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Resurgence of Temporal Patterns of Responding

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Abstract

Resurgence of Temporal Patterns of Responding

Carlos Renato Xavier Cançado

The resurgence of temporal patterns of key pecking by pigeons was studied in two experiments. In Experiment 1, positively accelerated and linear patterns of responding were established under a discrete-trial multiple fixed-interval (FI) variable-interval (VI) schedule. Subsequently, responding on a different key produced reinforcers according to a VI schedule. When extinction was in effect, resurgence of previously established temporal patterns was observed for each pigeon. That is, positively accelerated and linear patterns recurred in the presence of the stimuli previously correlated with the FI and VI components of the multiple schedule, respectively – suggesting that these temporal patterns, although not directly reinforced, functioned as behavioral units. In Experiment 2, resurgence was assessed after positively accelerated patterns of responding were directly reinforced. Responding was reinforced only if the patterns approximated a predetermined temporal distribution of responses. Resurgence of previously reinforced patterns occurred for each pigeon and for 2 of 3 pigeons during a replication of the procedure. Although variability in patterns increased during the resurgence phases in Experiment 2, those patterns that occurred most frequently when reinforcement was in effect occurred at a higher relative frequency during extinction. These results (a) demonstrate the resurgence of temporally defined complex operants, (b) replicate and extend previous findings on resurgence of spatially defined operants, and (c) are discussed as they contribute to understanding the selection and recurrence of more complex behavioral units.

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Table of Contents

Abstract ii

Acknowledgements iii

List of Tables v

List of Figures vi

Introduction 1

Literature Review 2

- Discrete-Response Resurgence 2
- Resurgence of Spatially Organized Responding 6
- Temporally Defined Response Units 8

Statement of the problem 10

Experiment 1 13

- Method 14
  - Subjects 14
  - Apparatus 14
  - Procedure 15
- Results and Discussion 18

Experiment 2 32

- Method 32
  - Subjects 32
  - Apparatus 33
  - Procedure 33
- Results and Discussion 38

General Discussion 51

References 59

Appendix 65

List of Tables

Table 1. Schedules of Reinforcement, Stimulus Conditions and Number of Sessions, for Each Pigeon, on Each Phase of Experiment 1 16

Table 2. Schedules of Reinforcement and Number of Sessions, for Each Pigeon, on Each Phase of Experiment 2....................35

List of Figures

Figure 1. Responses per minute during each schedule component for the last 10 sessions of training and all sessions of response elimination and resurgence phases of Experiment 1 20

Figure 2. Reinforcers per minute during each schedule component for the last 10 sessions of training and all sessions of response elimination and resurgence phases of Experiment 1 21

Figure 3. Cumulative response distributions in 0.25-s bins for each pigeon in Experiment 1. Each panel shows, from upper to lower diagonal, distributions for the last six sessions of training and response elimination, and all sessions of the resurgence phase during FI (black) and VI (grey) components. Phases are separated by white lines in the horizontal plane on each panel ..24

Figure 4. Cumulative response distributions in 0.25-s bins for each pigeon in Experiment 1. Each panel shows, from upper to lower diagonal, distributions for all sessions of the resurgence phase. Other details as in Figure 3 25

Figure 5. Overall quarter-life values during each schedule component for the last six sessions of training and the first six sessions of the resurgence phase of Experiment 1.................................28

Figure 6. Median latency (seconds) for the occurrence of the first center-key response within a trial, during each schedule component. Latencies are shown for the last 10 sessions of training and the first 10 sessions of the resurgence phase of Experiment 1. Error bars extend from the 25th to the 75th percentile...29

Figure 7. Cumulative response distributions in 0.25-s bins for each pigeon in Experiment 1. Each panel shows, from upper to lower diagonal, right-key response distributions for all sessions of the resurgence phase. Other details as in Figure 3 30

Figure 8. Responses per minute during the last 10 sessions of training and response elimination, and all sessions of the resurgence phase of Experiment 2. For each pigeon, data are shown for the first and second exposures to each phase...40

Figure 9. Proportion of reinforced trials for the last 10 sessions of training and response elimination of Experiment 2. For each pigeon, data are shown for the first and second exposures to each phase 41

Figure 10. Cumulative response distributions in 0.5-s bins for each pigeon during the first exposure (left panels) and replication (right panels) of each phase of Experiment 2. Each panel shows, from upper to lower diagonal, distributions for the last six sessions of training and response elimination, and the first 15 sessions of the resurgence phase. Phases are separated by white lines in the horizontal plane on each panel 42

Figure 11. Overall quarter-life values for the last 10 sessions of training and the first 10 sessions of the resurgence phase of Experiment 2. For each pigeon, data are shown for the first exposure and replication of each phase 45

Figure 12. Median latency (seconds) for the occurrence of the first response within a trial during the first exposure (left panels) and replication (right panels) of each phase of Experiment 2. Each panel shows latencies for the last 10 sessions of training and the first 10 sessions of the resurgence phase. Error bars extend from the 25th to the 75th percentile.....................................46

Figure 13. Proportion of reinforced patterns for the last six sessions of training and response elimination, and the first six sessions of the resurgence phase of Experiment 2. For each pigeon, data are shown for the first exposure and replication of each phase 49

Figure 14. Relative frequency distribution of each class of patterns (from most to least frequent) for the last six sessions of training (closed circles) and the first six sessions of the resurgence phase (open circles), during the first exposure to each phase of Experiment 2............................52

Figure 15. Relative frequency distribution of each class of patterns (from most to least frequent) for the last six sessions of training (closed circles) and the first six sessions of the resurgence phase (open circles), during the replication of each phase of Experiment 2 53

Figure A1. Cumulative response distributions (hypothetical data) in 1-s sub-intervals of a 5-s trial, showing the pattern described by Hawkes and Shimp's (1975) model. Also shown are the deviations from this model that defined reinforcement contingencies for Pigeons 617 and 955 (upper panel) and Pigeon 119 (lower panel) during the first exposure and replication of each phase of Experiment 2 67

Introduction

Resurgence is the occurrence of previously reinforced responding when current responding is extinguished (da Silva, Maxwell & Lattal, 2008; Doughty, da Silva & Lattal, 2007; Epstein, 1983, 1985). It typically is studied by arranging a sequence of three experimental phases (Lieving & Lattal, 2003). In the first phase (hereafter, *training*), responding of a given form is reinforced (e.g., a pigeon's key pecking). In the second phase (hereafter, *response elimination*), an alternative form of responding is reinforced (e.g., not pecking or pecking a different key), and reinforcement of the first response is discontinued. In the third phase (hereafter, *resurgence*), extinction of the first response continues and reinforcement of the alternative response is discontinued. During this last phase, resurgence is defined as an increase in the occurrence of previously reinforced (i.e., training) responding, relative to its rate of occurrence during the response elimination phase (da Silva et al.; Epstein, 1983).

Doughty and Oken (2008) suggested that resurgence is a refined description of extinction-induced behavior, because responses predicted to occur in extinction are those previously reinforced under similar stimulus conditions. The study of resurgence, then, could add to behavior-analytic accounts of phenomena observed when a change in contingencies leads to periods of no reinforcement, such as problem solving (Epstein, 1996; Shahan & Chase, 2002), clinical relapse (e.g., of problem behavior and of drug-maintained behavior; Lieving, Hagopian, Long & O'Connor, 2004; Podlesnik, Jimenez-Gomez & Shahan, 2006; Volkert, Lerman, Call & Trosclair-Lasserre, 2009) and extinction-induced variability (Kinloch, Foster & McEwan, 2009; Morgan & Lee, 1996).

Most analyses of resurgence have focused on discrete responses (e.g., key pecking by pigeons and lever pressing by rats; da Silva et al., 2008; Doughty et al., 2007; Epstein, 1983;

Epstein & Skinner, 1980; Lieving & Lattal, 2003; Podlesnik & Shahan, 2009; Reed & Morgan, 2007) but studies also have been conducted to assess the resurgence of more complex operants (Bachá-Mendez, Reid, & Mendoza-Soylovna, 2007; Reed & Morgan, 2006; Sánchez-Carrasco & Nieto, 2005). In the latter studies, complex operants were defined as *spatial* response sequences (i.e., sequences of discrete responses across two or more operanda; e.g., Schwartz, 1981, 1986) and the spatial organization of discrete responses defined the behavioral unit of interest.

In the study of complex operants thus defined, of interest is how contingencies of reinforcement affect sequences of discrete responses as a whole (e.g., Schwartz, 1982, 1988). Similarly, of interest in the study of resurgence of complex operants is if response sequences recur as integrated behavioral units (e.g., Bachá-Mendez et al., 2007). The resurgence of other forms of complex operants (e.g., the temporal organization of responding), however, has not been previously studied. In what follows, a review of previous results of both types of analyses of resurgence (i.e., discrete-response resurgence and resurgence of spatially organized responding) is presented. It is followed in turn by the statement of the research problem addressed by the present experiments, the resurgence of temporal patterns of responding, and the presentation and discussion of the main results.

Literature Review

Discrete-Response Resurgence

Much of what is known about the controlling variables of resurgence comes from studies in which discrete responses were analyzed. In addition to establishing that resurgence is a repeatable phenomenon (i.e., it occurs even after repeated exposures of the same organism to each phase of the experimental procedure used to assess resurgence; Lieving & Lattal, 2003), the results of these studies have demonstrated that the occurrence and magnitude of resurgence are affected by variables operative during training, response elimination and resurgence phases (for reviews, see Doughty & Oken, 2008; and Lattal & St. Peter Pipkin, 2009). More specifically, the characteristics of responding established during training and response elimination, and reinforcement rates during these phases have been shown to affect resurgence (da Silva et al., 2008; Doughty et al., 2007; Epstein, 1983; Lieving & Lattal, 2003; Podlesnik & Shahan, 2009; Reed & Morgan, 2007).

In general, more resurgence is observed when responding during training occurs at higher rates (da Silva et al., 2008; Reed & Morgan, 2007) and is maintained by higher rates of reinforcement (Podlesnik & Shahan, 2009; but see da Silva et al., Experiment 3). In a series of experiments, da Silva et al. systematically manipulated both variables. In their Experiment 2, pigeons were exposed to concurrent tandem variable-interval (VI) fixed-ratio (FR) tandem VI differential-reinforcement-of-low-rate (DRL) schedules of reinforcement in the training phase. This ensured that differential response rates were obtained while reinforcement rates were equated across components. When extinction was in effect, more resurgence occurred in the component previously correlated with high rates of responding (tandem VI FR), as assessed by absolute measures (i.e., responses per minute). When responding in each component was assessed as a proportion of responding during the training phase, however, no systematic differences in resurgence were observed between components. Similar results were obtained by Reed and Morgan (2007). In their study, groups of rats were initially exposed to multiple random-ratio (RR) random-interval (RI) schedules (Experiment 1) and to multiple DRL differential-reinforcement-of-high-rate (DRH) schedules (Experiment 2). During the resurgence phase, more responding occurred in the presence of the stimuli previously correlated with schedules that maintained higher response rates during training (RR and DRH schedules, respectively).

Mixed findings have been reported on the effects of previous reinforcement rates arranged during training and response elimination on subsequent resurgence. Da Silva et al. (2008; Experiment 3), exposed pigeons to concurrent tandem VI DRL tandem VI DRH schedules during training. Schedule parameters were arranged so almost equal response rates were obtained in each schedule component, while reinforcement rates were systematically manipulated across components. Resurgence was not systematically related to differences in training reinforcement rates. Da Silva et al. suggested that response rates were, consequently, better predictors of resurgence than reinforcement rates. Podlesnik and Shahan (2009), in contrast, reported that reinforcement rates during training can affect resurgence. Pigeons were exposed to a multiple VI 120-s VI 120-s schedule during training, and additional food-deliveries were arranged during one component according to a variable-time (VT) schedule of reinforcement. Measured as proportion of baseline responding, more resurgence was obtained in the component that arranged higher reinforcement rates (i.e., with the added VT schedule).

Although da Silva et al. (2008) suggested that previous response rates are better predictors of resurgence than previous reinforcement rates, they also indicated that resurgence might be a function of both variables. According to the authors, previous reinforcement rates would determine the occurrence of resurgence while the contingencies in effect during training would affect the structure of responding that resurges. In addition to being a question of interest per se, the fact that the concurrent resurgence of responding that differs in structure (da Silva et al.) can occur should be taken into account when there is an interest in analyzing the effects of other variables (e.g., relative reinforcement rate) on resurgence. This would clarify interpretations of the occurrence and magnitude of resurgence based on relative (e.g., responding on resurgence phase sessions as a proportion of training responding) or absolute measures of behavior (e.g., responses per unit time) by specifying which behavioral units were selected under a given set of contingencies of reinforcement (Zeiler, 1977, 1986) and, thus, which units are expected to recur. Also as indicated by da Silva et al., differential resurgence in absolute terms (e.g., the high and low rates of key pecking observed, respectively, in the components previously correlated with tandem VI FR and tandem VI DRL in their Experiment 2) can reflect the recurrence of different operants, not of the same operant occurring at different rates.

During the response elimination phase, scheduling reinforcers for alternative responding that is topographically different from that established during training produces relatively more resurgence than when both forms of responding are similar. In a series of experiments with pigeons, Doughty et al. (2007) examined the effects of different response elimination procedures on the onset and magnitude of resurgence. Resurgence of key pecking previously maintained under multiple VI 30-s VI 30-s schedules was greater and occurred sooner when a differential-reinforcement-of-other-behavior (DRO) schedule was arranged in one component, relative to pecking a different key under a VI schedule in the other component of the multiple schedule. In addition, no systematic differences in resurgence were obtained when both a DRO and a VI schedule correlated with treadle pressing were arranged as each schedule component during the response elimination phase (Experiment 4).

In general, the conditions in effect during the resurgence phase consist of arranging extinction for responding established during the response elimination phase. Lieving and Lattal (2003) used, in addition to extinction, schedules of response-dependent and response-independent reinforcement – respectively, VI (Experiment 4) and VT schedules (Experiment 3) arranging an overall reduction in reinforcement rates relative to the response elimination phase. Resurgence was observed under extinction and under VI schedules with reduced reinforcement rates, but the effects were not systematic under VT schedules. Thus, in addition to a given history of reinforcement established during training (i.e., which establishes responding that eventually resurges; Epstein, 1983; da Silva et al., 2008; Experiment 1), more extended or local periods in which reinforcement is withheld seem to be necessary conditions for the occurrence of resurgence (Lieving & Lattal).

Resurgence of Spatially Organized Responding

Although the study of resurgence has focused on the analysis of discrete responses, such as key pecking by pigeons or lever pressing by rats (e.g., da Silva et al., 2008; Doughty et al., 2007; Epstein, 1983; Epstein & Skinner, 1980; Lieving & Lattal, 2003; Reed & Morgan, 2007), the resurgence of response sequences on two or more operanda also has been assessed (Bachá-Mendez, et al., 2007; Carey, 1951; Reed & Morgan, 2006; Sánchez-Carrasco & Nieto, 2005). These studies extend previous analyses of resurgence in terms of discrete responses, with implications for understanding the processes of selection and maintenance of more complex patterns of responding.

The resurgence of spatial response sequences was studied systematically by Sánchez-Carrasco and Nieto (2005), in an experiment conducted with rats. Two groups of rats initially were trained to emit three-lever press sequences across two levers (right-left-right or right-left-left sequences). During response elimination, a different response sequence (a left-left-left sequence, for both groups) was reinforced. In the resurgence phase, an increase in sequence variability was observed for both groups, but the response sequences that were reinforced during training occurred at a higher frequency in relation to other sequences. In addition to demonstrating the resurgence of a complex operant, their results empirically established some relations between resurgence and extinction-induced variability. That is, part of the behavioral variability observed when extinction was in effect could be accounted for by the resurgence of previously reinforced response sequences and, thus, by the rats' behavioral history (Lieving & Lattal, 2003; see also Lee & Morgan, 1996; Neuringer, Kornell, & Olufs, 2001)

Bachá-Mendez et al. (2007) replicated the results of Sánchez-Carrasco and Nieto (2005; see also Reed & Morgan, 2006) in two experiments in which rats were trained to emit homogeneous (right-right or left-left) or heterogeneous (right-left or left-right) two-lever press response sequences in a discrete-trial procedure. In Experiment 1, heterogeneous sequences were established before (first and second phases) homogeneous sequences (third and fourth phases). In Experiment 2, transitions from heterogeneous to homogeneous sequences were arranged across phases. In both experiments, reinforcement of a given sequence was scheduled concurrently with the extinction of all previously trained sequences, which yielded a condition for assessing resurgence when two (third phase) or three (fourth phase) response sequences had been previously reinforced. Resurgence of homogeneous and heterogeneous sequences was observed for each rat in Experiments 1 and 2.

Bachá-Mendez et al. (2007) suggested that the occurrence of previously reinforced sequences in extinction could indicate that the sequences were established as integrated behavioral units, and also that the resurgence procedure could be used to further study the selection and recurrence of these complex operants. That is, in addition to demonstrating that a given form of responding is a functional, or conditionable, unit of behavior – i.e., varying in frequency of occurrence as changes in contingencies of reinforcement are effected (Zeiler, 1977)

– the occurrence of previously reinforced responding during extinction could serve as an additional test to assess the establishment of behavioral units.

The study of resurgence of complex operants has focused exclusively on the analysis of spatially defined response sequences (Bachá-Mendez et al., 2007; Reed & Morgan, 2006; Sánchez-Carrasco & Nieto, 2005; but see Carey, 1951). Although it has been suggested that the organization of discrete responses in time can function as a behavioral unit (Hawkes & Shimp, 1975, 1998; Shimp, 1979; Wasserman, 1977), the resurgence of complex operants defined as temporal patterns of responding has not been systematically studied.

Temporally Defined Response Units

Characteristic distributions of responses in time are consistently established as a function of temporal criteria for reinforcement (Ferster & Skinner, 1957; Shull, 1970; Shull, Guilkey & Witty, 1972, Zeiler, 1968, 1977). After extended exposure to FI schedules, for example, interreinforcer-interval (IRI) behavior consists of pauses followed by an increasing rate of responding until the next reinforcer is produced. It has been suggested that this pattern of responding might be strengthened as a unit under such schedules (Dews, 1970; Hawkes & Shimp, 1975; Zeiler, 1977; but see Zeiler, 1979), even though reinforcement is not contingent on the occurrence of the patterns. This reasoning could be extended to other schedules (e.g., VI schedules of reinforcement, which generate a constant rate of responding during the IRI) in which temporal criteria for reinforcement are in effect.

Temporally organized responding also has been reinforced directly. Hawkes and Shimp (1975) exposed pigeons to a discrete-trial procedure in which reinforcement was contingent on positively and negatively accelerated patterns of responding. The patterns were defined based on a model which specified a constant rate of change in rate of key pecking during each 5-s trial (0, 1, 2, 3 and 4 responses occurring at each 1-s subinterval of a trial was the model for positively accelerated patterns; negatively accelerated patterns were modeled by requiring 4, 3, 2, 1 and 0 responses in each 1-s subinterval). The criterion for reinforcement was based on how much the obtained patterns deviated from the models and as it was made successively more stringent, the frequency of patterns that approximated the models increased systematically. Using the same procedure, Hawkes and Shimp (1998) extended these results by reinforcing pausing (i.e., not responding) and linear patterns of responding (i.e., responding at constant rates during each 1-s subinterval). The authors suggested that, under such conditions, the temporal patterns were established as behavioral units.

Wasserman (1977) also reported the direct reinforcement of temporal patterns of key pecking by pigeons. As in the studies by Hawkes and Shimp (1975, 1998) a discrete-trial procedure was used and reinforcers were contingent on the occurrence of pauses and at least one key peck across 4-s subintervals of an 8-s trial (e.g., positively accelerated patterns were defined as the emission of responses during the first 4-s subinterval and no responses during the last 4-s subinterval of a trial). Positively and negatively accelerated patterns of responding were systematically observed under these conditions. The occurrence of these patterns was not a function of reinforcers being scheduled at the end of trials, but of the contingencies in effect (i.e., the direct reinforcement of patterns). In a control condition, when reinforcers depended on at least one response within the trial, with no requirement of when responses should occur, patterning was variable and not as systematic as those observed when requirements for pausing and responding were in effect.

Previous studies have supported the fact that rate of responding is determined by the dependency between responses and reinforcers, while the pattern of responding is determined by the distribution of reinforcers in time (Lattal, 1974; Lattal & Abreu-Rodrigues, 1997; Lattal & Bryan, 1976; Zeiler, 1968). Although the establishment of temporal patterns as behavioral units can be inferred from the results of such studies (i.e., their occurrence when response-dependent and response-independent reinforcement is in effect), additional tests, such as resurgence tests, are necessary because mere occurrence does not qualify a given pattern of responding as a functional unit (Zeiler, 1977). Hawkes & Shimp (1975, 1998) and Wasserman (1977) are more conclusive in this respect because reinforcers were contingent on the occurrence of specific patterns, which varied in frequency as contingencies of reinforcement were changed.

In a seminal study, Carey (1951) assessed the recurrence of different sequences of lever presses by rats. Groups of rats were exposed initially to two conditions, in which reinforcers were contingent on lever presses with interresponse times (IRT) ≤ 0.25-s (double lever-press training) or on the occurrence of a single lever press (single lever-press training). The order of exposure to each condition was manipulated across groups. Rats of one group were exposed first to the double and then to single lever-press training, while the order of conditions was reversed for the rats in the other group. When extinction was in effect, recently reinforced responding occurred consistently for both groups. With extended exposure to extinction, an increased frequency of previously reinforced responding (i.e., resurgence of double or single lever presses) was observed.

Statement of the problem

The occurrence of previously reinforced responding when reinforcement for current responding is withheld, or resurgence (Doughty, et al., 2007; Epstein, 1983, 1985), has been reported when both discrete responses (e.g., key pecking by pigeons or lever pressing by rats; da Silva et al., 2008; Doughty et al.; Epstein, 1983; Epstein & Skinner, 1980; Lieving & Lattal, 2003; Reed & Morgan, 2007) and spatially organized complex operants (i.e., response sequences on two or more operanda; Bachá-Mendez et al., 2007; Reed & Morgan, 2006; Sánchez-Carrasco & Nieto, 2005) have been studied.

Results of studies in which the resurgence of discrete responses has been assessed indicate that, in general, the occurrence and magnitude of resurgence are affected by previously established response rates and reinforcement rates. That is, more resurgence is observed when responding during training occurs at higher rates (da Silva et al.; Reed & Morgan, 2007) and is maintained by higher rates of reinforcement (Podlesnik & Shahan, 2009; but see da Silva et al., Experiment 3). In addition, more resurgence occurs when, during the response elimination phase, responding that is topographically different from previously reinforced responding is selected (Doughty et al., 2007). Finally, more extended or local periods in which reinforcement is withheld seem to be necessary conditions for the occurrence of resurgence (Lieving & Lattal, 2003).

Although the study of resurgence has focused on the analysis of discrete responses (e.g., Doughty et al., 2007; Lieving & Lattal, 2003; Reed & Morgan, 2007), the studies of resurgence of response sequences (Sánchez-Carrasco & Nieto, 2005) extend previous analysis of discrete-response resurgence, with implications for understanding the processes of selection and recurrence of more complex behavioral units. Of interest in the study of resurgence of complex operants is whether previously reinforced response sequences recur as *integrated* behavioral units (e.g., Bachá-Mendez et al., 2007; Schwartz, 1982, 1988).

This, in turn, has been a common finding in studies of resurgence of spatial response sequences (e.g., Bachá-Mendez et al., 2007; Sánchez-Carrasco & Nieto, 2005). Bachá-Mendez et al. (2007) suggested that the resurgence of previously reinforced sequences could indicate that past contingencies of reinforcement actually selected those sequences of discrete responses as integrated behavioral units. That is, in addition to demonstrating that a given form of complex responding is a functional unit of behavior (Zeiler, 1977) the resurgence of response sequences could serve as an additional test to assess the establishment of more complex behavioral units.

The study of resurgence of complex operants, however, has focused exclusively on the analysis of spatially defined response sequences (Bachá-Mendez et al., 2007; Reed & Morgan, 2006; Sánchez-Carrasco & Nieto, 2005). Although it has been suggested that the organization of discrete responses in time can also function as a behavioral unit (Hawkes & Shimp, 1975, 1998; Shimp, 1979; Wasserman, 1977), the resurgence of complex operants defined as temporal patterns of responding has not been systematically studied (but see Carey, 1951).

As previously indicated, characteristic distributions of responses in time are consistently established as a function of temporal criteria for reinforcement (e.g., in FI schedules of reinforcement; Ferster & Skinner, 1957; Shull, 1970; Shull, et al., 1972; Zeiler, 1968, 1977), and temporally organized responding also has been reinforced directly (Hawkes & Shimp, 1975, 1998; Wasserman, 1977). Hawkes and Shimp (1975), for example, exposed pigeons to a discrete-trial procedure in which reinforcement was contingent on positively and negatively accelerated patterns of responding. After extended exposure to the contingencies of reinforcement, positively and negatively accelerated patterns were consistently observed.

The purpose of the present study was to assess the resurgence of complex operants defined as *temporal patterns of responding*. The demonstration of resurgence of temporal patterns would extend the analysis of resurgence of complex operants to the organization of responses in time, with implications for understanding how such patterns can be established as behavioral units and under which conditions they recur. The resurgence of temporal patterns of responding could have implications for how resurgence is measured (i.e., the occurrence and magnitude of resurgence are generally assessed in terms of absolute measures, such as responses per minute; da Silva et al., 2008; Podlesnik & Shahan, 2009) when simple or complex operants are the units of analysis – especially if complex units (e.g., response sequences or specific temporal patterns of responding; Hawkes & Shimp, 1975) are established and resurge, but the analysis is conducted as if the units were discrete responses. To these ends, in Experiment 1 of the present study, the resurgence of temporal patterns of responding was assessed after different patterns were established (but were not directly reinforced) under each component of a multiple schedule. In Experiment 2, resurgence was assessed after training phases in which contingencies that directly reinforced temporal patterns of responding were in effect (Hawkes & Shimp, 1975, 1998).

Experiment 1

The question examined in this experiment was whether previously established temporal patterns of responding would resurge in a manner similar to the resurgence observed with discrete responses (Epstein, 1983; da Silva et al., 2008; Doughty et al., 2007). The most common strategy in the analysis of resurgence of complex operants is to establish different responses sequentially (e.g., Bachá-Mendez et al., 2007; Reed & Morgan, 2006; Sánchez-Carrasco & Nieto, 2005). Another strategy, not previously used in the study of resurgence of complex operants, is to train different responses by the same organism simultaneously in the presence of different stimulus conditions (i.e., by arranging a multiple schedule of reinforcement during each phase; Doughty et al., 2007; Freeman & Lattal, 1992; Okouchi, 2003 a, 2003 b; Reed & Morgan, 2007; Sidman, 1960). The latter offers a methodological advantage because a within-subject analysis of resurgence as a function of different independent variables, or different levels of the same independent variable (e.g., establishing different rates of responding or reinforcement in each schedule component; da Silva et al.; Podlesnik & Shahan, 2009) can be more directly performed. In the present experiment, different temporal patterns of responding were established in either component of a multiple schedule. Of interest was whether resurgence would occur differentially in the presence of the stimuli previously correlated with different patterns of responding.

Method

Subjects

Three male White Carneau pigeons (775, 847 and 691) were maintained at 80% (± 15 g) of their free-feeding body weights by food obtained during sessions and by post-session feedings, provided 30 minutes after each session. The pigeons were housed individually, with free access to water and health grit, in a colony room where a 12-hr light: 12-hr dark cycle was in effect. Each pigeon had experience responding under a schedule that differentially reinforced patterns of responding (cf. Hawkes and Shimp, 1975, 1998; see Method section of Experiment 2).

Apparatus

Two plywood operant chambers for pigeons (30-cm long x 32-cm wide x 38-cm high) were used. The front wall was an aluminum panel with three 2-cm diameter Gerbrands Co. response keys, 9-cm apart (center to center) and 25-cm from the floor. The center and right keys were used and each was operated by a force of at least 0.15 N. The center key could be transilluminated white or green. The right key was transilluminated red, in one chamber (Pigeons 691 and 775), and blue, in the other chamber (Pigeon 847). General illumination was provided by two 28-V white houselights located in the right lower corner of the aluminum panel for one chamber, and at the ceiling, 12-cm from the aluminum panel, for the other. A food hopper was located behind a rectangular aperture (5-cm x 4-cm) at the center of the aluminum panels, with its lower edge 8-cm from the floor of the chambers. When raised, the hopper was illuminated by a 28-V DC white light and provided 3-s access to mixed grain, during which the keylights and houselight were turned off. White noise and a ventilation fan in each chamber masked extraneous sounds. Programming of experimental conditions and data recording were conducted by using MED-PC® interfacing and software (MED Associates, Inc. & Tatham, 2003) and an IBM® microcomputer located in an adjacent room.

Procedure

A two-component discrete-trial multiple schedule of reinforcement was used. Across phases, sessions started with a 180-s blackout, during which the keylights and the houselight were off. During trials, the houselight and the response keys were transilluminated for 5-s (but see description of the training phase, below, for an exception). Trials were separated by 10-s intertrial intervals (ITI), during which the houselight and keylights were off. Responses during the first 5-s of the ITI had no programmed consequences, but a DRO 5-s schedule was in effect during the last 5-s of the ITI to preclude responses from occurring near trial onset. Each schedule component occurred with a 0.5 probability at the beginning of each session, and thereafter alternated semirandomly such that the same component could not occur on more than three consecutive trials. Sessions ended after 180 trials – 90 trials of each schedule component– and were conducted 7 days a week, at approximately the same time each day, during the light period of the light/dark cycle. Table 1 shows the schedules of reinforcement and stimulus conditions in effect during each phase of Experiment 1, and the number of sessions that each was in effect for each pigeon.

Training. A multiple FI 5-s VI 15-s was in effect on the center key. In the presence of a white keylight, responding was reinforced according to a VI 15-s schedule, arranged according to the distribution described by Fleshler and Hoffman (1962). The timer controlling the VI schedule operated only when the keylight was white. Reinforcers made available but not collected in one VI component were carried over to the next VI component. In the presence of a green keylight, an FI 5-s schedule was in effect. To equate reinforcement rates between the two schedule components, on FI trials reinforcers were produced with a probability of .3 by the first response after 5-s elapsed. These schedule parameters yielded a programmed reinforcement rate of 4 reinforcers per minute during each schedule component within a session. VI trials always were 5-s in duration and reinforcers could happen at any time within a trial. FI trials varied in actual duration depending on how soon a response occurred after 5-s elapsed, and reinforcer deliveries, when scheduled, always occurred at the end of trials.

Table 1[1]

Schedules of Reinforcement, Stimulus Conditions and Number of Sessions, for Each Pigeon, on Each Phase of Experiment 1

	Schedules of Reinforcement/ Stimulus Conditions			Sessions		
Phase	Center Key		Right Key	Pigeon		
	Green	White	Red/Blue	775	847	691
Training	FI 5-s	VI 15-s	OFF	46	45	45
Response Elimination	EXT	EXT	VI 15-s	15	15	17
Resurgence	EXT	EXT	EXT	15	15	15

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[1] A two- component discrete-trial multiple schedule of reinforcement was in effect across phases. During training, schedule components were correlated with the center key, only. During response elimination and resurgence phases, each component of the multiple schedule was a concurrent schedule of reinforcement and both center and right keys were operative. The right key was transilluminated red, for Pigeons 775 and 691 and blue for Pigeon 847.

This phase lasted for a minimum of 20 sessions and until positively accelerated and linear patterns of responding consistently occurred when the FI and VI components were in effect, respectively. These patterns were assessed in two ways: (a) by visual inspection of session cumulative response distributions in 0.25-s bins for each schedule component, and (b) by the obtained quarter-life values (Herrnstein & Morse, 1957) for each schedule component during each session. A difference in quarter-life values between the components of at least .25 for 6 consecutive sessions was necessary before changing to the next phase.

Response elimination. A multiple concurrent EXT VI 15-s concurrent EXT VI 15-s schedule was in effect during this phase to establish alternative patterns of responding in the presence of the stimuli correlated with each schedule component. The structure of the multiple schedule was as described for the training phase, except that during each 5-s trial both the center and right keylights were transilluminated. The center keylight was white or green, but the color of the right keylight was the same across components (blue, for Pigeon 847 and red for Pigeons 691 and 775). In both components, responses on the center key were extinguished, and right-key responding was reinforced according to a VI 15-s schedule, arranged as described for the training phase (i.e., the VI timers operated only when the keylights correlated with each component were in effect, and reinforcers made available but not collected in one VI component were carried over to the next trial in which the same VI component was in effect). A 2-s pause-response changeover delay (Shahan & Lattal, 1998) was in effect such that, during each trial, responding on the right key only could be reinforced 2-s since the last response on the center key. This phase was in effect for a minimum of 15 sessions and until responding on the right key occurred consistently, and response rates on the center key were less than 1 response per minute for both schedule components for 3 consecutive sessions.

Resurgence. The multiple schedule as described under the response elimination phase was in effect; however, extinction was arranged on both the center and right keys in both components. This phase lasted for 15 sessions.

Results and Discussion

Figures 1 and 2 show, respectively, response rates and reinforcement rates in each schedule component during the last 10 sessions of training and all sessions of response elimination and resurgence phases. Figure 1 shows that response rates on the center key during training were higher in the VI component for each pigeon, although a less pronounced difference between the two components occurred for Pigeon 775. Across response elimination sessions, responding on the center key decreased initially, eventually ceasing altogether, while response rates on the right key increased and were relatively stable and similar across components. Figure 2 shows that, although more variability in reinforcement rates was observed between FI and VI components during training, the procedure maintained more or less equivalent reinforcement rates across components in both the training and response elimination phases. During the training phase, there were more sessions with higher reinforcement rates during the VI component. This occurred because FI reinforcers were not always collected immediately after they became available, thereby adding time onto the FI component.

Resurgence of key pecking occurred for each pigeon during the resurgence phase. Relative to the last three sessions of the response elimination phase, rate of responding on the right key decreased, while responding on the center key increased in both schedule components for all pigeons across sessions of the resurgence phase (see Figure 1). For each pigeon, this occurred within the first three sessions of the resurgence phase. In absolute terms (i.e., responses per minute) more resurgence occurred on the center key in the presence of the stimuli previously correlated with the VI, than with the FI, schedule of reinforcement during training. After extended exposure to the conditions in effect during the resurgence phase, response rates on both the center and right keys fell to zero or near zero for all pigeons (although an increase in responding on the right key was observed for Pigeon 847 during the last three sessions of this phase).

Figure 3 shows center-key cumulative response distributions in 0.25-s bins, accumulated across the 90 trials of each schedule component within a session, for each pigeon in Experiment 1. In each panel, distributions are shown, from upper to lower diagonal, for the last 6 sessions each of training and response elimination phases and for all sessions of the resurgence phase. Using a different scale in each panel, similar data for all resurgence phase sessions are shown in Figure 4 (individual session distributions were modified when necessary so that distributions of all sessions could be displayed).

As seen in Figure 3, during the last 6 sessions of training, positively accelerated and linear patterns of responding on the center key were observed consistently in the FI and VI components, respectively, for each pigeon. Pauses followed by positively accelerated response patterns during the 5-s trials occurred during the FI components. By contrast, a constant, linear distribution of responses during the 5-s trials occurred during the VI components. Although brief pauses (around 0.25-s) occurred with each pigeon before responding started during the VI trials, they were constant across the last 6 sessions of training and could have been a function of the procedure (i.e., the keylight was turned on, on trials of either component, after 10-s ITIs during which the pigeons might have been away from the key). For each pigeon, these positively accelerated and linear patterns were absent during the last 6 sessions of response elimination, when extinction was correlated with the center key and VI 15-s schedules were in effect on the

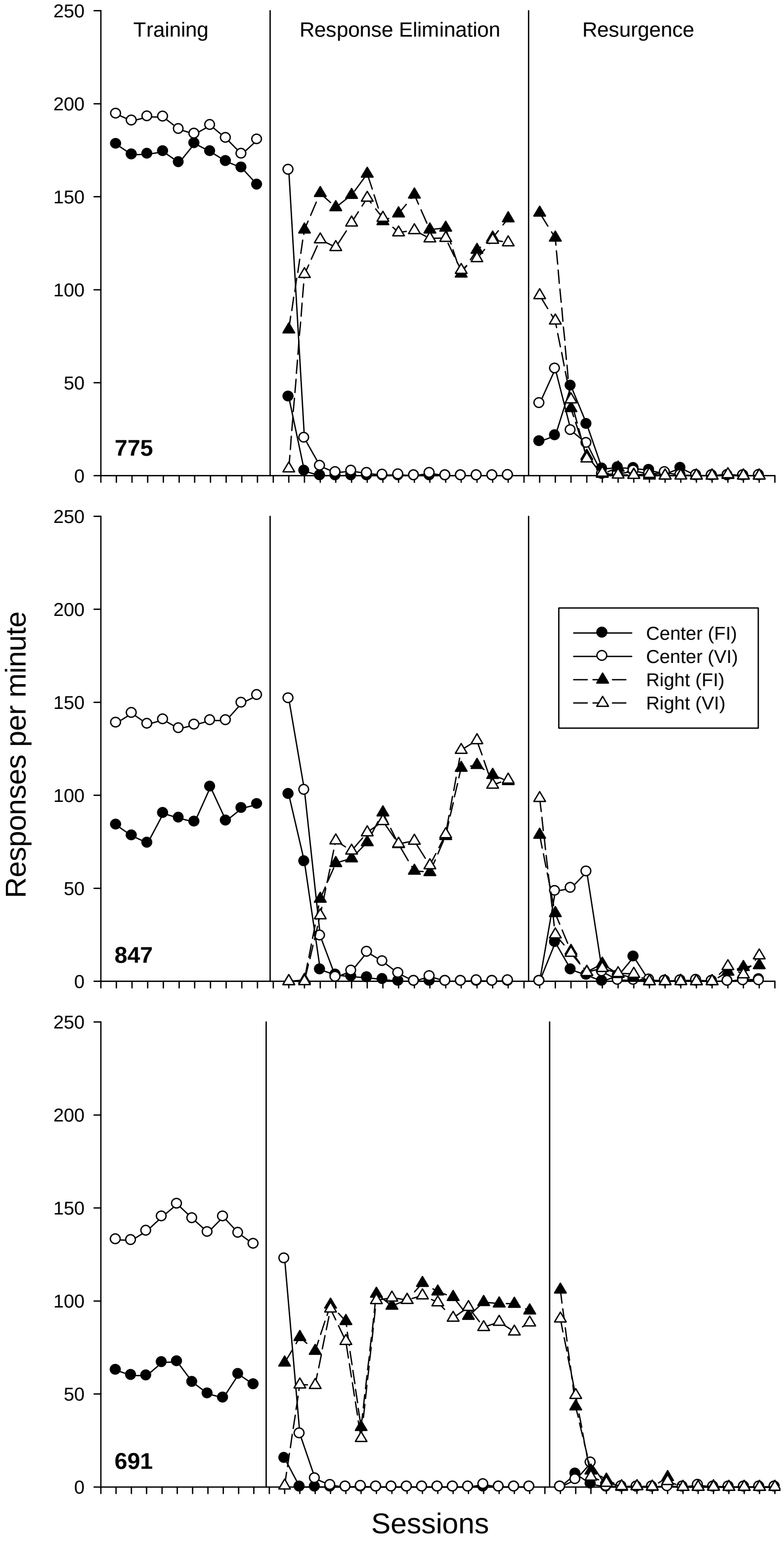

***Figure 1*. Responses per minute during each schedule component for the last 10 sessions of training and all sessions of response elimination and resurgence phases of Experiment 1.**

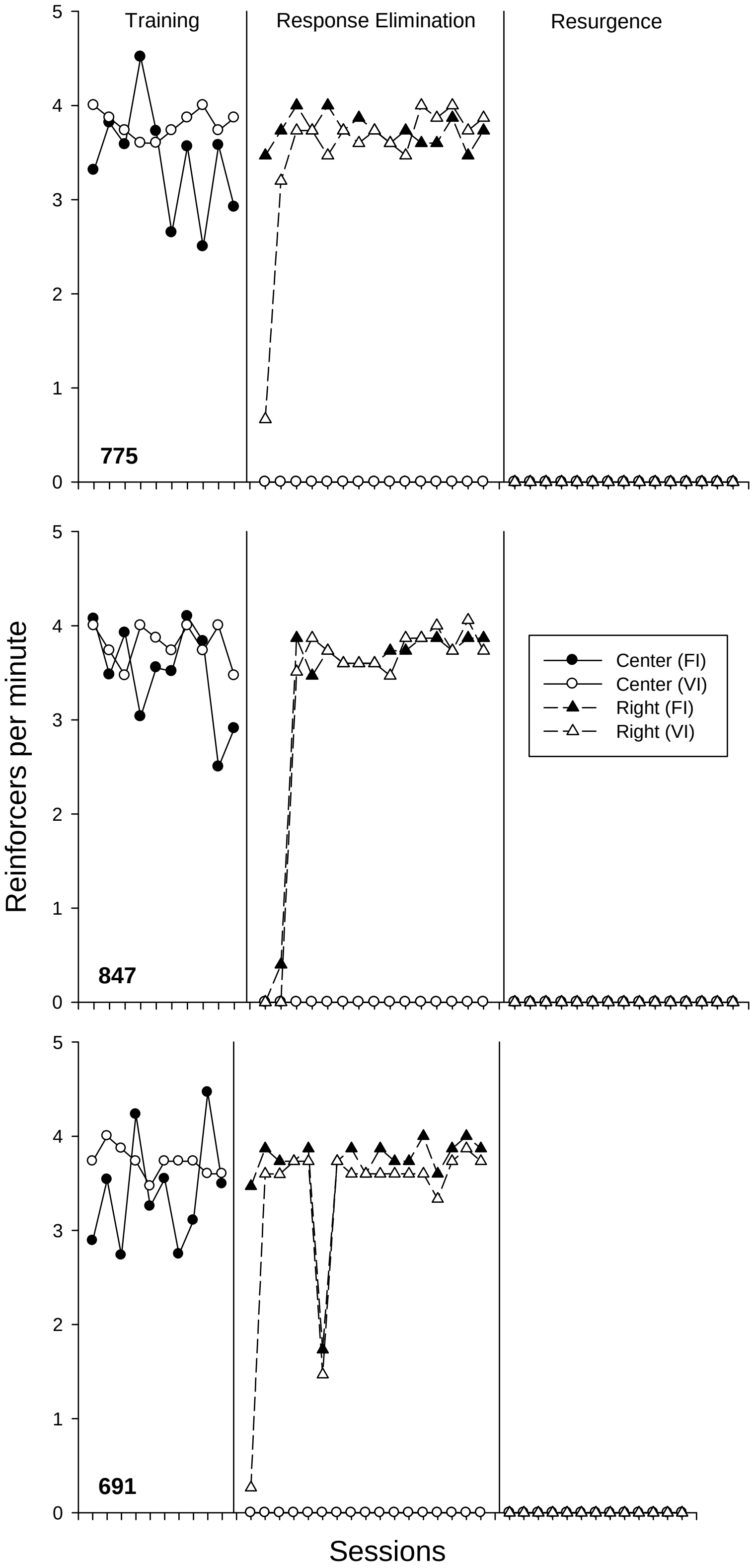

***Figure 2.* Reinforcers per minute during each schedule component for the last 10 sessions of training and all sessions of response elimination and resurgence phases of Experiment 1.**

right key in both components (right-key response distributions are discussed in detail, below, and are presented in Figure 7).

As seen in Figures 3 and 4, for Pigeons 775 and 847, clear resurgence of the temporal patterns of responding established in the training phase was observed. During the first 5 sessions of the resurgence phase, positively accelerated and linear patterns of responding were consistently observed for both pigeons in the presence of the stimuli correlated with the FI and VI schedules during training, respectively. Although slight negative acceleration occurred for Pigeon 847 in the presence of the stimuli previously correlated with the VI schedule (see Figure 4), differential patterning occurred for this pigeon in the presence of each stimulus condition, with positively accelerated patterns systematically occurring in the presence of the stimulus correlated with the FI schedule during training. For Pigeon 691, the response distributions for each schedule component during the resurgence phase show less differentiation, and a lower frequency of responding, relative to those obtained for Pigeons 775 and 847. Although 691 exhibited positively accelerated patterns of responding in the presence of both stimuli, patterning was nonetheless different in the presence of each stimulus, suggesting that responding was differentially affected by the two stimulus conditions as a function of a previous exposure to the FI and VI schedules of reinforcement during training (Freeman & Lattal, 1992; Okouchi, 2003 a, 2003 b).

Analyses of quarter-life values and of latencies for the occurrence of the first response within a trial support the conclusion that response patterns differentially resurged in the two components. Overall session quarter-life values for center-key responding in each schedule component, calculated for the last 6 sessions of training and the first 6 sessions of the resurgence phase, are shown in Figure 5. Quarter-life values were calculated from the session cumulative response distributions (shown in Figures 3 and 4) only if more than 25 responses occurred across trials of a component within a session, which accounts for the missing data for each pigeon in Figure 5 during the resurgence phase.

As seen in Figure 5, during training quarter-life values of .5 or higher, and ranging from .3 to .35 were observed on FI and VI components, respectively, for all pigeons. Similar quarter-life values were obtained for pigeons 775 and 847 during the first 6 sessions of the resurgence phase, indicating the occurrence of positively accelerated and linear patterns of responding in the presence of the stimuli previously correlated with the FI and VI components, respectively. Quarter-lives for Pigeon 691 on the resurgence phase indicate positive acceleration in both components (i.e., .6 or higher). Interestingly, quarter-lives for this pigeon during the resurgence phase were higher in the presence of the stimulus previously correlated with the FI schedule, reflecting a slight differentiation in responding between components, as was previously indicated.

Figure 6 shows, for the last 10 sessions of training and the first 10 sessions of the resurgence phase, the median latency (in seconds) for the occurrence of the first response on the center key within a trial in each component. Missing data, for either component, reflect sessions in which responding did not occur. Data points without error bars indicate sessions in which only one response occurred and, thus, represent the latency for the occurrence of that response (shown especially for the later sessions of the resurgence phase to indicate an overall reduction of responding in both components and no systematic relation between the latencies observed during training and those occurring after extended exposure to extinction).

During training, latencies were relatively stable for both components, and were higher during FI than during VI components. Thus, more pausing occurred at the beginning of trials in

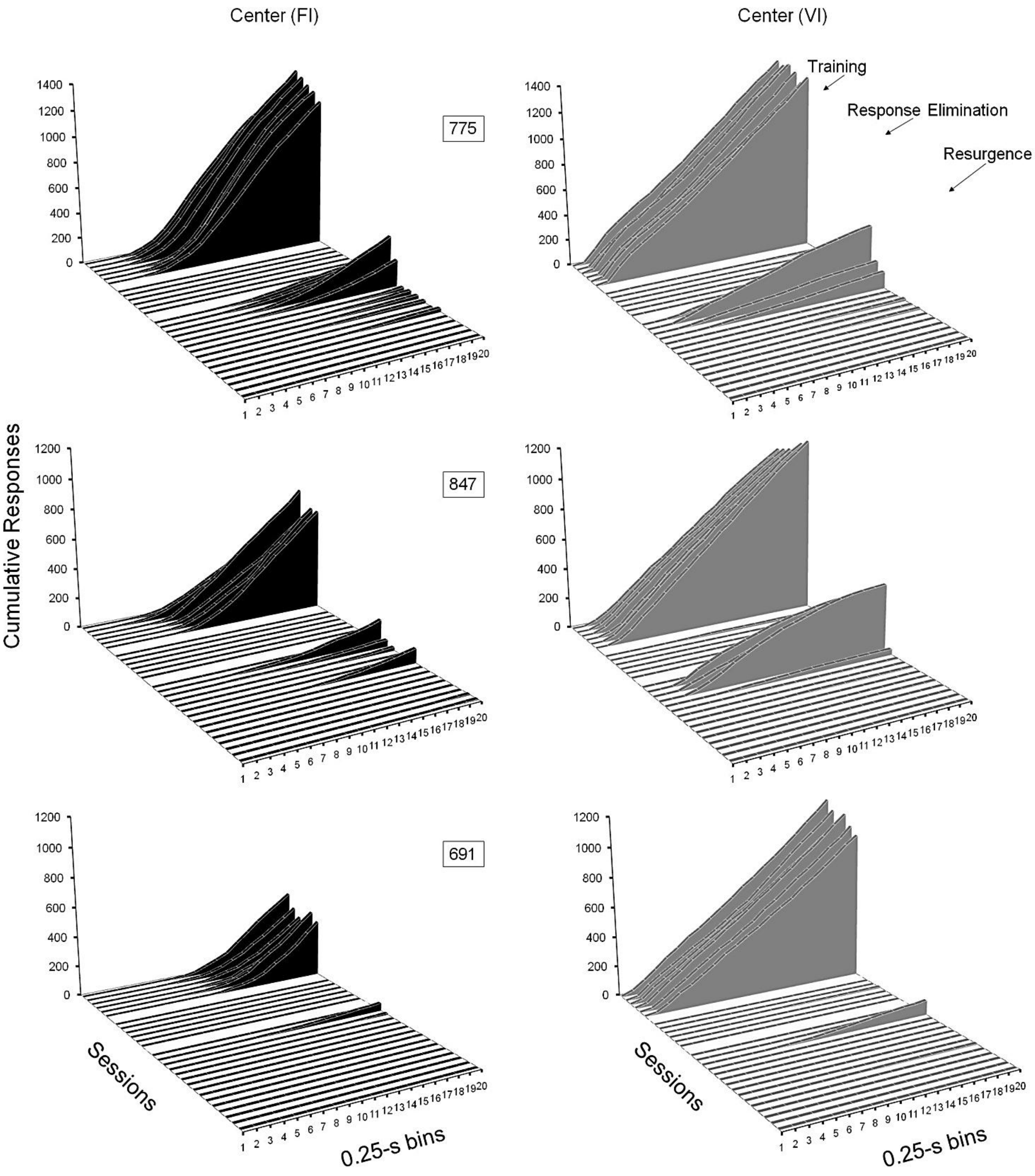

Figure 3. **Cumulative response distributions in 0.25-s bins for each pigeon in Experiment 1. Each panel shows, from upper to lower diagonal, distributions for the last six sessions of training and response elimination, and all sessions of the resurgence phase during FI (black) and VI (grey) components. Phases are separated by white lines in the horizontal plane on each panel.**

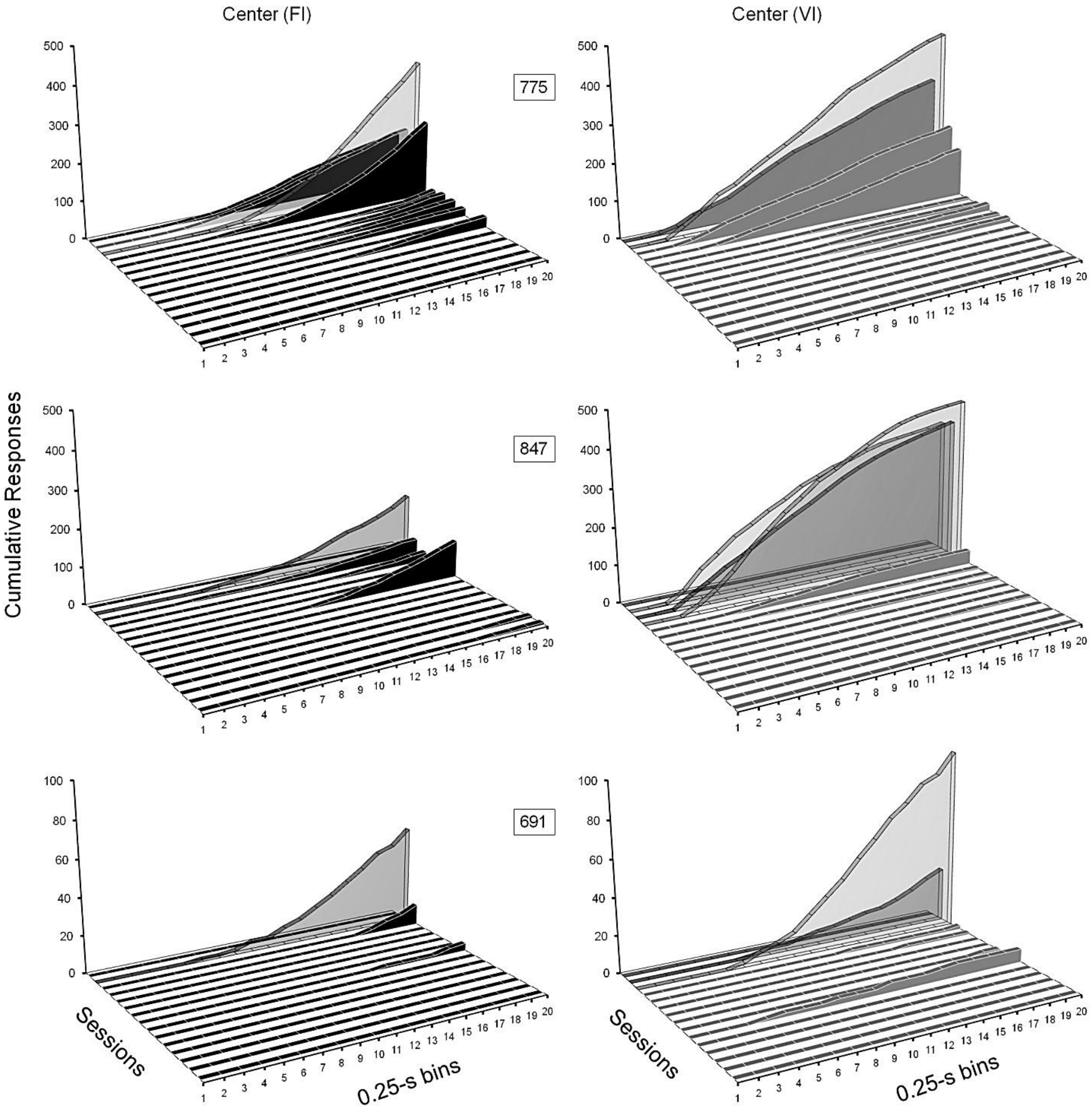

Figure 4. **Cumulative response distributions in 0.25-s bins for each pigeon in Experiment 1. Each panel shows, from upper to lower diagonal, distributions for all sessions of the resurgence phase. Other details as in Figure 3.**

which the FI, rather than the VI, component was in effect, although slight pausing (0.5 to 1.0-s) also occurred when VI components were in effect. During the initial sessions of the resurgence phase, for all pigeons, latencies increased during both components, but were higher in the presence of the stimuli previously correlated with the FI schedule component. With extended exposure to extinction, latencies during each component tended to become undifferentiated. This, however, was more a function of a decrease in rate of responding in both components (as seen in Figures 1, 3 and 4) than of the patterns in both components becoming more similar (i.e., positively accelerated or linear). The differentiation in latencies between components during the initial sessions of the resurgence phase further suggests the resurgence of different patterns of responding in the presence of each stimulus.

The resurgence of patterns observed on the center key was not affected by right-key responding that occurred during the resurgence phase. This can be seen in Figure 7, which shows cumulative response distributions in 0.25-s bins on the right key, for each pigeon, during all sessions of the resurgence phase. During the first five sessions of this phase, linear patterns of responding occurred consistently on the right key, in both components, for all pigeons. Responding decreased in frequency with continued exposure to extinction, and the resurgence of different patterns on the center key (especially the positively accelerated patterns observed during the FI components, as shown in Figures 3 and 4) was observed, for each pigeon, independent of right-key response patterns. This suggests that the patterns of responding observed on the center key during the resurgence phase (i.e., when extinction was in effect on the center and right keys) were not an artifact of the procedure used for assessing resurgence (i.e., concurrent schedules; da Silva et al., 2008; Epstein, 1983).

The results of Experiment 1 replicated those of previous studies (da Silva et al., 2008; Epstein, 1983; Lieving & Lattal, 2003; Podlesnik & Shahan, 2009) in which resurgence of discrete responding was assessed. The present results are also in accordance with those described, respectively, by da Silva et al. and by Podlesnik and Shahan in that more resurgence was observed for responding that previously occurred at higher rates (i.e., VI component) and that, in general, was maintained by relatively higher rates of reinforcement (i.e., VI component; see Figures 1 and 2). This interpretation of the magnitude of resurgence, however, is based on the number of responses per minute, which does not take into account topographical differences between responding in both schedule components. Higher or lower response rates during sessions of the resurgence phase could reflect differences in patterns of responding between the two schedule components, not necessarily differences in the magnitude of resurgence. In this sense, the present results extend these previous findings by demonstrating that responding that resurged did so with similar temporal patterns to those observed during the training phase.

The present results also suggest that the patterns established under each schedule component might have functioned as behavioral units, or more complex operants (Bachá-Mendez et al., 2007; Zeiler, 1977, Schwartz, 1981, 1982, 1986). As previously indicated, the occurrence of these patterns (e.g., on FI and VI components during training) is not sufficient, *prima facie,* to conclude that the patterns are actually units. To be considered as functional behavioral units, their occurrence should change as a result of changes in the contingencies of reinforcement (i.e., a demonstration that a given form of responding is actually a *conditionable* unit of behavior; Zeiler, 1977). The three-phase procedure arranged in the present study established the conditions for this test, and the resurgence of such patterns (after exposed to extinction and after alternative patterns of responding were established – i.e., right-key

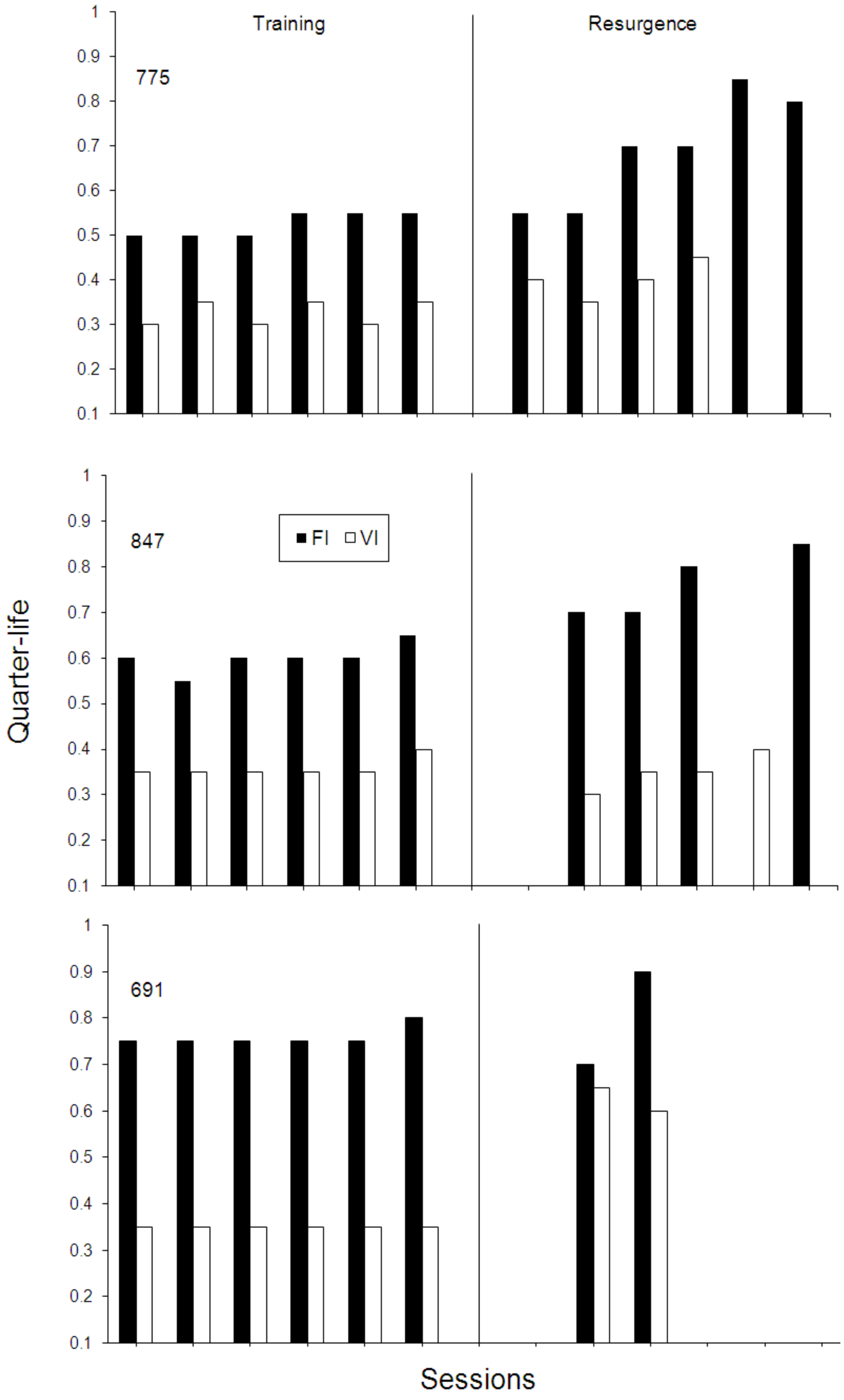

Figure 5. **Overall quarter-life values during each schedule component for the last six sessions of training and the first six sessions of the resurgence phase of Experiment 1.**

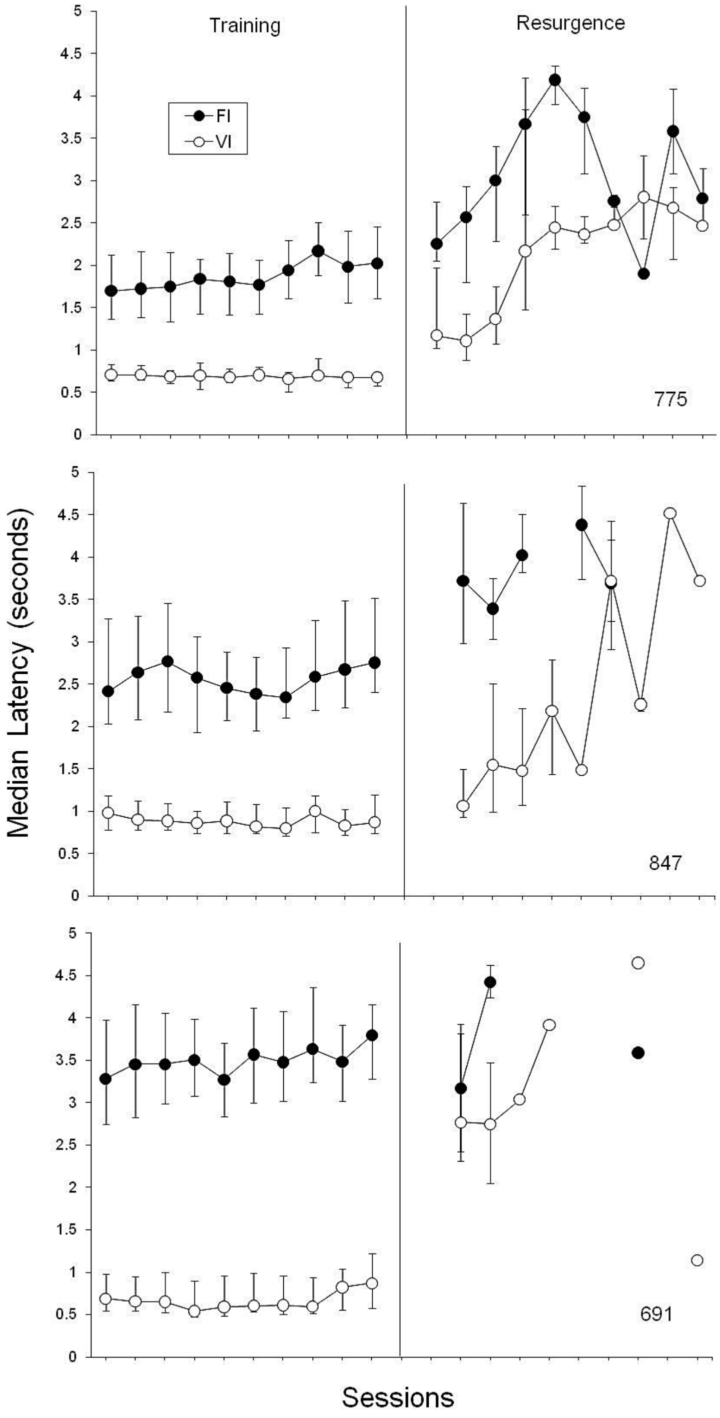

Figure 6. **Median latency (seconds) for the occurrence of the first center-key response within a trial, during each schedule component. Latencies are shown for the last 10 sessions of training and the first 10 sessions of the resurgence phase of Experiment 1. Error bars extend from the 25th to the 75th percentile. See text for details.**

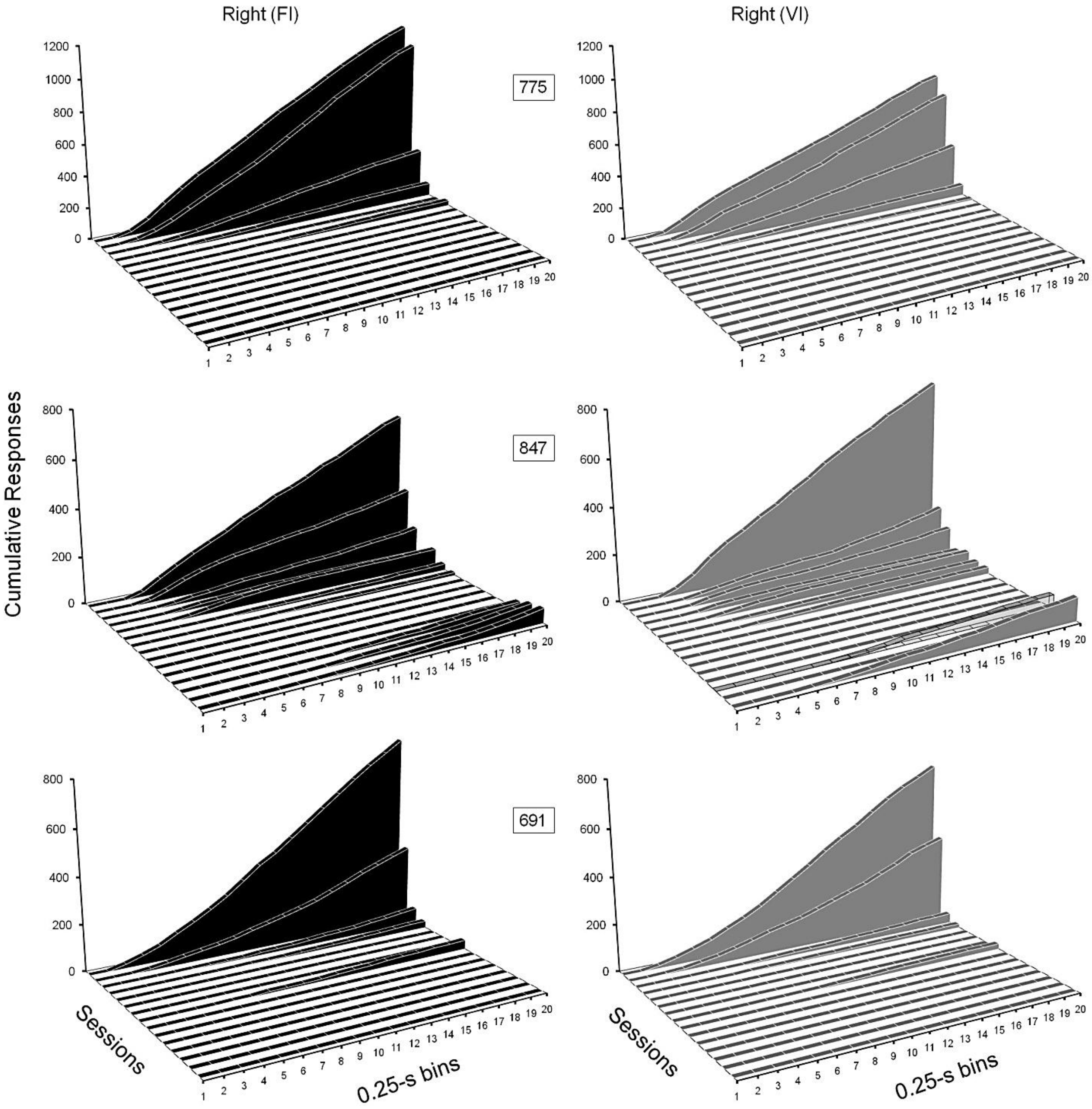

Figure 7. **Cumulative response distributions in 0.25-s bins for each pigeon in Experiment 1. Each panel shows, from upper to lower diagonal, right-key response distributions for all sessions of the resurgence phase. Other details as in Figure 3.**

responding on VI schedules) might suggest that they were actually established as behavioral units.

Schwartz (1988), in a discussion of how discrete responses are integrated as functional behavioral units, suggested that specifications of functional units are done *a posteriori*, i.e., after the organism has been exposed to the contingencies of reinforcement in effect and after some sort of responding consistently occurs. The author suggested that “the contingency of reinforcement has not *revealed* a functional behavioral unit so much as it has *created* one” (p. 94; italics in original). The present results add to Schwartz’s statement in that the resurgence of previously established patterns of responding during extinction actually “revealed” units previously “created”, or selected, by the contingencies of reinforcement in effect during training (Mechner, Hyten, Field & Madden, 1997). That is, before the resurgence phase was conducted, the patterns of responding in each component would not necessarily be described as units.

Although not a requirement for reinforcement under such contingencies, positively accelerated and linear patterns of responding are usually established after extended exposure to FI or VI schedules of reinforcement (Catania & Reynolds, 1968; Ferster & Skinner, 1957; Shull, 1970; Shull, et al., 1972; Zeiler, 1968, 1977). In the present experiment, after exposure to FI and VI schedules during training, the units of behavior could well have changed from discrete responses into more complex distributions of responses in time (Hawkes & Shimp, 1975, 1998; Wasserman, 1977). The temporal distribution of reinforcers under the FI and VI components might have initially established such patterns (e.g., Lattal, 1974; Lattal, & Bryan, 1976; Zeiler, 1968, 1977) which could be strengthened as integrated units by the contingencies in effect in both components. This is plausible, especially if it is considered that trials were 5-s in duration (and, thus, relatively brief; Zeiler, 1979) and that the direct reinforcement of temporal patterns occurring within 5-s (Hawkes & Shimp) and even within 8-s (Wasserman), was previously reported. Given that reinforcement was not contingent on the occurrence of temporal patterns in the present experiment, their establishment as behavioral units would be the outcome of indirect variables (i.e., variables that result from the interaction of an organism's responding with those variables that are directly programmed by a given schedule of reinforcement; Zeiler, 1977) arranged by the VI and FI schedules of reinforcement in effect during the training phase.

Experiment 2

The results of Experiment 1 extend the study of resurgence of complex operants – previously conducted by analyzing spatial sequences of responses across two or more operanda (e.g., Reed & Morgan, 2006) – to temporally organized responding. As previously noted, the occurrence of a particular temporal pattern was not required by the contingencies in effect during the training phase of Experiment 1. Nonetheless, the resurgence of both linear and positively accelerated patterns of responding during extinction suggests that these patterns were selected as behavioral units by such contingencies (i.e., VI and FI schedules, respectively). In Experiment 2, conditions were arranged so that the resurgence of temporal patterns of responding could be assessed after specific temporal patterns were directly reinforced during training (Hawkes & Shimp, 1975).

Method

Subjects

Three male White Carneau pigeons (617, 955 and 119) were maintained at 80% (± 15 g) of their free-feeding body weights by food obtained during sessions and by post-session feedings, provided 30 minutes after each session. The pigeons were housed as described in

Experiment 1. Each pigeon had an extensive experimental history of responding under different schedules of food reinforcement.

Apparatus

Three operant chambers for pigeons were used. The chambers were as those described in Experiment 1, except that the front panel of one chamber contained two 2-cm diameter Gerbrands Co. response keys, separated by 15-cm (center to center). The right key was used in one chamber (Pigeon 119) and the center key in the other two (Pigeons 617 and 955). The keys were transilluminated red and no houselight was used in Experiment 2. Reinforcer deliveries, extraneous sound attenuation, the programming of experimental conditions and data recording were as described in Experiment 1.

Procedure

A discrete-trial procedure was used in Experiment 2. Across phases, sessions started after a 60-s blackout, during which the keylight was off. During trials, the keylight remained on for 5-s (but see description of pretraining, below, for an exception). As in Experiment 1, trials were followed by 10-s ITIs, during which the keylight was off. Responses during the first 5-s of the ITI had no programmed consequences, but, as in Experiment 1, responses during the last 5-s of the ITI reset a timer such that trial onset could not occur within 5-s of a keypeck response. Sessions ended after 60 trials, and were conducted 7 days a week at approximately the same time each day, during the light period of the light/dark cycle. Table 2 summarizes for each pigeon the schedules of reinforcement in effect, and number of sessions conducted during each phase of Experiment 2.

Pretraining. Each pigeon received five 60-reinforcer sessions during which an FI 5-s schedule of reinforcement was in effect on each trial to assure that the pigeons responded consistently when the keylight was on. All procedural details were as previously described, except that trials varied in actual duration depending on how soon a response occurred after 5-s elapsed.

Training. To directly reinforce positively accelerated patterns of responding, the schedule described by Hawkes and Shimp (1975) was in effect during each trial. Considering a 5-s trial and sub-intervals of 1-s, the required positively accelerated response pattern was defined based on the function:

$$f(t) = t - 1, \qquad [1]$$

where $f(t)$ is the response rate at time *t*, which is an interval in seconds from the beginning of a trial. Another parameter, $f(t)'$, is the first derivative of $f(t)$, and specifies the rate of change in rate of responding across successive 1-s sub-intervals of a 5-s trial. Because positively accelerated patterns were required in the present experiment, $f(t)'$ was set to +1. Thus, the function specifies the number of responses required to occur during each sub-interval of a trial.

The required pattern was the model against which obtained patterns in each trial were compared, and the deviation of obtained from required pattern was calculated as the sum of squared deviations (hereafter, *D*). Mathematically, it is expressed as (Hawkes & Shimp, 1975, p.6):

$$D = \sum_{i=1}^{5} (\mathrm{fi} - \mathrm{oi})^2 , \qquad [2]$$

where f_i and o_i refer to, respectively, the required and the obtained number of responses at the i^{th} -s sub-interval of a 5-s trial. Thus, the lower the value of *D*, the better is the match between obtained and required patterns. Similarly, the higher the value of *D*, the greater the deviation of obtained from required patterns of responding. On any trial, if *D* = 0, obtained and required response patterns perfectly match and if *D* = 30, no responses were emitted.

Table 2[2]

Schedules of Reinforcement and Number of Sessions, for Each Pigeon, on Each Phase of Experiment 2

Phase	Schedule of Reinforcement	*C*			Sessions		
		Pigeon			Pigeon		
		617	955	119	617	955	119
Pre-training	FI 5-s	–	–	–	5	5	5
Training: Initial Stage	$f(t) = t - 1; f(t)' = +1$	Variable			13	13	60
Training: Terminal Stage		8	8	10	41	41	60
Response Elimination	$f(t) = \mathrm{t} - 1; f(t)' = +1$	30	30	30	19	19	19
Resurgence	EXT	–	–	–	30	30	30
Training	$f(t) = t - 1; f(t)' = +1$	16	16	20	30	30	30
Response Elimination		30	30	30	19	21	17
Resurgence	EXT	–	–	–	30	30	21

To permit reinforcement of temporal patterns that did not perfectly match the required pattern of responding, a goodness-of-fit criterion (hereafter, *C*; Hawkes & Shimp, 1975) was set as an arbitrary value against which the sum of square deviations [2] in each trial was compared. *C* was defined as an integer greater than zero and reinforcers were delivered at the end of a trial if responses were emitted (i.e., if $D \neq 30$) and if, $D \leq C$ (see Appendix for a detailed description). During the initial stage of training the pigeons were exposed to sessions in which the value of *C* changed, within sessions, based on their performance. This was done to determine a parameter that, once fixed on the terminal stage of training, would consistently generate and maintain positively accelerated patterns of responding across trials.

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[2] The function describes the response rate at each 1-s sub-interval, *t*, of a 5-s trial (Hawkes & Shimp, 1975). *f(t)'* is the first derivative of *f(t)*, and specifies the required rate of change in rate of responding across sub-intervals of a trial. *C* is the maximum accepted deviation from the required pattern under which reinforcers can be produced (Hawkes & Shimp, 1975). See the Appendix for a detailed description.

Initial stage: Variable C. Within a session, the value of *C* was decreased by one unit after four consecutive trials ending in reinforcer delivery. Similarly, if four consecutive trials in which responding occurred (i.e., $D \neq 30$) ended without reinforcement, the value of *C* was increased by one unit. As an example, if *C* was initially set to 10, after four consecutive reinforced or non-reinforced trials, its value would be 9 or 11, respectively.

During the first session, the value of *C* was set to 20 for each pigeon. Across subsequent sessions, the initial value of *C* on any given session was set equal to its terminal value during the immediately preceding session. This procedure was in effect unless the terminal value of *C* was greater than its initial value within a session, in which case *C* was set equal to the lower of the two values (e.g., if during Session 2, the initial and terminal values of *C* were, respectively, 9 and 15, *C* was set to 9 at the beginning of Session 3).

A minimum of 10 sessions were conducted under this stage of training, which remained in effect until (a) responding consistently occurred across trials; (b) the terminal values of *C* did not increase or decrease systematically across sessions; and (c) at least 10% of the programmed reinforcers were obtained during a session. These criteria were achieved after 13 sessions for Pigeons 617 and 955, and 60 sessions for Pigeon 119. During the last six sessions of this stage of training, mean terminal values of *C* (with standard deviation and range in parenthesis) for Pigeons 617, 955 and 119 were, respectively, 6.33 (*SD* = 2.33; 3-9), 8.16 (*SD* = 1.32; 6-10) and 9.16 (*SD* = 1.32; 7-11). Performance during these sessions was used as a basis to establish a fixed value of *C* in the following stage of training.

Terminal stage: Fixed C. The value of C was set at a fixed value across sessions. For each pigeon, *C* was initially set to 8. This value was maintained for Pigeons 617 and 955 but, after 6 sessions Pigeon 119's responding ceased completely. For this reason, *C* was set at 10 for this pigeon. The contingencies of reinforcement in effect, then, established that reinforcers would occur only if $D \leq 8$ (Pigeons 617 and 955) and if $D \leq 10$ (Pigeon 119). This stage of training was in effect for a minimum of 15 sessions and until positively accelerated patterns of responding occurred consistently across sessions. This was assessed by visual inspection of session cumulative response distributions in 0.5-s bins, and by requiring that overall session quarter-lives greater than or equal to .6 were obtained for 6 consecutive sessions.

Response elimination. During this phase, *C* was set equal to 30, such that reinforcers were presented only if no responses occurred within a trial. The first response within a trial cancelled the programmed reinforcer for that trial (e.g., if a response occurred at 3-s, a reinforcer to be delivered at the end of a trial would be cancelled), and additional responses were recorded but had no programmed consequences. This phase was in effect for a minimum of 10 sessions, and until positively accelerated patterns of responding were not systematically observed for 6 consecutive sessions. As during the training phase, session cumulative response distributions in 0.5-s bins were examined to determine whether responding was stable.

Resurgence. Extinction was arranged during trials of this phase, which was in effect for 30 sessions. As described for the previous phases, responding was analyzed by assessing overall session quarter-life values and by visually inspecting session cumulative response distributions in 0.5-s bins.

Replication. A second exposure to training (Fixed *C*), response elimination and resurgence phases was conducted to assess whether repeated exposure to the conditions in each phase would affect resurgence, particularly when the parameters of the schedule of reinforcement in effect during training were changed, permitting more variability in patterning (i.e., *C* was set to 16, for Pigeons 617 and 995 and to 20 for Pigeon 119). Procedural details, the minimum number of sessions and stability criteria for each phase were as previously described, with the exception that Pigeon 119 was exposed to 21, rather than 30, sessions during the replication of the resurgence phase.

Results and Discussion

Figures 8 and 9 show, respectively, response rates and the proportion of reinforced trials within a session during the first exposure and replication of each phase of Experiment 2. Response rates are shown for the last 10 sessions of training and response elimination, and all sessions of the resurgence phases, while the proportion of reinforced trials are shown only for the last 10 sessions of training and response elimination. As shown in Figure 8, stable responding was maintained for the 10 last sessions of training, for all pigeons, on the first exposure and replication of the procedure. A comparison between response rates during training phases shows that (especially for Pigeons 955 and 119) relatively lower rates of responding were maintained by the schedules of reinforcement in effect during the replication of this phase. For each pigeon, response rates were systematically reduced in relation to training phases during the last 10 sessions of both response elimination phases.

Inspection of Figure 9 shows that the proportion of reinforced trials, although reduced during the last sessions of the first training phase (especially for Pigeon 119, and ranging from .3 to .6 for Pigeons 617 and 955), was sufficient to maintain consistent responding across sessions. During all subsequent phases shown in this figure, the proportion of reinforced trials increased relative to the first training phase, indicating that responding was meeting the requirements of the contingencies of reinforcement in effect during each phase. This indicates that the procedure was successful in establishing and eliminating responding during training and response elimination phases, respectively. As can be seen in Figure 8, resurgence was observed for all pigeons during resurgence phase sessions of the first exposure, and was also consistently observed for Pigeons 617 and 955 during the replication of this phase. In both resurgence phases, response rates increased relative to those occurring during the last sessions of the response elimination phases – sometimes to values that were similar to those observed during training (e.g., Pigeon 617 during both resurgence phases, and Pigeon 955 during the replication of the resurgence phase).

Figure 10 shows, for each pigeon, session cumulative response distributions in 0.5-s bins (for a total of 60 trials within a session) during the first exposure (left panels) and replication (right panels) of each phase of Experiment 2. On each panel, from upper to lower diagonal, distributions are shown for the last 6 sessions of training and response elimination, and the first 15 sessions of the resurgence phase. As was the case for the presentation of similar results in Experiment 1, response distributions for some sessions were modified as necessary, to facilitate visual analysis and display.

For each pigeon, during the last 6 sessions of the first and second exposures to training phases, positively accelerated patterns of responding were consistently observed – i.e., pauses at the beginning of trials followed by positively accelerated responding until the end of trials. These results replicate those reported by Hawkes & Shimp (1975, 1998) by demonstrating that the direct reinforcement of patterns arranged by the schedules of reinforcement in effect during both training phases (i.e., when C= 8 or 10, and when C = 16 or 20) established and maintained positively accelerated patterns of responding. During the last 6 sessions of both response elimination phases (i.e., when C = 30), responding was systematically reduced within and across sessions and previously observed positively accelerated patterns did not occur (Pigeons 617 and 119) or occurred at lower frequencies as compared to the terminal sessions of both training

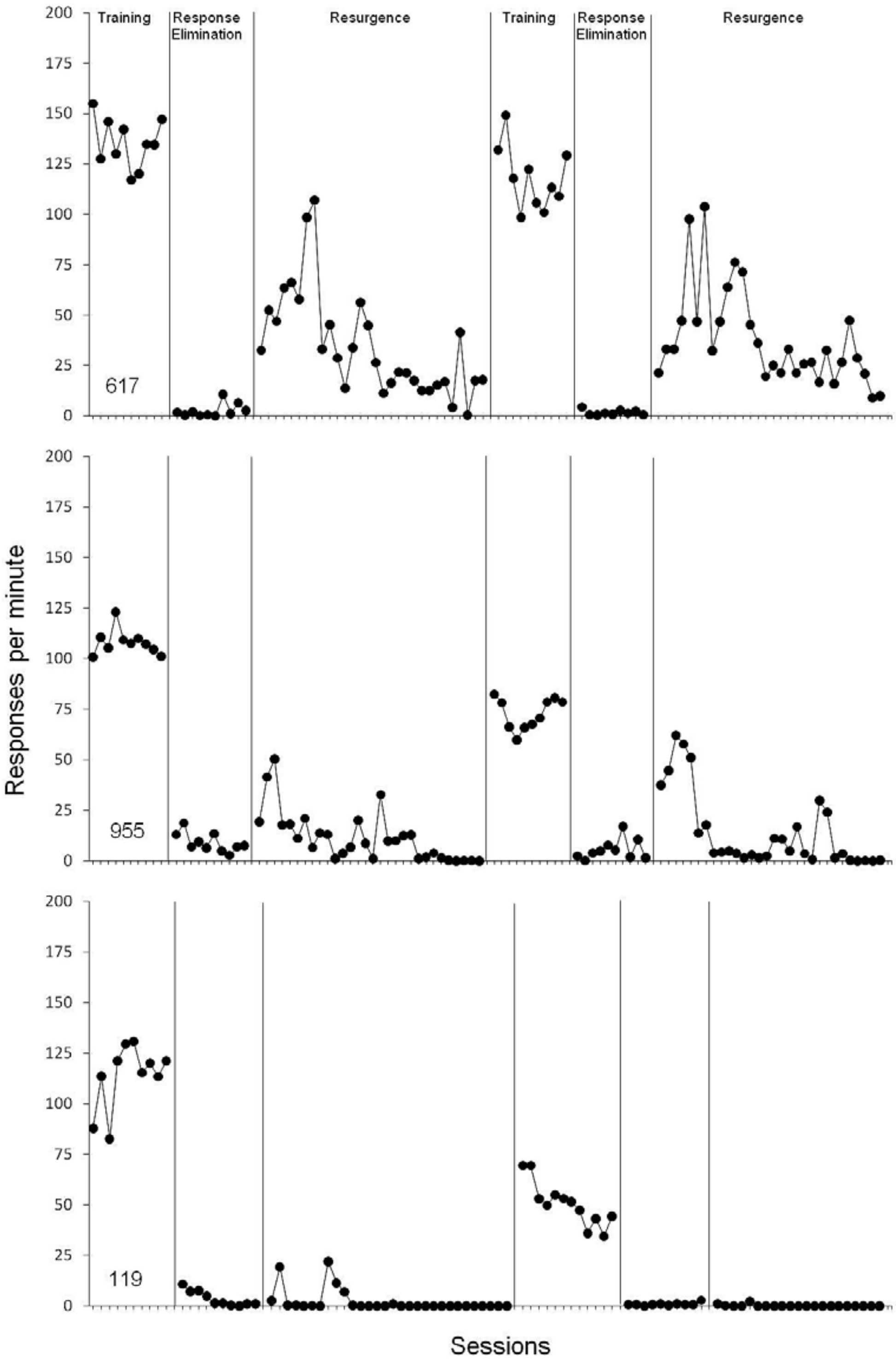

***Figure 8*. Responses per minute during the last 10 sessions of training and response elimination, and all sessions of the resurgence phase of Experiment 2. For each pigeon, data are shown for the first and second exposures to each phase.**

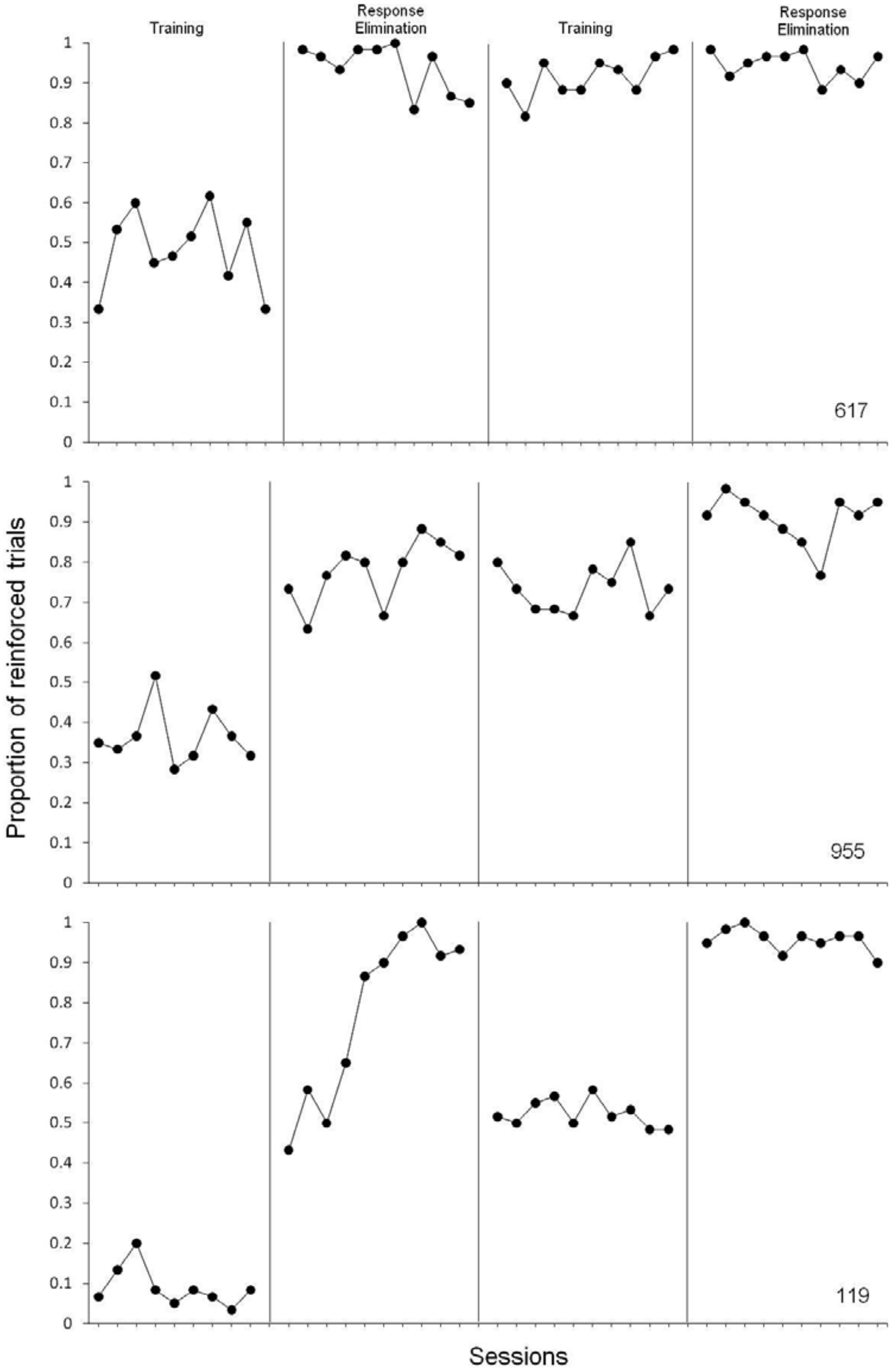

Figure 9. **Proportion of reinforced trials for the last 10 sessions of training and response elimination of Experiment 2. For each pigeon, data are shown for the first and second exposures to each phase.**

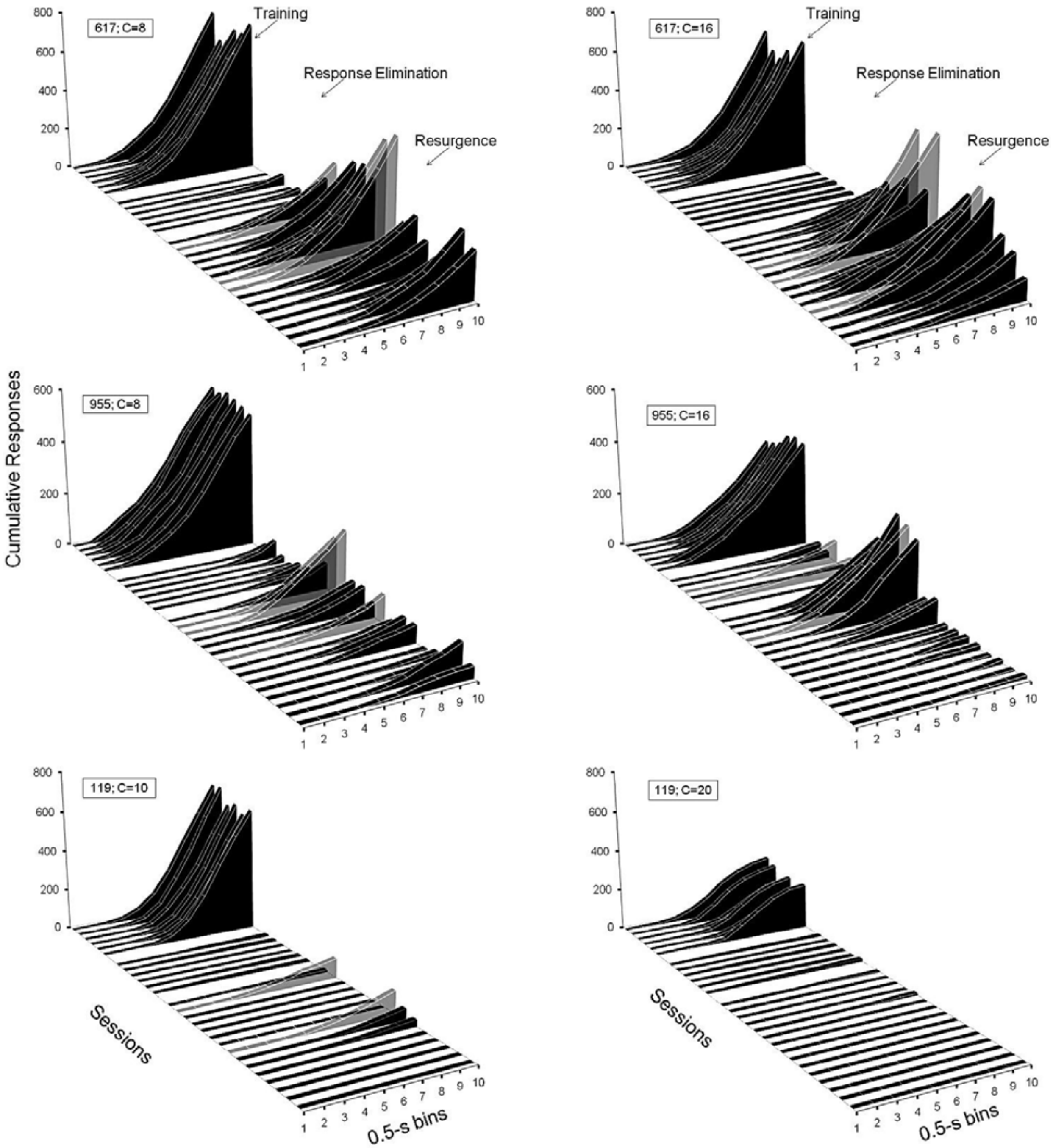

Figure 10. **Cumulative response distributions in 0.5-s bins for each pigeon during the first exposure (left panels) and replication (right panels) of each phase of Experiment 2. Each panel shows, from upper to lower diagonal, distributions for the last six sessions of training and response elimination, and the first 15 sessions of the resurgence phase. Phases are separated by white lines in the horizontal plane on each panel.**

phases (Pigeon 955). These results suggest that the pigeons were pausing, or not pecking, for almost all trials within response elimination sessions (which is reflected in the relatively higher proportion of reinforced trials for the terminal sessions of this phase, as shown in Figure 8).

Resurgence of positively accelerated patterns of responding was observed for all pigeons, during the first exposure, and for 2 of 3 pigeons (Pigeons 617 and 955) during the replication of each phase. As can be seen in Figure 10, positively accelerated patterns occurred consistently during the first 7 sessions of both resurgence phases for Pigeons 617 and 955, and during the initial sessions and sessions 7-10 for Pigeon 119 (left panel only). As was observed in Experiment 1, with extended exposure to extinction, frequency of responding (and consequently, patterning) was systematically reduced across sessions of both resurgence phases. For Pigeons 617 and 955 (left and right panels), however, positively accelerated patterns of responding were still observed after 15 sessions in which extinction was in effect. Analyses of quarter-life values and of latencies for the occurrence of the first response within a trial during the first exposure and replication of each phase of Experiment 2 are presented in Figures 11 and 12, respectively. These analyses complement the visual analysis of patterning as previously described and were conducted in a similar way as described for Experiment 1. In each figure, data are presented for the last 10 sessions of the training phases and the first 10 sessions of the resurgence phases.

As seen in Figure 11, quarter-life values of .5 to .7, indicating positively accelerated patterns of responding, were observed for all pigeons during the last sessions of both training phases. For Pigeons 617 and 955, similar quarter-life values were observed during sessions of both resurgence phases, corroborating the previous description of resurgence of positively accelerated patterns based on these pigeon’s session cumulative response distributions. For Pigeon 119, when responding occurred during the first resurgence phase, quarter-life values approximated those observed during training (i.e., .7 or higher), indicating also that when responding resurged, patterns were positively accelerated. Quarter-life values were not calculated for this pigeon during sessions of the second resurgence phase, due to extremely low frequency or absence of responding within trials and across sessions.

The resurgence of positively accelerated patterns is further corroborated by assessing the median latencies for the occurrence of the first response within a trial during training and response elimination phases, shown in Figure 12. During the first exposure (left panels) and replication (right panels) of each phase, median latencies of 2.0 to 3.0-s, indicating pausing at the beginning of trials, were consistently observed during the last sessions of each training phase. Similar results, indicating the occurrence of positively accelerated patterns, were observed during the initial sessions of each resurgence phase. In general, median latencies increased across sessions of both resurgence phases and, on terminal sessions, might reflect more the decreasing frequency of responding (or its absence, e.g., Pigeon 119 on the second resurgence phase) than necessarily the occurrence of positively accelerated patterns within a session. This interpretation is supported by the session cumulative response distributions during both resurgence phases (especially for Pigeons 955 and 119), as shown in Figure 10.

The results of Experiment 2 replicated those from Experiment 1. Additionally, they extend the analysis of resurgence of temporal patterns of responding to a context in which specific response patterns were required for reinforcement during both training phases. As in Experiment 1, the resurgence of positively accelerated patterns of responding suggests that those patterns were established as behavioral units when the contingencies of reinforcement during training were in effect.

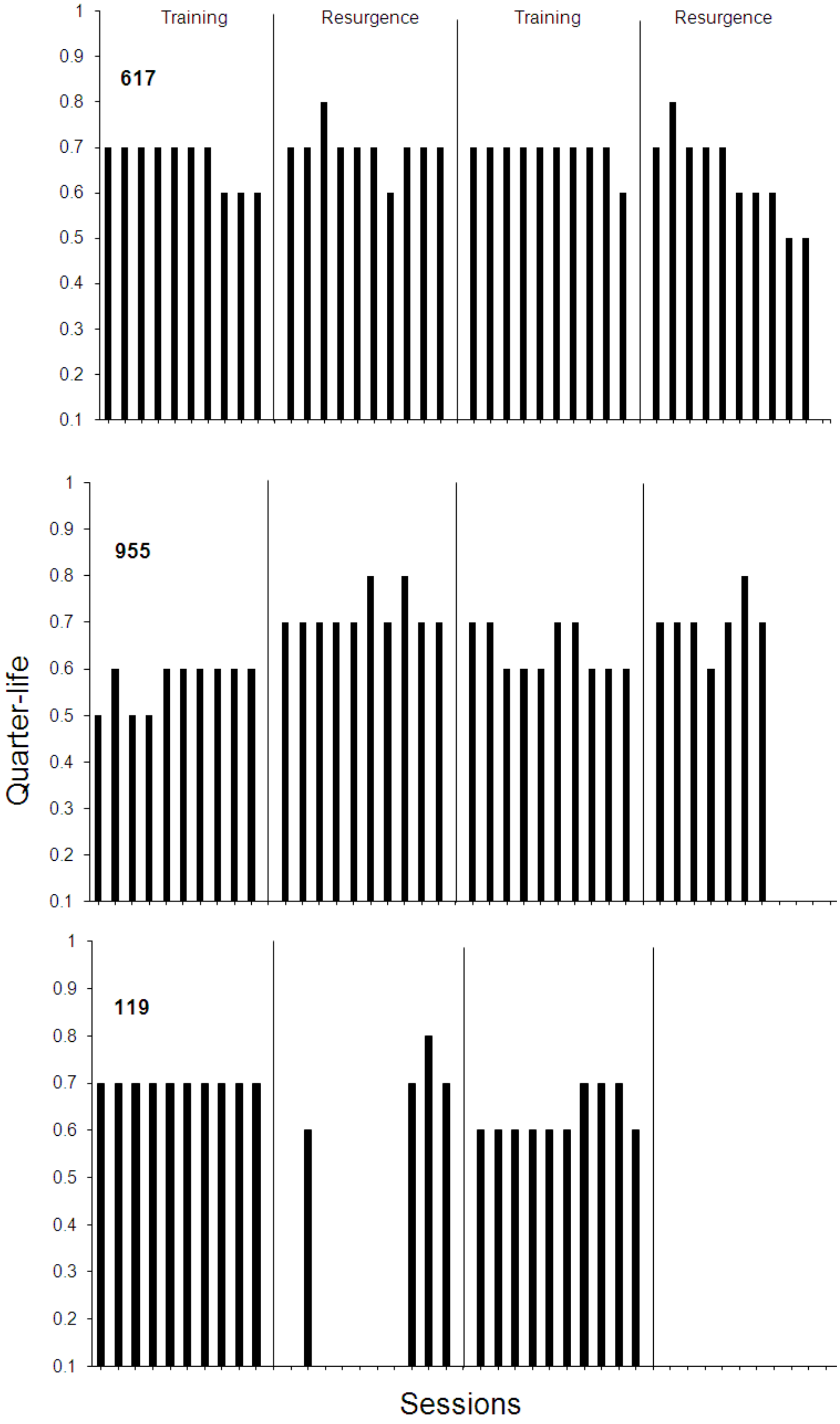

Figure 11. **Overall quarter-life values for the last 10 sessions of training and the first 10 sessions of the resurgence phase of Experiment 2. For each pigeon, data are shown for the first exposure and replication of each phase.**

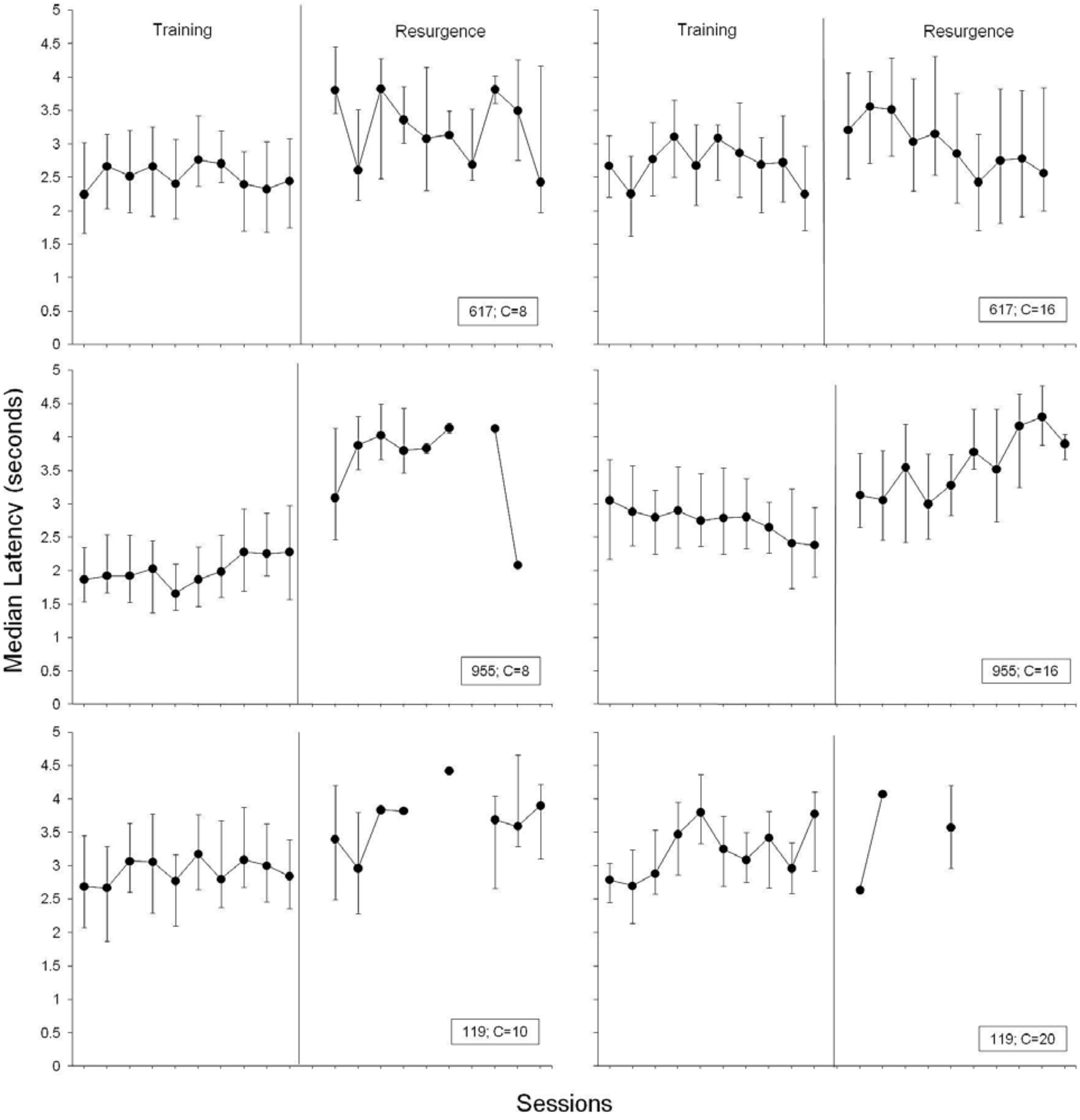

Figure 12. **Median latency (seconds) for the occurrence of the first response within a trial during the first exposure (left panels) and replication (right panels) of each phase of Experiment 2. Each panel shows latencies for the last 10 sessions of training and the first 10 sessions of the resurgence phase. Error bars extend from the 25th to the 75th percentile. See text for details.**

An advantage of using the procedure described by Hawkes and Shimp (1975, 1998) was that individual classes of patterns could be identified, and their relative frequency during training and resurgence phases could be further assessed. This offers a more detailed analysis of temporal patterns as behavioral units in that it was possible to identify which positively accelerated patterns were established by the schedules in effect during training, and if those patterns recurred during the resurgence test. In the present experiment, patterns were identified by calculating the deviation (*D*) of obtained patterns (within each trial) from the required pattern of responding (as described by Hawkes & Shimp, 1975; see the function in [1], above, and Figure A1, in the Appendix, for examples of different patterns of responding occurring with different deviations from the model). As previously described, a criterion was in effect for reinforcement of specific patterns, for each pigeon, during both training phases (i.e., to produce reinforcement, patterns had to occur such that $D \leq 8$ or 16 for Pigeons 617 and 955, and $D \leq 10$ or 20 for Pigeon 119). These criteria defined the theoretical unit – i.e., that required by the contingencies of reinforcement in effect – not necessarily the functional behavioral units – or what was actually established by the contingencies (Bachá-Mendez et al., 2007; Zeiler, 1977).

Figure 13 shows the proportion of reinforced patterns occurring during the last six sessions of training and response elimination, and the first six sessions of the resurgence phase, during the first exposure and the replication of each phase of Experiment 2. For each pigeon, closed and open circles represent the proportion of patterns that met (during training) or would meet (during response elimination and resurgence phases) the requirements for reinforcement, respectively, on the first and second exposures to the procedure. The closed circles connected by a dotted line represent the proportion of the patterns occurring on each phase during the replication of the procedure that would meet the requirements for reinforcement under the contingencies in effect during the first training phase.

As seen in Figure 13, the proportion of patterns that produced reinforcers during the terminal sessions of both training phases decreased, or approached zero, on the last six sessions of both response elimination phases. During the resurgence phases, the proportion of these patterns increased relative to the response elimination phase (except for Pigeon 119 on the replication of the resurgence), demonstrating that the patterns that were previously reinforced resurged. Interestingly, a similar proportion of the patterns that occurred during the second training phase would have met the criterion for reinforcement in effect during the first training phase. This is also the case for the data of the second resurgence phase for Pigeons 617 and 955, and suggests that the conditions in effect during the first training phase (i.e., $C = 8$) – and also the similarities between those contingencies and the contingencies arranged during the second training phase – affected the pigeons' performance on subsequent phases of the study.

Analyses of relative frequency distributions of individual classes of patterns provide an additional account of how patterns occurred during training, and how they recurred during the resurgence phases. Figures 14 and 15 present such analyses, respectively, for the first and second exposures to the procedure. In both figures, relative frequency distributions were generated for the last six sessions of training (closed circles) and the first six sessions of the resurgence phase (open circles); thus, each distribution represents responding for a total of 360 trials. Each distribution was constructed by dividing the frequency of occurrence of each class of pattern (as identified by the pattern's deviation from the model, D) by the total number of classes. These values were then ordered, for each pigeon, from most to least frequent. Data for trials in which no responses occurred (i.e., $D = 30$) were excluded from this analysis.

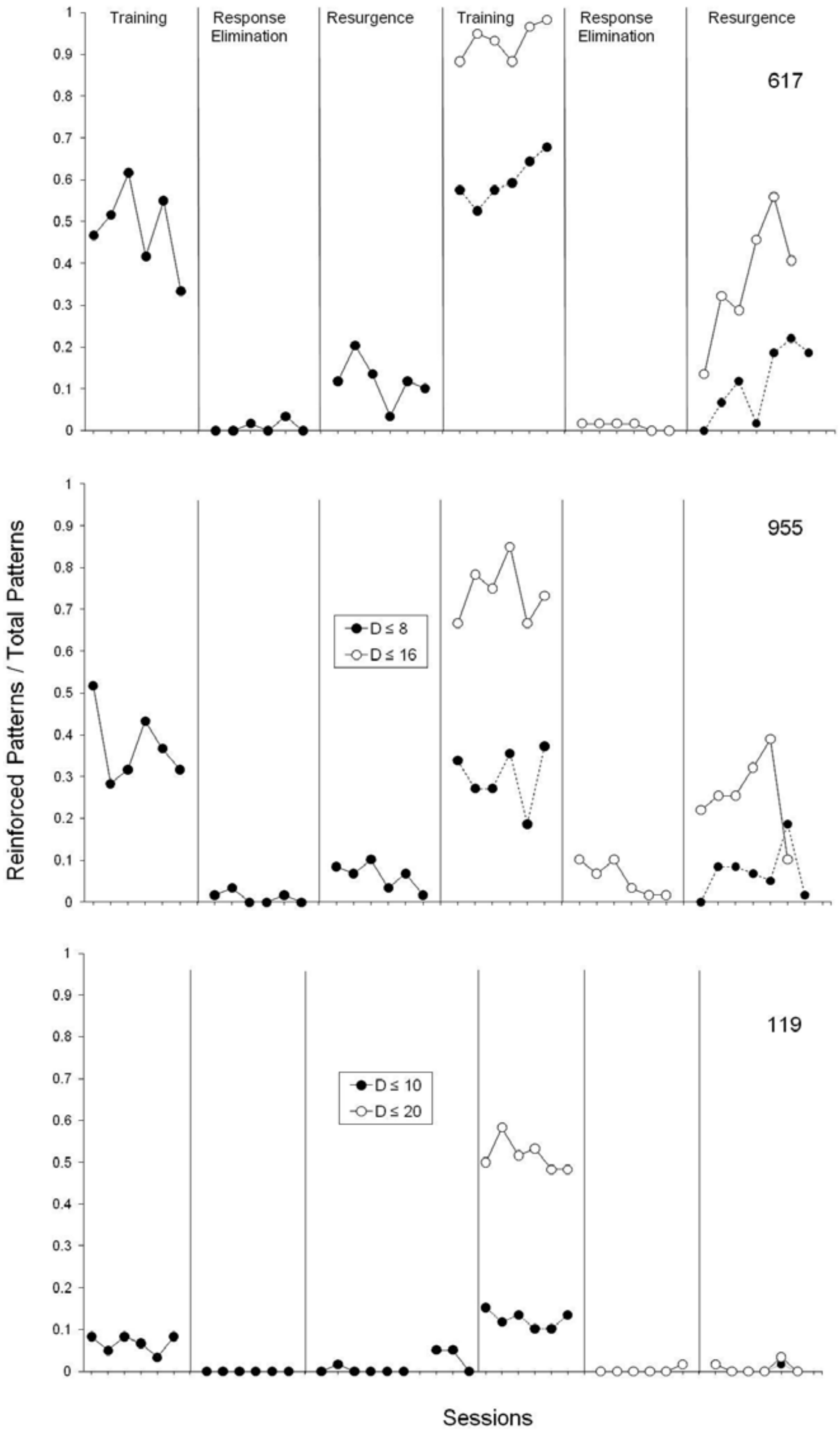

Figure 13. **Proportion of reinforced patterns for the last six sessions of training and response elimination, and the first six sessions of the resurgence phase of Experiment 2. For each pigeon, data are shown for the first exposure and replication of each phase. See text for details.**

As seen in Figures 14 and 15, the most frequent classes of patterns during both training phases varied for each pigeon, and *D* values that fell above those required by the contingencies of reinforcement in effect were among the most frequent patterns for all pigeons. When extinction was in effect during the resurgence phase (except for Pigeon 119 during the second resurgence phase), pattern variability increased – i. e., *D* values that did not occur, or were infrequent during training, were observed during the resurgence phase. Nonetheless, patterns that were most frequent during training consistently recurred for each pigeon during the first resurgence phase, and for 2 of 3 pigeons (Pigeons 617 and 955) during the second resurgence phase. These results replicate the results reported by Sánchez-Carrasco and Nieto (2005; see also Neuringer et al., 2001) and offer support for the notion that specific classes of patterns were selected as behavioral units during training. In addition, as Lieving & Lattal (2003) suggested, part of the variability in patterning induced by extinction was a function of each pigeon's previous exposure to contingencies of reinforcement (i.e., both training phases). As suggested by Doughty and Oken (2008), such analysis permits a more detailed characterization of extinction-induced behavior.

In general, the present results replicate and extend those of Experiment 1 by using a using a procedure in which positively accelerated patterns of responding were directly reinforced. Additionally, the present results provide unequivocal evidence that complex behavioral patterns that are temporally organized will resurge as behavioral units. Although some degree of variability (within and across classes of patterns) was permitted by the contingencies in effect during both training phases (especially during the second exposure to each phase), the procedure was effective in establishing positively accelerated patterns of responding, and also the conditions for analyzing their resurgence.

General Discussion

The results of the present study are the first demonstration that temporally organized complex operants are susceptible to resurgence in the same way that discrete operants and spatially organized complex operants are (Bachá-Mendez et al., 2007; da Silva et al., 2008; Doughty et al., 2007; Epstein, 1983; Lieving & Lattal, 2003; Reed & Morgan, 2006, 2007; Sánchez-Carrasco & Nieto, 2005). Additionally, the resurgence of previously established (Experiment 1) or directly reinforced (Experiment 2) temporal patterns of responding suggests that these patterns were established as functional units by the contingencies of reinforcement in effect during the training phases of the present experiments (Bachá-Mendez et al., 2007; Schwartz, 1981, 1988; Schneider & Morris 1992; Zeiler, 1977, 1986).

In Experiments 1 and 2, the frequency of specific temporal patterns of responding varied as a function of the contingencies in effect during training and response elimination phases (which would be sufficient to state that the temporal patterns were functional units; cf. Zeiler, 1977) and, most important, these previously established temporal patterns recurred during the resurgence phases (see the cumulative response distributions shown in Figures 3, 4, 7 and 10). As previously noted, the resurgence of temporal patterns of responding was further corroborated by the analyses of quarter-life values and latencies for the occurrence of the first response within a trial in both experiments (see Figures 5 and 6, for Experiment 1, and Figures 11 and 12, for Experiment 2).

In general, the present results extend previous findings on resurgence of spatially defined complex operants, and also replicate previous analyses of resurgence of both discrete responses and spatial response sequences. The differential resurgence of patterns under each component of the multiple schedule observed in Experiment 1 (see Figure 4), and the resurgence of previously

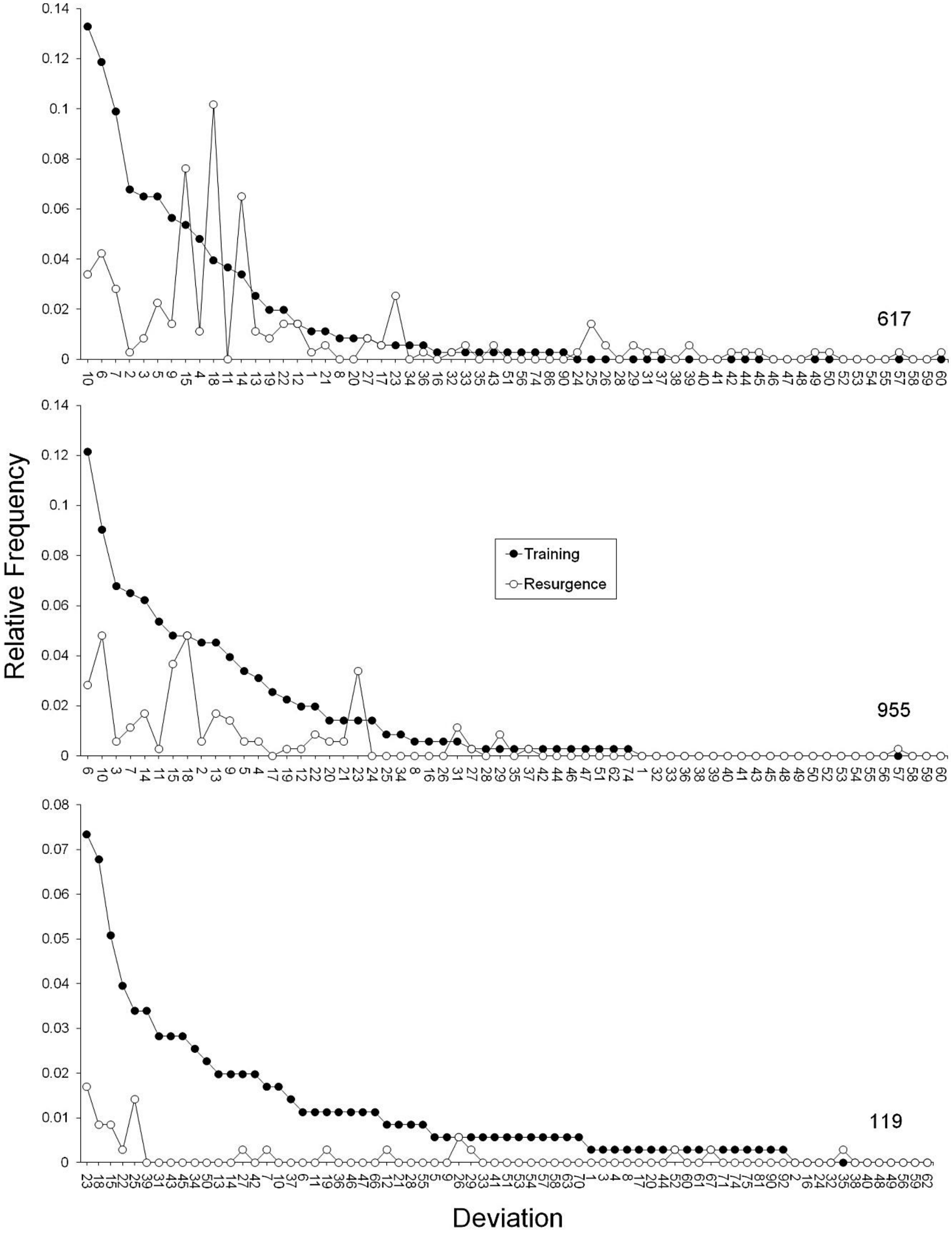

***Figure 14.* Relative frequency distribution of each class of patterns (from most to least frequent) for the last six sessions of training (closed circles) and the first six sessions of the resurgence phase (open circles), during the first exposure to each phase of Experiment 2.**

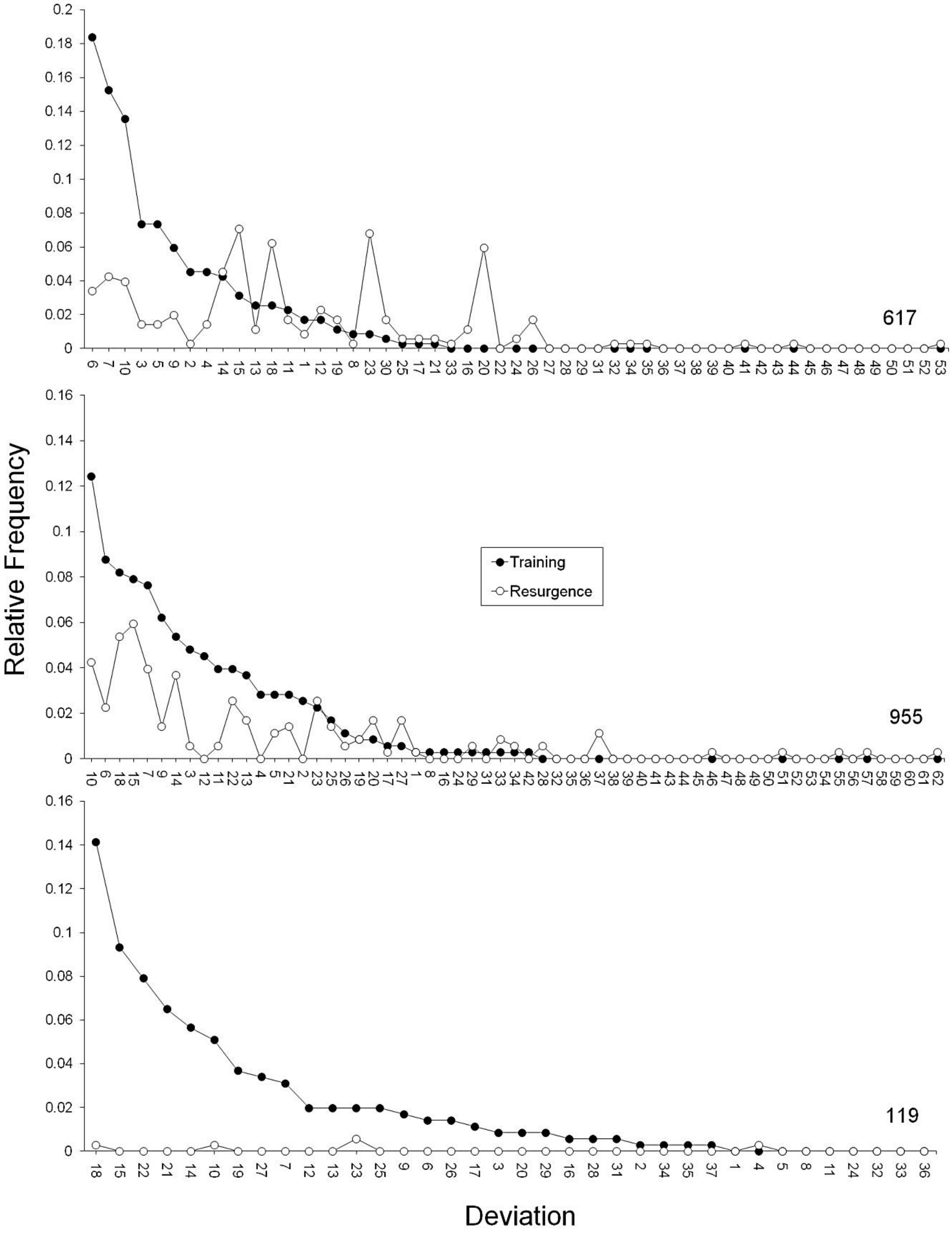

Figure 15. **Relative frequency distribution of each class of patterns (from most to least frequent) for the last six sessions of training (closed circles) and the first six sessions of the resurgence phase (open circles), during the replication of each phase of Experiment 2.**

reinforced, positively accelerated, patterns in Experiment 2 (see Figure 10, and especially the analyses of relative frequency of patterns presented in Figures 13, 14 and 15) support the notion that extinction-induced behavior can be, in part, considered instances of resurgence (Doughty & Oken, 2008; Epstein, 1985; Lieving & Lattal, 2003). That is, part of what organisms do when reinforcers for current behavior are discontinued (i.e., when behavior is no longer effective; da Silva et al., 2008) is to respond as they did in previous, similar contexts. The present results add to this general finding that responding recurring during extinction can manifest the same temporal organization as the previously, but not presently, reinforced responding.

Some results of the present experiments also replicate previous findings reported in studies of discrete-response resurgence related to the replicability of resurgence and its time course once extinction is in effect. The results of Experiment 2 support Lieving and Lattal's (2003) findings that resurgence is a replicable phenomenon within individuals, i.e., it is observed after repeated exposures to training, response elimination and resurgence phases. For 2 of 3 pigeons in Experiment 2 (617 and 955; the reasons for the absence of resurgence during the replication of the procedure with Pigeon 119 are not known), resurgence of previously reinforced temporal patterns was observed during the replication of the procedure. Additional replications of the three phases and their effects on resurgence of temporal patterns of responding is a topic for future analyses (e.g., are effects of repeated exposures to the three phases cumulative, in the sense that the occurrence of resurgence is reduced proportionally to the number of exposures to each phase – or abrupt, after a given number of replications of each phase?).

The time course of resurgence in Experiments 1 and 2 was also similar to that previously reported in the study of resurgence of discrete responses (da Silva et al., 2008; Doughty et al., 2007; Lieving & Lattal, 2003). As shown in measures of responses per minute (Figures 1 and 8), and in the cumulative response distributions (Figures 4 and 10), responding during the resurgence phase sessions occurred at its maximum some time after extinction had been in effect (usually on the second or third sessions of this phase). This may be a common finding in resurgence studies because responding that was established during the response elimination phase has to contact the current (extinction) contingency before resurgence occurs (da Silva et al.). Future studies focused on a more systematic analysis of behavior during the transition between response elimination and resurgence phases would contribute to the understanding of resurgence and other related phenomena. Additionally, the assessment of different procedures by which the resurgence phase is implemented (e.g., Lieving & Lattal, 2003) also could clarify the analysis of the time course of resurgence. In the present experiments and in all previously described resurgence studies (e.g., Doughty et al.), the resurgence test was initiated on a different session and not within a session (but see Bruzek, Thompson & Peters, 2009 for an exception). This, as indicated by Sidman (1960), could introduce potential extraneous factors in analyzing the onset and the time course of resurgence.

As previously discussed, the results of Experiment 1 and 2 qualify analyses of the magnitude of resurgence in terms of absolute measures, e.g., responses per minute, and the fact that higher response rates during training predict more resurgence than when training responding is maintained at low rates (da Silva et al., 2008; Reed & Morgan, 2007). The fact that different patterns of responding resurged in Experiment 1(and that different contingencies might select different behavioral units that might subsequently resurge), however, might compromise predictions that more resurgence of responding previously maintained at higher rates will be a necessary outcome of experimental procedures (e.g., VI components during training phase in Experiment 1) and that have been reported when results are analyzed as responses per minute (da

Silva et al.; but see Podlesnik & Shahan, 2009). If complex, or even different, behavioral units are established by the contingencies of reinforcement in effect, previous response rates might not be the best predictors of resurgence and should be, as in the present experiments, qualified by more detailed analysis of what constitutes the functional behavioral units and by alternative measurement methods (e.g., the session cumulative response distributions in the present study; see also the analysis of the relative frequency of patterns of responding as shown in Figures 14 and 15).

As an example of the implications of the present findings for how resurgence is analyzed, consider the results of Experiment 1. After an analysis of the patterns that occurred during the resurgence phase (Figures 3 and 4), differences in the magnitude of resurgence in responses per minute (Figure 1) between FI and VI components would be expected. Lower (i.e., FI) and higher (i.e., VI) response rates during resurgence phase sessions, in the present experiment, reflect more or less pausing followed by responding within a trial. If different units of behavior (e.g., different patterns of responding) were selected, response rates on resurgence phase sessions would be a by-product of the occurrence of such units. Consequently, the units of behavior that were previously selected, or the temporal patterns of responding in the case of the present experiments, should be taken into account when assessing the magnitude and occurrence of resurgence. In this context, no systematic differences in the magnitude of resurgence would be expected if similar units, or similar patterns of responding during trials (e.g., linear) were established in both schedule components.

These implications for how resurgence is analyzed are not a problem when the behavioral units are clearly defined (e.g., right-left-right lever press; Reed & Morgan, 2006). They should be taken into account, however, when behavior can be organized into more complex units that are not analyzed and, consequently, are not reflected accurately in the data analyses usually conducted (e.g., in terms of responses per minute). Future studies in which similar units (complex, or simple units such as short or long IRTs) are established as baselines (e.g., on components of a multiple schedule) seem relevant to address questions related to the effects of other variables on resurgence and also to achieve a better systematization of research findings (Doughty & Oken, 2008; Lieving & Lattal, 2003).

Procedurally, the present study contributes in replicating the results obtained by Hawkes and Shimp (1975, 1998), and offers the possibility of future analyses using the schedule of reinforcement first described, and only used previously, by these authors. Parametric analyses and modifications of the procedure (as conducted during the first exposure to training on Experiment 2) could be conducted to further assess the processes by which more complex behavioral units that are temporally defined are selected and also the conditions under which they are likely to resurge. The schedule of reinforcement arranged in Experiment 2 is rather complex (e.g., Table 2 shows the relatively high number of sessions conducted for each pigeon during the first exposure to the conditions in effect during training), and manipulations of specific parameters under which it is arranged (e.g., trial duration, terminal values of *C*) would be interesting to refine such procedure so that reliable baselines can be more readily established and the processes by which it controls behavior clarified (Hawkes & Shimp, 1998).

The present experiments assessed the resurgence of temporal patterns of responding. Complex operants that are temporally organized resurged in a similar manner to discrete operants and spatially organized complex operants (Sánchez-Carrasco & Nieto, 2005). The present results establish the context for future studies about the processes of selection and recurrence of complex behavioral units, temporally or spatially defined, and about how an organism’s behavioral history might affect such processes (Lieving & Lattal, 2003).

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Appendix

According to the function described in [1] – see Method section of Experiment 2 – considering a 5-s trial and 1-s sub-intervals, if $f(t)' = +1$, the required number of responses specified by the function during the interval from 0-s to 1-s is zero, and during the interval from 1-s to 2-s is one (i.e., at t = 1-s, $f(1) = 0$, and at t = 2-s, $f(2) = 1$; Hawkes & Shimp, 1975). At the interval from 4-s to 5-s, the required number of responses is 4 and the total number of required responses within a trial equals 10 (i.e., 0, 1, 2, 3 and 4 responses, if t= 1-s, 2-s, 3-s, 4-s and 5-s, respectively). Although the required number of responses within each 1-s sub-interval is specified, no restrictions are in effect as to exactly when these responses should occur during each sub-interval (e.g., as long as one response occurs during the 1-s to 2-s sub-interval, the requirement as specified by the function in [1] is achieved; this is true if the response occurs at 1.25-s, at 1.75-s or at 1.98-s). Hawkes and Shimp also described a function to arrange the direct reinforcement of negatively accelerated patterns of responding, not used as a model in Experiment 2, in which $f(t) = 5 - t$ and $f(t)' = -1$.

The value of the goodness-of-fit criterion, *C*, specified the maximum accepted deviation of obtained and required patterns and set the conditions for reinforcer delivery. Setting $C = 1$, for example, establishes a more restrictive condition in which only patterns that almost match the required pattern will produce the reinforcer at the end of a trial. In contrast, if *C* is set to a higher value (e.g., $C = 20$), higher levels of variability in responding are allowed, and patterns that considerably deviate from the required patterns might produce a reinforcer. If the value of *C* is not controlled, the contingencies in effect would be similar to an FI 5-s schedule of reinforcement. The use of a fixed value of *C* during the terminal stage of training in Experiment 2 served also as a reference for subsequent analyses of relative frequency of patterns during the first exposure and the replication of the training and the resurgence phases (see Results and Discussion section of Experiment 2, and Figures 14 and 15).

Hypothetical cumulative response distribution in 1-s sub-intervals of a 5-s trial are shown in Figure A1. The required pattern described by Hawkes and Shimp's (1975) model (i.e., the function in [1]) is represented in closed circles in both upper and lower panels. Also shown are examples of positively accelerated patterns in which deviations from this model occurred (i.e., classes of patterns in which $D = 8$ or 16, in the upper panel; and when $D = 10$ or 20, in the lower panel). In both panels, patterns in which no responses occurred within a trial (i.e., $D = 30$) are also shown. These deviations from the model, as described in the Method section of Experiment 2, defined the contingencies of reinforcement in effect for Pigeons 617 and 955 (upper panel) and Pigeon 119 (lower panel) during the first exposure and replication of each phase of Experiment 2.

Two sources of pattern variability can operate under this schedule of reinforcement (Hawkes & Shimp, 1975, 1998). One of these sources results from no restrictions being imposed by the contingencies on when responses should occur within each 1-s sub-interval of a trial. Another source of variability is under the experimenter's control and is defined by the value at which C is set. It should also be noted that, a given value of D (e.g., 2) defines not a single response pattern, but a *class of responses* of which that pattern is a member, because different distributions of responses within a trial can yield the same value of D (see function in [2] in the Method section of Experiment 2).

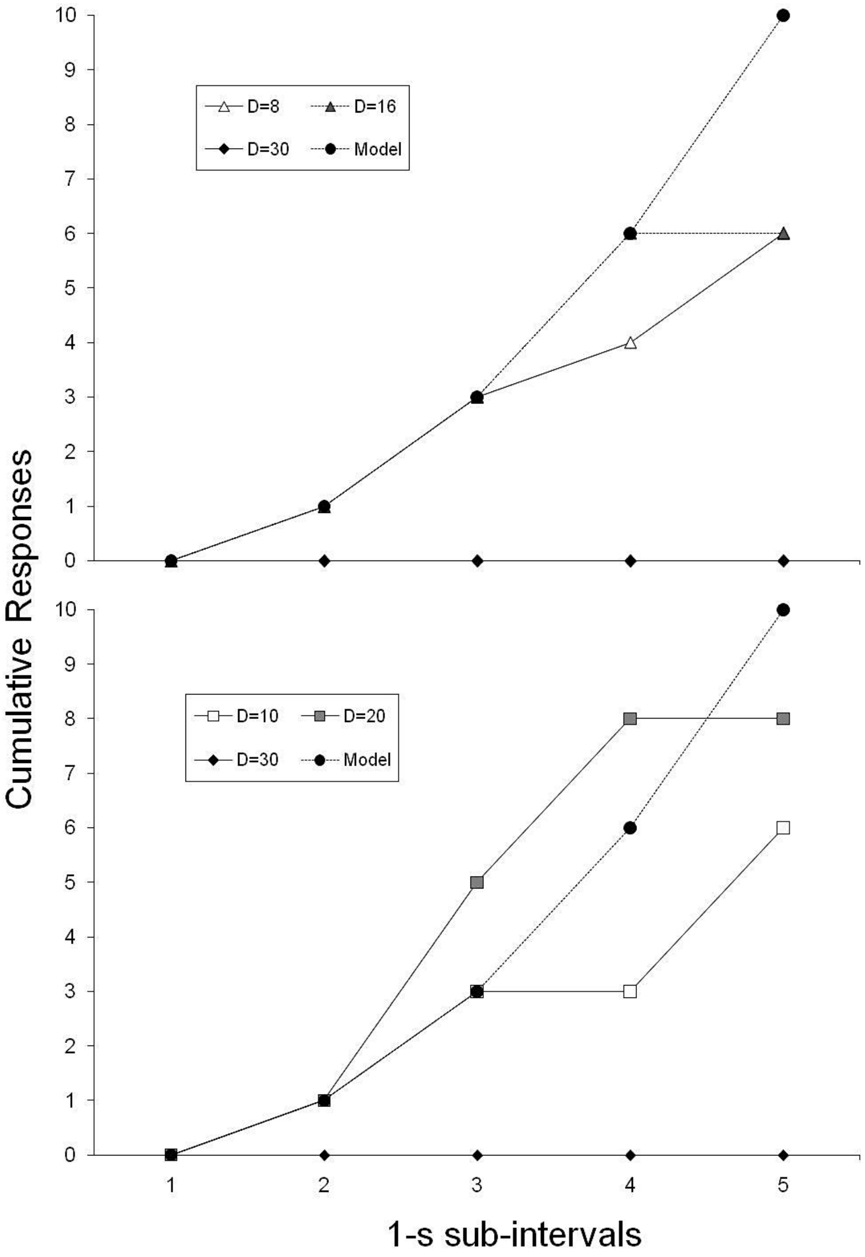

Figure A1. **Cumulative response distributions (hypothetical data) in 1-s sub-intervals of a 5-s trial, showing the pattern described by Hawkes and Shimp's (1975) model. Also shown are the deviations from this model that defined reinforcement contingencies for Pigeons 617 and 955 (upper panel) and Pigeon 119 (lower panel) during the first exposure and replication of each phase of Experiment 2.**