RESURGENCE OF LEVER PRESSING DURING A DRO CHALLENGE

By

Jennifer L. Hudnall, B.A.

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Chairperson, David P. Jarmolowicz

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Edward K. Morris

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Dean C. Williams

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The Thesis Committee for Jennifer L. Hudnall

certifies that this is the approved version of the following thesis:

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Chairperson, David P. Jarmolowicz

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The purpose of the present study was to experimentally investigate the effects of differential reinforcement of other behavior (DRO) on potential resurgence of a previously reinforced response. During Phase 1, rats' left lever pressing was reinforced on a fixed-ratio (FR) 20 schedule while extinction was in place for right lever presses. Then, extinction was in effect for all lever presses throughout Phase 2. Phase 3 consisted of an FR 20 schedule for right lever presses while left lever presses were on extinction. Finally, Phase 4 continued the extinction contingency for left lever presses while a 15-second DRO was in effect for right lever presses. The results indicate higher rates of resurgence and more persistent resurgence in this experiment than obtained in previous studies. Characteristics of DRO may have contributed to this effect, including a potential to allow adventitious reinforcement of left lever pressing.

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INTRODUCTION

Resurgence has been defined in a variety of ways, but the most common definition characterizes it as an instance of previously reinforced behavior recurring after reinforcement for a current behavior is discontinued (Epstein, 1983, 1985). Resurgence is generally described to be a phenomenon induced by extinction (Lieving & Lattal, 2003), but there are other conditions under which it has been observed. It has been obtained experimentally during such challenges as delay of reinforcement (Jarmolowicz & Lattal, 2014), during lean schedules of reinforcement (Lieving & Lattal, 2003), and during punishment of another response (Wilson & Hayes, 1996).

Resurgence occurs in a systematic fashion, and its stages of development have been previously studied and delineated in the literature. It has been observed in humans (e.g., Doughty et al., 2009; Lieving, Hagopian, Long, & O'Connor, 2004; Wilson & Hayes, 1996), pigeons (e.g., Cançado & Lattal, 2013; Epstein, 1983; Lieving & Lattal, 2003), rats (e.g. Podlesnik, Jimenez-Gomez, & Shahan, 2006; Reed & Morgan, 2006; Sweeney & Shahan, 2015), and even fish (da Silva, Cançado, & Lattal, 2014). It is typically studied using a three-phase procedure: (1) A specific response is reinforced; (2) That initial response is extinguished while a different response is reinforced; and (4) Both responses are placed on extinction to look for resurgence of the first (Cançado & Lattal, 2014). Resurgence differs from the several other mechanisms whereby previously reinforced behaviors re-emerge--namely, spontaneous recovery, reinstatement, and renewal.

During spontaneous recovery, a behavior that was previously reinforced and extinguished reappears some time after the conclusion of the extinction period (Mazur, 2006, p. 132). Thus, spontaneous differs from resurgence in that does not happen during extinction and does not involve systematic reinforcement of another response. Spontaneous recovery has been most

studied in the context of respondent conditioning, but Lerman and colleagues (1999) observed spontaneous recovery of screaming in a 21-year old woman during functional communication training of hand clapping. Systematic reinforcement of another response is not necessarily part of the process involved in spontaneous recovery as it is in resurgence (Lattal & St. Peter Pipkin, 2009).

Reinstatement is similar to resurgence with one significant difference. Like resurgence, the behavior that reappears was previously subjected to a period of reinforcement and then extinction. However, reinstatement occurs when reinforcers that once maintained the initial behavior are delivered *independent* of any particular response (Franks & Lattal, 1976; Lattal & St. Peter Pipkin, 2009; Rescorla & Skucy, 1969). Reinstatement is studied by using a three-phase arrangement similar to the procedure commonly employed to study resurgence, but the final phase consists of reinforcer delivery that is not correlated with any particular response. Reinstatement of previously reinforced responding has been observed in the animal laboratory with rats and pigeons responding for food (e.g., Doughty, Reed, & Lattal, 2004) as well as in applied settings with humans, including those engaging in destructive behavior (Falcomata et al., 2013) and previously reinforced arbitrary responses (Spradlin, Fixsen, & Giradeau, 1969). Reinstatement is frequently the topic of drug studies and sometimes referred to as "relapse" (see Shaham et al., 2003).

Renewal is very similar to resurgence and differs only in that it occurs in a context different from that of the original reinforced response (Sweeney & Shahan, 2015). For example, a response previously reinforced and extinguished in one room reappears after a later response is reinforced and then extinguished in a different room. Renewal would more likely be observed under naturalistic conditions rather than in the laboratory where different experimental

conditions are usually experienced within the same apparatus. It has, however, been obtained in the basic lab with rats pressing a lever for food reinforcement. Bouton, Todd, Vurbic, and Winterbauer (2011) observed renewal of rats' lever pressing in a chamber different from the one in which training occurred. The second chambers were differentiated from the baseline chambers by way of visual and olfactory stimuli. Spontaneous recovery, reinstatement, and renewal all occur well after the response elimination phase, but resurgence is a side effect seen *during* extinction of the second response.

Extinction and Variability

Researchers have long known that extinction initiates variations in behavior (Antonitis, 1951; Pryor, Haag, & O'Reilly, 1969; Skinner, 1938). When a current response proves unproductive, those variations often originate with the resurgence of a response that previously resulted in reinforcement. Behavioral variability is often an adaptive process. For example, Chase (2003) writes that extinction can give rise to a combination of responses that ultimately results in novel behaviors that may aid in problem solving (p. 360). This combination includes currently reinforced and recently reinforced responses, as well as re-emerging behaviors that were effective in the more distant past (Lieving & Lattal, 2003). The potential for variation depends on current changes in stimuli and contingencies (Neuringer, 2009). As the transition is made from a rich reinforcement schedule to a condition under which reinforcement is more intermittent, non-existent, or now dependent on a different response, one could expect to see a mechanism like resurgence.

Resurgence is typically seen as an extinction-related phenomenon, described primarily as one brought about by the discontinuation of reinforcement. However, extinction itself has been defined in more than one way. Conventional operant extinction is most commonly described as

the withholding of reinforcement during a response that once produced it and the resulting decrease in probability of that response (Ferster & Skinner, 1957), but removing the existing response-reinforcer contingency can also result in a decrease in response probability (Rescorla & Skucy, 1969).

There are other conditions under which reinforcement may be so intermittent that these conditions resemble extinction (Lieving & Lattal, 2003; St. Peter Pipkin, Vollmer, & Sloman, 2010). Both extinction and lean intermittent reinforcement schedules consist of relatively long periods of time without reinforcement. Intermittent schedules can become very lean, leading to long periods of time without reinforcement. If this occurs, extinction may occur at a local level (Epstein, 1985; Lieving & Lattal, 2003). In other words, as inter-reinforcement intervals (IRIs) become longer and longer, conditions are more extinction-like even when extinction is not programmed. For example, Lieving and Lattal (2003, Experiment 4) changed pigeons' reinforcement for treadle pressing from a variable-interval (VI) 30-s schedule to a VI 360-s schedule in an attempt to produce resurgence of key pecking. Although a small increase in key pecking was observed for two of three pigeons, no significant resurgence effects were seen until conventional extinction was implemented. Jarmolowicz and Lattal (2014) did observe resurgence of pigeons' key pecking when delays in reinforcement were imposed on a VI 60-s schedule. Longer delays resulted in more resurgence. Therefore, it is reasonable to expect resurgence to occur under challenges other than extinction. This is relevant to application because of the variety of real-world conditions that exist other than the simple discontinuation of reinforcement for one response.

Unfortunately, resurgence has generally been studied under the discontinuation of reinforcement definition of extinction. There are other conditions that arrange reinforcement that

is not contingent on a specific response, removing the response-reinforcer contingency. Fixed-time (FT) and variable-time (VT) schedules consist of periodic reinforcer delivery regardless of responding, but both FT (Marsteller & St. Peter, 2014) and VT (Lieving & Lattal, 2003, Experiment 3) have been found to impede the development of resurgence.

Differential reinforcement of other behavior (DRO) is a common component in the treatment of problem behavior (Lennox, Miltenberger, Spengler, & Erfanian, 1988), and it provides periodic reinforcement when the target behavior is *not* occurring. DRO is a behavior-reduction procedure that can avoid extinction-induced problem behavior by continuing to provide reinforcement for behaviors other than the target. DRO does function as extinction for the target behavior by breaking the response-reinforcer contingency (Rescorla & Skucy, 1969). Some studies have utilized DRO rather than conventional extinction during the Response Elimination phase, but thus far, none has employed DRO as a challenge during the final resurgence phase.

Limitations of Existing Literature

Cançado and Lattal (2013) described the three phases typical of a standard resurgence procedure. In the first phase, labeled the Training Phase, a specific response (Response A) is reinforced. During the second phase, characterized as Response Elimination, Response A is extinguished at the same time a different response (Response B) is reinforced. During the final phase, Resurgence, both responses are placed on extinction. This is when resurgence of Response A, if it occurs, is observed. Existing research suggests that conditions in each of these phases can differentially affect the magnitude of resurgence. For example, greater resurgence has been observed when both response rate and reinforcement rate are high during the Training Phase (da Silva, Maxwell, & Lattal, 2008; Podlesnik & Shahan, 2009, 2010; Winterbauer,

Lucke, & Bouton, 2013). In addition, the degree of resurgence appears to be affected by the reinforcement schedule, response topography, and the reinforcement rate of Response B during the Response Elimination phase (da Silva, Maxwell, & Lattal, 2008; Winterbauer, Lucke, & Bouton, 2013). However, some resurgence may occur during this phase even without rich reinforcement of Response B (Lieving and Lattal, 2003). Resurgence brings about change, but our knowledge about all of the challenges that engender resurgence and these resulting changes is incomplete.

In addition to the under-exploration of these challenges, there are at least two barriers to the interpretation of the resurgence literature. (1) The three-phase approach routinely employed to study resurgence can be problematic by failing to extinguish the initial response; and (2) there is an over-reliance on VI schedules while neglecting other reinforcement schedules that are commonly used in the laboratory and application. Most studies of resurgence have implemented conventional extinction of Response A *while* Response B concurrently earns reinforcement during the Response Elimination phase. Leitenberg, Rawson, and Bath (1970) suggested that Response B *replaces* and *suppresses* Response A, thus preventing Response A from contacting the extinction contingency. For example, a rat cannot press Lever Two at the same time he is pressing Lever One; it is engaging in one response *instead of* the other. The rat may not have the opportunity to learn that presses on Lever One are no longer reinforced, and Response A would still need to go through an extinction procedure after reinforcement of Response B has been discontinued. More recently, Podlesnik and Kelley (2014) found further evidence that an available alternative response can compete with the target response in the typical three-phase procedure.

Previous studies have routinely used interval schedules to study resurgence, usually a variable-interval (VI) schedule, with one (Bouton, Winterbauer, & Todd, 2012) employing a variable ratio (VR) schedule. Few studies have examined resurgence of fixed-ratio (FR) responding. Because FR schedules are commonly used in clinical settings, understanding the potential for resurgence is relevant and necessary. The acquisition and generalization of new behaviors are often accomplished by reinforcing responses on an FR schedule. Hoffman and Falcomata (2014) tested for resurgence of appropriate communicative behavior (mands) in three human participants after reinforcing responses on an FR 1 schedule. Resurgence was observed during the final phase during which both responses were placed on extinction, but the phase was much shorter than the one used in the present experiment. In another study utilizing FR, Thompson, Bruzek, and Cotnoir-Bichelman (2011) observed resurgence of a 3-second caregiving response that had been *negatively* reinforced on an FR 1 schedule by cessation of a crying sound.

Most previous experiments have been comprised of the three phases described by Cançado and Lattal (2013), with the second phase consisting of reinforcement of Response B while Response A is on extinction. Like Jarmolowicz and Lattal (2014), the following experiment consists of four phases, with conventional extinction in effect for both responses during Phase 2. Phase 3 resembles the Response Elimination phase described in most previous studies: extinction for Response A and reinforcement of Response B. Programming extinction on both levers for Phase 2 avoids any response competition that could occur if an alternate response is reinforced and ensures that left lever pressing contacts the extinction contingency. In general, we have an underdeveloped understanding of the various challenges under which resurgence occurs. This experiment examines resurgence after reinforcement is delivered on a fixed-ratio

(FR) schedule, during which reinforcement rate is directly related to response rate (Jarmolowicz & Lattal, 2013) and extinction conditions are likely more easily discriminated (Sweeney & Shahan, 2013) compared to variable schedules. The resurgence literature is comprised almost exclusively of studies employing conventional extinction in the final phase, and none have investigated resurgence under DRO. This is an oversight given DRO's behavior-reduction capabilities and its common use in application.

METHOD

In this experiment, Phase 4 deviates from previous studies by imposing DRO rather than extinction on Response A in order to test for resurgence during a challenge other than conventional extinction. Response B is under extinction. While some studies have implemented DRO as a response elimination procedure (in place of extinction), none have used it to test resurgence following actual extinction. DRO is a commonly applied treatment component, so the potential for resurgence is of real-world concern.

Subjects

Five male Sprague-Dawley albino rats with brief experimental histories, numbered 1B1, 2G1, 2G3, 2R1, and 1R1 were used. Rat 1R1 had been used in a previous study that included some of the same conditions used in the present study. The rats were maintained on a 22-hour food deprivation schedule with water freely available in the home cages, located in a colony room with a 12 hr:12 hr light-dark cycle. All sessions were conducted during the light phase of the light-dark cycle. All of the procedures were in accordance with the guidelines established by the University of Kansas Institutional Animal Care and Use Committee. Note: 1R1 had run a previous experiment identical to this one except for a Phase 4 that consisted of Extinction on both levers. Data are available upon request.

Apparatus

Four identical commercial operant chambers were used (30.5 cm long, 24.1 cm wide, 21.0 cm high; Med Associates, Inc., St. Albans, VT). Chambers were housed in sound attenuating cubicles (ENV-022V) with fans to mask extraneous noise. Centered on the front wall, 1 cm above the floor grid was a pellet receptacle (3 cm X 4 cm) into which a pellet dispenser (ENV-203M) dispensed grain-based pellets (45 mg; Bio-Serv, Frenchtown, NJ). Retractable levers were positioned on either side of the pellet receptacle (11cm apart; 5 cm from the floor). The rats could press and release these levers, and this defined a response. Reinforcement consisted of a single grain-based pellet. A 28-V DC cue light was positioned 2 cm above each lever, and a 28-V house light centered on the back wall (19 cm from the floor) provided general illumination. All experimental events were programmed and recorded using MED-PC IV software controlled by a PC.

Procedure

Experimental sessions were conducted with all five rats, 6 to 7 days per week, at approximately the same time each day. Each session began with illumination of the house light and extension of both levers in to the chamber. With each reinforcer delivery, both levers retracted for a 5-second consumption period. Due to experimental histories, no pre-training was necessary. The following sections describe the specific procedure used in each experimental condition, and Table 1 indicates the number of sessions run by each rat in each phase:

Phase 1: Reinforcement (FR20, Extinction). An FR20 schedule was in effect on the left lever while right lever presses resulted in no programmed consequences. Every 20 presses on the left lever produced food reinforcement. Each session continued until 60 reinforcers were earned. This phase lasted minimally 15 sessions and until left lever pressing stabilized (i.e., when the

mean response rates of the first and last three sessions of the final six sessions did not deviate from the grand mean by more than +/- 10% and without systematic trends). Due to procedural errors, 2G3 was moved to the next phase after 10 sessions.

Phase 2: Response Elimination (Extinction, Extinction). Following Phase 1, lever pressing was placed on extinction for 30 sessions or until one session with zero responses was recorded, whichever occurred first. Lever presses on either lever resulted in no consequence. All session times for each rat were constant during this phase and equaled the average of the last six session times of Phase 1.

Phase 3: Reinforcement of Alternate Response (Extinction, FR20). Following the EXT EXT condition, an FR20 schedule was in effect on the right lever while left lever presses resulted in no programmed consequence. Every 20 presses on the right lever produced food reinforcement. Each session continued until 60 reinforcers were earned or a one-hour time limit was reached. This phase lasted minimally 15 sessions and until left lever pressing stabilized according to the criteria described above.

Phase 4: Resurgence (Extinction, DRO). During this phase, left lever presses resulted in no programmed consequence. A 15-s DRO schedule was in effect for the right lever. Every 15 seconds that elapsed without a right lever press resulted in reinforcer delivery. A right lever press reset the 15-s timer and did not result in reinforcer delivery. Each session continued until 60 reinforcers were earned. This phase lasted a minimum of 30 sessions.

RESULTS

Overall response rates on each lever across phases are displayed in Figure 1, with the last six sessions of Phases 1 and 3 and all sessions of Phases 2 and 4 graphed. Response rates on the left lever during the terminal sessions of the initial Reinforcement Phase averaged between 60

and 80 presses per minute for rats 1B1 and 2R1. 2G3 averaged 185 presses per minute. Response rates for 2G1 and 1R1 averaged between 210 and 225. By the final sessions of Response Elimination, response rates on the left lever had decreased to near zero for all rats. During Phase 3, right lever presses during the final six sessions averaged approximately 99 responses per minute between for 1B1. 2R1 and 2G1 averaged between 145 and 160 responses per minute. 2G3 and 1R1 averaged 215 and 220 right lever presses per minute. During the Resurgence phase, all five rats exhibited resurgence of left lever pressing.

This resurgence was robust and long lasting, never completely disappearing throughout the entire phase consisting of 30-40 sessions. For 1B1, 2R1, and 1R1, average response rates for the left lever across Phase 4 were between 40 and 60 presses per minute. The two rats with the least amount of left lever resurgence were 2G1 and 2G3, averaging approximately 25 and 12 presses per minute, respectively. The DRO schedule effectively eliminated right lever pressing for all rats. Resurgence on the left lever continued throughout the phase after cessation of right lever responses.

Within-session response patterns were examined by constructing cumulative records from the data displayed in Figure 1. Records were created by plotting cumulative lever presses as a function of time in seconds. Figure 2 shows cumulative records for each rat's final Phase 3 session. At the end of Phase 3, the records for each rat indicate steady break-and-run performance on the right lever typical of FR-schedule responding. The patterns of resurgence obtained during the three initial sessions of Extinction/DRO are shown in Figure 3, and resurgence during the final three sessions of Extinction/DRO are shown in Figure 4. 1B1, 2G1, and 1R1 demonstrated a rapid and lasting cessation of right lever pressing during Phase 4, but left lever pressing persisted throughout the phase. 2G3 ceased lever pressing on both levers

almost entirely near the end of Phase 4 but exhibited some resurgence of left lever pressing during the last two sessions.

Figure 5 displays each rat's relative frequency of left lever presses in each one-second bin of the ten seconds before and ten seconds after DRO reinforcer delivery throughout the first five sessions of Phase 4. After 1B1's first DRO session, the subsequent four sessions saw an overall increase in left lever pressing in the ten seconds immediately prior to delivery of a food pellet. Relative frequency of left lever pressing for 2R1, 2G1, and 2G3 was variable during these ten seconds throughout the first five DRO sessions. By contrast to 1B1, left lever pressing for 1R1 saw an overall decrease in the ten seconds leading up to reinforcer delivery. For all rats, left lever pressing was most likely to occur within the 10 seconds immediately prior to food delivery. One exception was 2G3's next to last session where no left lever pressing was seen within ten seconds before or after DRO reinforcement.

Figure 6 displays each rat's relative frequency of left lever presses in each one-second bin of the ten seconds before and ten seconds after DRO reinforcer delivery throughout the last five sessions of Phase 4. In four of the five final Phase 4 sessions, 1B1 still exhibited an increasing trend in left lever pressing just before delivery of the DRO reinforcer. 2G3 again showed great variability throughout the last five sessions. An overall decrease continued for 1R1, as seen in the first five DRO sessions. During these sessions, the decreasing trend of left lever pressing of 2R1 and 2G1 was similar to that of 1R1, although 2R1 and 2G1 engaged in more behavior throughout. As mentioned in the Method section, the levers were retraced for 5 seconds after food delivery, and the graphs in Figures 4 and 5 reflect the lack of behavior during this time. However, some lever pressing occurred as the lever was retracted, as evidenced by presses within one second after reinforcement.

Figure 7 displays the median relative frequency of left lever presses in one-second bins for each rat's first, middle, and last ten sessions of Phase 4. This indicates the number of resurgence responses on the left lever and their location in time with respect to food with notable changes between early DRO sessions and later ones. With the exception of 1B1, all the rats started to show a similar pattern in which most left lever pressing began to occur further away from food after 20-30 sessions on DRO. Left lever presses became less likely as food delivery drew near. For 1B1, left lever presses remained equally distributed across time. The median was used rather than the mean because the relative frequency was not normally distributed. Error bars indicate one standard deviation. Few responses occurred in the five seconds after reinforcement due to lever retraction.

Correlational data for left lever presses are displayed in Figure 8. In the panels on the left, graphs depict the relations between total left lever presses and left lever presses in the 1-second bin immediately before reinforcer delivery. For comparison, the relationships between total left lever presses and left lever presses in the 5-6-second bin *after* reinforcement are shown on the right. Data for 1B1 and 2G3 indicate strong positive correlations between total left lever presses and left lever presses during the one-second before reinforcer delivery, while weaker positive correlations were found for 2G1 and 1R1. Data for 2R1 indicate no relation. The right panels of Figure 8 indicate a moderate positive correlation between total left lever presses and left lever presses occurring during the 5-6 seconds after reinforcement for 2R1. For the other rats, no direct relations can be determined, as the lines of best fit are skewed by outliers.

Figure 9 displays, in two ways, the change in reinforcement rate between Phase 3 and Phase 4. The top panel shows the reduction in reinforcement rate between the mean of the last six sessions of Phase 3 and the mean of the first ten sessions of Phase 4. The bottom panel shows

the proportion of Phase 3's mean reinforcement rate earned during Phase 4 for those same sessions. For 1B1, there was a reduction in reinforcement rate of 0.53 reinforcers per minute. The reduction in reinforcers per minute for 2R1, 2G1, 2G3, and 2R1 was 1.57, 1.75, 2.7, and 2.61, respectively. During the first ten sessions of Phase 4, 1B1 was earning approximately 85% of the reinforcement it earned during the last six sessions of Phase 3. For the same sessions, 2R1 and 2G1 were earning between 60% and 65% of the reinforcers earned during Phase 3. 2G3 and 1R1 were earning approximately 50% of the food in Phase 4 that they had earned in Phase 3.

DISCUSSION

The purpose of the present experiment was to examine the potential for resurgence of previously reinforced lever pressing when faced with a challenge other than conventional extinction. The results reveal a 15-s DRO was capable of producing consistent and persistent resurgence. Left lever pressing was reinforced on an FR 20 schedule then extinguished. Subsequently, right lever pressing was reinforced on an FR 20 schedule. Appreciable resurgence of left lever pressing was then obtained during an arrangement consisting of continued extinction of presses on the left lever and a 15-s DRO for presses on the right lever. The DRO successfully eliminated right lever pressing in all subjects, and resurgence of left lever pressing was both immediate and long lasting for all five rats in the study. Overall left lever response rates for two rats, 1B1 and 2G1, remained above zero throughout Phase 4, and all five subjects continued to respond on the left lever for thirty to forty sessions. There are five additional points notable about the present data.

Substantial resurgence was observed

The amount of left lever pressing observed during the resurgence phase of this study is significant compared to resurgence observed in previous studies. Thirty to forty sessions is quite

a lengthy period of time to engage in behavior that produces no reinforcement, particularly after a prolonged Response Elimination phase. In comparison, the resurgence observed in other studies was minimal and short-lived, a fact that led Lattal (2012) to describe the phenomenon as transitory. Da Silva, Maxwell, and Lattal (2008) saw fewer than twelve sessions of resurgence, and Jarmolowicz and Lattal (2014) and Lieving and Lattal (2003) saw fewer than ten. Podlesnik & Kelley (2014) observed five or fewer sessions of resurgence. Some researchers have run only two or three sessions of a resurgence phase (e.g., Winterbauer, Lucke, & Bouton, 2013).

With few exceptions (e.g., Jarmolowicz & Lattal, 2014; Lieving & Lattal, 2003, Experiment 3), previous studies have explored resurgence obtained under conventional extinction. Despite the lack of any programmed consequences on the left lever in Phase 4 of this experiment, responding persisted to some degree for all rats throughout the phase, producing much more resurgence than is typically observed during extinction. When Lieving and Lattal (2003, Experiment 3) implemented a VT 30-s schedule rather than extinction during the resurgence phase, no resurgence was observed, even though the response-reinforcer contingency was removed. The current experiment also eliminated the contingency, using DRO, and a substantial amount of resurgence was obtained.

Expanded understanding of baseline schedules on which resurgence can be obtained

Whereas most previous studies have primarily looked for resurgence of behavior maintained on VI schedules, this study utilized an FR 20 schedule for lever pressing. FR schedules are among those not commonly used in resurgence studies, even though they are utilized in laboratory and clinical settings. With fixed ratio schedules, reinforcement rates are proportional to response rates. The schedules most often used to study resurgence are variable ones, and these schedules typically result in more persistent behavior (but lower rates) than fixed

schedules (Doughty, da Silva, & Lattal, 2007), but response rate can be a good predictor of how much resurgence occurs (da Silva, Maxwell, & Lattal, 2008; Reed & Morgan, 2007).

DRO may tell us more about extinction

The nature of DRO itself may have made resurgence more likely in the current study. The following characteristics of the DRO schedule could have produced the observed effects: (a) A resetting DRO acts as a punisher for the target response (Baum, 1973), making an alternate response more likely; (b) The DRO arranges reinforcement periodically and predictably, almost exactly every 15 seconds. Temporal regularity in food delivery might induce variability (in this case left lever pressing) that is adjunctive-like in nature (Wetherington, 1982); (c) Elimination of responding has been noted to be more rapid with DRO than with extinction (Zeiler, 1971); (d) Even though the goal of DRO is to decrease an unwanted target behavior, by definition it may increase behaviors other than the target. However, the literature on this phenomenon is limited (see Henton & Iversen, 1978; Jessel, Borrero, & Becraft, 2015; Madden & Perone, 2003) and warrants further investigation. Under DRO, reinforcement is nearly free, requiring only the absence of a specific target response. This, coupled with periodic food delivery, creates an opportunity for adventitious reinforcement.

A DRO arrangement involves not only reinforcing any behavior other than the target (in this case right lever pressing) but also punishing the target behavior by postponing the time to reinforcement delivery. Additionally, the observed decrease in overall reinforcement rate (Fig. 9) between Phases 3 and 4 created a transition to a leaner schedule of reinforcement. A much leaner schedule, as mentioned previously, can resemble extinction and result in resurgence of a previously reinforced response. However, one might expect the rats with lowest proportional

reinforcement rate, relative to the previous phase, to engage in the highest rates of resurgence. That was not necessarily the case in this experiment.

Manipulating the response-reinforcer contingency has been shown to degrade responding without bringing about resurgence (Lieving & Lattal, 2003, Experiment 3). What the current experiment did was manipulate the response-reinforcer dependency on the right lever to examine effects on left lever responding. Lieving and Lattal's suggestion that "resurgence may be a function only of the absence of reinforcing events" (p. 227) is not supported by this study. Although extinction was still imposed on left lever presses, the right lever press DRO arrangement allowed for them to occur closely in time to reinforcement. The resurgence obtained in this experiment is more consistent and persistent than the resurgence observed in either Lieving and Lattal (2003) or Jarmolowicz and Lattal (2014).

Unclear mechanism maintaining behavior

Resurgence alone likely does not account for the amount of response recovery observed in this experiment. The initial recovery of left lever pressing during Phase 4 can be explained by resurgence, but responding continued much longer than what has been produced by conventional extinction. Another mechanism of recovery was likely working in conjunction with resurgence to maintain the behavior over so many sessions. Response patterns on the left lever during Phase 4 suggest that some left lever pressing may have been superstitious behavior (Skinner, 1948) maintained by pellet delivery on the 15-s DRO schedule in effect for the right lever. In other words, left lever pressing could have been adventitiously reinforced by food delivery not actually dependent on that response.

Cumulative records and relative frequency graphs elucidate how DRO reinforcers associated with absence of right lever pressing maintained left lever pressing. Relative frequency

graphs for the first and last five DRO sessions show the rats engaging in much more left lever pressing in the five seconds before reinforcer delivery than during other times. Interestingly, median relative frequency data indicate that, for all rats except 1B1, lever presses decreased in frequency in the ten seconds leading up to food delivery. Additionally, left lever pressing still occurred with greater frequency within ten seconds of reinforcement compared to other times. It should be noted that left lever presses during the 5-6-second bin *after* reinforcer delivery were still occurring within ten seconds *before* the next scheduled food pellet. This lends credence to the interpretation that responding on the left lever was adventitiously reinforced by food delivered on the 15-s DRO schedule associated with absence of right lever pressing. Further support is presented in the correlation graphs in Figure 8. Positive correlations exist between total left lever presses in a session and left lever presses within one second before food delivery for all rats except 2R1, whose data indicate a stronger relationship between total left lever presses and left lever presses in during the 5-6 seconds after reinforcement. For the other four rats, total left lever presses and left lever presses have a stronger relationship with those occurring during the one second immediately prior to food delivery. This offers some evidence, although indirect, that pressing the left lever may have been adventitiously reinforced for 1B1, 2G1, and 2G3.

Adventitious reinforcement occurs when a behavior occurs just before delivery of a reinforcer, but the closeness in time happens by chance rather than as a result of any arranged contingency (Sidman, 1960, p. 106). This accidental pairing results in an ”adventitious correlation” between responses and reinforcing events (Sidman, 1960, p. 106) or what Reynolds (1975) described as an “accidental relation”. Rachlin and Baum (1972) posited that some responding in their experiment must have occurred immediately before reinforcers being

delivered independently of that response. Adventitious reinforcement is already a known drawback of using non-contingent (or response-independent) reinforcement (NCR) to reduce problem behavior (Vollmer, Samaha, & Sloman, 2009). Although the DRO reinforcers in the present experiment were not altogether response-independent, they *were* delivered independent of activity on the left lever. The result of this could be as suggested by Rachlin and Baum: "These reinforcements could have increased the rate of responding, just as they would have if they were response-dependent" (p. 237). However, responding decreased with response-independent reinforcement in that study—the opposite of what transpired in this experiment. Even if accidental, a positive correlation between reinforcement and an organism's behavior under certain conditions can result in more of that behavior in those conditions (Herrnstein & Hineline, 1966). Even a few accidental pairings could have maintained right lever pressing for some period of time, as continuous reinforcement is not necessary for a behavior to be acquired or maintained (Baum, 1973). The cumulative records shown in Figure 4 show the rats in this study continued to press the left lever through the end of the experiment and did not learn the true contingent relationship between responding and reinforcement delivery.

Epstein (1983) noted that reinforcers delivered non-contingently during an extinction period acquire discriminative properties and may reinstate the responding that once produced those reinforcers (see also Franks & Lattal, 1976). Again, although reinforcer delivery in this experiment was contingent on the *absence* of right lever pressing, it was *not* dependent upon any behavior in relation to the left lever. If pellet delivery acted as a discriminative stimulus in this experiment, the duration of resurgence obtained indeed showed "characteristics normally observed when the contingency [between left lever presses and reinforcement] is a real one" (Sidman, 1960, p. 351).

The resurgence obtained in this experiment was not a transient phenomenon; something was maintaining left lever pressing. In contrast to Staddon & Simmelhag's (1971) observation of food-related behavior (prior to when food delivery would normally occur) appearing after prolonged exposure to regular intervals ending with food, the rats in the present study engaged in left lever pressing from the start of the DRO phase. The occurrence of what appears to be adventitious reinforcement in this experiment was not entirely expected. Variable reinforcement schedules typically bring about more variability in behavior (Page & Neuringer, 1985) and therefore likely create more opportunities for adventitious reinforcement than do FR schedules. Responding for these rats, when not on extinction, was maintained on a fixed-ratio throughout the experiment. This would allow for a history with less chance of adventitious reinforcement prior to the DRO phase. However, some previous research using ratio schedules has obtained greater resurgence than what is typically seen with interval schedules (e.g., Winterbauer, Lucke, & Bouton, 2013).

Applied implications

The present findings have a number of implications for applications. The findings of this study extend the resurgence literature to include a challenge other than conventional extinction that produces resurgence of previously reinforced behavior. The results are meaningful for those who may use DRO as a treatment component. Extinction and differential reinforcement are commonly used together as components in the treatment of problem behavior (Doughty & Oken, 2008). A problem behavior is placed on extinction while differential reinforcement of alternative behavior (DRA), differential reinforcement of a behavior of incompatible behavior (DRI), or differential reinforcement of other behavior (DRO) is implemented. Recurrence of problem behavior may occur if differential reinforcement is not properly maintained and more adaptive

behaviors begin to contact extinction. The mechanism in effect could be resurgence, although it may not be immediately recognized and labeled as such. If a newly acquired adaptive response is no longer being systematically reinforced, an older, functionally equivalent maladaptive behavior may return. This can be especially problematic if a long history exists of reinforcement for multiple topographies of the target behavior or others in the same response class (Lieving, Hagopian, Long, & O'Connor, 2004), which is often the case with complex human repertoires (Lattal & St. Peter Pipkin, 2009). Even if a targeted behavior does not resurge, another problematic behavior could.

To identify the functions of problem behavior, functional analyses (FA) are conducted to determine what stimuli have been reinforcers (Iwata, Dorsey, Slifer, Bauman, & Richman, 1994) and what responses have historically been emitted to obtain them (Lieving & Lattal, 2003). The resurgence of those responses during an FA can be observed and measured to inform treatment. Sometime, however, FAs do not reveal all topographies of problem behavior in a response class, and further analysis is necessary. For example, Lieving Hagopian, Long, and O'Connor (2004) performed extinction analyses with a 7-year old girl and a 9-year old boy who each had histories of engaging in multiple topographies of disruption and aggression. Some of these had not been elucidated during the FAs. Resurgence during the extinction analyses allowed the researchers to observe the behaviors and address them in treatment plans.

Differential reinforcement of alternative behavior (DRA) is more commonly utilized because it identifies a specific (and more appropriate) alternative response to be reinforced. However, application of DRO is useful in some situations and has been found to avoid spontaneous recovery that can occur after a period of conventional extinction. If the function of a target behavior is sensory or automatic reinforcement, or cannot be identified, DRO can be used

to reinforce other behaviors while functioning as an ethical form of punishment of the target behavior. Our results suggest that, in addition to concerns about treatment integrity, practitioners also have to worry about resurgence of problem behavior and the possibility of it being adventitiously reinforced. Thus, resurgence is a concern even when a treatment plan is being followed correctly. The recurrence of problem behavior can be particularly common during reinforcement schedule thinning to make treatment more manageable, and this could be resurgence. (Hagopian, Boelter, & Jarmolowicz, 2011). Additionally, with so much less control outside of a clinical setting, parents and caregivers could see even more resurgence as they struggle to follow a treatment plan.

These concerns are not limited to the behaviors of children and/or those with developmental disabilities. Loss of reinforcement can trigger relapse for those trying to overcome other complex problems such as addiction and obesity (e.g., Bouton, Winterbauer, & Todd, 2012; Podlesnik, Jimenez-Gomez, & Shahan, 2006). Part of the treatment for these problems often includes reinforcement of new, adaptive behaviors to replace drug-seeking behavior (e.g., Podlesnik, Jimenez-Gomez, & Shahan, 2006) or excessive eating (e.g., Bouton, 2011; Volpp et al., 2008). If these newly acquired therapeutic behaviors contact extinction (or extinction-like conditions), resurgence of the original maladaptive behaviors can quickly occur.

Limitations

The likelihood of adventitious reinforcement in this experiment could make replication difficult (Sidman, 1960). Additionally, this experiment used only five rats. While this is fairly standard for the experimental analysis of behavior (EAB), it may not necessarily translate well to human application. Extended periods of fixed reinforcement are not realistic (Bouton et al, 2012) and are not typically implemented outside of clinical application. There was no control

condition, but schedules employed as controls in these types of studies, usually fixed time (FT), do not maintain responding the way DRO did in this experiment. This was a demonstrative experiment that has raised some questions that would be worth investigating in the future

Future Investigations

Although Ferster and Skinner (1957) found that repeated exposure to extinction did not result in lower rates of resurgence (see also Lieving & Lattal, 2003, Experiment 2), prolonged exposure to extinction did. There is a possibility that the levels of resurgence would differ if response rates were brought to zero for one or more sessions. A DRO interval longer than 15 seconds may offer less opportunity for adventitious reinforcement, and a gradual change from brief to longer intervals could produce less resurgence. This would be relevant in application. Humans have much longer and more complex behavioral histories than do lab rats or pigeons. If, as Catania (2013) suggests, punishment and reinforcement are mirror images of each other, one could expect to see resurgence of right lever pressing if another extinction phase were run after DRO. This study could be replicated with an FT schedule in place of DRO. Like DRO, FT disrupts the response-reinforcer contingency, and results could be compared to the behavior obtained during DRO in this experiment.

Rat	Phase 1 FR 20, EXT	Phase 2 EXT, EXT	Phase 3 EXT, FR 20	Phase 4 EXT, DRO
1B1	20	29	21	40
2R1	25	30	19	39
2G1	37	22	25	40
2G3	10	30	29	38
1R1	15	30	16	30

Number of Sessions

Table 1. The number of sessions per phase run by each rat.

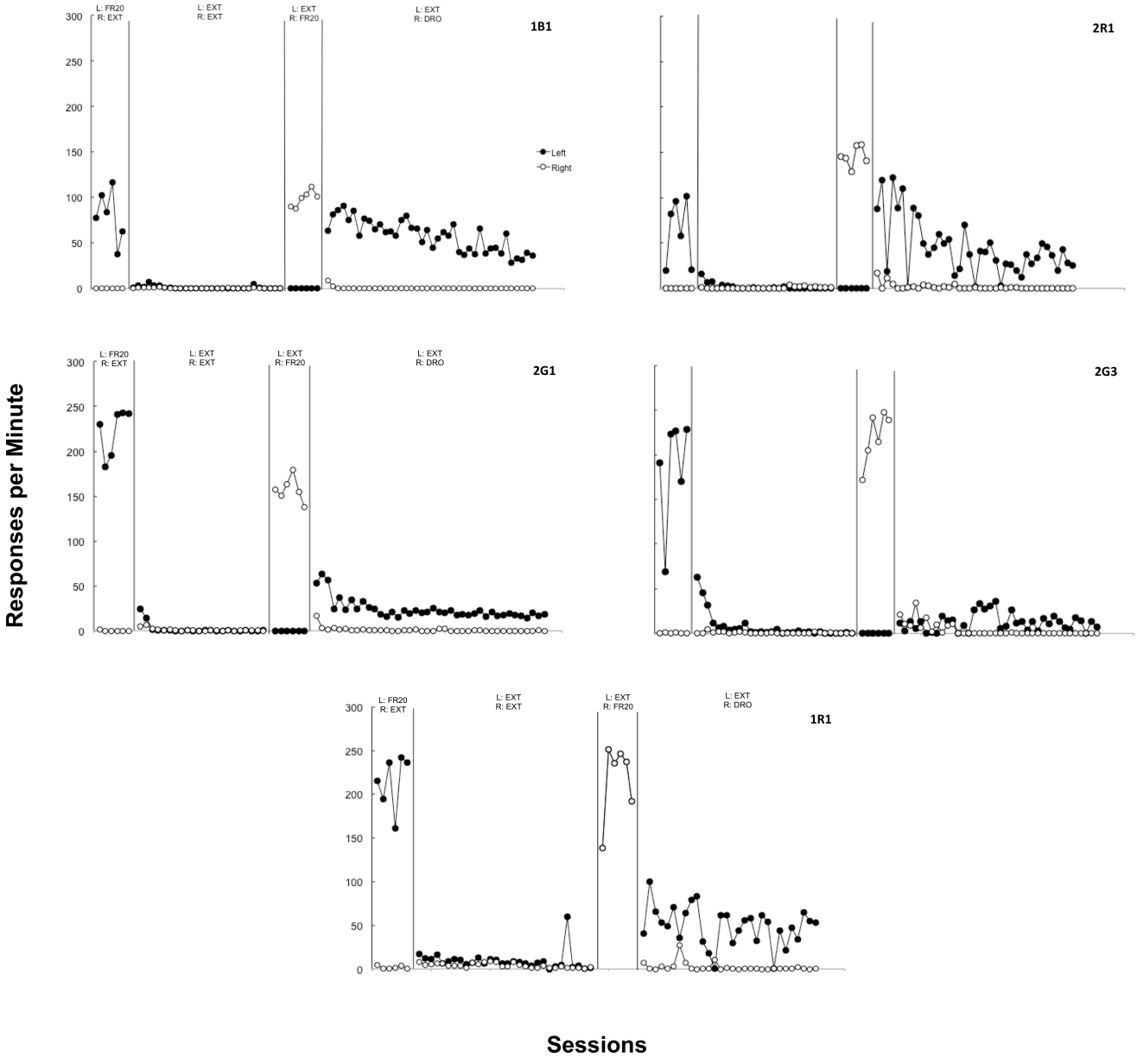

Figure 1. Responses per minute across all phases of the study.

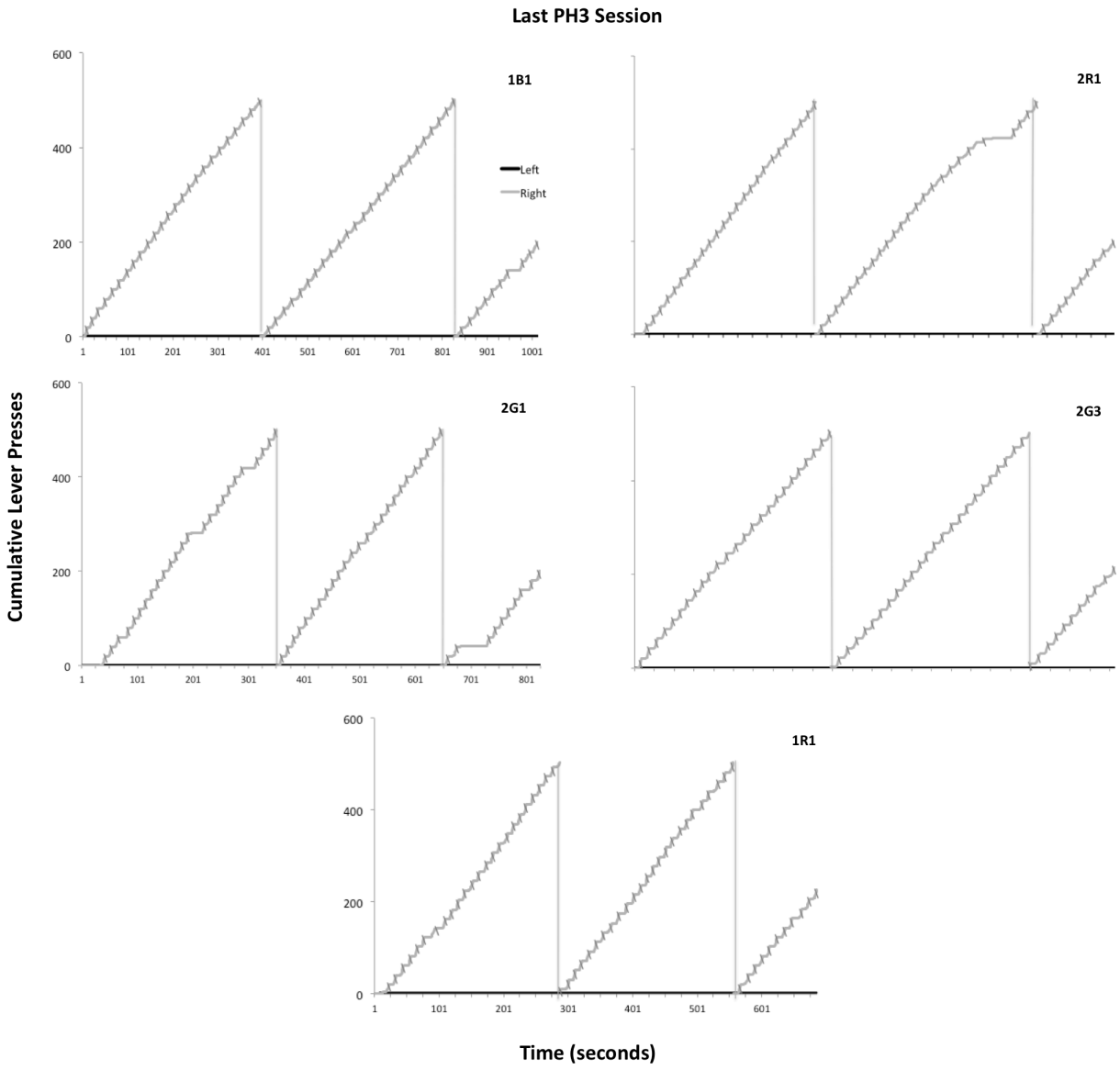

Figure 2. Cumulative lever presses per 1-second bins for the final session of Phase 3.

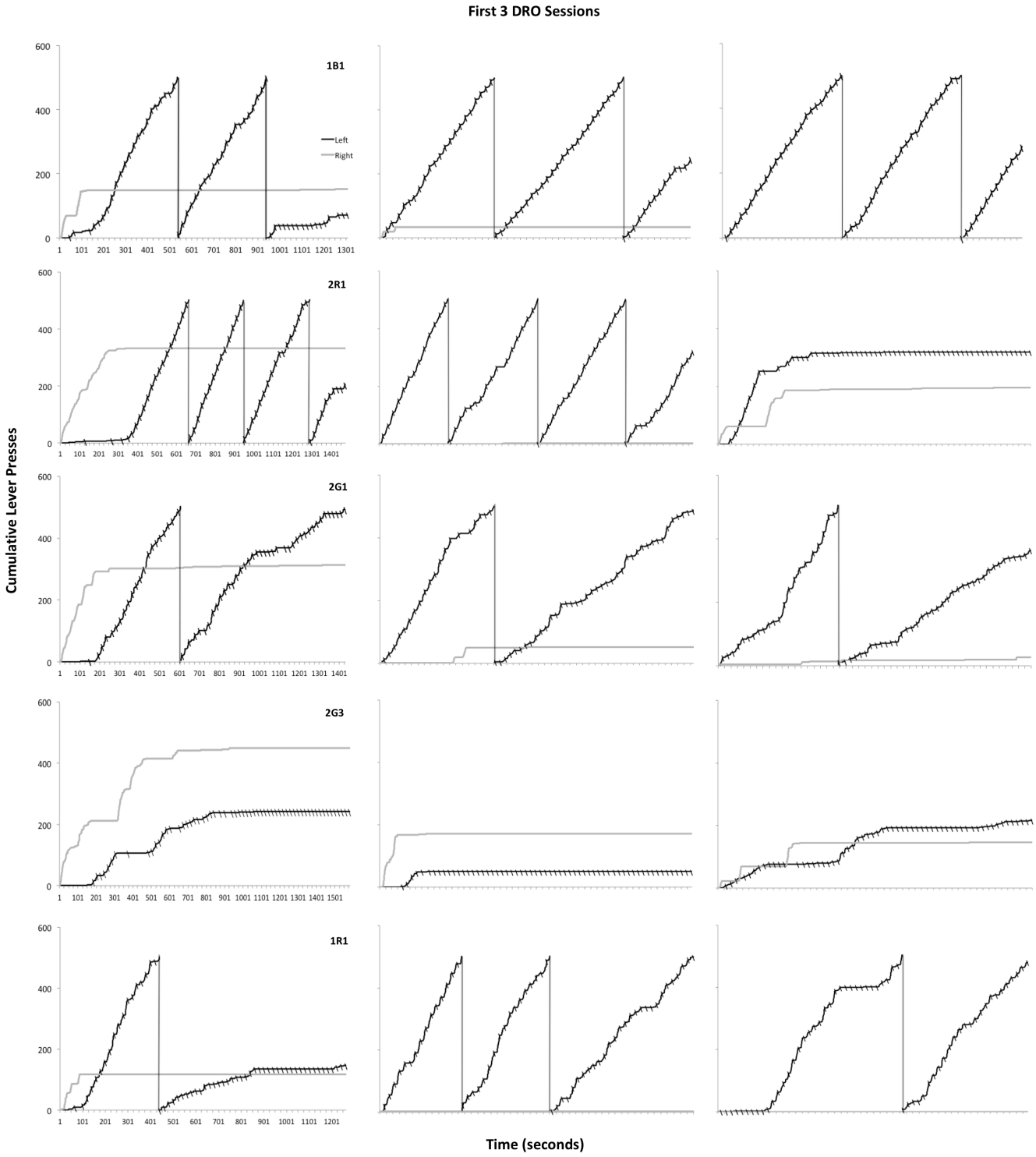

Figure 3. Cumulative lever presses per 1-second bins for the first three sessions of Phase 4.
Note: Pips denoting reinforcement indicate the moments in time when DRO reinforcers were delivered. Although they were not contingent on left lever presses, they are marked on the left lever line to show the relationship between reinforcer delivery and responding on the left lever.

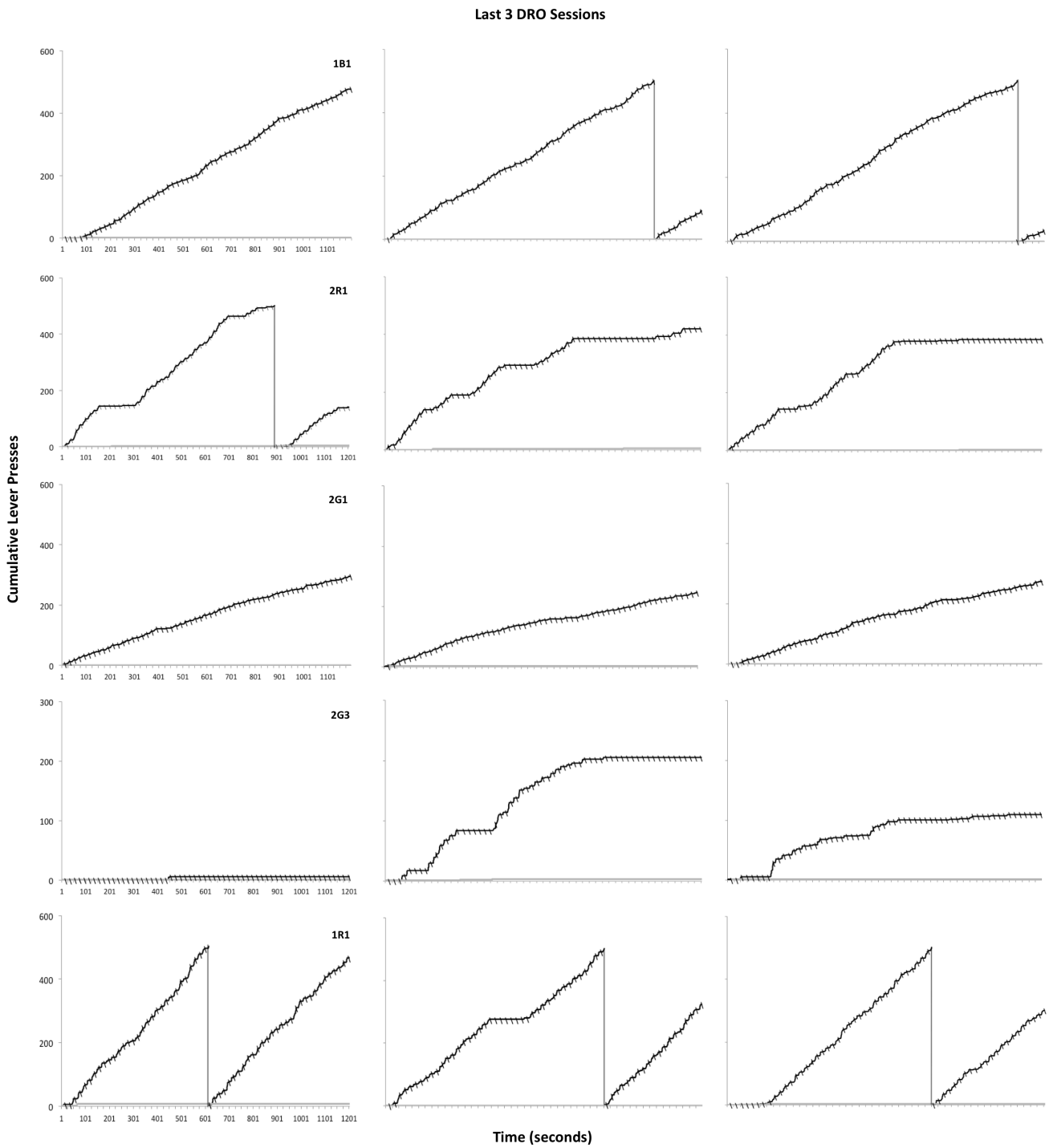

Figure 4. Cumulative lever presses per 1-second bins for the last three sessions of Phase 4. (Note the difference in scale for 2G3.)
Note: Pips denoting reinforcement indicate the moments in time when DRO reinforcers were delivered. Although they were not contingent on left lever presses, they are marked on the left lever line to show the relationship between reinforcer delivery and responding on the left lever.

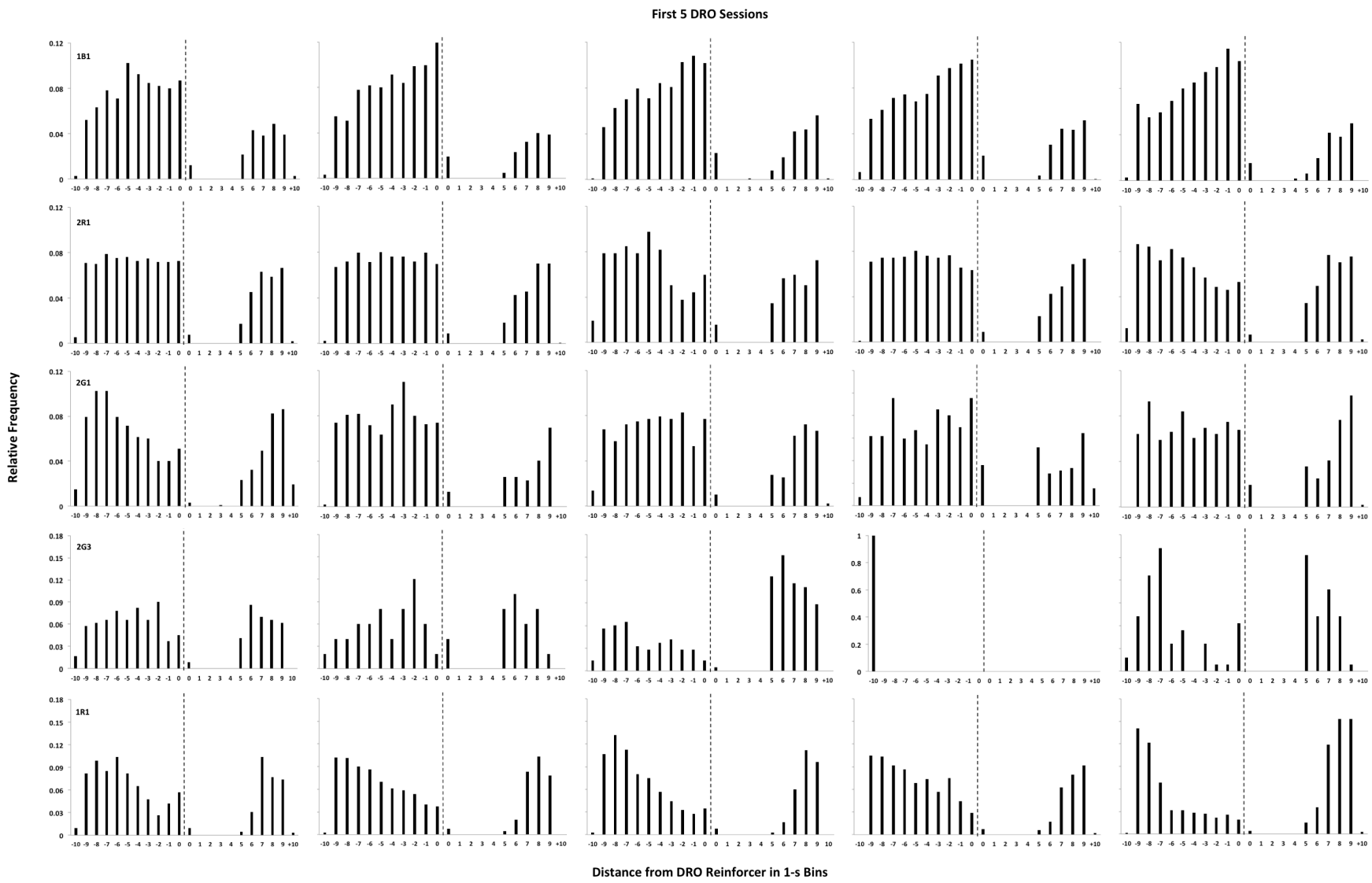

Figure 5. Relative frequency of left lever presses per 1-second bin during the ten seconds before and ten seconds after delivery of the DRO reinforcer in the first five sessions of Phase 4. (Note the different scale for 2G3 and 1R1.)

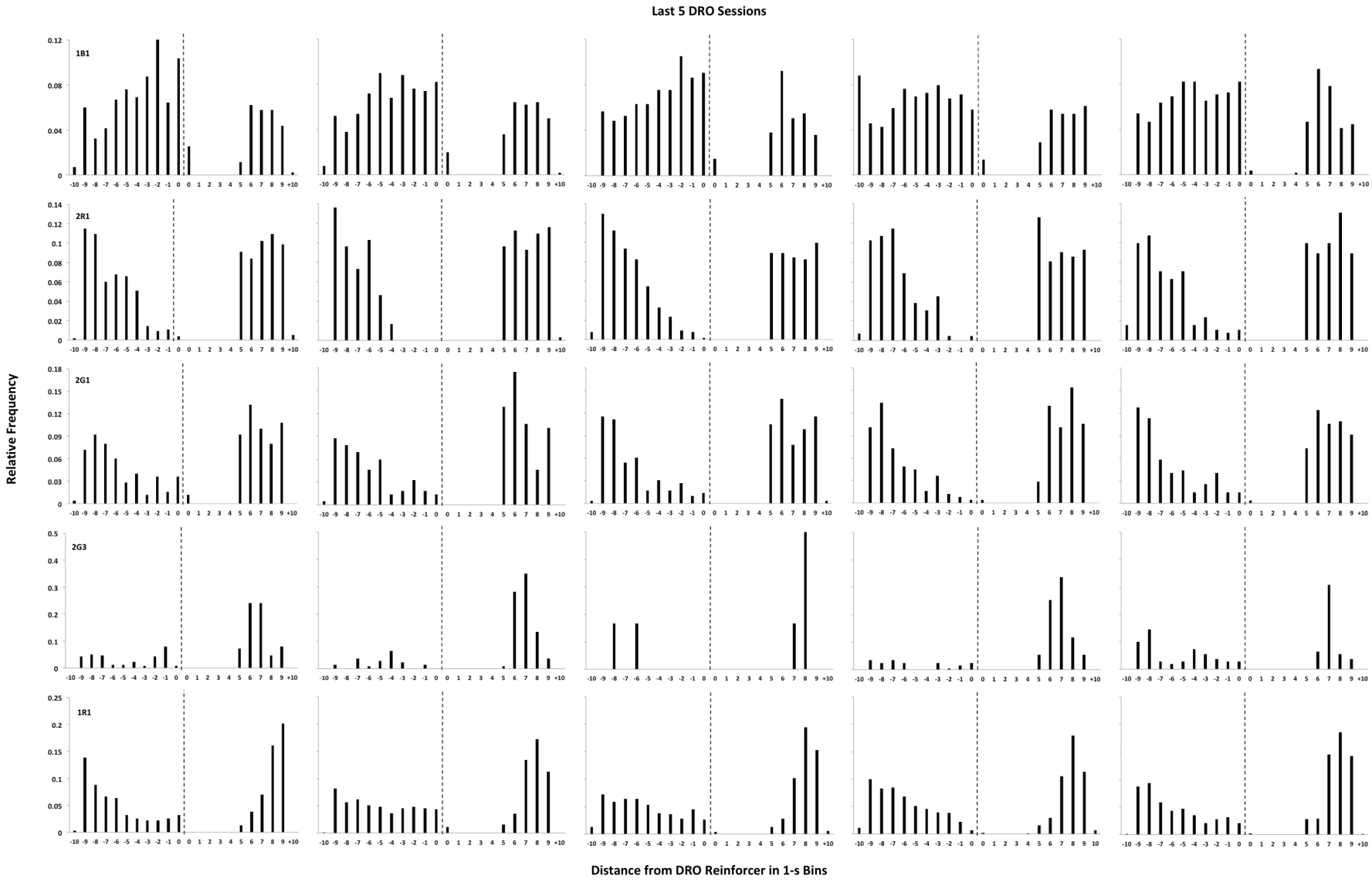

Figure 6. Relative frequency of left lever presses per 1-second bin during the ten seconds before and ten seconds after delivery of the DRO reinforcer in the last five sessions of Phase 4.

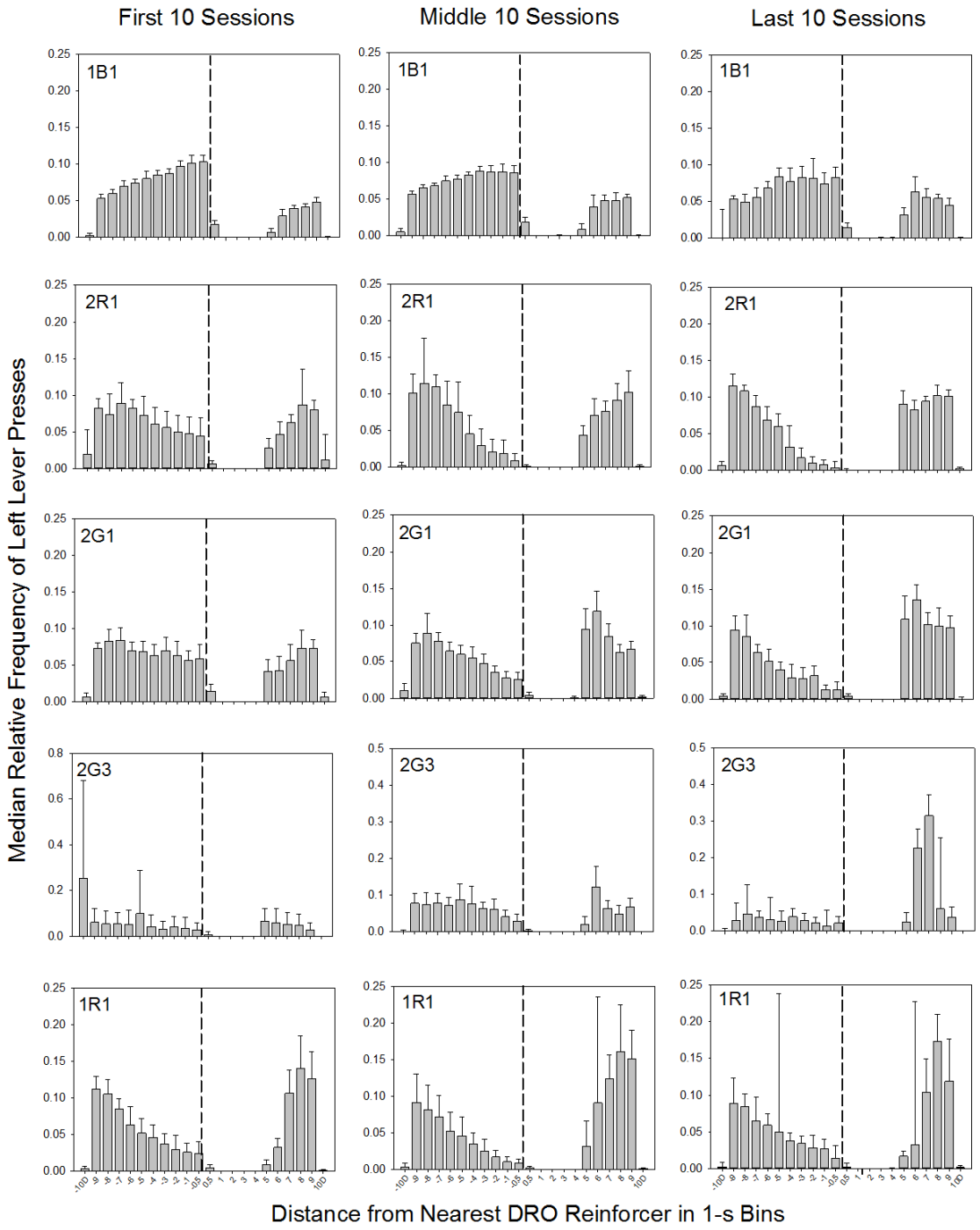

Figure 7. Median Relative Frequency of Left Lever Presses for the first, middle and last 10 sessions of Phase 4 (DRO). (Note the difference in scale for 2G3.)

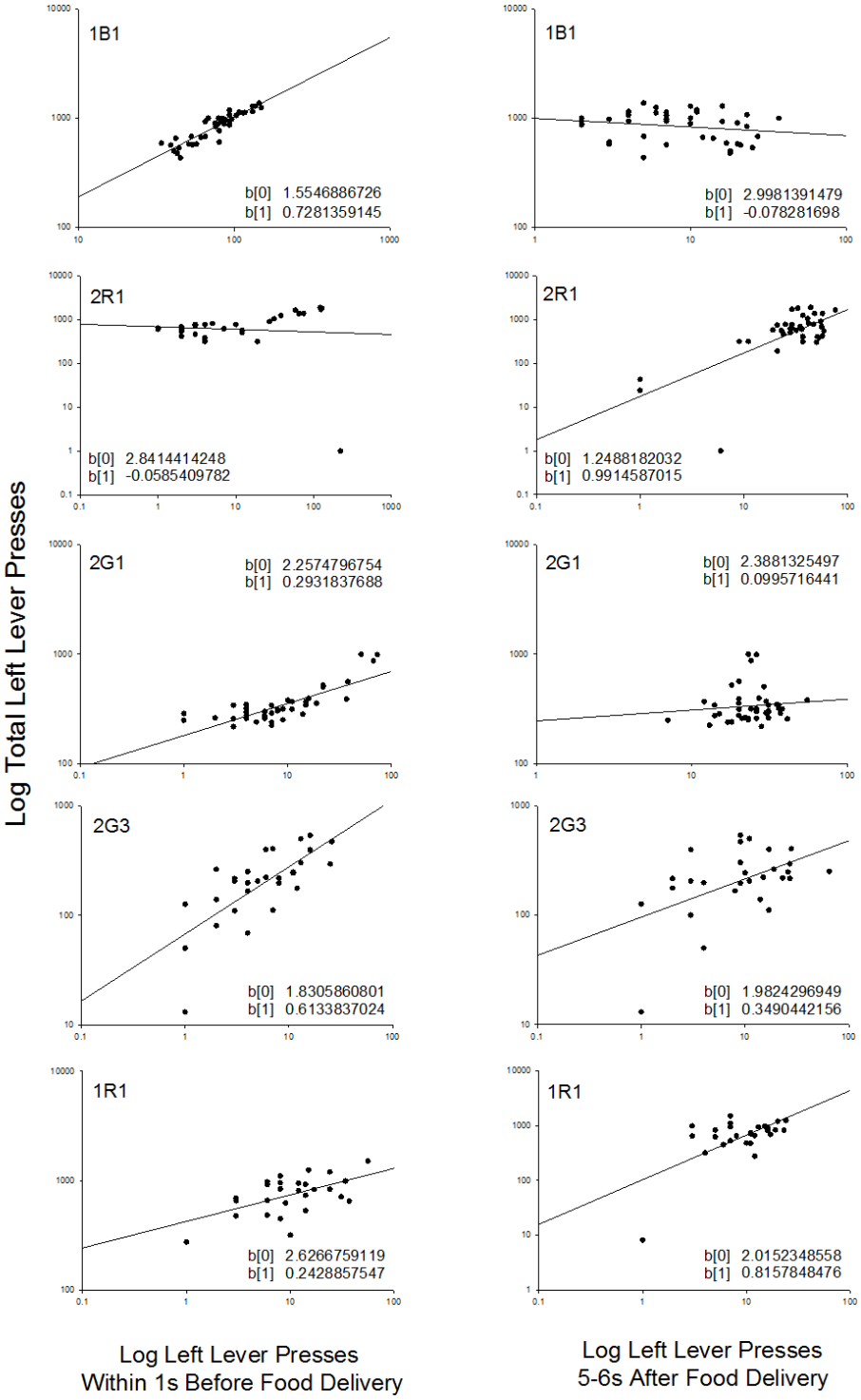

Figure 8. Correlational data between total left lever presses during DRO and left lever presses in the 1-second bin before reinforcer delivery are displayed in the panels on the left. Correlational data between total left lever presses and left lever presses in the 5-6-second bin after reinforcer delivery are displayed in panels on the right. Each data point represents all left lever presses in one Phase 4 session. b[0] indicates the y-intercept, and b[1] indicates the slope.

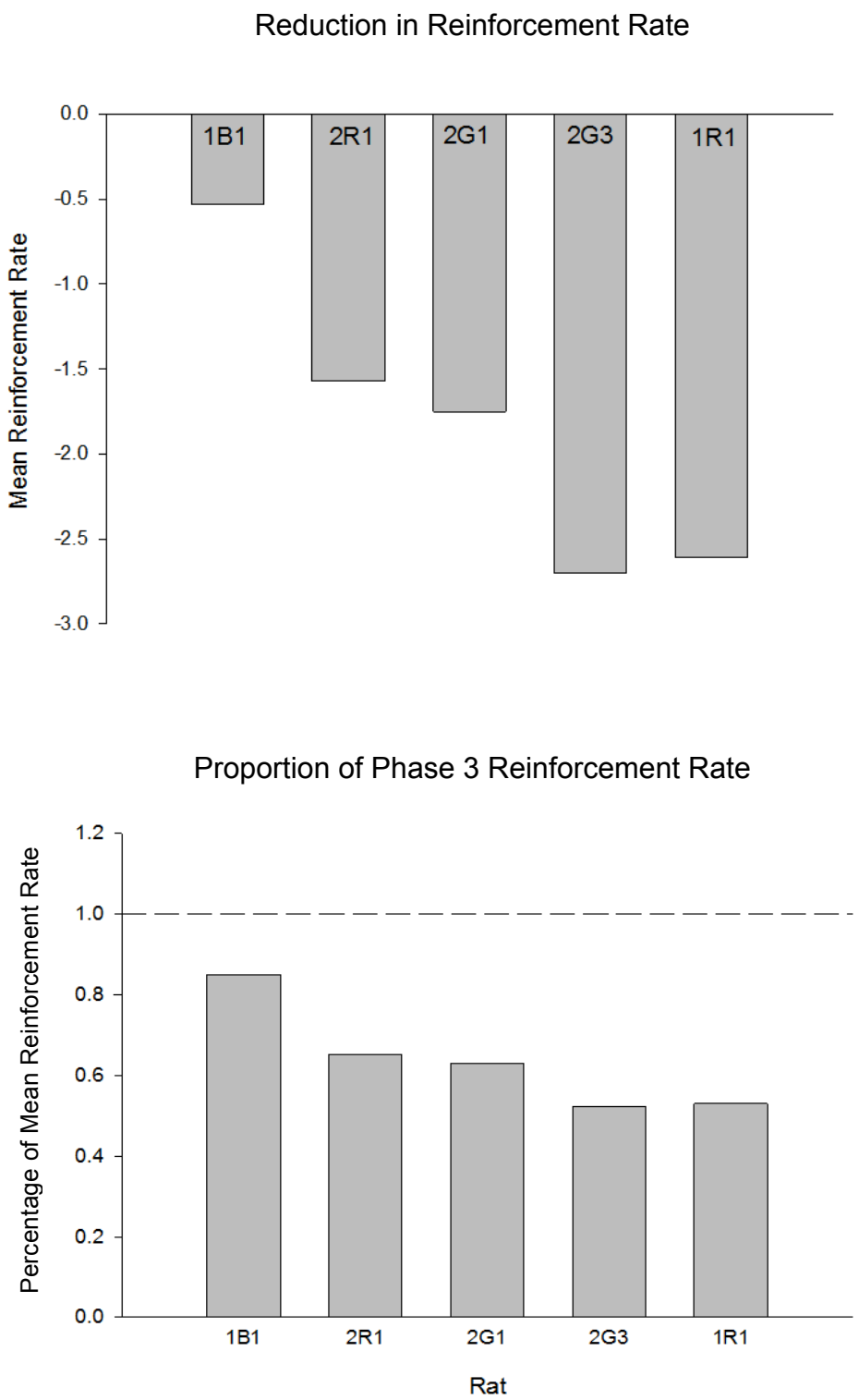

Figure 9. The top panel displays the reduction in reinforcement rate between the mean of the last six sessions of Phase 3 and the mean of the first ten sessions of Phase 4. The bottom panel displays the same sessions' mean Phase 4 reinforcement rates divided by the Phase 3 reinforcement rates.

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