 1 and 2 was increased from .25 to .50 and their effect on resurgence was examined.

Method

Subject and Apparatus. The subjects and apparatus were the same as Experiment 2-1.

Procedure. Immediately after Experiment 2-1, all rats were exposed to the three-phase procedure, which was identical to Experiment 2-1 except for the probability of reinforcement in Phases 1 and 2. In Experiment 2-2, the target and alternative responses were reinforced on RR 2 schedule so that the probability of reinforcement was increased from .25 to .50. Stability criterion in each phase was the same as Experiment 2-1.

Results and Discussion

Figure 14 shows the numbers of the target and alternative responses across all phases of Experiment 2-2. All rats again showed resurgence in Phase 3. In addition, the magnitude of resurgence was greater than that of Experiment 2-1. Figure 15 shows the cumulative number of the target responses emitted in Phase 3 of Experiments 2-1 and 2-2. Except for Rat B02, the total number of the target responses during Phase 3 was higher in Experiment 2-2. Slopes of the cumulative curves gradually decreased from the beginning to the end of Phase 3 in both experiments. However, steeper slope for the first few sessions of Experiment 2-2 resulted in the greater total number of the target response for 4 rats. In contrast to Experiment 2-1, the number of responses for each lever of Phase 1 was stable and almost equal for all rats, although Rats B02 and B06 showed a slight bias to one lever. This was perhaps due to the use of inter-dependent scheduling of Stubbs and Pliskoff (1969) from the beginning of Phase 1. The acquisition and extinction process of the target and alternative responses did not differ from Experiment 2-1.

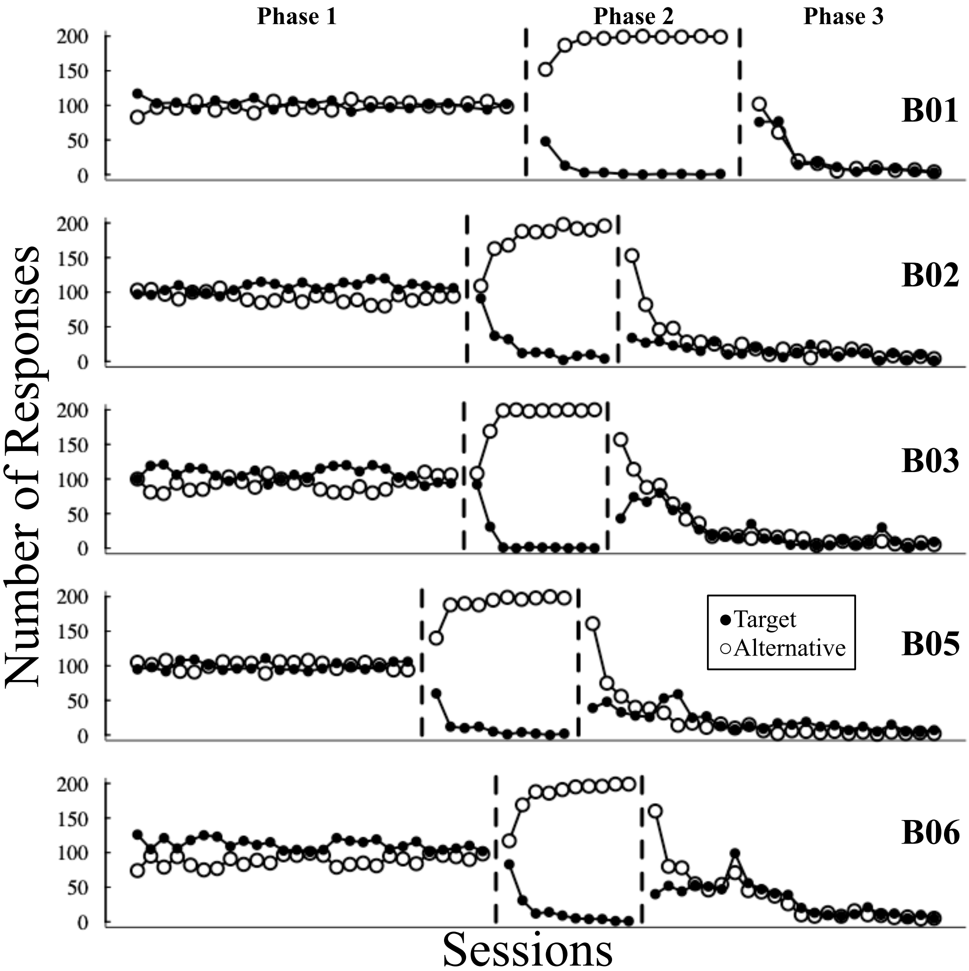

Figure 14. The number of responses on the target and alternative levers across 3 phases of Experiment 2-2. The dashed vertical lines separate successive phases.

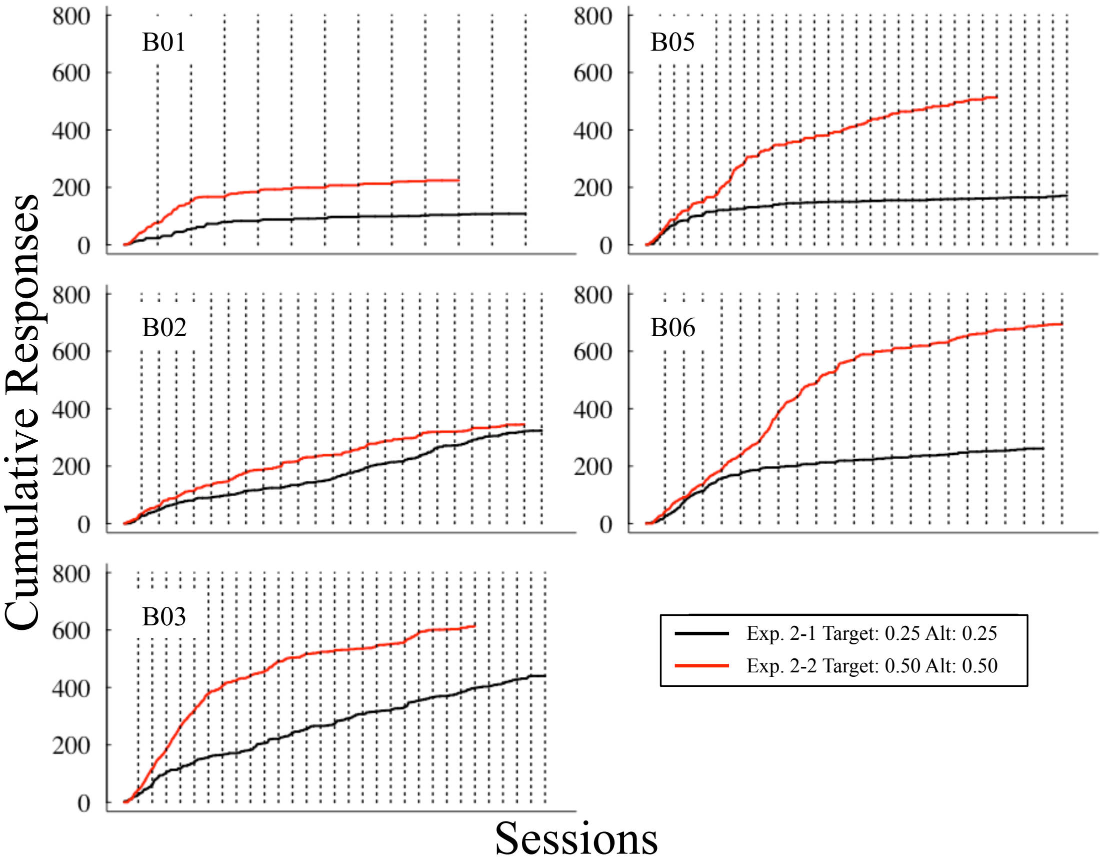

Figure 15. Cumulative numbers of target responses during Phase 3 of Experiments 2-1 and 2-2. The dashed vertical lines separate each session of Phase 3.

Experiments 2-1 and 2-2 demonstrate that resurgence in the discrete-trial procedure was also affected by the frequency of reinforcement. However, probabilities of reinforcement in both phases were changed from .25 to .50 in Experiment 2-2. It therefore is still unknown whether the higher probability of reinforcement in Phase 1, Phase 2, or a combination of these two variables affected the magnitude of resurgence. This question is addressed in Experiments 2-3a and 2-3b.

Experiment 2-3a & 2-3b

In Experiments 2-3a and 2-3b, probability of reinforcement in either Phase 1 or 2 was decreased to .25 from that of Experiment 2-2 to further examine which phase of reinforcement probability strongly affects the magnitude of resurgence.

Method

Subject and Apparatus. Subject and Apparatus was the same as the Experiments 2-1 and 2-2.

Procedure. Experiment 2-3 consisted of two conditions in which the probability of reinforcement was different for each phase. The probability of reinforcement in Phase 2 of Experiment 2-3a and Phase 1 of Experiment 2-3b was changed from .50 to .25, respectively. The order of Experiments 2-3a and 2-3b differed across rats: Rats B01 and B02 were exposed to Experiment 2-3a at first and then 2-3b; for the other rats, the order was reversed. Stability criterion in each phase was the same as Experiments 2-1 and 2-2.

Results and Discussion

Figure 16 shows the numbers of the target and alternative responses across all phases of Experiments 2-3a and 2-3b. Figure 17 shows the cumulative number of the target responses emitted in Phase 3 of Experiments 2-3a and 2-3b. Three Rats showed greater magnitude of resurgence in Experiment 2-3b. It should be emphasized that, as shown in Table 4, the mean-obtained probability of reinforcement in Phase 1 of both Experiments 2-3a and 2-3b were about 20% less than the programmed probability for all rats, while the obtained probability in Phase 2 approximated to the programmed one. Nevertheless, the magnitude of resurgence was generally greater in the condition where the probability of reinforcement for the target responding was higher than that for the alternative one. These results clearly suggest that the magnitude of resurgence was more sensitive to the probability of reinforcement for the target response in Phase 1 than that for the alternative response in Phase 2.

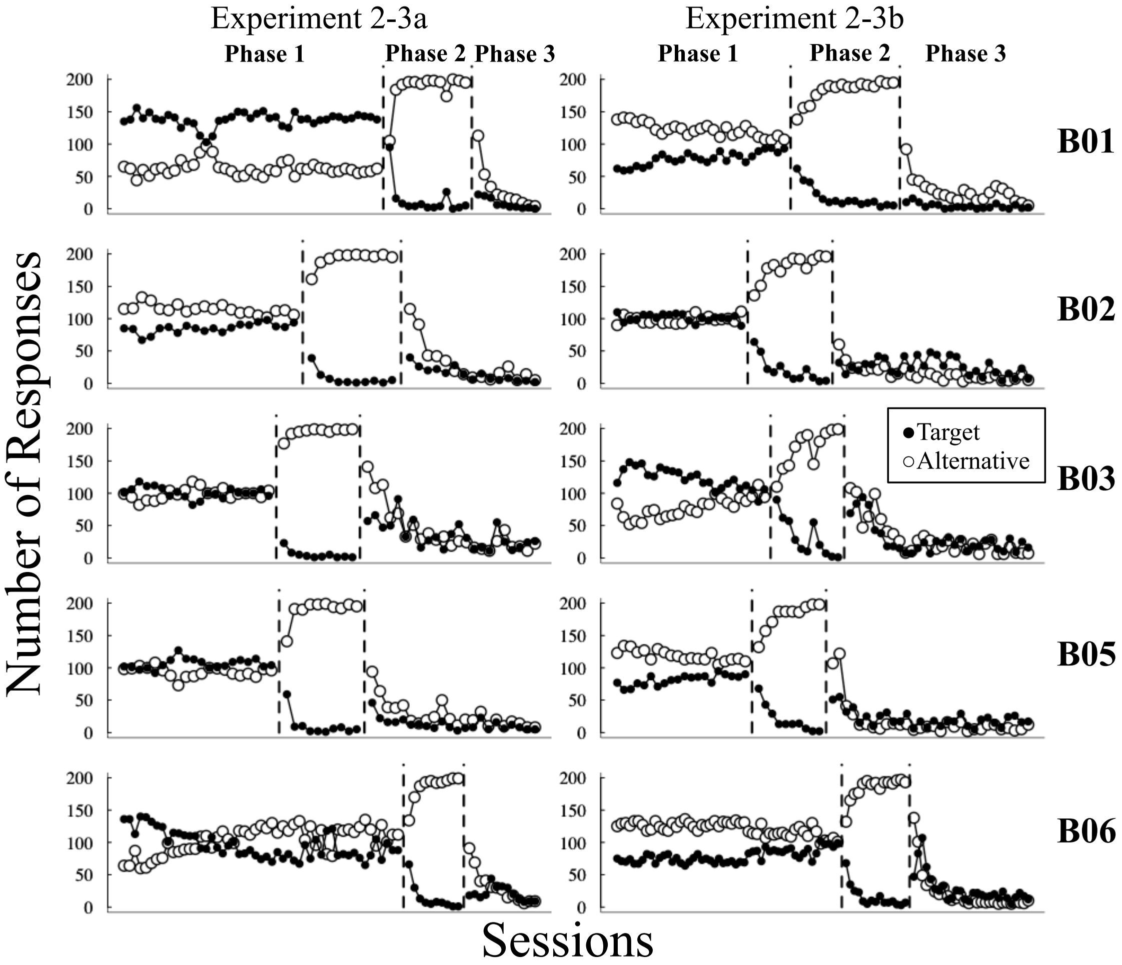

Figure 16. The number of responses on the target and alternative levers across 3 phases. The left and right panels show the results from Experiments 2-3a and 2-3b, respectively. The dashed vertical lines separate successive phases.

The other two Rats, however, showed the same level of resurgence between Experiments 2-3a and 2-3b. For Rat B01, only the slight increase of the target response resulted in the same level of resurgence between conditions. Rat B05, on the other hand, showed a greater resurgence for each condition, but their magnitude did not differ. It therefore seems reasonable to suppose that the magnitude of resurgence for Rat B05 was affected by the probability of reinforcement for both the target and alternative responses. However, it should be noted that in Experiment 2-3a, the target response immediately decreased to near zero levels when the alternative response was only reinforced in Phase 2. As response-prevention hypothesis (e.g., Leitenberg et al., 1975; Rawson et al., 1977) predicts, it was possible that greater resurgence shown in Experiment 2-3a of Rat B05 was due to the insufficient extinction of the target response during Phase 2.

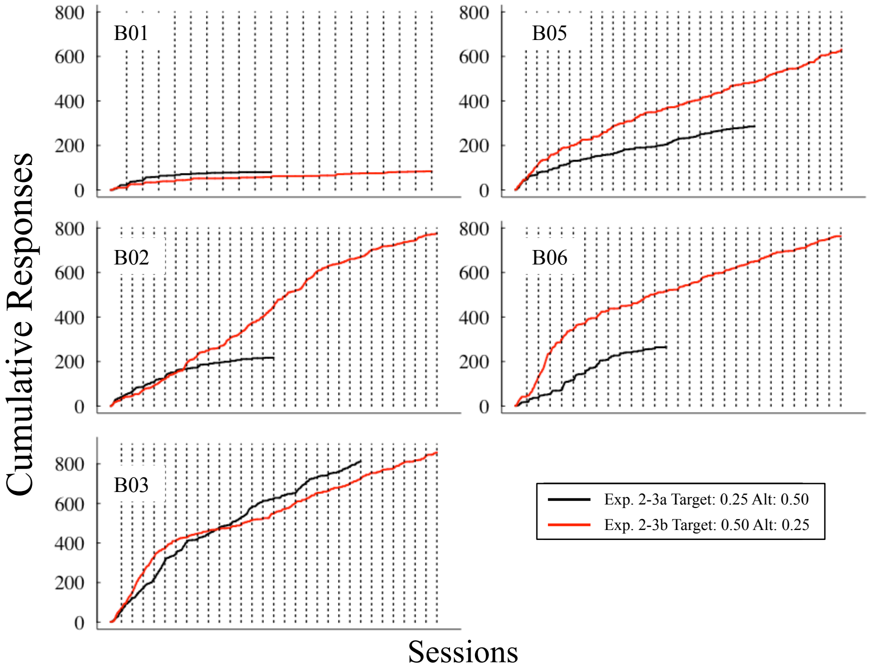

Figure 17. Cumulative numbers of target responses during Phase 3 of Experiments 2-2a and 2-3b. The dashed vertical lines separate each session of Phase 3.

It also is noteworthy that five rats except for Rat B01 showed long-lasting resurgence in Experiment 2-3b. One notable pattern, especially for Rat B01, was that the greatest level of resurgence was observed from the 7th to the 19th session with a cycle of increase and decrease. Other 3 rats also showed this increase/decrease cycle of resurgence, although the peak of resurgence was observed within the first few sessions of Phase 3. These patterns of resurgence have never been reported in the free-operant procedure and it is unclear whether or not these patterns were connected to the discrete-trial procedure.

In Phase 1, all rats again showed bias to one of the side levers in either or both conditions. In some cases, response ratio between levers tended to be equal as sessions progressed. In the others, consistent bias to one side lever did not cease even after 30 sessions. However, as with Experiments 2-1 and 2-2, there was no systematic relation between resurgence and response bias.

Comparison of the results from Experiments 2-3a and 2-3b generally support that the probability of reinforcement in Phase1 (but not in Phase 2) strongly affect the magnitude and the pattern of resurgence.

General Discussion

The general purpose of Experiment 2 was to examine whether resurgence would occur in the discrete-trial procedure and whether the variables that have already been shown to affect the magnitude of resurgence in the free-operant procedure also affect resurgence in the discrete-trial procedure. The results of Experiments 2-1 and 2-2 show that robust resurgence occurred in the discrete-trial procedure, and was repeatedly observed within individual subjects as shown in previous studies (e.g., Lieving & Lattal, 2003; Doughty et al., 2007). These results meet the prerequisite for conducting the parametric analysis of resurgence mentioned in the Introduction.

Also of importance is that the magnitude of resurgence is affected by the reinforcement frequency, as shown in the free-operant procedure (e.g., Podlesnik & Shahan, 2009, 2010). Figure 18 shows the total number of the target responses during Phase 3 across all Experiments. All rats showed greater magnitude of resurgence when the probabilities of reinforcement in Phases 1 and 2 were changed from .25 to .50 in Experiment 2-2. Experiment 2-3 further examined which phase of reinforcement probability strongly affected the magnitude of resurgence. The magnitude of resurgence in Experiment 2-3a was almost the same as Experiment 2-1, while resurgence in Experiment 2-3a was greater than that in Experiment 2-1. Thus, these results indicate that the probability of reinforcement in Phase 1, but not Phase 2, strongly affects the magnitude of resurgence. This is compatible with previous findings that the higher reinforcement rate for the target response generally produces the greater magnitude of resurgence (e.g., Craig & Shahan, 2016; Podlesnik & Shahan, 2009, 2010; see also Shahan & Sweeney, 2011). In addition, results from Experiment 2-3a are consistent with the results of Experiment 1 and the previous studies that failed to show the systematic relation between resurgence and the rate of alternative reinforcement (e,g, Cançado & Lattal, 2013; Cançado et al., 2015; Winterbauer & Bouton, 2010). It also is notable that 4 rats except for B01 showed more resurgence in Experiment 3b than in Experiment 2-2. It might be partly explained by the fact that the probability of reinforcement for the target response was higher in Experiment 2-3b than 2-2. Another possibility is that the higher probability of reinforcement for the alternative response inversely related to the magnitude of resurgence.

To summarize, the present results shows that the discrete-trial procedure used in this study may be suitable to conduct a parametric manipulation of variables affecting the magnitude of resurgence. In Experiments 4 and 5, the parametric analysis will be conducted by using this discrete-trial procedure to examine the relation between resurgence and, the probability and amount of reinforcement.

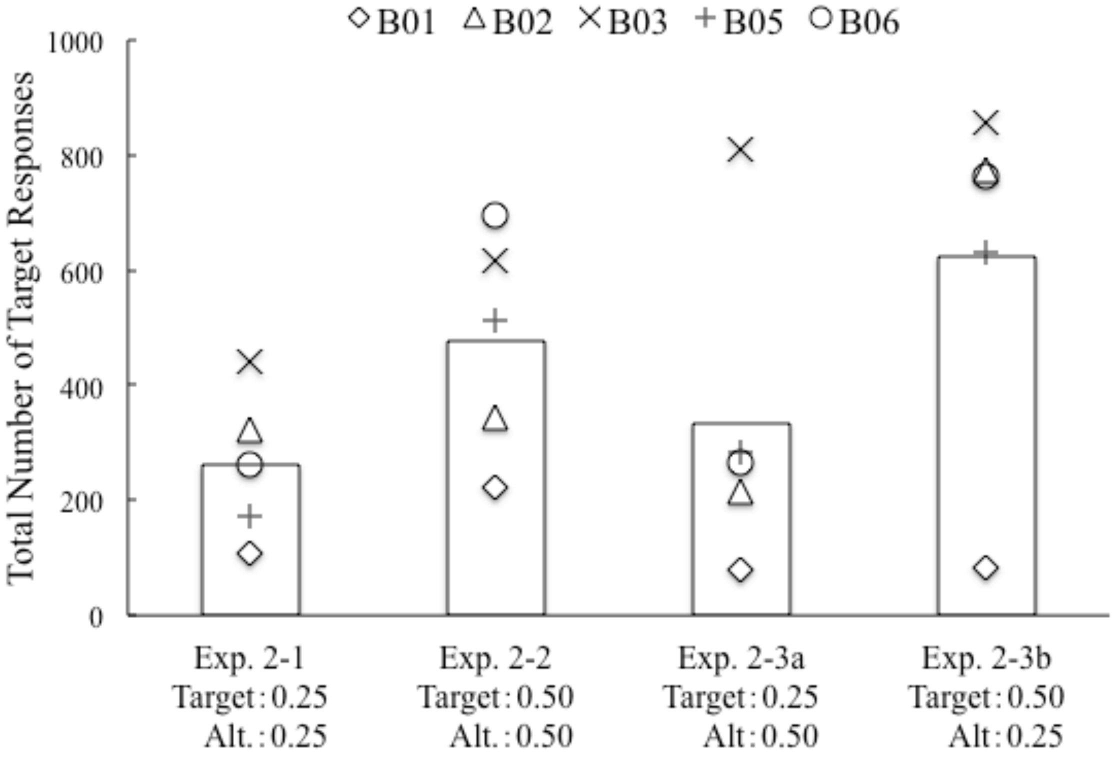

Figure 18. Total number of target responses during Phase 3 of each experiment.

Experiment 3
Resurgence in a Within-session Procedure

As shown in Experiment 1, given that resurgence is highly variable even within an individual subject, mean performance through repeated exposure to the three-phase procedure seems more reasonable way for studying resurgence. However, typical resurgence experiment takes at least 1 month to complete one condition, so that too much time is required if one tries to conduct the parametric analysis by this way (see Cançado et al., 2015). This consideration highlights the necessity for developing a method for repeatedly generating the resurgence effect in a shorter time. As noted in Section 1.5, one solution is to establish a procedure in which three phases of resurgence test is conducted within a single session. If resurgence could be obtained in a single session, it would be possible to conduct a repeated test of resurgence in the same and different conditions, and thus a parametric analysis. Recently, Bai, Cowie, and Podlesnik (in press) demonstrated that pigeons show resurgence in a shorter period of time by using free-operant psychophysical procedure (FOPP). Cook and Lattal (2014) also showed resurgence can be repeatedly obtained within a single session in pigeons. These studies introduce novel method for studying resurgence with shorter period compared to typical procedure (see also Sweeney & Shahan 2016, for human study). In Experiment 3, it was tested whether resurgence can be obtained with rats in the within-session procedure introduced by Cook and Lattal (2014).

Method

Subjects. Four experimentally naive male *Wistar* rats were maintained at 80% of their free-feeding weights throughout the experiment. They were approximately 4 month old at the start of the experiment and were housed individually with free access to water in a temperature-controlled room on a 12:12 light-dark cycle (lights on 8:00 pm).

Apparatus. Apparatus was the same as that used in Experiment 2 except that each of four chambers was equipped with a chain that hung from the ceiling. Each of the left or right levers served as the target or control levers, respectively. For Rat A20, the left and right levers served as the target and control levers, respectively. This assignment was reversed for Rat A21. For the other rats, assignment of the left or right lever to the target or control lever was randomly changed for each session. Chain-pulling response served as the alternative response for all rats.

Procedure. Daily 40 min experimental session divided into 3 phases and began after 30-s blackout. Durations of each phase were 15, 15, and 10 minutes. Both levers and a chain were presented throughout the session. In the first Phase, the target response was reinforced on a VI 30-s schedule. The target response was then placed on extinction and chain pulling was reinforced on a VI 30-s schedule in Phase 2. A 3-s changeover delay (COD) was in effect during Phases 1 and 2. In Phase 3, all responses were extinguished. Responses to the control lever were recorded but had no programmed consequences. Experimental sessions lasted for 30 days.

Results

Rates of the target and alternative responses for each 1-min bin were averaged for each 10-session block and are shown in Figure 19. As expected, all rats acquired and maintained the target response in Phase 1 while the alternative response (chain-pulling) did not increase. Although responses to the control lever also observed during the first few minutes, but gradually decreased as time elapsed. The target response then decreased to near zero toward the end of Phase 2 while the alternative response initially increased and became stable. When all reinforcers were withheld in Phase 3, the alternative response sharply decreased and subsequently the target response reappeared. Magnitude of resurgence was greater in the first 10-session block than the latter blocks for all rats. Although moderate level of resurgence was observed in the second block, resurgence did not occur for Rats B07 and B08 in the last block. These results show that the acquisition and extinction process of the target and alternative responses did not change across 30 sessions, while the magnitude of resurgence only was affected by the repeated testing.

To further examine the cause of weakened resurgence in the latter sessions, a temporal distribution of all responses is shown in Figure 20. Across all sessions, the alternative response was dominantly distributed during the first few minutes. Extinction of the alternative response was followed by the increase of target and control responses. Although this temporal relation was generally consistent across 30 sessions for all rats, the pattern of responding was greatly changed. Especially in the first 10 sessions, bout-and-pause like pattern of responding was observed in all rats. In contrast, the target response occurred only sporadically in the latter half of the session. This decrement of the length and density of response bout might contribute to the weak resurgence in the latter sessions.

Figure 21 shows cumulative numbers of the target and control responses across all sessions of Phase 3. As shown in Figures 19 and 20, increased responses on control lever were observed during Phase 3. There was large difference in the cumulative number of responses between the target and control responses for all rats. The difference, however, disappeared in the second and last blocks. It is important to note that the total number of control response across all sessions did not exceed that of target response for all rats. Also, there was no systematic difference in the magnitude of resurgence between conditions in which the location of the target lever was fixed or randomly changed for each session.

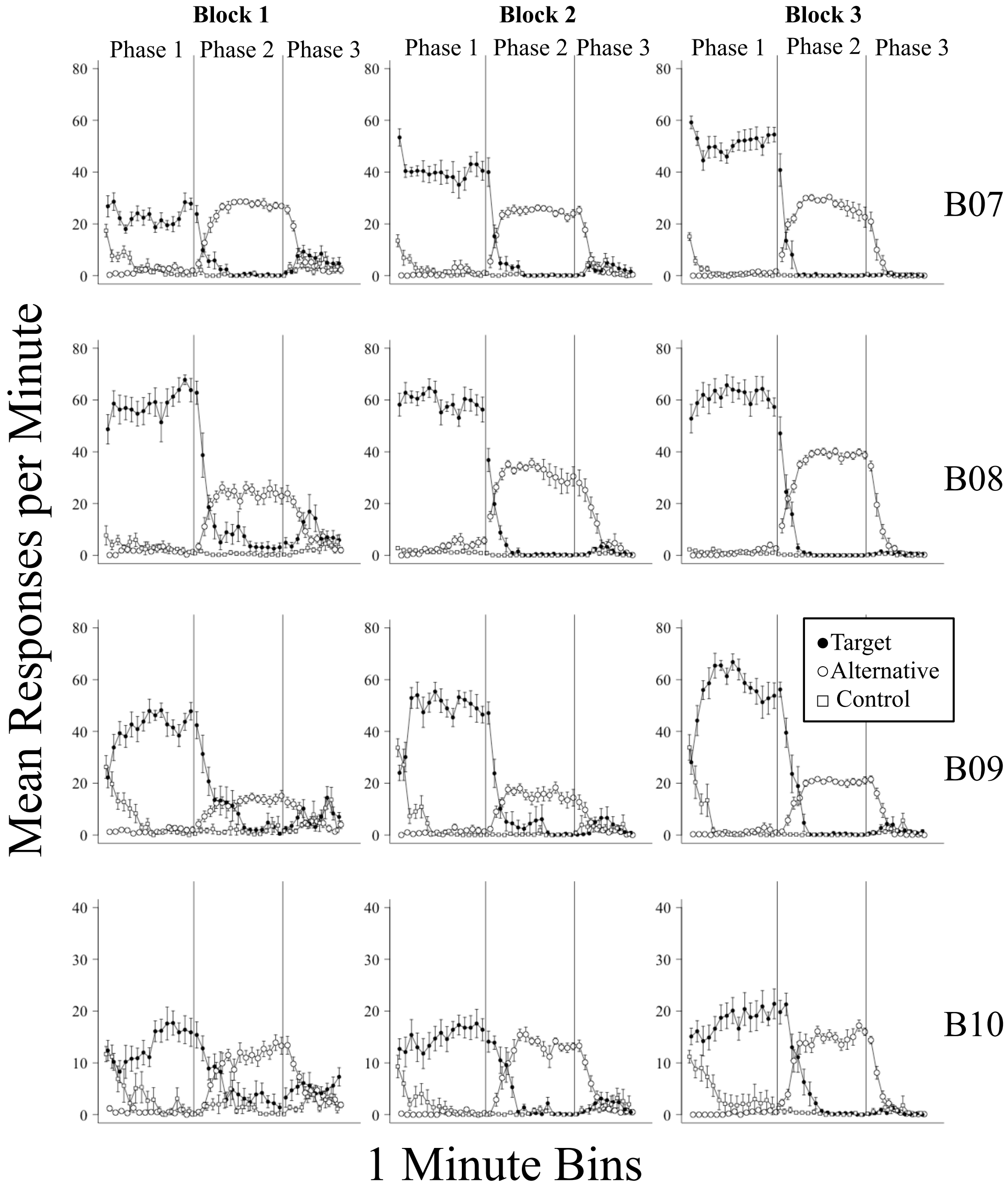

Figure 19. Mean rates of the target, alternative, and control response in 1-min bin for each of 10 sessions. Error bars represent standard errors.

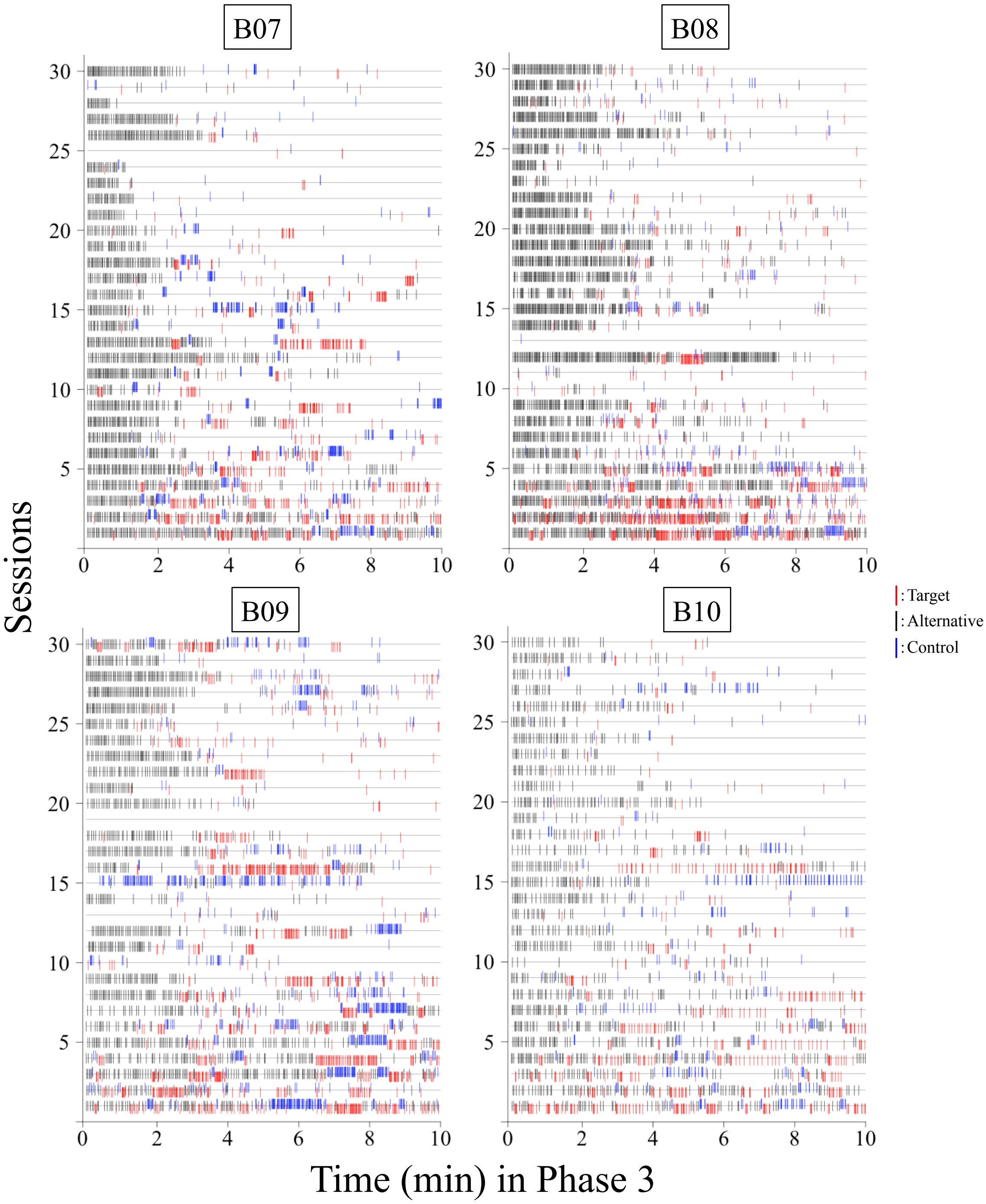

Figure 20. Raster plot of the target, alternative, and control responses across 30 sessions. Each plot represents a single response on each operandum.

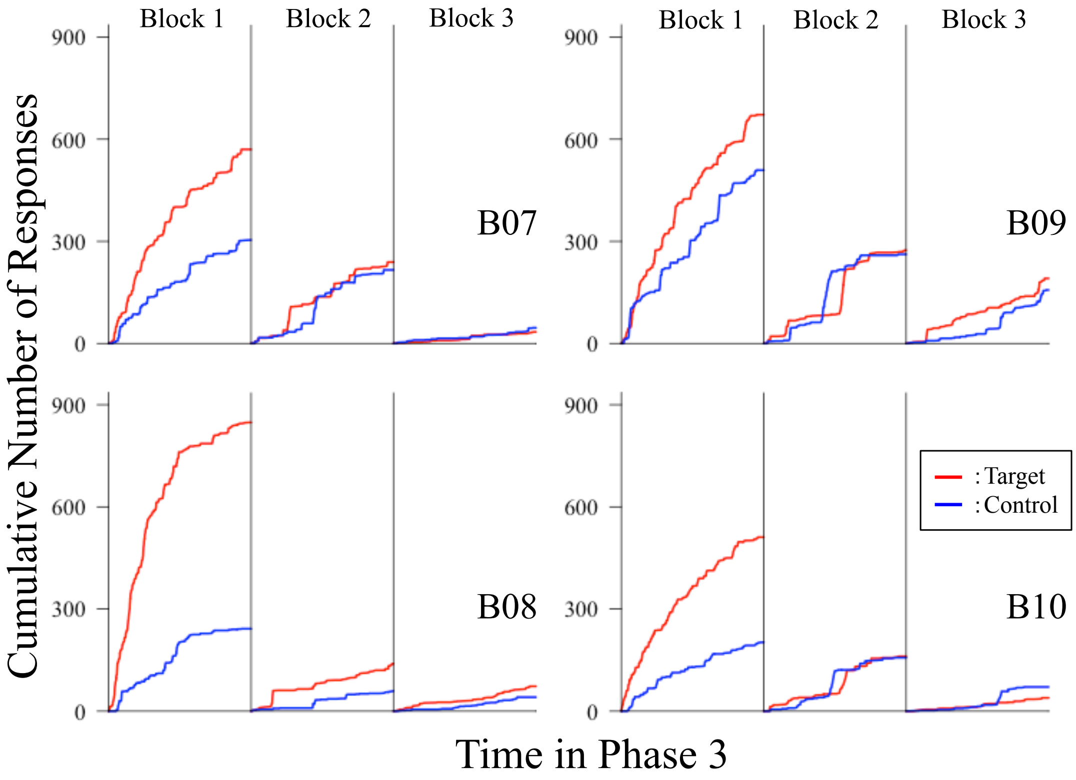

Figure 21. Cumulative number of responses on the target and control lever during Phase 3. The vertical lines separate each 10-session block.

Discussion

The results of Experiment 3 show that resurgence can be observed in the within-session-free-operant procedure introduced by Cook and Lattal (2013). It also clearly shows that the repeated exposures to resurgence testing greatly weaken the resurgence effect and extend previous studies which show resurgence can be repeatedly observed within individual subject even after several times of exposure to resurgence testing (e.g., Cançado et al., 2015; Lieving & Lattal, 2003; Doughty, da Silva, & Lattal, 2007).

As noted, increased responses on the control lever was also observed during Phase 3 for all rats. It seems reasonable if the increased responses on control lever were observed only for Rats B09 and B10. For these rats, the location of the target lever was randomly changed for each condition so that the responses on the control lever could be affected especially when the assignment of the target and control levers was reversed from the previous session. However, Rats B07 and B08 also showed remarkable increase of the control response and there was no quantitative difference from Rats A26 and A27, even though the location of the target and control levers was fixed for these rats. It therefore is impossible to interpret this result from the perspective of whether assignment of the left or right lever to the target and alternative response was fixed or randomly changed across sessions. Perhaps this result could be explained by the brief period of training in the present procedure. In many laboratory studies, resurgence is often tested after the long history of reinforcement for the target response is established, unlike the present procedure. Indeed, some studies suggested that longer training history produces the greater resurgence in both human (Bruzek et al., 2009; Doughty et al., 2010) and animals (Winterbauer et al., 2013). In addition, a recent study with human subject reported that the rates of the control response could exceed the target response if resurgence is tested in a procedure with a brief-training period (Sweeney & Shahan, 2016). This finding is consistent with the present results except that the increase of the target response in Phase 3 consistently exceeded that of the control response for all rats.

Use of within-session procedure makes it easier to conduct a parametric analysis of resurgence in that each experimental condition of resurgence can be tested in one day. On the other hand, it is a disadvantage that the repeated exposure to resurgence testing within individual-subject greatly weakens the resurgence effect. This problem might make it difficult to examine the effect of independent variable separately from the influence of the repeated exposure. One solution is to conduct the resurgence testing after some periods of training sessions where the Phases 1 and 2 only are conducted. When resurgence is repeatedly tested in the typical three-phase procedure, each testing should be distant at least several weeks (e.g., Lieving & Lattal, 2003). This temporal distance may prevent from attenuating the resurgence effect. In addition, it seems necessary to conduct some training sessions for more effectively reflecting the effects of rates and magnitude of reinforcement assigned for each condition to resurgence testing. For these reasons, in Experiments 6 and 7, the training session were conducted for 15 days for each experimental condition and then the resurgence testing successively conducted for the next 3 days. This cycle are repeated within an individual subject until all experimental conditions are tested.

2.3 Parametric Analysis of Resurgence: Effects of Probability, Rate, and Magnitude of Reinforcement

Experiment 4

Reinforcement Probability and Resurgence in the Discrete-trial Procedure

The purpose of Experiment 4 was to examine the relation between resurgence and the probability of reinforcement in the discrete-trial procedure. Typically, the resurgence effect has been tested after establishing the reinforcement history with the interval schedule (e.g., a VI schedule). Few studies have employed ratio schedules (e.g., a VR, RR, and FR schedules) for maintaining the target and alternative responses (e.g., Winterbauer & Bouton 2010, Experiment 4; Winterbauer et al., 2013). It is reasonable to assume that resurgence can be influenced by the type of reinforcement schedule, which is used for the training of the target and alternative responses. However, Winterbauer and Bouton (2010) reported that resurgence did not depend on the type of reinforcement schedule for the alternative response in Phase 2 if the total number of reinforers were equated across all conditions. Furthermore, behavioral momentum theory emphasizes the total reinforcers delivered in a stimulus context as well as the context-change hypothesis. Hence, both Shahan and Sweeney's BMT model and the context-change hypothesis should provide a consistent prediction regardless of which type of reinforcement schedule is used for the training phase. With respect to the relation between resurgence and the probability of reinforcement for the target response, the BMT model should predict the inverted U-shape function of resurgence as shown in Figure 6. Experiment 4-1 tested this prediction by parametrically manipulating the probability of reinforcement for the target response in Phase 1.

No studies have yet been reported the effects of probability of reinforcement on resurgence, though some studies investigated the relation between resurgence and the rates of alternative reinforcement (e.g., Bouton & Trask, 2016; Cançado & Lattal, 2013; Craig et al., 2016; Leitenberg et al., 1975). The context-change hypothesis should predict the sigmoid function of resurgence when the probability of reinforcement for the alternative response was manipulated parametrically. In contrast, the BMT model predicts linear function of resurgence as shown in Figure 6. Experiment 4-2 tested these predictions.

Experiment 4-1

Method

Subjects and Apparatus. Four experimentally naive male *Wistar* rats were maintained at 80% of their free-feeding weights throughout the experiment. They were approximately 4 months old at the start of the experiment. Two rats were housed together for each cage with free access to water in a temperature-controlled room on a 12:12 light-dark cycle (lights on 8:00 pm). Apparatus was the same as that used in the Experiment 2. Assignment of the left or right lever to the target lever or alternative lever was balanced across rats.

Procedure. After the hand shaping of the lever-pressing response, each rat was exposed to the four experimental conditions shown in Table 5, each of which consists of 3 phases. The order of each condition was counter balanced across rats. Throughout the experiment, sessions ended after 200 trials and occurred 7 days a week at approximately the same time each day. Each trial ended after a single response on either the target or alternative lever, or 10-sec after the trial onset if no response occurred within 10-sec. An adjusted ITI separated each trial in the same manner as Experiment 2.

In Phase 1, only a target lever extended into the chamber at the start of the trial and a single response on this lever produced a reinforcer according to the probability assigned for each condition. Phase 1 lasted for at least 15 sessions and until the target response occurred more than 95% of all trials at least 3 consecutive sessions. In Phase 2, the target response was placed on extinction while the response on the alternative lever was reinforced on the probability of .375 across all conditions. For the first 5 sessions of Phase 2, only the target lever was presented and extinguished in order to expose the target response of rats to extinction schedule. Most of resurgence studies simultaneously conducted the extinction of target response and acquisition of alternative response in the second phase. In the present study, the rats experienced 4 conditions and therefore it was expected that, especially in the latter conditions, the presentation of alternative lever in Phase 2 served as a discriminative stimulus signaling that reinforcement was available only for the alternative lever. In such a case, the target response would decrease to near-zero level soon after the phase changes and the extinction of the target response would be prevented. To avoid this potential problem, only the target lever was presented during the first 5 sessions of Phase 2 and the target response was extinguished. The alternative lever was presented from the 6th session and produced a reinforcer on assigned probability of reinforcement. Note that the target lever was presented throughout the all sessions of Phase 2. This phase lasted for at least 10 sessions excluding the first 5 sessions of extinction period. The resurgence test began when the number of the target responses was no more than 10 responses at least 3 consecutive sessions. In Phase 3, both levers were presented but reinforcement for the alternative lever was discontinued. Phase 3 lasted for 10 sessions.

Table 5. Design of Experiments 4-1 and 4-2.

Condition	Phase 1	Phase 2	Phase 3
Experiment 4-1			
RR1.6	TR: .125	TR: .000	TR: .000
	Alt: —	Alt: .375	Alt: .000
RR2	TR: .250	TR: .000	TR: .000
	Alt: —	Alt: .375	Alt: .000
RR4	TR: .500	TR: .000	TR: .000
	Alt: —	Alt: .375	Alt: .000
RR8	TR: .625	TR: .000	TR: .000
	Alt: —	Alt: .375	Alt: .000
Experiment 4-2			
RR1.6	TR: .375	TR: .000	TR: .000
	Alt: —	Alt: .125	Alt: .000
RR2	TR: .375	TR: .000	TR: .000
	Alt: —	Alt: .125	Alt: .000
RR4	TR: .375	TR: .000	TR: .000
	Alt: —	Alt: .125	Alt: .000
RR8	TR: .375	TR: .000	TR: .000
	Alt: —	Alt: .125	Alt: .000

Note. Reinforcer was a 45-mg pellet in all conditions. TR and Alt represent the target and alternative levers, respectively. Each figure represents the probability of reinforcement. The alternative lever was removed in Phase 1.

Results and Discussion

Figure 22 shows the numbers of target and alternative responses across 3 phases of each condition. Table 6 shows mean numbers of target and alternative responses and mean obtained reinforcers per session in the last three sessions of Phases 1 and 2. In general, all rats showed a similar pattern of responding across conditions. In Phase 1, all rats readily learned to press the target lever and the target response occurred in most of the trials across sessions. Note that Rat B04 pressed the alternative lever in the RR 4 condition, even though the lever was not presented in Phase 1. As noted later, visual observation of Rat B14 in Experiment 5-2 revealed that the rat reached for the retracted lever and pressed it. Therefore it can be inferred that Rat B04 behaved in the same way. During the first 5 sessions of Phase 2, the target response sharply decreased in all conditions and the alternative response increased when the alternative lever was presented in the 6th session. When all reinfocers were removed in Phase 3, the alternative response decreased and the substantial resurgence occurred in all rats over the conditions. However, the patterns of resurgence differed across rats. For Rat B01, the number of target response increased during the first few sessions, and after which it gradually decreased. Rats B02 and B03 showed the almost constant numbers of the target response over 10 sessions. In contrast to these rats, Rat B04 showed the different patterns of resurgence across conditions. In the RR 8 and RR 4 conditions, the target response decreased over sessions as with Rat B01. On the other hand, the similar level of resurgence was observed across sessions in the RR 1.6 condition, as shown in Rats B02 and B04. In the RR 2 conditions, the target response dramatically increased from

4th to 6th sessions and it decreased in the 7th session and became stable over the remaining sessions. Although the reason for this dramatic increase in the target response in the middle of Phase 3 was unclear, this pattern of resurgence was sometimes observed in the previous studies (e.g., Doughty et al., 2007, Podlesnik & Shahan, 2010).

Figure 23 shows the total number of target responses in all sessions of Phase 3 for each condition. In all rats except B02, the magnitude of resurgence increased from the RR 8 to RR 2 conditions, but it decreased in the RR 1.6 condition. However, it is noteworthy that there were little differences in the magnitude of resurgence for Rat B03. Only Rat B02 showed different pattern from the other rats. For this rat, the greatest level of resurgence was observed in the RR 8 condition, though the linear increase of resurgence was shown across conditions except the RR 8 condition. Thus, the results from three of four rats support the prediction by the BMT model.

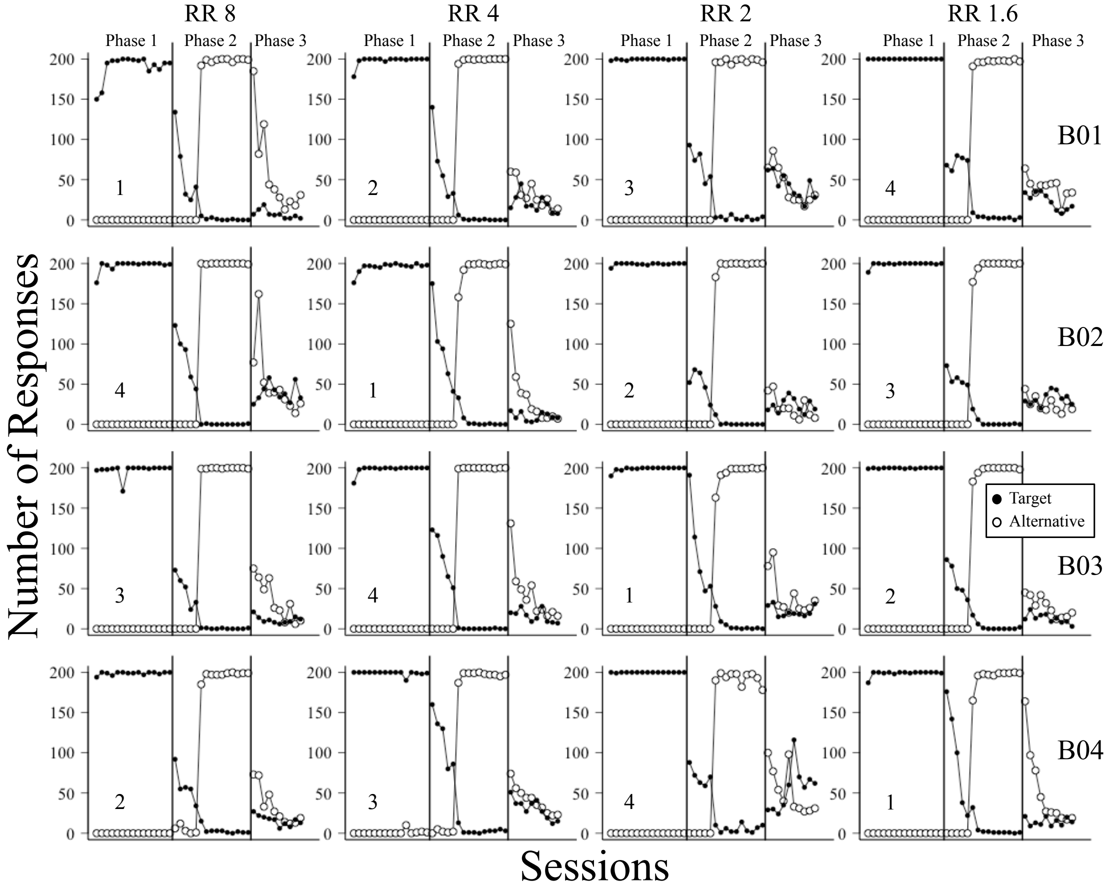

Figure 22. The numbers of the target and alternative responses in all sessions for each condition. The dashed vertical lines separate successive phases. The numbers in each panel refer to the order of conditions to which the rat was exposed.

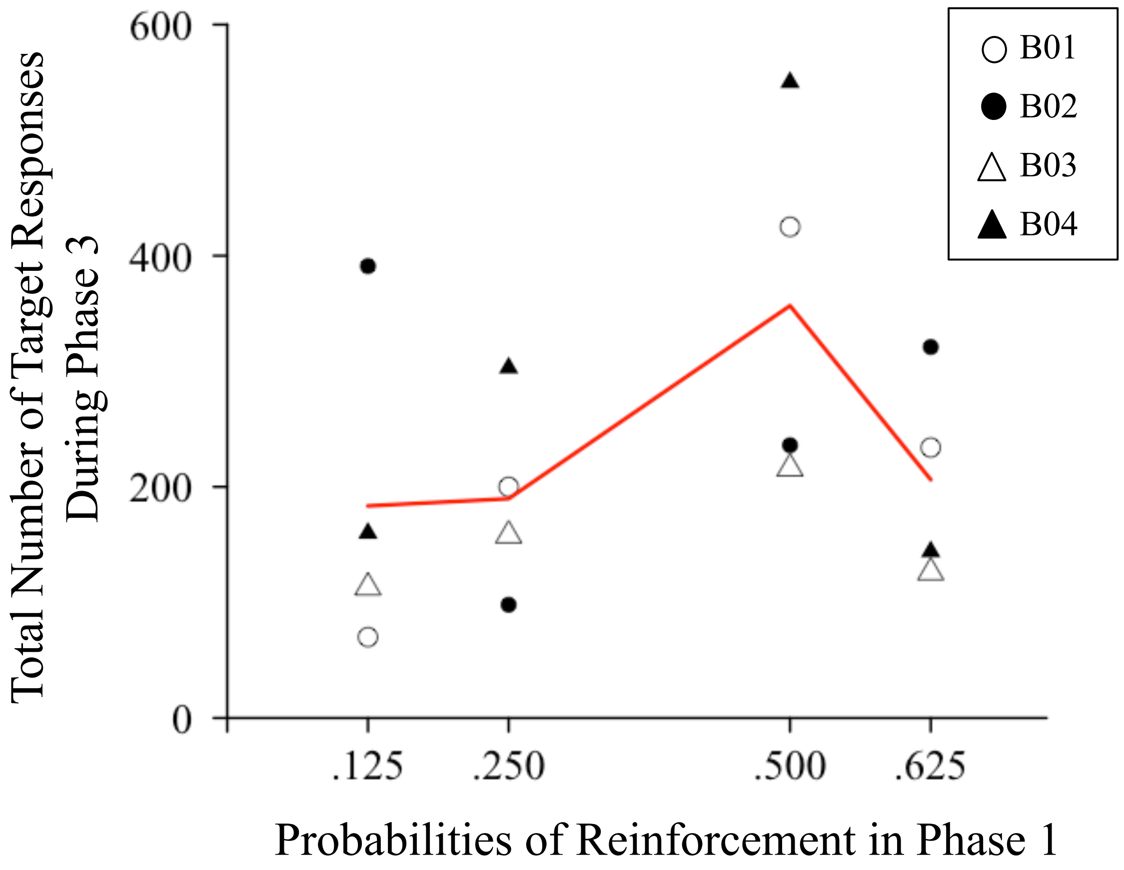

Figure 23. Total number of target responses during Phase 3 for each condition. The red line shows mean total number of the target responses across all rats in each condition.

Table 6. Mean numbers of responses and reinforcers per session across the last 3 sessions of Phases 1 and 2. Standard deviations are shown in parenthesis

		Condition							
Rat	Response	RR 1.6		RR 2		RR 4		RR 8	
Responses per Session									
B01	Target	200.00	(0.00)	200.00	(0.00)	200.00	(0.00)	192.33	(4.62)
	Alt.	198.00	(1.73)	198.33	(2.08)	200.00	(0.00)	199.67	(0.58)
B02	Target	199.67	(0.58)	200.00	(0.00)	198.33	(1.53)	199.00	(1.00)
	Alt.	199.67	(0.58)	200.00	(0.00)	199.33	(0.58)	199.67	(0.58)
B03	Target	200.00	(0.00)	200.00	(0.00)	200.00	(0.00)	200.00	(0.00)
	Alt.	199.33	(1.15)	199.67	(0.58)	199.67	(0.58)	199.67	(0.58)
B04	Target	199.67	(0.58)	200.00	(0.00)	198.67	(0.58)	199.33	(1.15)
	Alt.	199.33	(0.58)	189.67	(10.41)	196.33	(1.15)	198.67	(0.58)
Reinforcers per Session									
B01	Target	125.00	(0.00)	100.00	(0.00)	50.00	(0.00)	24.33	(0.58)
	Alt.	74.67	(0.58)	74.33	(1.15)	75.00	(0.00)	74.67	(0.58)
B02	Target	124.67	(0.58)	100.00	(0.00)	49.33	(0.58)	25.00	(0.00)
	Alt.	75.00	(0.00)	75.00	(0.00)	74.67	(0.58)	74.67	(0.58)
B03	Target	125.00	(0.00)	100.00	(0.00)	50.00	(0.00)	25.00	(0.00)
	Alt.	75.00	(0.00)	74.67	(0.58)	75.00	(0.00)	74.67	(0.58)
B04	Target	124.67	(0.58)	100.00	(0.00)	50.00	(0.00)	25.00	(0.00)
	Alt.	75.00	(0.00)	72.67	(3.21)	74.33	(0.58)	74.33	(0.58)

Note. The probability of reinforcement for the target response in Phase 1 was varied across conditions while that for the alternative response in Phase 2 was .375 across conditions.

Experiment 4-2

Method

Subjects and Apparatus. Four experimentally naive male *Wistar* rats were maintained at 80% of their free-feeding weights throughout the experiment. They were approximately 4 months old at the start of the experiment. Two rats were housed together for each cage with free access to water in a temperature-controlled room on a 12:12 light-dark cycle (lights on 8:00 pm). Apparatus was the same as that used in the Experiment 4-1. Assignment of the left or right lever to the target lever or alternative lever was balanced across rats.

Procedure. Details of the procedure were as described for Experiment 4-1 except that the probability of reinforcement in Phases 2 was varied over the four conditions. The probability of reinforcement for the target response in Phase 1 was .375 across conditions.

Results and Discussion

Figure 24 shows the numbers of target and alternative responses across 3 phases of each condition. Table 7 shows mean numbers of target and alternative responses and mean obtained reinforcers per session in the last three sessions of Phases 1 and 2. Figure 24 indicates that the patterns of change in the target and alternative responses were similar to those found in Experiment 4-1. Across all sessions of Phase 1, all rats pressed the target lever in almost all trials. Extinction of the target response in Phase 2 resulted in the increase of the alternative lever in all rats. In most cases, stability criterion was met within the minimum number of sessions (i.e., 15 sessions), only Rat B08 required

18 sessions in the RR 8 condition where the probability of reinforcement for the alternative response was the lowest of all conditions. In Phase 3, all rats showed resurgence of the target response. As shown in Experiment 4-1, the magnitude of resurgence was almost constant across sessions in some cases, while in other cases resurgence weakened monotonically over 10 sessions. Again, the greater increase of the target response around the middle of Phase 3 was found in Rats B05 and B06

Figure 25 shows the total number of target responses in all sessions of Phase 3 for each condition. Although the patterns of resurgence over the test sessions were similar to those in Experiment 4-1, the total number of target response in Phase 3 differed from Experiment 4-1. Rats B07 and B08 showed relatively weak resurgence in the RR 8 and RR 4 conditions, while they showed greater magnitude of resurgence in the other two conditions. Importantly, there was no quantitative difference in resurgence between the lower conditions (i.e., RR 4 and RR 8) and between higher conditions (i.e., RR 2 and RR 1.6). These results were consistent with Bouton and Trask (2016, see also Craig et al., 2016; Leitenberg et al., 1975; Winterbauer & Bouton, 2010), and support for the context-change hypothesis, but not for the BMT model. However, the magnitude of resurgence increased linearly for Rat B05, and there was no systematic relation between probability of reinforcement and resurgence for Rat B06. Thus, only the results from two of four rats provided evidence supporting the context-change hypothesis. It should be noted that the total number of target responses was less than 250 responses in the RR 4 and RR 8 conditions in all rats except Rat B06. By contrast, the total number of target response in conditions RR 1.6 and RR 2 was more than 250 responses in all rats. This finding clearly indicates that greater magnitude of resurgence was more likely to appear under the conditions with higher probability of alternative reinforcement.

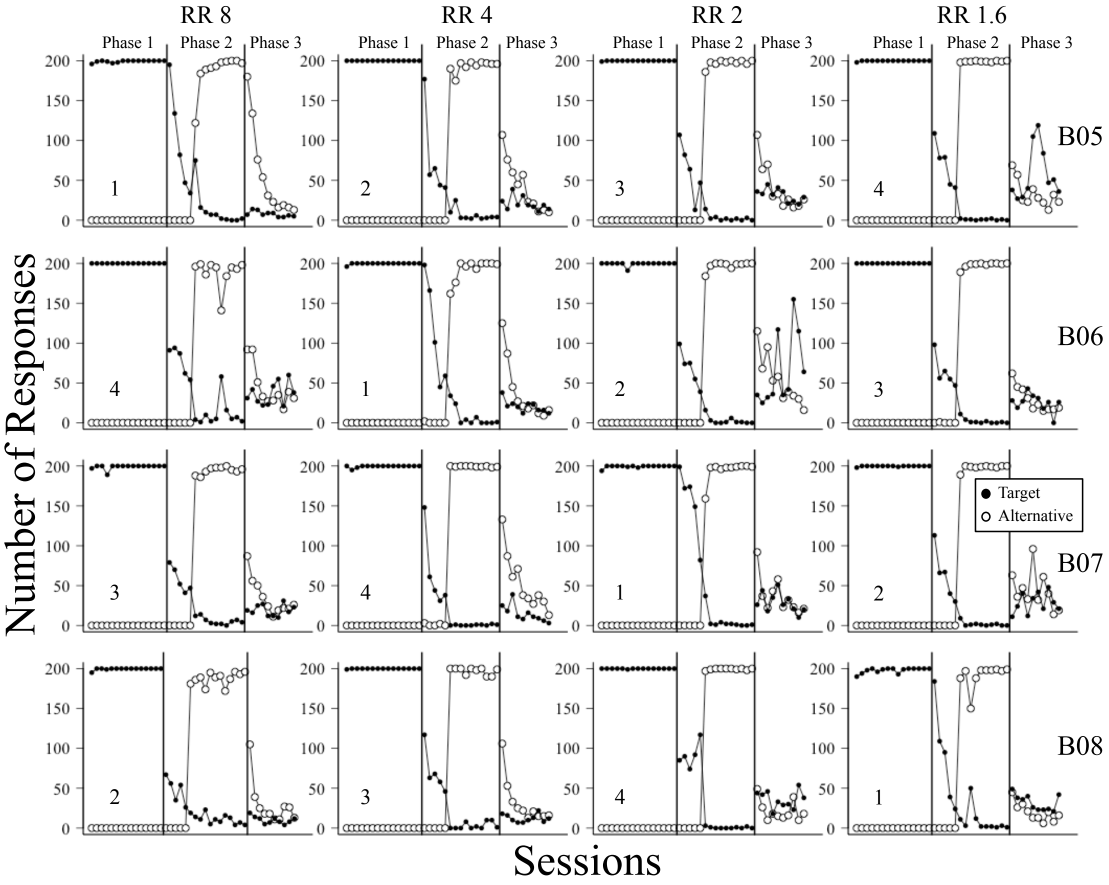

Figure 24. The numbers of the target and alternative responses in all sessions for each condition. The dashed vertical lines separate successive phases. The numbers in each panel refer to the order of conditions to which the rat was exposed.

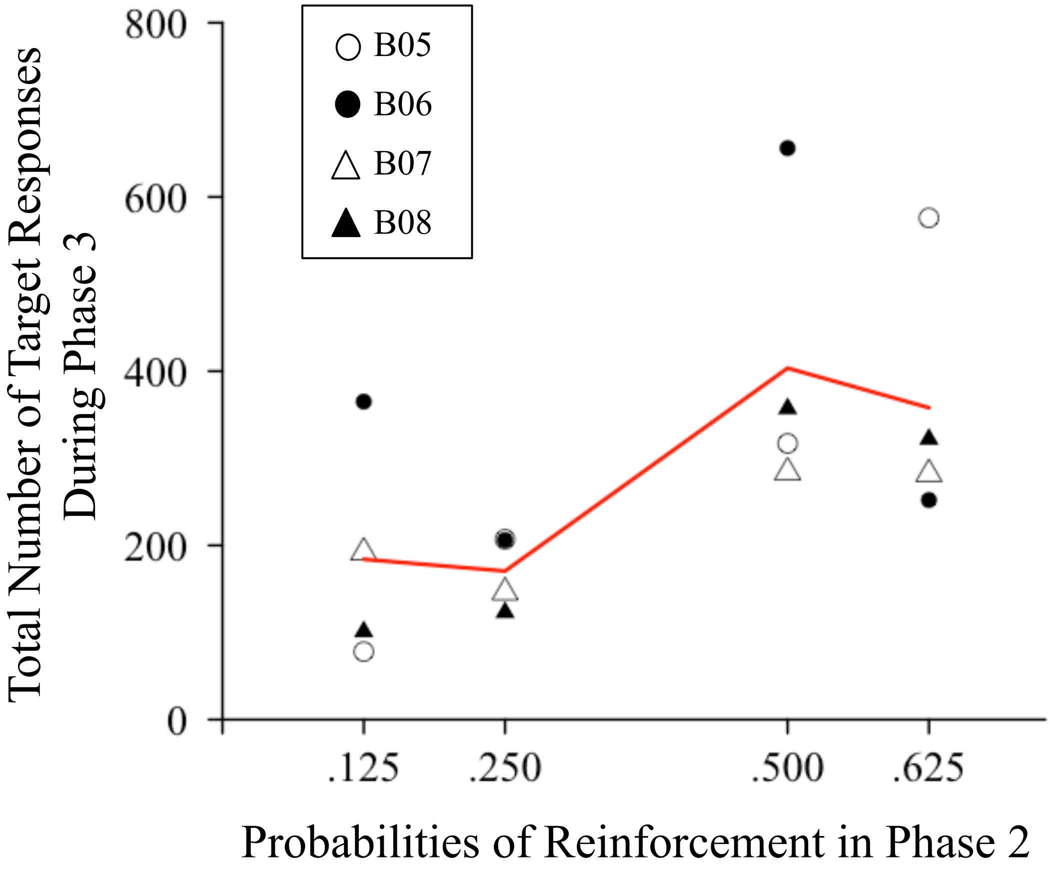

Figure 25. Total number of target responses during Phase 3 for each condition. The red line shows mean total number of the target responses across all rats in each condition.

Table 7. Mean numbers of responses and reinforcers per session across the last 3 sessions of Phases 1 and 2. Standard deviations are shown in parenthesis.

		Condition							
Rat	Response	RR 1.6		RR 2		RR 4		RR 8	
Responses per Session									
B05	Target	200.00	(0.00)	200.00	(0.00)	200.00	(0.00)	200.00	(0.00)
	Alt.	199.67	(0.58)	198.67	(2.31)	196.33	(0.58)	199.00	(1.73)
B06	Target	200.00	(0.00)	200.00	(0.00)	200.00	(0.00)	200.00	(0.00)
	Alt.	199.67	(0.58)	199.67	(0.58)	199.67	(0.58)	195.33	(2.52)
B07	Target	200.00	(0.00)	200.00	(0.00)	200.00	(0.00)	200.00	(0.00)
	Alt.	199.33	(1.15)	199.67	(0.58)	199.00	(1.00)	194.67	(1.53)
B08	Target	200.00	(0.00)	200.00	(0.00)	200.00	(0.00)	200.00	(0.00)
	Alt.	198.33	(1.15)	199.33	(1.15)	193.00	(5.20)	195.00	(1.73)
Reinforcers per Session									
B05	Target	75.00	(0.00)	75.00	(0.00)	75.00	(0.00)	75.00	(0.00)
	Alt.	125.00	(0.00)	99.00	(1.73)	49.33	(1.15)	25.00	(0.00)
B06	Target	75.00	(0.00)	75.00	(0.00)	75.00	(0.00)	75.00	(0.00)
	Alt.	124.67	(0.58)	100.00	(0.00)	50.00	(0.00)	24.67	(0.58)
B07	Target	75.00	(0.00)	75.00	(0.00)	75.00	(0.00)	75.00	(0.00)
	Alt.	124.67	(0.58)	100.00	(0.00)	50.00	(0.00)	25.00	(0.00)
B08	Target	75.00	(0.00)	75.00	(0.00)	75.00	(0.00)	75.00	(0.00)
	Alt.	124.33	(0.58)	99.67	(0.58)	48.33	(1.53)	25.00	(0.00)

Note. The probability of reinforcement for the target response in Phase 2 was varied across conditions while that for the alternative response in Phase 1 was .375 across conditions.

General Discussion

Experiment 4 examined the relation between resurgence and the probability of reinforcement. In Experiment 4-1, the probability of reinforcement for the target response was parametrically manipulated, while that for the alternative response was fixed at .375. Three of four rats showed the inverted-U curve of resurgence and therefore supported the prediction of the BMT model. Importantly, this is the first study demonstrating that the magnitude of resurgence was weakened when the target responses was maintained in Phase 1 under the extremely high probability of reinforcement.

In Experiment 4-2, two of four rats showed the sigmoid-like curve of resurgence when the probability of reinforcement for the alternative response was manipulated parametrically. This finding is consistent with the results by Bouton and Schepers (2016). In addition, the magnitude of resurgence was not weakened in three of four rats in condition with the highest probability of reinforcement, unlike Experiment 4-1. These results indicate that reinforcement for the alternative response has different effects from that for the target response, and seem to support the context-change hypothesis. However, the two of four rats did not show sigmoid-like function of resurgence. Furthermore it should be emphasized that in the present study, substantial resurgence was observed in all conditions. The context-change hypothesis should predict that little to no resurgence is observed in the condition with lower probability of reinforcement, because it should produce very little change in context. A plausible objection is that the lower probability conditions (i.e., the RR 4 and RR 8 conditions) in the present study was sufficient to produce the change in context so that resurgence was observed also in these conditions, though it is a circular argument. In addition, the resurgent response was not eliminated even after 10 sessions for all rats in the present study, as with the results of Experiment 2. Typically, the resurgent response in Phase 3 gradually decreased to near zero over the test sessions (e.g., Lieving & Lattal, 2003; da Silva et al., 2008). Therefore, it was possible that resurgence is more likely to occur in the discrete-trial procedure and thus, substantial resurgence can be observed even in the conditions with sufficiently lower probability of reinforcement. In conclusion, it is unclear whether the results of Experiment 4-2 can be evidence supporting the context-change hypothesis. One thing that is clear is that the more resurgence was more likely to occur when the alternative response was maintained in Phase 2 with the higher probability of reinforcement.

Experiment 5

Reinforcement Magnitude and Resurgence in the Discrete-trial Procedure

The results of Experiment 4 indicated that the parametric manipulation of the probability of reinforcement for the target and alternative responses produced differential pattern of resurgence. The purpose of Experiment 5 was to examine the relation between resurgence and the reinforcer magnitude in the discrete-trial procedure. Many studies with the free-operant procedure have shown that reinforcement rates affect the magnitude of resurgence, as noted in the Introduction. In contrast, little is known about effects of reinforcer magnitude on resurgence (see e.g., Podlesnik & Shahan, 2010). From the perspective of behavioral momentum theory, all reinforcers obtained in that context contribute to the response strength so that manipulation of reinforcer magnitude also contributes to the magnitude of resurgence. Although it is unclear if Bouton and his colleagues consider that the number of reinforcers per session, not only the frequency of reinforcement, produces a contextual change, it is operationally defined in the present study that the context change is produced by manipulating the total number of reinforcers delivered in each session. On this assumption, the context-change hypothesis also predicts that the magnitude of resurgence is affected when the reinforcer magnitude for the alternative response is varied across conditions.

Experiment 5-1

Method

Subjects and Apparatus. Four experimentally naive male *Wistar* rats were maintained at 80% of their free-feeding weights throughout the experiment. They were approximately 4 months old at the start of the experiment. Two rats were housed together for each cage with free access to water in a temperature-controlled room on a 12:12 light-dark cycle (lights on 8:00 pm). Apparatus was the same as that used in the Experiment 4. Assignment of the left or right lever to the target lever or alternative lever was balanced across rats.

Procedure. Details of the procedure were as described for Experiments 4-1 and 4-2, except for the following changes. First, probabilities of reinforcement in Phases 1 and 2 were fixed at .125 in all conditions. Second, the reinforcer magnitude for the target response in Phase 1 was varied for each condition, while the alternative response was reinforced with 3 pellets in all conditions. Details of the reinforcer magnitude for each condition are shown in Table 8.

Table 8. Design of Experiments 5-1 and 5-2.

Condition	Phase 1	Phase 2	Phase 3
Experiment 5-1			
1-pellet	TR: .125 (1 pellet)	TR: .000	TR: .000
	Alt: —	Alt: .125 (3 pellet)	Alt: .000
2-pellet	TR: .125 (2 pellet)	TR: .000	TR: .000
	Alt: —	Alt: .125 (3 pellet)	Alt: .000
4-pellet	TR: .125 (4 pellet)	TR: .000	TR: .000
	Alt: —	Alt: .125 (3 pellet)	Alt: .000
5-pellet	TR: .125 (5 pellet)	TR: .000	TR: .000
	Alt: —	Alt: .375	Alt: .000
Experiment 5-2			
1-pellet	TR: .125 (3 pellet)	TR: .000	TR: .000
	Alt: —	Alt: .125 (1 pellet)	Alt: .000
2-pellet	TR: .125 (3 pellet)	TR: .000	TR: .000
	Alt: —	Alt: .125 (2 pellet)	Alt: .000
4-pellet	TR: .125 (3 pellet)	TR: .000	TR: .000
	Alt: —	Alt: .125 (4 pellet)	Alt: .000
5-pellet	TR: .125 (3 pellet)	TR: .000	TR: .000
	Alt: —	Alt: .125 (5 pellet)	Alt: .000

Note. Reinforcer was a 45-mg pellet in all conditions. TR and Alt represent the target and alternative levers, respectively. Each figure represents the probability of reinforcement. The number of pellets for each reinforcement is shown in parenthesis. Note that the alternative lever was removed in Phase 1.

Results and Discussion

Figure 26 shows the numbers of target and alternative responses across 3 phases of each condition. Table 9 shows mean numbers of target and alternative responses and mean obtained reinforcers per session in the last three sessions of Phases 1 and 2.

All rats acquired the target and alternative responses in Phases 1 and 2, respectively. In some conditions, all rats except B10 required more than 15 sessions in Phase 2 to meet the stability criterion, probably due to the lower probability of reinforcement. Mean obtained reinforcers during the last 3 sessions in both Phases were approximated to the programmed number of reinforcers. During the first 5 sessions of Phase 2, there were no consistent differences in resistance to change of the target response. In Phase 3, all rats showed resurgence across conditions. The patterns of resurgence were similar to those in Experiment 4: in many cases, the increased target response gradually decreased towards the end of Phase 3. In the other cases, consistent magnitude of resurgence was observed across sessions of Phase 3.

Figure 27 shows the total number of target responses in all sessions of Phase 3 for each condition. Rats B09 and B12 showed the inverted U-shape curve of resurgence as with Experiment 4-1. Although Rat B10 showed more resurgence under the conditions with higher reinforcer magnitude, the function of resurgence was similar to the sigmoid shape rather than inverted U-shape. Rat B11 did not show consistent difference in resurgence across conditions.

Although the result of Experiment 5-1 was not consistent across rats, magnitude of resurgence increased from the 1-pellet to 4-pellet conditions. This result is consistent with Podlesnik and Shahan (2010). Furthermore, relatively weaker resurgence was observed in the 8-pellet condition for these rats. This finding is consistent with the results of Experiment 4-1. In conclusion, the results of Experiment 5-1 did not provide strong evidence supporting the prediction of BMT model, but demonstrated that the reinforcer magnitude affects the magnitude of resurgence.

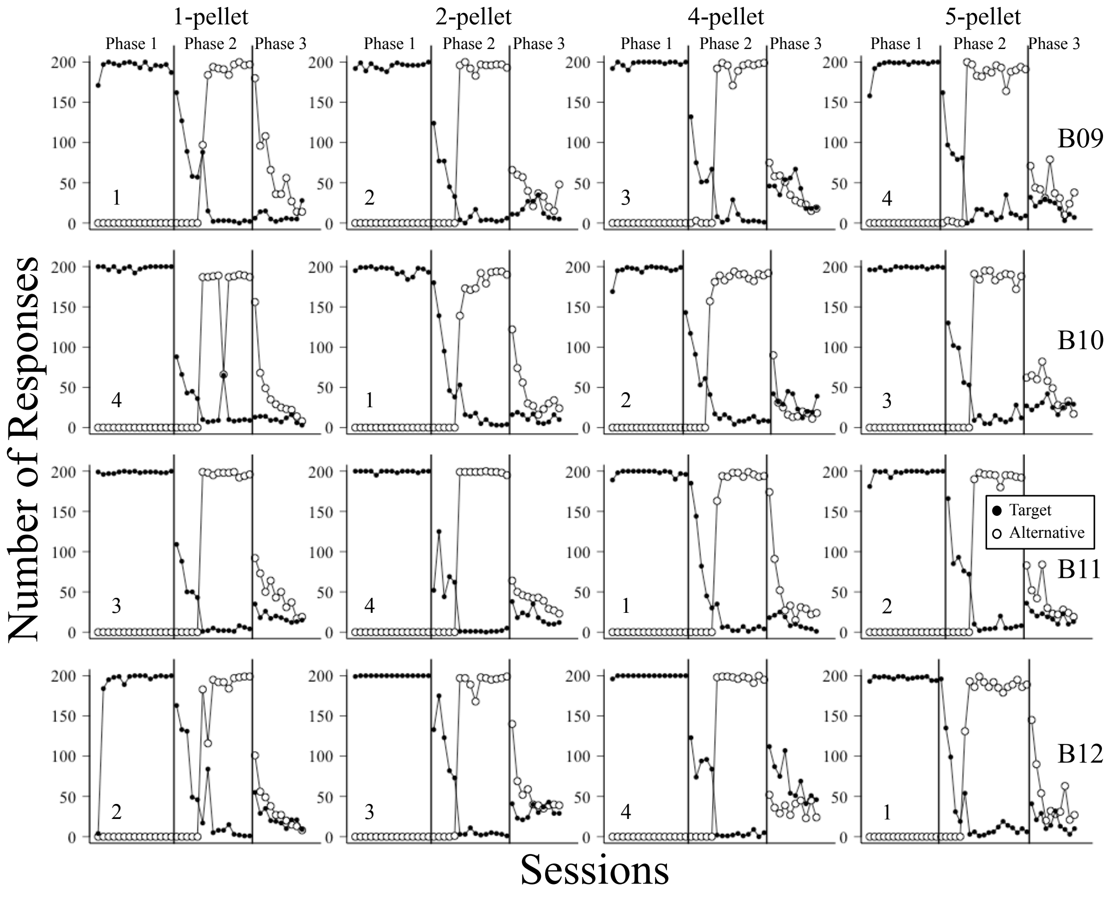

Figure 26. The numbers of target and alternative responses in all sessions for each condition. The dashed vertical lines separate successive phases. The numbers in each panel refer to the order of conditions to which the rat was exposed.

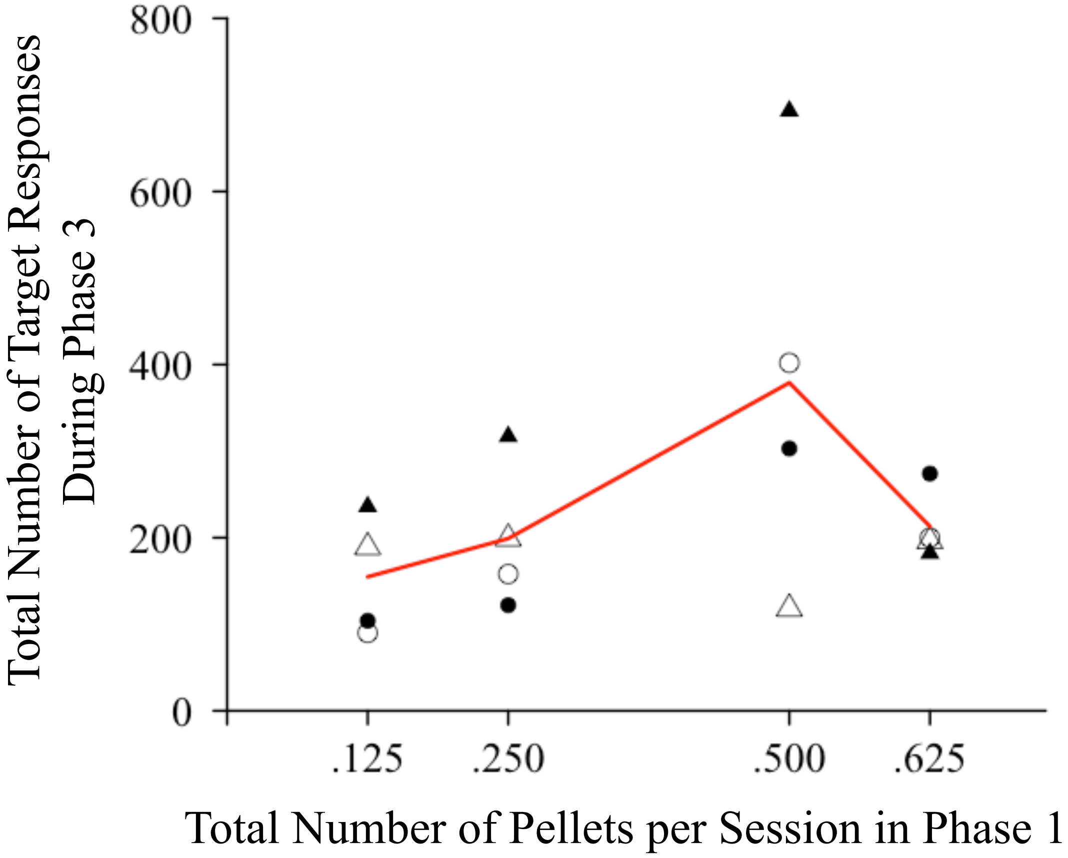

Figure 27. Total number of target responses during Phase 3 for each condition. The red line shows mean total number of the target responses across all rats in each condition.

Table 9. Mean numbers of responses and reinforcers per session over the last 3 sessions of Phases 1 and 2. Standard deviations are shown in parenthesis.

		Condition							
Rat	Response	5-Pellet		4-Pellet		2-Pellet		1-Pellet	
Responses per Session									
B09	Target	199.33	(1.15)	199.00	(1.73)	197.67	(2.08)	193.00	(5.29)
	Alt.	191.67	(2.08)	197.67	(1.53)	195.67	(2.31)	197.67	(2.08)
B10	Target	199.33	(0.58)	196.67	(2.08)	196.00	(2.65)	200.00	(0.00)
	Alt.	183.33	(9.87)	190.67	(1.53)	192.67	(2.31)	188.67	(1.53)
B11	Target	200.00	(0.00)	194.33	(3.79)	199.33	(1.15)	198.67	(1.15)
	Alt.	193.33	(1.53)	194.33	(1.53)	197.33	(2.08)	194.00	(2.00)
B12	Target	195.67	(2.89)	200.00	(0.00)	200.00	(0.00)	199.67	(0.58)
	Alt.	190.00	(4.58)	195.33	(4.51)	197.33	(1.53)	198.67	(0.58)
Reinforcers per Session									
B09	Target	125.00	(0.00)	98.67	(2.31)	50.00	(0.00)	23.67	(0.58)
	Alt.	73.00	(1.73)	75.00	(0.00)	75.00	(0.00)	75.00	(0.00)
B10	Target	125.00	(0.00)	98.67	(2.31)	48.67	(1.15)	25.00	(0.00)
	Alt.	71.00	(4.58)	74.00	(1.73)	73.00	(1.73)	73.00	(1.73)
B11	Target	125.00	(0.00)	97.33	(2.31)	50.00	(0.00)	25.00	(0.00)
	Alt.	75.00	(0.00)	74.00	(1.73)	75.00	(0.00)	73.00	(3.46)
B12	Target	123.33	(2.89)	100.00	(0.00)	50.00	(0.00)	25.00	(0.00)
	Alt.	73.00	(3.46)	73.00	(3.46)	75.00	(0.00)	75.00	(0.00)

Note. The probabilities of reinforcement in Phases 1 and 2 were fixed at .125 across conditions. The number of pellets in Phase 1 differed for each condition, while 3 pellets were delivered in Phase 2 across conditions. See text further details.

Experiment 5-2

Method

Subjects and Apparatus. Four experimentally naive male *Wistar* rats were maintained at 80% of their free-feeding weights throughout the experiment. They were approximately 4 months old at the start of the experiment. Two rats were housed together for each cage with free access to water in a temperature-controlled room on a 12:12 light-dark cycle (lights on 8:00 pm). Apparatus was the same as that used in the Experiment 4. Assignment of the left or right lever to the target lever or alternative lever was balanced across rats.

Procedure. Details of the procedure were as described for Experiment 5-1, except that the reinforcer magnitude for the alternative response was manipulated (see Table 8). The reinforcer magnitude for the target response in Phase 1 was fixed at 3 across all conditions.

Results and Discussion

Figure 28 shows the numbers of target and alternative responses across 3 phases of each condition. In Phases 1 and 2, all rats readily acquired the target and alternative responses, as with Experiment 5-1. Table 10 shows mean numbers of target and alternative responses and mean obtained reinforcers per session in the last three sessions of Phases 1 and 2. Mean obtained number of pellets in Phases 1 and 2 did not differ from the programmed number of pellets. It should be noted that Rats B14 and Rat B16 pressed the alternative lever in Phase 1, even though the lever was not presented across all sessions of Phase 1. The experimenter found that Rat B14 pressed the alternative lever in the 1st session of 5-pellet condition. Therefore, the experimenter observed the behavior of Rat B14 during the 2nd session of this condition and found that this rat reached for the retracted lever and pressed it. Since the alternative lever did not produce a reinforcer in Phase 1, this atypical behavior occurred only once in each session.

In Phase 3, all rats showed resurgence in all conditions, but there were no consistent tendencies between rats. Figure 29 shows the total number of target responses in all sessions of Phase 3 for each condition. For Rat B13, greater magnitude of resurgence was found in the 4- and 5-pellet conditions. However, the magnitude of resurgence was greater in the 4-pellet condition than the 5-pellet one. Rat B14 showed the greatest resurgence in the 5-pellet condition, but the magnitude of resurgence in the 4-pellet condition was weaker than the two fewer pellets conditions. For Rat B15, more resurgence was observed in the 2- and 5-pellet conditions. For Rat B16, resurgence was weakened as a function of the number of pellets, indicating the negative relation between resurgence and the reinforcer magnitude.

The results of Experiment 5-2 indicate that the difference in the reinforcer magnitude in Phase 2 did not produce the consistent difference in the magnitude of resurgence. Therefore, the results do not seem to support both the BMT and the context-change hypothesis.

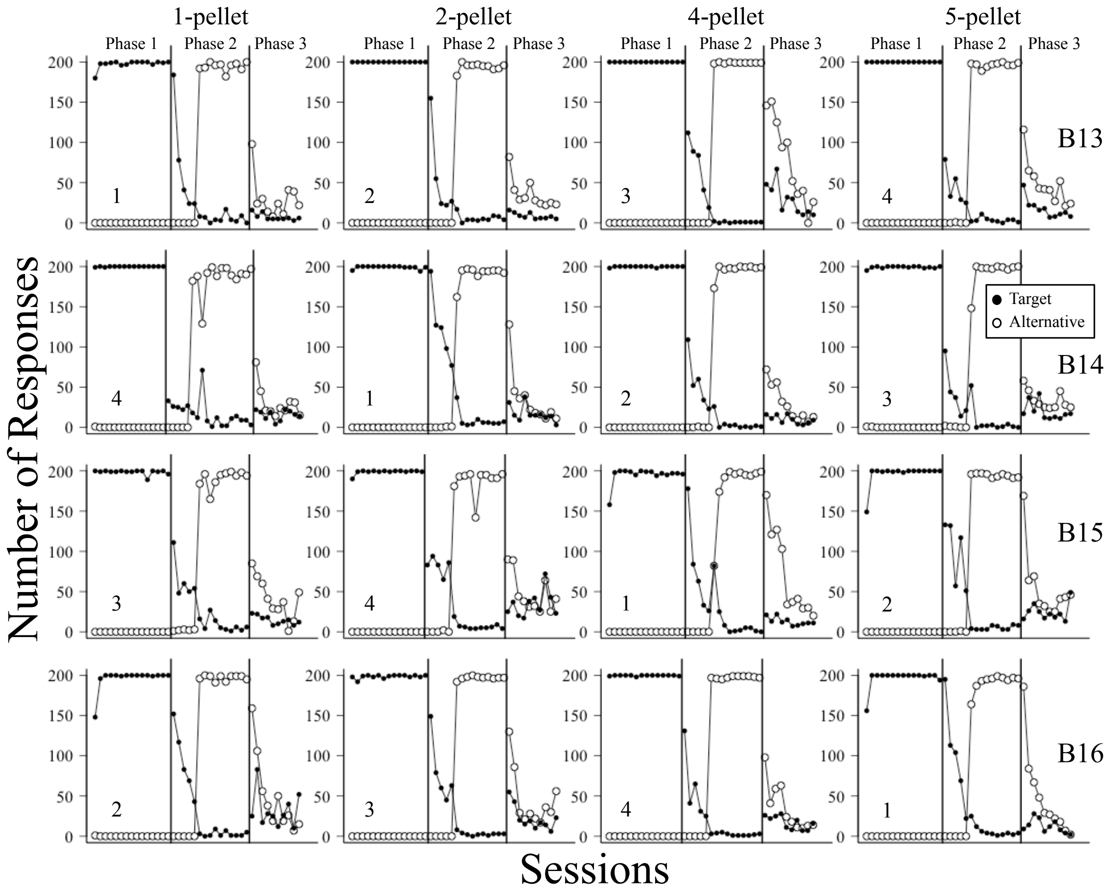

Figure 28. The numbers of target and alternative responses in all sessions for each condition. The dashed vertical lines separate successive phases. The numbers in each panel refer to the order of conditions to which the rat was exposed.

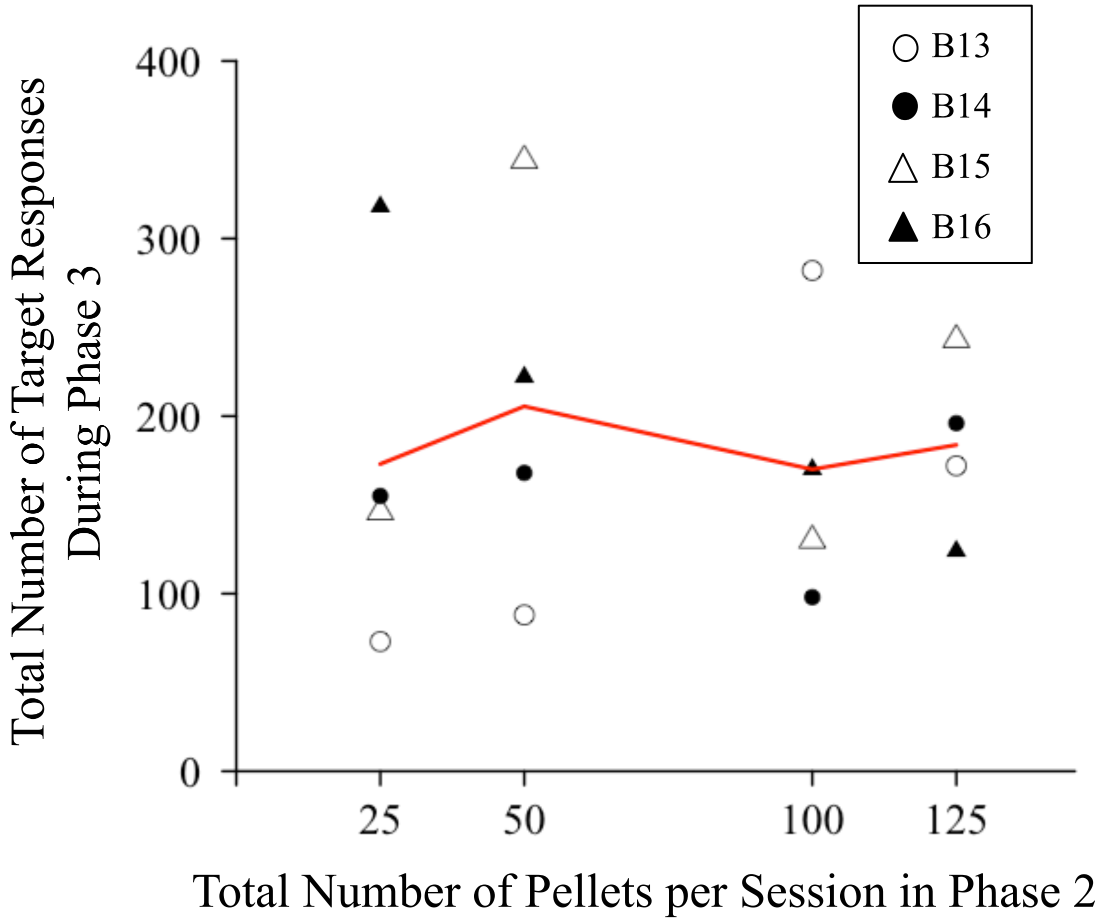

Figure 29. Total number of target responses during Phase 3 for each condition. The red line shows mean total number of the target responses across all rats in each condition.

Table 10. Mean numbers of responses and reinforcers per session across the last 3 sessions of Phases 1 and 2. Standard deviations are shown in parenthesis.

		Condition							
Rat	Response	5-Pellet		4-Pellet		2-Pellet		1-Pellet	
Responses per Session									
B13	Target	200.00	(0.00)	200.00	(0.00)	200.00	(0.00)	199.67	(0.58)
	Alt.	197.00	(1.73)	199.00	(0.00)	193.00	(2.65)	196.33	(4.73)
B14	Target	199.00	(1.00)	200.00	(0.00)	197.33	(2.89)	200.00	(0.00)
	Alt.	198.33	(2.08)	199.00	(1.00)	194.00	(1.73)	192.67	(3.79)
B15	Target	200.00	(0.00)	196.67	(0.58)	199.67	(0.58)	198.33	(2.08)
	Alt.	192.33	(1.53)	196.67	(2.52)	192.67	(2.89)	195.33	(2.31)
B16	Target	198.00	(3.46)	199.67	(0.58)	199.33	(1.15)	200.00	(0.00)
	Alt.	195.67	(1.53)	198.00	(1.00)	196.67	(0.58)	197.67	(2.31)
Reinforcers per Session									
B13	Target	75.00	(0.00)	75.00	(0.00)	75.00	(0.00)	75.00	(0.00)
	Alt.	121.67	(2.89)	100.00	(0.00)	49.33	(1.15)	24.67	(0.58)
B14	Target	74.00	(1.73)	75.00	(0.00)	74.00	(1.73)	75.00	(0.00)
	Alt.	125.00	(0.00)	100.00	(0.00)	50.00	(0.00)	25.00	(0.00)
B15	Target	75.00	(0.00)	75.00	(0.00)	75.00	(0.00)	75.00	(0.00)
	Alt.	125.00	(0.00)	100.00	(0.00)	48.00	(0.00)	24.67	(0.58)
B16	Target	75.00	(0.00)	75.00	(0.00)	75.00	(0.00)	75.00	(0.00)
	Alt.	125.00	(0.00)	98.67	(2.31)	49.33	(1.15)	25.00	(0.00)

Note. The probabilities of reinforcement in Phases 1 and 2 were fixed at .125 across conditions. The number of pellets in Phase 2 differed for each condition, while 3 pellets were delivered in Phase 1 across conditions. See text further details.

General Discussion

Experiment 5 examined the relation between resurgence and the reinfocer magnitude using the discrete-trial procedure. In Experiment 5-1, three of four rats showed the increase of the target response during Phase 3 (i.e., resurgence) as a function of the reinforcer magnitude. This finding is consistent with the results from Podlesnik and Shahan (2010). In addition, these rats showed weaker resurgence in the 5-pellet condition. Although this result seems to support the BMT model that predicts inverted U-shape curve of resurgence, one of these three rats showed sigmoid-like curve of resurgence. Thus, the results of Experiment 5 provide only weak evidence supporting the BMT model.

In Experiment 5-2, there were no systematic relations between resurgence and the reinforcer magnitude in Phase 2 and thus, the BMT model is not supported. The results of Experiment 5-2 do not seem to support the context-change hypothesis. It is unclear whether the differences in the reinforcer magnitude produce any changes in context. If the context-change did not occur by manipulating the reinforcer magnitude, the context-change hypothesis is not inconsistent with the results of Experiment 5-2. On the other hand, if it assumes that the total number of reinforcers per session also produces the context change, this hypothesis was not supported in Experiment 5-2. Obviously, it is a circular argument that stemmed from the ambiguous definition of the “context”. This point is further argued later in General Discussion.

Experiment 6

Reinforcement Rate and Resurgence in the Within-session Procedure

In Experiment 6, the relation between resurgence and rates of reinforcement was examined in the within-session procedure. Reinforcement rates for the target and alternative responses were separately manipulated in Experiments 6-1 and 6-2 (see Table 11). The results of Experiment 3 clearly showed that the repeated exposure to three-phase procedure within an individual subject greatly weaken the resurgence effect. In addition, sufficiently reflecting the effect of reinforcement rate for each condition to resurgence, 15 days of training session were introduced before the 3 sessions of resurgence test.

Experiment 6-1

Method

Subjects and Apparatus. Four male *Wistar* rats were maintained at 80% of their free-feeding weights throughout the experiment. All had histories of lever-pressing response on the RR and extinction schedules and were approximately 14 months old at the start of the experiment. Two rats were housed together for each cage with free access to water in a temperature-controlled room on a 12:12 light-dark cycle (lights on 8:00 pm). Apparatus was the same as that used in the Experiments 4 and 5. For Rats A01 and A03, the left and right levers served as the target and alternative levers, respectively, across all conditions. For the other rats, this assignment was reversed.

Procedure. All rats required no shaping and were exposed to training on a VI schedule. Each VI training session lasted for 30 min. The VI values are gradually increased from 5 to 120-sec across the 5 sessions. Each interval is sampled without replacement from 12 intervals generated using the Fleshler and Hoffman (1962) progression. Following this training, rats were exposed to the 4 conditions as shown in Table 11. The order of each condition was counter-balanced across rats. Each condition consisted of the 15 days of Training and 3 days of Test.

Training The Training session divided into 2 phases with 15-min duration for each. Daily sessions started after the 30-sec blackout and occurred 7 days a week at approximately the same time each day. At the start of the session, both the target and alternative levers were extended into chambers. In Phase 1, responses on the target lever were reinforced on either a VI 15-s, VI 30-s, VI 60-s, or VI 120-s schedule. Extinction schedule was in effect for the alternative lever. Then, the target response was placed on extinction and the alternative response was reinforced on a VI 15-s schedule in Phase 2. A 5-sec COD was in effect across these phases. After the 15 days of this training session, resurgence testing was conducted.

Resurgence Testing A 40-min test session divided into 3 phases. The first two phases were identical with those of the Training session. In Phase 3 the target and alternative responses were extinguished for 10 minutes. After the 3 sessions of testing, the next condition started.

Table 11. Designs of Experiments 6-1 and 6-2.

Conditions		Phase 1 15-min		Phase 2 15-min		Phase 3 10-min
Experiment 6-1						
VI 15-s	TR:	VI 15-s	TR:	EXT	TR:	EXT
	Alt:	EXT	Alt:	VI 15-s	Alt:	EXT
VI 30-s	TR:	VI 30-s	TR:	EXT	TR:	EXT
	Alt:	EXT	Alt:	VI 15-s	Alt:	EXT
VI 60-s	TR:	VI 60-s	TR:	EXT	TR:	EXT
	Alt:	EXT	Alt:	VI 15-s	Alt:	EXT
VI 120-s	TR:	VI 120-s	TR:	EXT	TR:	EXT
	Alt:	EXT	Alt:	VI 15-s	Alt:	EXT
Experiment 6-2						
VI 15-s	TR:	VI 15-s	TR:	EXT	TR:	EXT
	Alt:	EXT	Alt:	VI 15-s	Alt:	EXT
VI 30-s	TR:	VI 15-s	TR:	EXT	TR:	EXT
	Alt:	EXT	Alt:	VI 30-s	Alt:	EXT
VI 60-s	TR:	VI 15-s	TR:	EXT	TR:	EXT
	Alt:	EXT	Alt:	VI 60-s	Alt:	EXT
VI 120-s	TR:	VI 15-s	TR:	EXT	TR:	EXT
	Alt:	EXT	Alt:	VI 120-s	Alt:	EXT

Note. Reinforcer was a 45-mg pellet in all conditions. TR and Alt represent the target and alternative levers, respectively. VI and EXT represent variable-interval and extinction schedules, respectively.

Results and Discussion

Figure 30 shows mean rates of target and alternative responses across 3 phases of each condition. Changes in the rates of responding were similar across all conditions. The target response maintained for all rats in Phase 1. In some conditions, the rates were gradually decreased towards the end of Phase 1. This tendency might be partly due to an increase of the alternative response as the time for introduction of Phase 2 approached. In Phase 2, the target response sharply decreased to near-zero level in all rats and the alternative response increased and became stable across Phase 2. When all reinforcers were withheld in Phase 3, the alternative response decreased during the first few minutes and subsequently the target response resurged.

Figure 31 shows mean total number of responses during Phase 3 of all sessions for each condition. Overall, the magnitude of resurgence increased from the VI 120-s condition to VI 30-s condition. However, the highest reinforcement rates in the VI 15-s condition yielded weaker resurgence than that in the VI 30-s for all rats except A03. Magnitude of resurgence for Rat A03 was the greatest in the VI 15-s condition, but this rat showed the same level of resurgence also in the VI 60-s condition. Rat A04 also showed the similar tendency between the VI 120-s and VI 30-s conditions. For the other rats, resurgence of target responding linearly increased from the VI 120-s to the VI 30-s condition.

Response rates and reinforcement rates for the target and alternative responses in 3 test sessions of each condition were averaged and are shown in Table 12. The rates of reinforcement for the target and alternative responses were approximated to the programmed one in all condition. Thus, the rates of reinforcement were successfully manipulated for each condition. The rates of target responses were generally increased as a function of reinforcement rate of each condition. However, the target response rates in the VI 15-s condition for Rats A02 and A04 were lower than that in the VI 30-s condition. It should be noted that these rats showed weaker resurgence in the VI 15-s conditions than that in VI 30-s condition as noted. In contrast, the target response rate in the VI 15-s condition was the highest for Rat A03 that showed the greatest level of resurgence in the VI 15-s condition. It therefore is possible that the response rate, but not the reinforcement rate, more strongly affected the magnitude of resurgence in the present experiment (see e.g., da Silva et al., 2008). To identify which one is responsible for the greater magnitude of resurgence under the high reinforcement rate, further experiment should be conducted in which the reinforcement rate is different between conditions while equating the response rates. This point is reconsidered in Experiment 7-1.

In general, the results of Experiment 6-1 showed the positive relation between resurgence and reinforcement rates for the target responding. However, three of four rats showed weaker resurgence in the VI 15-s condition, indicating that this relation only held over the limited range of reinforcement rate. The present results support the prediction of Shahan and Sweeney's BMT model, which could predict this inverted U-shape curve of resurgence. On the other hand, it is unknown whether the present results support the context-change hypothesis because it seems to give no predictions about the relation between resurgence and the rates of target responsding.

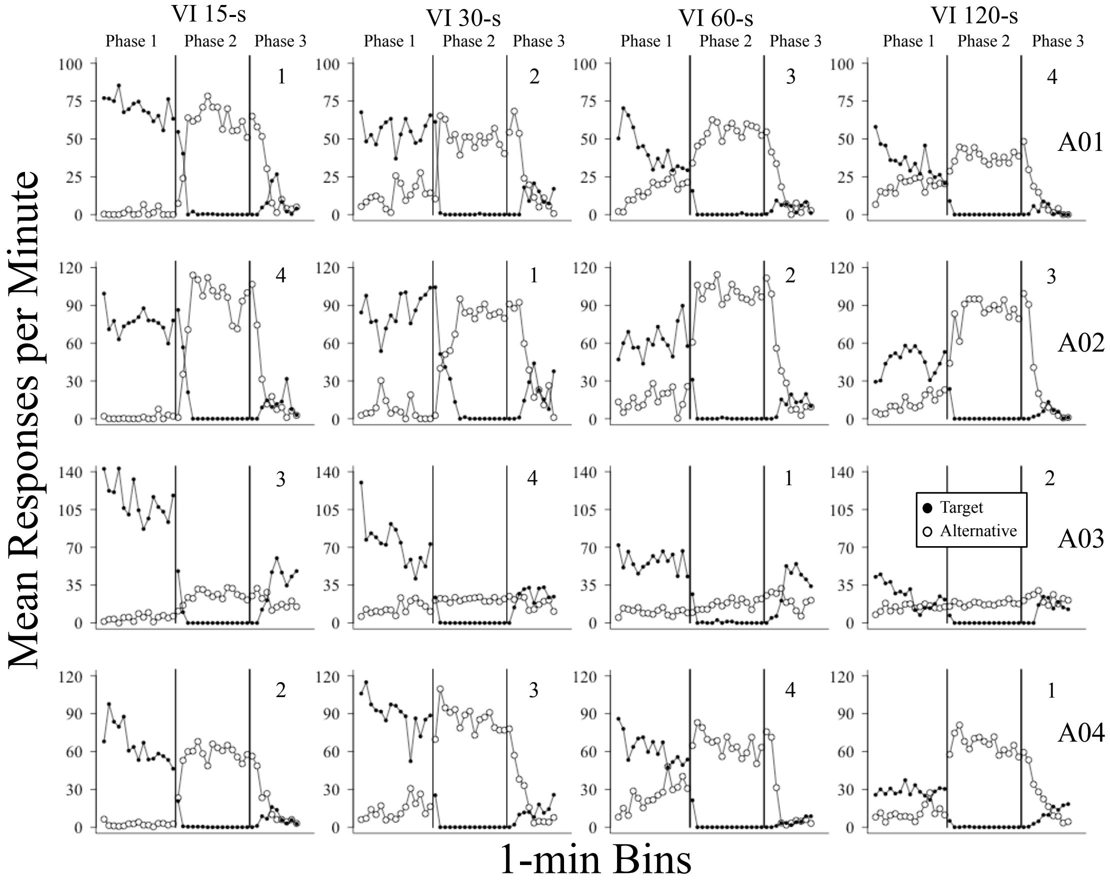

Figure 30. Mean rates of the target and alternative responses across 3 phases of each condition. Note the different Y-axis scales across rats. The dashed vertical lines separate successive phases. The numbers in each panel refer to the order of conditions to which the rat was exposed.

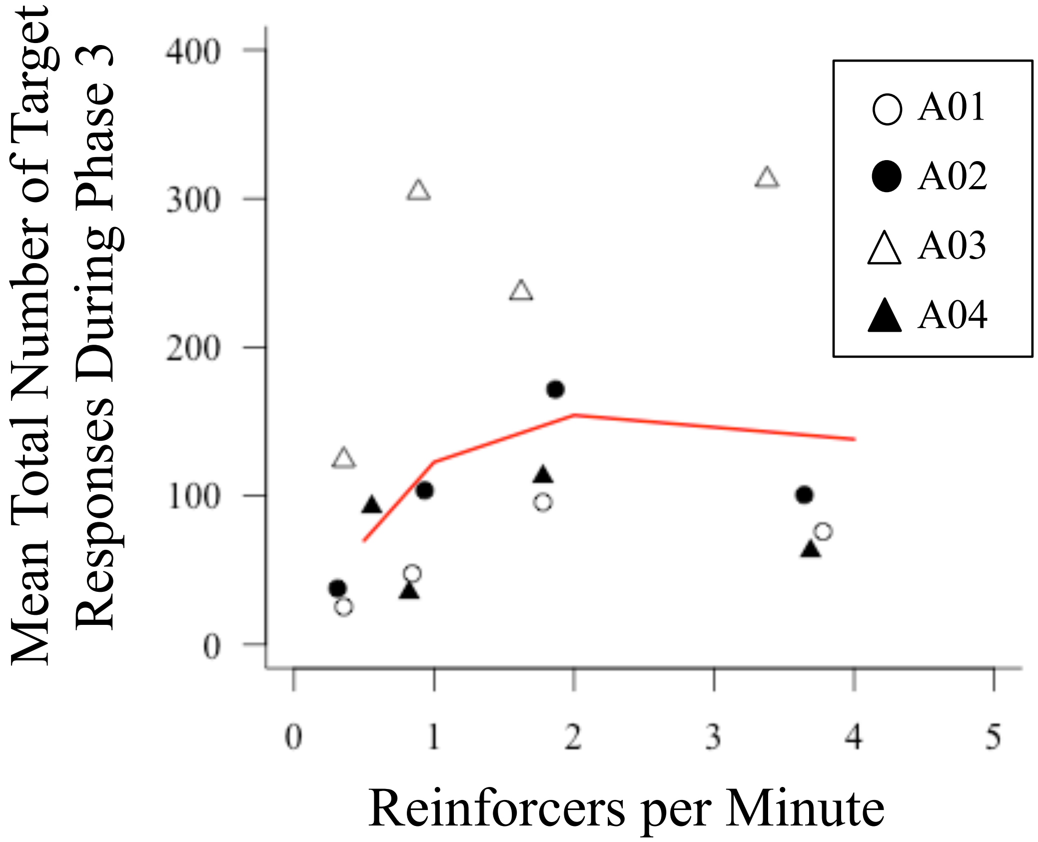

Figure 31. Mean total number of target responses across three test sessions of each condition. The total number of responses for each test session was calculated by summing the number of responses in each 1-min bin during Phase 3, and then, mean total number of target responses was calculated by averaging these values for each condition. Each point was plotted as a function of mean obtained rates of reinforcement. Value of each point was averaged for each condition and is shown in red line as a function of programed reinforcement rates.

Table 12. Mean response rates and reinforcement rates in test sessions of each condition. Standard deviations are shown in parenthesis.

		Conditions							
Rats	Response	VI 15-s		VI 30-s		VI 60-s		VI 120-s	
Responses per Minute									
A01	Target	70.51	(7.04)	55.07	(7.33)	42.33	(9.59)	35.24	(5.31)
	Alt.	57.44	(8.38)	48.09	(7.37)	53.71	(5.07)	37.82	(2.80)
A02	Target	76.53	(6.68)	85.33	(4.18)	61.56	(12.04)	45.62	(10.27)
	Alt.	85.22	(8.28)	71.00	(7.15)	97.53	(10.88)	83.58	(11.09)
A03	Target	113.00	(4.21)	73.67	(2.72)	57.02	(3.55)	25.82	(6.97)
	Alt.	24.93	(1.33)	21.76	(2.27)	17.04	(1.97)	17.87	(0.87)
A04	Target	65.58	(8.44)	89.69	(10.38)	62.20	(2.16)	28.56	(6.83)
	Alt.	56.76	(12.44)	85.84	(6.03)	65.62	(5.34)	65.84	(8.84)
Reinforcers per Minute									
A01	Target	3.78	(0.08)	1.78	(0.10)	0.84	(0.08)	0.36	(0.10)
	Alt.	3.38	(0.15)	3.62	(0.15)	3.62	(0.14)	3.44	(0.08)
A02	Target	3.64	(0.10)	1.87	(0.18)	0.93	(0.12)	0.31	(0.04)
	Alt.	3.27	(0.18)	3.18	(0.52)	3.73	(0.07)	3.67	(0.12)
A03	Target	3.38	(0.14)	1.62	(0.04)	0.89	(0.04)	0.36	(0.04)
	Alt.	3.47	(0.07)	3.49	(0.10)	3.04	(0.32)	3.42	(0.10)
A04	Target	3.69	(0.14)	1.78	(0.14)	0.82	(0.04)	0.56	(0.10)
	Alt.	3.69	(0.15)	3.78	(0.08)	3.71	(0.08)	3.64	(0.14)

Experiment 6-2

Method

Subjects and Apparatus. Four male *Wistar* rats were maintained at 80% of their free-feeding weights throughout the experiment. All had histories of lever-pressing response on the RR and extinction schedules and were approximately 14 months old at the start of the experiment. Two rats were housed together for each cage with free access to water in a temperature-controlled room on a 12:12 light-dark cycle (lights on 8:00 pm). Apparatus was the same as that used in the Experiment 6-1. Assignment of the left or right lever to the target lever or alternative lever was balanced across rats.

Procedure. All rats required no shaping and were exposed to the four experimental conditions shown in Table 11 after the training on the VI schedule. The target response in Phase 1 was reinforced on VI 30-s schedule across conditions, while a value of VI schedule for the alternative response in Phase 2 was varied according to the experimental condition shown in Table 11. The other details of procedure were as described for Experiment 6-1.

Results and Discussion

Figure 32 shows mean rates of target and alternative responses across 3 phases of each condition. As expected, the target response was acquired and maintained in Phase 1. In Phase 2, the target response decreased while the alternative response increased. Table 13 shows mean response rates and obtained reinforcement rates of each condition. In most cases, obtained rates of alternative reinforcement systematically differed between conditions in all rats. Removal of reinforcers in Phase 3 decreased the alternative response rates in all conditions and subsequently the target response resurged in some conditions with some rats. It is notable that resurgence was less likely to occur than Experiment 6-1 probably because the target response was reinforced on the VI 15-s schedule in Phase 1.

Figure 33 shows mean total number of responses during Phase 3 of for each condition. In contrast to Experiment 6-1, the target response did not decreased to near zero during Phase 2 in VI 60-s condition of Rat A08. Therefore, the number of resurgent responding was calculated after subtracting the mean target response rates during the last 3 minutes of Phase 2 from the rates of target responses for each 1-min bin of Phase 3 in all cases. Figure 33 revealed that there was little to no resurgence in the VI 60-s and VI 120-s conditions for all rats. However, Rats A06 and A08 showed the grater magnitude of resurgence in the VI 15-s and VI 30-s conditions, and the magnitude did not systematically differ between these conditions. Although the magnitude of resurgence did not differ from the VI 120-s to the VI 30-s conditions for Rat A05, strong resurgence was again found in the VI 15-s condition. These results are consistent with Schepers and Bouton (2016). Rat A07, on the other hand, consistently showed weak resurgence across all conditions. It should be emphasized that weakened resurgence under the highest reinforcement condition was not observed in contrast to Experiment 6-1. This finding strongly suggests that reinforcements for the target and alternative reinforcement have differential effects on resurgence.

The results of Experiment 6-2 indicate that the changes in the magnitude of resurgence were similar to the sigmoid curve. Resurgence was more likely to occur in the condition where the alternative response was maintained on the higher rates of reinforcement. These results are inconsistent with the prediction of BMT model, while the context-change hypothesis can provide an explanation.

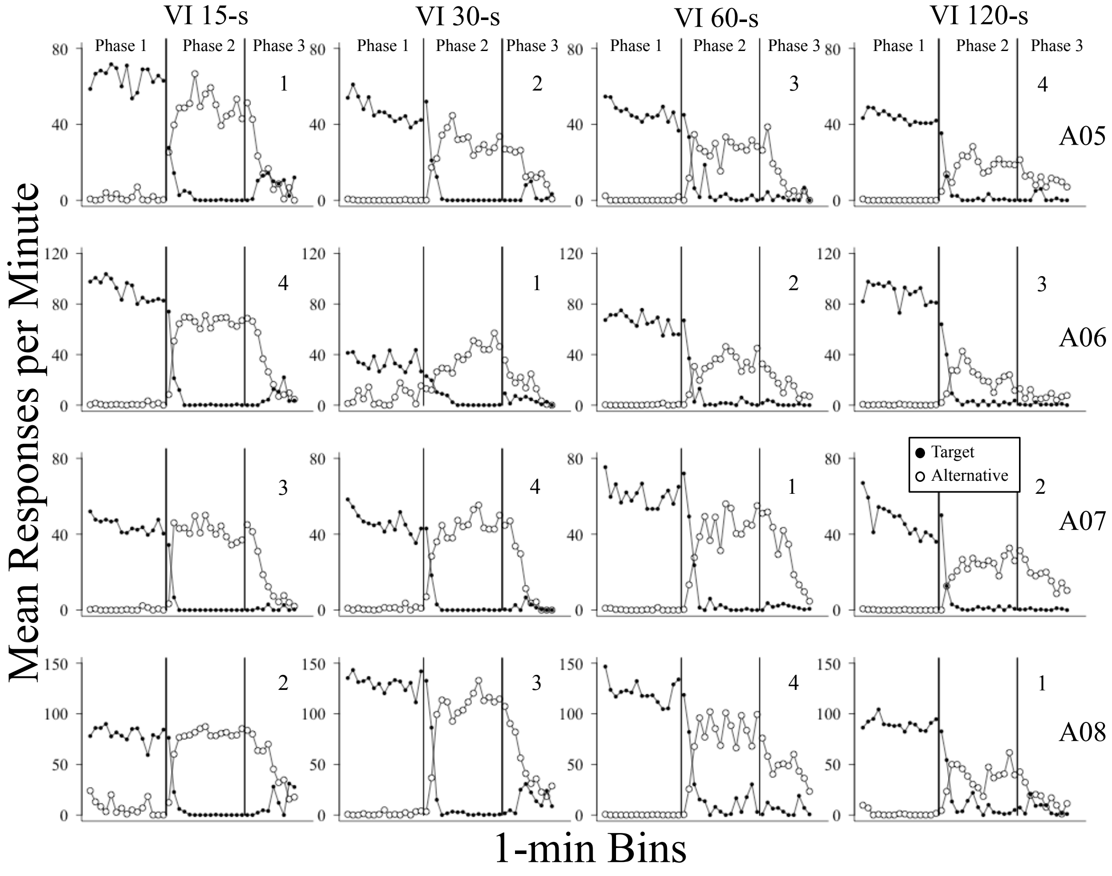

Figure 32. Mean rates of the target and alternative responses across 3 phases of each condition. Note the different Y-axis scales across rats. The vertical lines separate successive phases. The numbers in each panel refer to the order of conditions to which the rat was exposed.

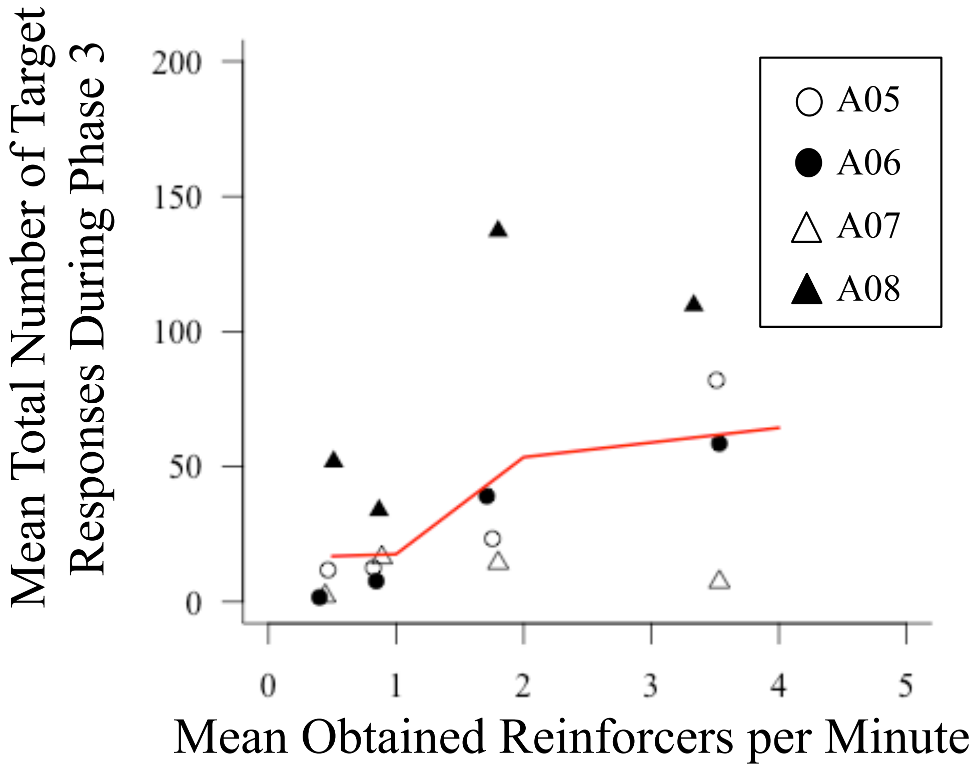

Figure 33. Mean total number of target responses across three test sessions of each condition. The total number of responses for each test session was calculated in the same manner as Experiment 6-1, except that the mean target response rates during the last 3 minutes of Phase 2 was subtracted from the rates of target responses for each 1-min bin of Phase 3 in all cases (see text for details). The red line shows mean total number of the target responses across all rats in each condition.

Table 13. Mean response rates and reinforcement rates in test sessions of each condition. Standard deviations are shown in parenthesis.

		Conditions							
Rats	Resp.	VI 15-s		VI 30-s		VI 60-s		VI 120-s	
Responses per Minute									
A05	Target	64.82	(3.64)	46.98	(6.84)	45.96	(2.82)	43.56	(2.22)
	Alt.	48.04	(0.38)	28.07	(7.49)	24.96	(6.86)	17.89	(4.71)
A06	Target	90.82	(3.30)	34.18	(10.96)	66.22	(10.19)	88.76	(5.66)
	Alt.	61.38	(6.68)	36.04	(2.76)	30.18	(4.93)	21.29	(0.68)
A07	Target	44.56	(2.57)	46.02	(0.25)	60.64	(7.03)	47.13	(1.12)
	Alt.	39.31	(1.19)	41.02	(2.92)	38.78	(4.82)	22.02	(4.41)
A08	Target	79.84	(37.67)	130.38	(5.44)	121.58	(3.73)	89.89	(0.95)
	Alt.	74.80	(40.86)	98.84	(2.96)	75.18	(5.36)	36.84	(2.34)
Reinforcers per Minute									
A05	Target	3.64	(0.20)	3.67	(0.20)	3.67	(0.18)	3.69	(0.10)
	Alt.	3.51	(0.10)	1.76	(0.15)	0.82	(0.04)	0.47	(0.07)
A06	Target	3.87	(0.07)	3.16	(0.89)	3.67	(0.07)	3.71	(0.15)
	Alt.	3.53	(0.18)	1.71	(0.28)	0.84	(0.04)	0.40	(0.07)
A07	Target	3.73	(0.07)	3.67	(0.12)	3.69	(0.08)	3.67	(0.18)
	Alt.	3.53	(0.12)	1.80	(0.07)	0.89	(0.04)	0.44	(0.10)
A08	Target	3.73	(0.12)	3.76	(0.10)	3.78	(0.14)	3.64	(0.10)
	Alt.	3.33	(0.46)	1.80	(0.13)	0.87	(0.07)	0.51	(0.04)

Note. Reinforcer was a 45-mg pellet in all conditions. TR and Alt represent the target and alternative levers, respectively. VI and Ext represent variable-interval and extinction schedules, respectively.

General Discussion

Experiment 6 examined the effects of target and alternative reinforcement on resurgence in the within-session procedure. In Experiment 6-1, the greater magnitude of resurgence was observed in the higher rates of reinforcement for the target response, suggesting that the magnitude of resurgence is linear function of target reinforcement rates. However, weaker magnitude of resurgence was found in 3 of 4 rats under the highest reinforcement rates (i.e., VI 15-s) condition. Thus, although resurgence linearly increased from low to moderately high reinforcement rates, when the target responding was maintained under the extremely high reinforcement rates in Phase 1, the magnitude of resurgence was weakened. Thus, the inverted U-shape function was found in Experiment 6-1. These results extend the previous studies by Podlesnik and Shahan (2009, 2010), and support the prediction of BMT model.

The results of Experiment 6-2 provided the evidence that the rates of alternative reinforcement determine whether or not resurgence occur. In the VI 60-s and VI 120-s conditions, only the slight increase of the target response was observed. Furthermore, there was not difference in the number of target responses between these conditions in all rats. In the VI 15-s condition, however, three of four rats showed the grater magnitude of resurgence. Although Rats A06 and A08 showed the remarkable increase of the target response also in the VI 30-s condition, the magnitude of resurgence did not systematically differ between these higher reinforcement conditions. It means that the change in alternative reinforcement rate produced the qualitative, but not quantitative, difference in the magnitude of resurgence. These results are consistent with Bouton and

Schepers (2016), and therefore support the context-change hypothesis rather than the BMT model. Thus, as with Experiment 4, the results of Experiments 6-1 and 6-2 generally support the synthetic view of behavioral momentum theory and the context-change hypothesis.

Experiment 7

Reinforcement Magnitude and Resurgence in the Within-session Procedure

Experiment 7 examined the effect of the reinforcer magnitude on resurgence by using the within-session procedure. Details of the procedure were the same as Experiment 6, except that the reinforcer magnitude, but not the reinforcement rates, for the target and alternative responses were parametrically manipulated with 4 conditions.

In Experiment 7-1, the number of pellets per reinforcement for the target responding was manipulated and examined their effects on resurgence. Some studies have shown that the positive relation between reinforcer magnitude and resistance to change (e.g., Harper & McLean, 1992; Nevin, 1974). Given that the Shahan and Sweeney's BMT model assume that resurgence is governed by the same mechanism as resistance to change, differences in the reinforcer magnitude for the target responding impact the magnitude of resurgence in a manner similar to reinforcement rates as shown in Experiment 6-1.

Experiment 7-2 examined the effects of reinforcer magnitude for the alternative responding on resurgence. So far, no study investigated the relation between the reinfocer magnitude for the alternative responding and resurgence. From behavioral-momentum perspective, the number of reinforcers delivered in a session determines the response strength, so that BMT model should expect the same results as Experiment 6-2. As noted, if the reinforcer magnitude produces the changes in context, the context-change hypothesis should predict the sigmoid-like curve of resurgence.

Experiment 7-1

Method

Subjects and Apparatus. Four male *Wistar* rats were maintained at 80% of their free-feeding weights throughout the experiment. All had histories of lever-pressing response on the RR and extinction schedules and were approximately 14 months old at the start of the experiment. Two rats were housed together for each cage with free access to water in a temperature-controlled room on a 12:12 light-dark cycle (lights on 8:00 pm). Apparatus was the same as that used in the Experiment 6. Assignment of the left or right lever to the target lever or alternative lever was balanced across rats.

Procedure. All rats required no shaping and were exposed to the four experimental conditions shown in Table 14 after the training on the VI schedule. In Phase 1, the target response was reinforced on the VI 120-s with different number of pellets for each condition. In Phase 2, the target response was placed on extinction while the alternative response was reinforced with 8 pellets on the VI 120-s schedule of reinforcement across all conditions. In Phase 3, reinforcement for the alternative response was discontinued. The duration of each phase was the same as Experiment 6. Details of all conditions were shown in Table 14.

Table 14. Design of Experiments 7-1 and 7-2.

Conditions	Phase 1 15-min	Phase 2 15-min	Phase 3 10-min
Experiment 7-1			
VI 15-s	TR: VI 120-s (8 pellets)	TR: EXT	TR: EXT
	Alt: EXT	Alt: VI 120-s (8 pellets)	Alt: EXT
VI 30-s	TR: VI 120-s (4 pellets)	TR: EXT	TR: EXT
	Alt: EXT	Alt: VI 120-s (8 pellets)	Alt: EXT
VI 60-s	TR: VI 120-s (2 pellets)	TR: EXT	TR: EXT
	Alt: EXT	Alt: VI 120-s (8 pellets)	Alt: EXT
VI 120-s	TR: VI 120-s (1 pellets)	TR: EXT	TR: EXT
	Alt: EXT	Alt: VI 120-s (8 pellets)	Alt: EXT
Experiment 7-2			
VI 15-s	TR: VI 120-s (8 pellets)	TR: EXT	TR: EXT
	Alt: EXT	Alt: VI 120-s (8 pellets)	Alt: EXT
VI 30-s	TR: VI 120-s (8 pellets)	TR: EXT	TR: EXT
	Alt: EXT	Alt: VI 120-s (4 pellets)	Alt: EXT
VI 60-s	TR: VI 120-s (8 pellets)	TR: EXT	TR: EXT
	Alt: EXT	Alt: VI 120-s (2 pellets)	Alt: EXT
VI 120-s	TR: VI 120-s (8 pellets)	TR: EXT	TR: EXT
	Alt: EXT	Alt: VI 120-s (1 pellets)	Alt: EXT

Note. Reinforcer was a 45-mg pellet in all conditions. TR and Alt represent the target and alternative levers, respectively. VI and Ext represent variable-interval and extinction schedules, respectively. The number of pellets for each reinforcement is shown in parenthesis.

Results and Discussion

Figure 34 shows mean rates of target and alternative responses across 3 phases of each condition. In Phase 1, the target response was acquired as expected, and the alternative response also increased in all conditions, though the 5-s COD was in effect. This tendency was consistent to the results of the VI 120-s condition in Experiment 6-1, suggesting that the low frequency of reinforcer delivery resulted in the increase of alternative response. Table 15 shows mean response rates and mean obtained reinforcers per minute in all conditions. Figure 34 and Table 15 indicated the absence of systematic differences in the target response rates, while the number of reinforcers for the target responding consistently increased as a function of the number of pellets per reinforcement. In Phase 2, the alternative response increased further, and the target response decreased but was not completely eliminated in some cases. In Phase 3, the alternative response only slightly decreased in most cases despite that all reinforcers were removed, indicating that all rats showed the greater resistance to extinction of the alternative response as compared to Experiment 6-1. Nevertheless, all rats showed resurgence especially in the conditions where the large number of pellets was delivered.

Figure 35 shows mean total number of responses during Phase 3 in each condition. Each value was calculated in the same manner as Experiment 6-2. Generally, the magnitude of resurgence increased over the 1-pellet and 4-pellet conditions. Three of four rats, however, showed weaker resurgence in the 8-pellet condition than in the 4-pellet condition. One might assume that the lower target response rates in the 8-pellet condition resulted in the weaker resurgence, as with Experiment 6-1. Although the rate of target response in the 8-pellet condition was lower than that in 4-pellet condition for Rat A09 and A10, the other rats showed almost the same response rates between these conditions. Furthermore, the largest difference in target response rates was at most 16 responses per minute in Rat A09 (see Table 15), and thus the differences between the 8- and 4-pellet conditions were relatively smaller as compared to the VI 15-s and VI 30-s conditions of Experiment 6-1. Therefore, weakened resurgence could not be explained by the target response rates in Phase 1. Only Rat A12 showed the linear relation between the magnitude of resurgence and the number of pellets per reinforcement over the all conditions. However, it should be noted that the mean obtained number of reinforcers during Phase 1 of the 8-pellet condition was relatively lower in Rat A12 than the other rats (see Table 15). Therefore, it is more reasonable to consider that the lower obtained number of pellets prevented from the magnitude of resurgence being attenuated for Rat A12.

The results of Experiment 7-1 is consistent with Podlesnik and Shahan (2010) that showed the reinforcer magnitude affects the magnitude of resurgence in pigeons. More importantly, the results demonstrate the inverted U-shape function of resurgence as shown in Experiment 6-1, and thus supports the prediction of BMT model.

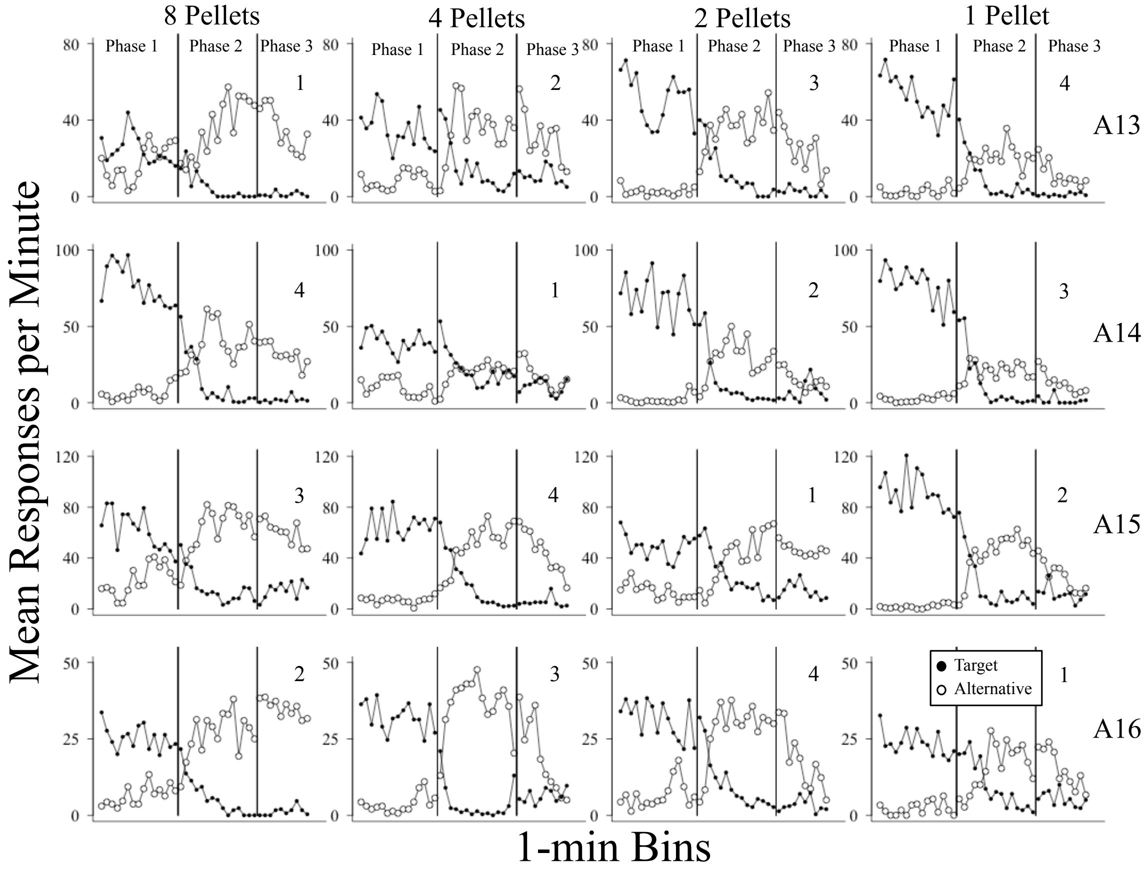

Figure 34. Mean rates of the target and alternative responses across 3 phases of each condition. The vertical lines separate successive phases. The numbers in each panel refer to the order of conditions to which the rat was exposed.

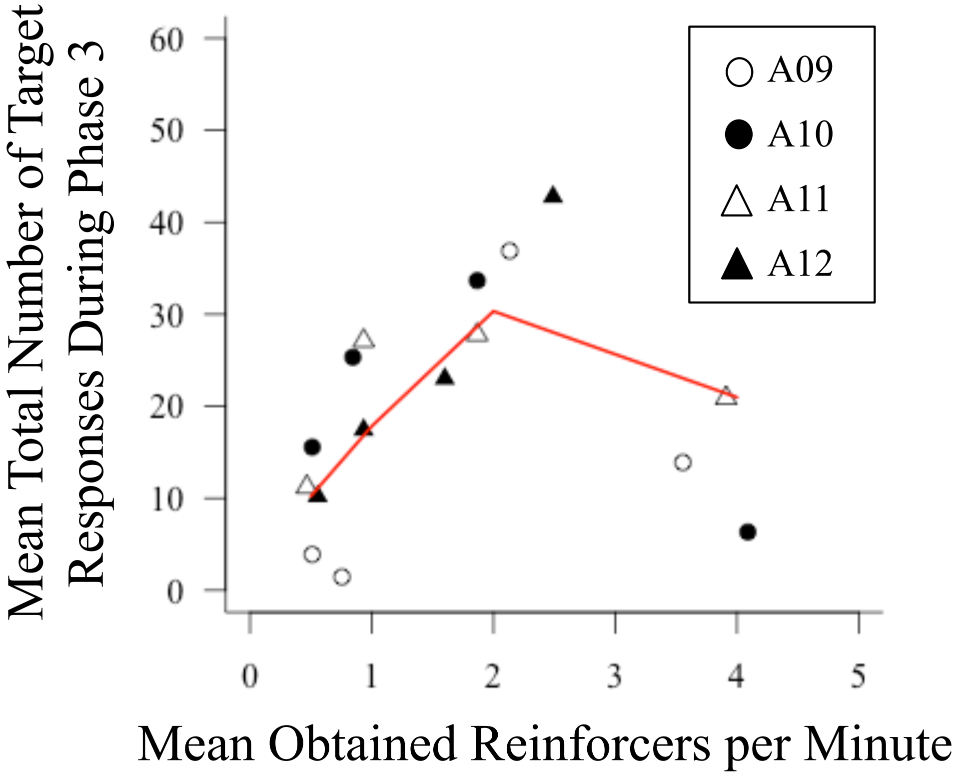

Figure 35. Mean total number of target responses across three test sessions of each condition. The total number of responses for each test session was calculated in the same manner as Experiment 6-2. The red line shows mean total number of the target responses across all rats in each condition.

Table 15. Mean response rates and the number of reinforcers per minute in test sessions of each condition. Standard deviations are shown in parenthesis.

		Conditions			
Rats	Responses	8-Pellet	4-Pellet	2-Pellet	1-Pellet
Responses per Minute					
A09	Target	21.02 (3.97)	37.00 (32.02)	30.02 (4.29)	23.16 (6.24)
	Alt.	19.31 (2.82)	33.69 (20.65)	32.67 (2.61)	23.84 (8.27)
A10	Target	12.89 (2.00)	21.78 (2.98)	11.11 (1.82)	16.82 (2.93)
	Alt.	15.33 (5.21)	14.49 (5.95)	15.51 (9.52)	17.80 (3.37)
A11	Target	20.18 (1.03)	22.22 (1.24)	19.89 (2.77)	19.60 (5.74)
	Alt.	16.44 (1.00)	19.11 (1.73)	16.82 (3.81)	18.60 (1.35)
A12	Target	16.89 (3.47)	16.29 (1.78)	23.24 (5.74)	21.87 (0.12)
	Alt.	45.93 (6.73)	42.69 (2.96)	41.62 (2.22)	30.56 (5.43)
Reinforcers per Minute					
A09	Target	3.56 (1.63)	2.13 (0.27)	0.76 (0.20)	0.51 (0.14)
	Alt.	2.49 (0.81)	3.20 (0.53)	3.38 (0.62)	3.56 (0.31)
A10	Target	4.09 (0.81)	1.87 (0.27)	0.84 (0.41)	0.51 (0.14)
	Alt.	2.84 (0.62)	2.67 (0.53)	3.38 (0.62)	2.67 (0.92)
A11	Target	3.91 (1.11)	1.87 (0.53)	0.93 (0.40)	0.47 (0.13)
	Alt.	3.38 (1.23)	3.73 (0.00)	4.09 (0.31)	3.38 (1.11)
A12	Target	2.49 (0.31)	1.60 (0.27)	0.93 (0.35)	0.56 (0.14)
	Alt.	2.67 (0.53)	3.56 (1.34)	3.73 (1.41)	3.38 (1.23)

Experiment 7-2

Method

Subjects and Apparatus. Four male *Wistar* rats were maintained at 80% of their free-feeding weights throughout the experiment. All had histories of lever-pressing response on the RR and extinction schedules and were approximately 14 months old at the start of the experiment. Two rats were housed together for each cage with free access to water in a temperature-controlled room on a 12:12 light-dark cycle (lights on 8:00 pm). Apparatus was the same as that used in the Experiment 6. Assignment of the left or right lever to the target lever or alternative lever was balanced across rats.

Procedure. All rats required no shaping and were exposed to the four experimental conditions shown in Table 14 after the training on the VI schedule. The target response in Phase 1 was reinforced with 8 pellets on a VI 120-s schedule across conditions. The alternative response was also reinforced on the VI 120-s schedule in Phase 2, but the number of pellets was varied according to the experimental conditions shown in Table 14. The other details of procedure were as described for Experiment 7-1.

Results and Discussion

Figure 36 shows mean rates of target and alternative responses across 3 phases of each condition. Table 16 shows mean response rates and mean obtained reinforcers per minute in all conditions. Figure 37 shows mean total number of responses during Phase 3 for each condition, which was calculated in the same manner as Experiments 6-2 and 7-1. As shown in Figure 36 it was similar to Experiment 7-1 that the acquisition and extinction processes of the target and alternative responses across three phases.

Resurgence of the target responding was observed in Phase 3 in most of the cases. However, Figure 37 revealed that there was no systematic relation between the reinforcer magnitude and resurgence. Rat A13 showed inverted U-shape function as shown in Experiment 7-1, while Rat A15 showed substantial resurgence in all condition but with no systematic difference. For Rat A14, the greatest magnitude of resurgence was observed in the 2-pellet condition, and the magnitude of resurgence was almost the same in the other conditions. Rat A16 showed relatively greater resurgence in the 1-pellet and 4-pellet conditions than the others. Obviously, systematic relation was not found and therefore the prediction of BMT model was not supported in Experiment 7-2.

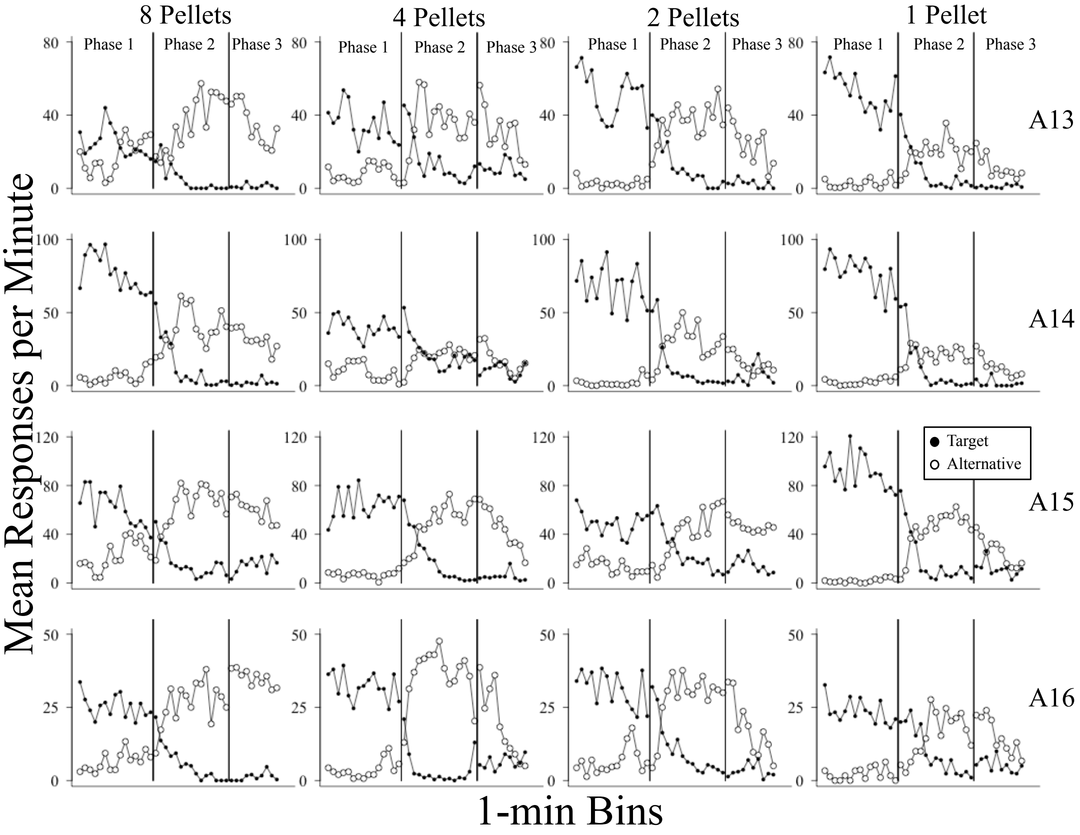

Figure 36. Mean rates of the target and alternative responses across 3 phases of each condition. Note the different Y-axis scales across rats. The vertical lines separate successive phases.

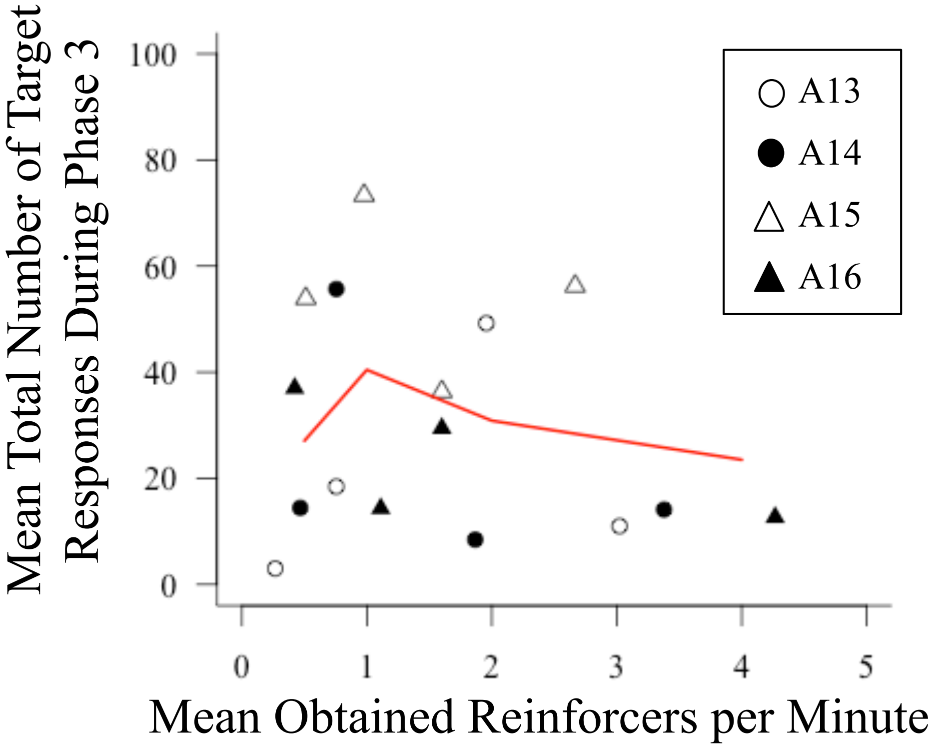

Figure 37. Mean total number of target responses across three test sessions of each condition. The total number of responses for each test session was calculated in the same manner as Experiment 6-2. The red line shows mean total number of the target responses across all rats in each condition.

Table 16. Mean response rates and the number of reinforcers per minute in test sessions of each condition. Standard deviations are shown in parenthesis.

		Conditions							
Rats	Responses	8-Pellet		4-Pellet		2-Pellet		1-Pellet	
Responses per Minute									
A13	Target	24.44	(4.78)	35.09	(4.32)	51.31	(5.29)	52.91	(13.09)
	Alt.	35.98	(8.50)	35.02	(10.03)	35.89	(7.25)	19.36	(8.54)
A14	Target	76.71	(6.60)	39.62	(5.49)	68.36	(6.06)	77.02	(1.74)
	Alt.	38.27	(3.88)	20.02	(2.67)	28.93	(11.67)	20.71	(5.96)
A15	Target	61.58	(11.63)	64.58	(1.18)	49.16	(11.01)	91.07	(9.61)
	Alt.	62.42	(10.68)	49.49	(9.45)	40.44	(15.42)	43.33	(16.04)
A16	Target	25.31	(1.06)	32.16	(3.23)	31.38	(1.51)	23.62	(2.52)
	Alt.	26.40	(6.98)	35.93	(2.95)	27.96	(1.99)	15.58	(3.94)
Reinforcers per Minute									
A13	Target	2.84	(1.11)	3.91	(1.11)	3.38	(1.23)	3.02	(0.62)
	Alt.	3.02	(0.81)	1.96	(0.41)	0.76	(0.15)	0.27	(0.12)
A14	Target	3.73	(0.53)	4.44	(0.62)	3.20	(0.53)	3.91	(0.81)
	Alt.	3.38	(1.11)	1.87	(0.27)	0.76	(0.15)	0.47	(0.07)
A15	Target	3.56	(0.81)	3.02	(0.31)	2.67	(1.41)	3.02	(1.11)
	Alt.	2.67	(0.53)	1.60	(0.00)	0.98	(0.20)	0.51	(0.04)
A16	Target	3.02	(0.31)	2.84	(0.81)	3.20	(0.53)	3.02	(0.31)
	Alt.	4.27	(0.00)	1.60	(0.00)	1.11	(0.08)	0.42	(0.04)

General Discussion

In Experiments 7-1 and 7-2, the effects of reinforcer magnitude on resurgence were examined in the within-session procedure. Across Experiments 7-1 and 7-2, mean obtained reinforcers per minute was successfully controlled in each condition, though somewhat lower than the programmed rates. The results of Experiment 7-1 demonstrated the inverted U-shape curve of resurgence. On the other hand no systematic differences were observed in Experiment 7-2. Hence, BMT model could predict the results of Experiment 7-1 but not of Experiment 7-2. Importantly, this conclusion is consistent with Experiment 5 in which the effects of the reinforcer magnitude on resurgence were examined by using the discrete-trial procedure. Again, it is unclear whether the results of Experiment 7-2 could support the context-change hypothesis. If this hypothesis assumes that only the frequency of reinforcement produces the differences in context, the results of Experiment 7-2 did not conflict with the context-change view. On the other hand, if it assumes that the total number of reinforcers per session also produces the context change, this hypothesis was not supported in Experiment 7-2. In any cases, it must be clearly defined what aspect of environment defines “context”. This point is further discussed later in General Discussion.

3. GENERAL DISCUSSION

The general purpose of the present study was to test the hypothesis that the reinforcement for the target response affects the magnitude of resurgence, while the reinforcement for the alternative response determines whether or not resurgence occurs. It is assumed that the quantitative model based on behavioral momentum theory (Shahan & Sweeney, 2011) and the context-change hypothesis (e.g., Winterbauer & Bouton, 2010) correspond to the former and latter, respectively. Therefore, if the hypothesis proposed here is empirically supported, the synthetic view of the BMT model and the context-change hypothesis could be a comprehensive model for predicting resurgence.

Shahan and Sweeney's (2011) BMT model assumes that resurgence and resistance to change share the same mechanism. This model predicts the inverted U-shape function of resurgence when the reinforcement for the target response is manipulated parametrically. With respect to the alternative reinforcement, this model predicts that the more reinforcers are delivered for the alternative response, the more resurgence occurs.

The context-change hypothesis focuses on the discriminative role of reinforcers delivered during Phase 2. The explanation of resurgence by this hypothesis is such that the removal of reinforcers for the alternative response in Phase 3 produces the context change, and it results in the occurrence of resurgence. Since there are no numerical measures evaluating the extent to which the context changes, this hypothesis essentially indicates that the amount of alternative reinforcement determines whether or not resurgence occur in an all-or-nothing manner. It should be noted that the context-change hypothesis provides no prediction about the relation between resurgence and the target reinforcement.

Although Podlesnik and Shahan (2009, 2010) have shown that the BMT model could predict the relation between resurgence and the rate of target response, conflicting results have been reported with respect to the effect of alternative reinforcement rate on resurgence (see section 1.2). Thus, it is still unknown which of the BMT model and the context-change hypothesis provide more reasonable prediction about the relationship between resurgence and the alternative reinforcement. Therefore, we first examined the relation between rates of alternative reinforcement and resurgence through three experiments using the multiple schedule.

The results of Experiment 1 indicated that there was no systematic relation between resurgence and the alternative reinforcement rates, as reported in several studies (e.g., Cançado & Lattal, 2013; Winterbauer & Bouton, 2010). Importantly, there was little to no resurgence in some conditions with some pigeons. It highlights the necessity of developing the procedure that produces resurgence more robustly. This problem addressed in Experiments 2 and 3 where the utility of two procedures, discrete-trial and within-session procedures, were tested. Some studies have reported the failure of producing resurgence (e.g., Cançado & Lattal, 2013; Cançado et al., 2015; Mulick, Leitenberg, & Rawson, 1976). Furthermore, the resurgence effect is transient and highly variant even in the individual subject. We considered that the lack of procedures that produces resurgence robustly is one of the biggest obstacles for the parametric analysis of resurgence. Therefore it is another purpose of the present study to develop new procedures for testing resurgence. The procedures tested in Experiments 2 and 3 successfully produced the substantial resurgence and thus were considered as suitable for conducting the parametric manipulation of independent variables. Using those procedures, the relation between resurgence and the amount of reinforcement was tested parametrically and assessed the validity of the synthetic view through Experiments 4 to 7.

3.1 Effect of Target Reinforcement on Resurgence

Figure 38 shows the relative magnitudes of resurgence across Experiments 4 to 7. The lines for each Experiment were calculated by dividing mean total number of target responses during Phase 3 across rats for each condition by the maximum value of all conditions in that Experiment. Experiments 4-1 and 5-1 examined the effects of target reinforcement on resurgence in the discrete-trial procedure. Although the probability of reinforcement and the number of pellets per reinforcement were manipulated in Experiment 4-1 and 5-1, respectively, assignment of total reinforcers for each condition was equated between these experiments (see Table 17). As shown in Figure 38, the relative magnitude of resurgence in these experiments changed as an inverted U-shape function with the increasing of total number of reinforcers per session. Similar results were found in Experiments 6-1 and 7-1, where the rate of reinforcement or the number of reinforcers during Phase 1 was manipulated parametrically in the within-session procedure. Note that assignment of reinforcers per session for each condition was again equated between Experiments 6-1 and 7-2. In conclusion, parametric manipulation of target reinforcement produced the inverted U-shape curve of resurgence consistently across 4 experiments. This result is consistent with the prediction of the BMT model.

3.2 Effect of Alternative Reinforcement on Resurgence

In Experiments 4-2 and 6-2, the frequency of the alternative reinforcement during Phase 2 was manipulated across four conditions by changing the probability and rate of reinforcement, respectively. As shown in Figure 38, the results of both Experiments 4-2 and 6-2 showed the sigmoid-like curve of resurgence. In two conditions with lean alternative reinforcement, weak resurgence was observed. On the other hand, a greater resurgence was found in two rich conditions and the magnitude of resurgence between these conditions did not differ. These results were consistent with the finding of Bouton and Trask (2016; see also Craig et al., 2016; Sweeney & Shahan, 2013) and thus, support the context-change hypothesis. However, the results from both Experiment 5-2 and 7-2 clearly indicate that there is no systematic relationship between resurgence and the reinforcer magnitude during Phase 2. One might assume that the lower sensitivity to the reinforcer magnitude produced the results of Experiments 5-2 and 7-2. Indeed, several studies have reported that the animals showed lower sensitivity to the reinforcement magnitude than the reinforcement frequency (e.g., Schneider, 1973; Todorov, 1973). However, most of the rats showed the systematic change in the magnitude of resurgence in Experiments 5-1 and 7-1 where the reinforcement magnitude for the target response was manipulated. If one considered that the lower sensitivity to the reinforcement magnitude produced the inconsistent results shown in

Experiments 5-2 and 7-2, it is, in turn, unclear why the resurgence effect was affected by the differences in the reinforcer magnitude for the target response. From the perspective of the context-change hypothesis, no systematic relation observed in Experiments 6-2 and 7-2 would be explained by assuming that the differences in the reinforcer magnitude did not produce any changes in context. This explanation seems reasonable, but it should explain why the contextual change did not occur despite the fact that the number of reinforers for each condition differed systematically. Thus, it remains unclear whether the results from Experiment 6-2 and 7-2 conflict with the context-change hypothesis.

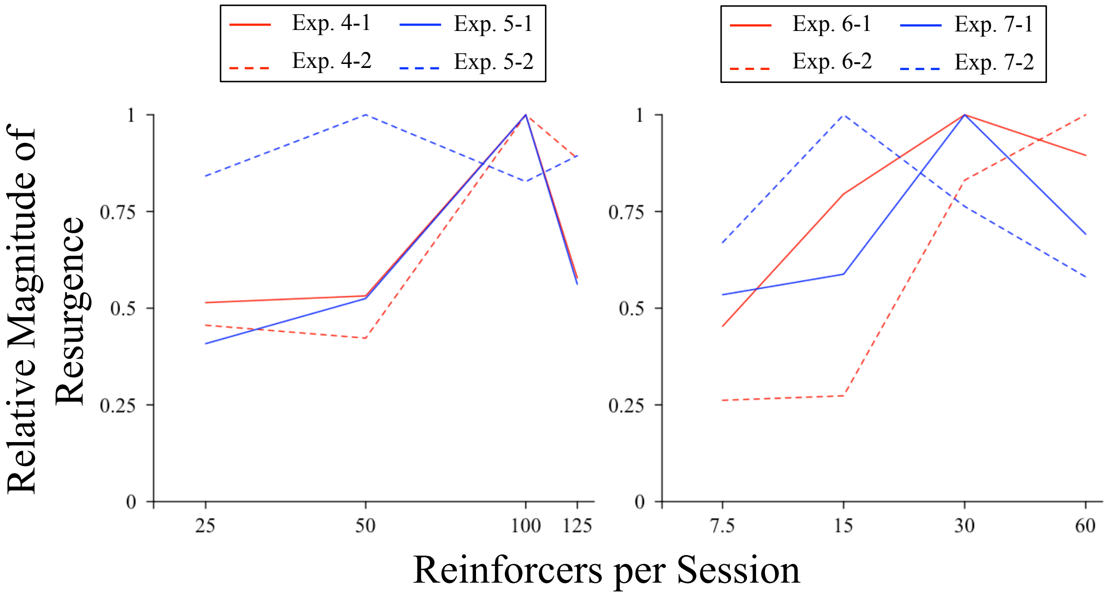

Figure 38. Mean relative magnitude of resurgence across rats from Experiments 4 to 7. Horizontal axis is the programmed reinforcers per session plotted on a log scale. Left and right panels represent the results from discrete-trial and within-session procedures, respectively. Note that horizontal axis of the right panel shows total reinforcers during Phase 1 or 2 in a session each of which was 15 minutes in duration.

Table 17. Design of reinforcer assignment in Experiments 4 and 5.

Condition	Probability of Reinforcement	Frequency of Reinf. per Session	Number of pellets per Trial	Number of pellets per Session
Experiment 4-1 & 4-2				
RR8	0.125	25.00	1.00	25
RR4	0.250	50.00	1.00	50
RR2	0.500	100.00	1.00	100
RR1.6	0.625	125.00	1.00	125
Experiment 5-1 & 5-2				
1-pellet	0.125	25.00	1.00	25
2-pellet	0.125	25.00	2.00	50
4-pellet	0.125	25.00	4.00	100
5-pellet	0.125	25.00	5.00	125

Notes. Experiments 6-1 and 7-1 refer to the assignments of reinforcement during Phase 1, while Experiments 6-2 and 7-2 refer to those during Phase 2. Reinf. = reinforcement.

Table 18. Design of reinforcer assignment in Experiments 6 and 7.

Condition	VI Value	Frequency of Reinf. per Session	Number of pellets per Reinf.	Number of pellets per Session
Experiment 6-1 & 6-2				
VI 120-s	120	7.50	1.00	7.5
VI 60-s	60	15.00	1.00	15
VI 30-s	30	30.00	1.00	30
VI 15-s	15	60.00	1.00	60
Experiment 7-1 & 7-2				
1-pellet	120	7.50	1.00	7.5
2-pellet	120	7.50	2.00	15
4-pellet	120	7.50	4.00	30
8-pellet	120	7.50	8.00	60

Notes. Experiments 6-1 and 7-1 refer to the assignments of reinforcement during Phase 1, while Experiments 6-2 and 7-2 refer to those during Phase 2. Note that durations of Phases 1 and 2 were 15 minutes, so that the right-most column represents total number of pellets during 15 minutes of Phases 1 or 2. Reinf. = reinforcement.

3.3 Validity of the Synthetic View of Behavioral Momentum Theory and the Context-change Hypothesis

As just noted, the inverted-U curve of resurgence was observed through Experiments 4 to 7 in which the probability or rate or magnitude of reinforcement during Phase 1 was manipulated. These results are consistent with the BMT prediction. On the other hand, when the frequency of alternative reinforcement was manipulated, the sigmoid-like curve of resurgence was found. This result supports for the context-change hypothesis, but not for the BMT model. More importantly, these results should support the synthetic view of these models.

A remaining question is the results obtained in Experiments 5-2 and 7-2 where the magnitude of alterntive reinforcer was manipulated parametrically. In both Experiments, no systematic was found between resurgence and reinforcer magnitude. Neither the BMT model nor the context-change hypothesis could explain these results. Although the context-change hypothesis could explain these results by assuming that the differences in reinforcer magnitude do not produce the context change, it is just a circular reasoning. This kind of argument highlights the potential and critical problems of the context-change hypothesis. As often pointed out, whether the context changes or not is always inferred through behavior change (e.g., Craig & Shahan, 2016). This post-hoc interpretation makes the context-change hypothesis unfalsifiable. However, in the present study, the context change was operationally defined as the change in the number of reinforcers delivered for each session. Manipulations of both the frequency and magnitude of reinforcement produced the differences in the number of reinforcers across conditions. Therefore, it was assumed that both manipulations produced the context change. Since the experiments were conducted on this assumption and no systematic difference in resurgence was found, it seems reasonable to conclude that the results of Experiments 5-2 and 7-2 did not support the context-change hypothesis. What is clear is that the frequency, but not total number, of alternative reinforcement produced the systematic differences in resurgence. Further experiments are needed to explain why the manipulation of the magnitude of alternative reinforcement did not produce the sigmoid-like curve of resurgence. However, it should be especially emphasized that this asymmetric effects of the target and alternative reinforcement on resurgence clearly support the hypothesis of the synthetic view that the reinforcements of the target and alternative responses have differential effects on resurgence.

Finally, there were several limitations in the present study. First, the results of the present series of experiments were not consistent across all rats. For this reason, the synthetic view of the BMT model and the context-change hypothesis was only roughly supported. Second, the present study used only the total number of target responses as the index of resurgence. The synthetic view provides no prediction of other aspects of resurgence, such as pattern of resurgence and timing at which resurgence occur. In almost all studies on resurgence, the pattern of resurgence was inconsistent within and between subjects. Also with respect to the timing at which resurgence occur, no consistent results were often found in many studies. Indeed, these aspects of resurgence were inconsistent between rats in the present study. To create a model providing the prediction for all of these aspects of resurgence, more experiments should be warranted.

3.4 Future Directions in the Study on Resurgence: Theory Driven or Data Driven?

More than 100 papers have been published since Carey (1951) first found the resurgence effect. However, the behavioral mechanism of resurgence is not well understood yet. Recently, the research on resurgence tends to proceed in accordance with some theories. However, the theory-driven approach will not necessarily orient the resurgence study towards the good direction where experiments produce new and important findings and their value is evaluated regardless of any theories behind them. In an influential paper, Skinner (1950) stated as follows:

> Research designed with respect to theory is also likely to be wasteful. That a theory generates research does not prove its value unless the research is valuable. Much useless experimentation results from theories, and much energy and skill are absorbed by them. Most theories are eventually overthrown, and the greater part of the associated research is discarded (p. 194)

The same situation seems to be occurring in the resurgence study. For example, Shahan and colleagues developed the quantitative model of resurgence based on behavioral momentum theory, but recently they are abandoning the BMT model (e.g., Shahan & Craig, in press) and perhaps even the value of experiments generated from the BMT model. It is the dark side of theory-driven approach that the value of the empirical findings obtained from experiment is only evaluated in terms of some models or theories. However, Skinner (1950) also stated,

> It will not stand in the way of our search for functional relations because it will arise only after relevant variables have been found and studied. (p. 216)

One of the most important implications by Skinner (1950) is, as Epstein (1982) noted, “a great deal of basic research must first be done”. After that, the good model of resurgence will arise. Although it is necessary to conduct the parametric analysis if one tries to create a quantitative model of resurgence, to our knowledge, only Cançado et al. (2015) have reported a parametric analysis of resurgence. Thus, at present, it seems to be premature to create the theory and/or model of resurgence. Procedures developed in the present study would contribute to the development of resurgence study and the parametric analysis. The data-driven, rather than theory-driven, approach will further advance our knowledge of the mechanisms of resurgence and will eventually provide a more comprehensive model of resurgence.

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