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REPEATED OPERANT RESPONSE RESURGENCE WITH A PEAK-INTERVAL PROCEDURE

RESURGIMIENTO OPERANTE REPETIDO CON UN PROCEDIMIENTO DE PICO

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Abstract

Resurgence is most often defined as the recurrence of previously reinforced behavior during extinction of another, more recently reinforced behavior. It provides a framework for deciphering the origin of operant responses, studying the effects of historical variables, and understanding socially relevant behaviors. The present manuscript proposes a novel procedure that incorporates the peak-interval procedure, typically used to examine temporal control, to examine resurgence repeatedly. Three experimentally naïve Long Evans rats were trained using a concurrent variable-interval (VI) 30-s fixed-interval (FI) 30-s schedule, with each schedule programmed on a different lever. After stability was reached, responding under the VI 30-s schedule was extinguished for 15 sessions. A peak-interval procedure then was employed to examine resurgence of the previously VI responding. The peak-interval procedure consisted of FI 30-s trials intermixed with 300-s peak trials, each separated by 20-s blackouts. Resurgence of operant responding was obtained and examined within and across sessions.

Keywords: peak-interval procedure, rats, resurgence

Resumen

El resurgimiento de la conducta operante se define comúnmente como la reaparición de una conducta previamente reforzada durante un período de extinción de otra conducta operante que ha sido más recientemente reforzada. El estudio del resurgimiento provee un marco conceptual y metodológico para descifrar el origen de conductas operantes a través del estudio de los efectos de variables de historia del reforzamiento, y también para comprender comportamientos socialmente relevantes. El presente manuscrito propone un procedimiento novedoso que incorpora el uso del procedimiento de pico usualmente empleado en el estudio del control temporal, para el estudio del resurgimiento. Tres ratas libres de previa historia experimental fueron expuestas a un programa de reforzamiento concurrente de intervalo-variable (IV) 30 s e intervalo fijo 30 s. Cada componente fue programado en una palanca diferente. Tras alcanzar un criterio de estabilidad, las respuestas en la palanca programada de acuerdo con el IV 30 s fueron extinguidas por 15 sesiones. Un procedimiento de pico fue implementado para examinar el resurgimiento de dichas respuestas al programa IV 30 s. El procedimiento de pico consistió de ensayos

de IF 30 s entremezclados con ensayos de pico de 300 s; cada ensayo fue separado por un intervalo entre ensayos de 20 s. El resurgimiento de respuestas operantes fue obtenido y examinado dentro y entre sesiones.

Palabras clave: procedimiento de pico, ratas, resurgimiento

The most common definition of resurgence is the recurrence of previously reinforced behavior during extinction of another, more recently reinforced behavior (Epstein, 1985). Resurgence typically is studied using a three-condition procedure: (a) a baseline condition during which responding is established by reinforcing it according to some schedule of reinforcement, then (b) the responding reinforced during the first condition is extinguished until it is eliminated or reaches low response rates, while concurrently reinforcing an alternative response, and, finally, (c) both responses are extinguished during the resurgence test (da Silva, Maxwell, & Lattal, 2011; Lattal & St. Peter-Pipkin, 2009). Resurgence occurs when the first response reinforced during baseline (a) that has been extinguished during (b), recovers to levels higher than those observed during the preceding extinction condition (da Silva, et al., 2011; Lieving & Lattal, 2003). The definition of resurgence has been revised as the reoccurrence of a response not currently reinforced when the conditions of reinforcement of a current response are worsened (Lattal, Cançado, Cook, Kincaid, Nighbor, & Oliver, 2017). It is important to note that resurgence is a transient phenomenon and sometimes replicated within an experiment or subject. (Cook & Lattal, 2019; Lattal et al., 2017).

Typically, the three phases of resurgence described above are investigated over successive blocks of sessions with one or the other of these phases in effect. In only a few experiments has resurgence been studied within individual sessions. In one of these experiments, Bai, Cowie, and Podlesnik, (2017) used a free-operant psychophysical procedure (FOPP) taking a more dynamic approach to the study of resurgence. Baseline consisted of 50-s trials of a FOPP in which the target response (left key) was reinforced during the first 25 s and not the alternative response (right key). During the following 25 s, contingencies were reversed. These conditions resembled Phases 1 and 2 described above in the three-phase condition approach. Resurgence of the target response was observed during 100-s probe trials.

In another experiment, Kincaid and Lattal (2018) first reinforced a target response according to a variable interval (VI) schedule before extinguishing it, while concurrently reinforcing a second response according to a progressive-ratio sched-

ule. As the progressive-ratio performance reached the breakpoint, the target response resurged, all within a single session. Cook and Lattal (2019) arranged the three-phase procedure within a single session. Target and alternative responding followed fixed-interval (FI) schedules in one experiment and VI schedules in another one. The general procedure was: first, the target response was reinforced until 10 reinforcers were earned and less than 5 responses were emitted on any of the other keys, then alternative responding was reinforced until 10 reinforcers were earned and less than 5 responses emitted on the other keys. A 3-s change-over delay was in effect during those two within-session phases. The resurgence test was then implemented for at least ten 30-s intervals. Cook and Lattal observed resurgence within individual sessions, and for as many as 30 successive sessions.

An experimental procedure seldom linked to the study of resurgence is the peak-interval procedure. Used to study temporal control, the peak-interval procedure consists of instances of fixed-interval (FI) schedules of reinforcement intermixed with longer periods of extinction referred to as peak trials (Catania, 1970; Roberts, 1981). After repeated exposure, responding during the peak trials is positively accelerated towards the beginning of the trial, reaching a peak near the end of the FI value, followed by a progressive decrease in responding. When the peak trial is thrice the FI value, or longer, responding starts reoccurring toward the end of the peak trial (Church, Miller, Meck, & Gibbon, 1991; Sanabria & Killeen, 2007; Stanley, 2013). Church et al. (1991) and Stanley (2013) found that such response recurrence occurs when the duration of the peak trials is fixed. Also, Taylor, Haskell, Appleby and Waran (2002) and Sanabria and Killeen (2007) found that when the duration of the peak time is less than twice of the corresponding FI value, such recurrence of responding at the end of the peak trial does not occur.

The interpolated periods of extinction and reinforcement that characterize the peak-interval procedure makes it another potential candidate for generating repeated instances of resurgence within and across sessions. The present experiment examined this possibility. The investigation of within-session resurgence permits for the examination of multiple levels of independent variables on resurgence (Cook & Lattal, 2019). It also yields repeatability of what has been mostly known as a transient phenomenon. Such advantage allows for a more efficient examination of resurgence (i.e., less time, less subjects) relative to the more conventional three-phase approach. Methodological adaptations to examine within-session resurgence have practical implications that highlight the advantages of within-subject over between-subject designs (Cook & Lattal, 2019; Sidman, 1960/1988).

Method

Subjects

Three experimentally naïve male Long Evans (Harlan, IN) rats (L9-L12) approximately two months old at the start of the experiment were used. Animals were individually housed and fed 15 g once a day 30-min post experiment in their individual home cages. Water and enrichment items (wood block, plastic house, and nesting bedding) were available always in the housing cage. Temperature and humidity of the housing and experimental rooms were kept constant. A 12-hr light/dark cycle was in effect in the housing room. Experiments were conducted during the light cycle.

Apparatus

Three modular standard operant conditioning chambers for rats (Coulbourn Instruments., PA) each kept in an isolation cubicle were used. Each chamber was 31 cm (length) by 26.4 cm (width) by 32.8 cm (height). Each chamber had modular walls with filler panels and two standard response lever each which required a force of 0.25 N to depress. Two standard stainless steel response levers protruded 2 cm from the wall, were 3.5 cm wide, were at a height of 6.6 cm from the bar floor and were 3.2 cm between the feeder trough on the same wall. A houselight was positioned in the upper-right corner of the same wall as the lever and the feeding trough. There were two halves of the trough, one for liquid reinforcers on the left and one for dry reinforcers on the right. Only the dry reinforcer half of the trough was used for this experiment and was illuminated each time a reinforcer was delivered. Grain-based pellets (45-mg) functioned as reinforcers. Experimental procedures and real-time data collection were programmed using Graphic State II (Coulbourn Inst., PA) software.

Procedure

Sessions were conducted seven days a week at approximately the same time each day. The rats were trained to press both levers and then the response requirement for reinforcement was increased progressively over sessions until a concurrent VI 30-s FI 30-s schedule was in effect. Schedules were counterbalanced across left and right levers. The interreinforcer intervals of the VI schedule were generated from the distribution described by Fleshler and Hoffman (1962); twenty intervals were used. All sessions lasted 30 min.

Figure 1. Sample sequence of trials in a resurgence test. From left to right: The session starts a 20-s inter-trial interval (ITI), followed by three instances of a FI 30-s, and then a 300-s peak trial; each interspersed by a 20-s ITI. The ellipses represent continuation of events as described on the procedure section.

The concurrent VI 30-s FI 30-s schedule was in effect for a minimum of 13 sessions and until stability criteria were met. A 2-s change-over-delay (COD) was programmed to delay reinforcer delivery upon switches from one lever to another. Stability criteria were such that for each schedule, the grand mean of the overall response rates of last six sessions was calculated, and the average of the first half and last half of those last six sessions did not vary by more than 15% of the grand mean. In addition, the criteria included absence of systematic increasing or decreasing trends in the overall response rates of the last six sessions. Rats L9, L10 and L11 were exposed to 27 sessions of the concurrent VI 30-s FI 30-s schedule before changing the VI 30-s schedule to extinction.

After responding stabilized, the VI 30-s schedule was changed to extinction for 15 sessions, while maintaining the FI 30-s schedule unchanged on the corresponding lever. The 2-s COD remained in effect during this phase. Each rat emitted three or fewer responses per minute during each of the last six sessions. Following extinction of the previously VI-maintained responding, the resurgence test was implemented during 10 sessions. Extinction remained in effect on the former VI lever and a peak-interval procedure, as described below, replaced the FI schedule.

The resurgence of responding on the former-VI lever was examined during the peak trials of a peak-interval procedure (diagrammed in Figure 1) that consisted of FI 30 s and 300-s peak trials, each separated by a 20-s inter-trial interval in which lights were turned off and there were no programmed consequences (i.e., blackout). The FI and peak trials were semirandomly programmed. Due to sessions ending after 30 min, the number of FI and peak trials varied across sessions. Also due to this termination criterion, occasionally FI and peak trials were truncated (i.e., unfinished). Excluding these truncated trials, for each session the number of FI trials ranged from one to eight, and the number of peak trials ranged from one to four.

Results

Resurgence was examined within and across sessions. Within-session resurgence was defined as response rates in a peak trial (300 s) higher than response rates on the VI-30-s lever during the last five minutes of the extinction phase. Resurgence across sessions was defined as a higher number of overall response rates during each resurgence test session than the average overall response rates per session during the last three sessions of extinction of responding on the VI 3-s lever.

During the last five minutes of the extinction phase, response rates for each rate were calculated. These local response rates were compared against response rates emitted on the VI 30-s lever during individual peak trials. Only the cumulative records of the peak trials of sessions in which within-session resurgence occurred are shown in Figure 2. In these records, for each rat, responding on the FI lever is represented by a solid line, and the VI lever, (also referred throughout the manuscript as resurgence lever) is indicated by the dotted line. Response rates during the last five minutes of extinction for each rat are indicated within each record (top left corner).

Resurgence, according to the within-session definition of resurgence presented above, was obtained during peak trials. Figure 2 shows instances of such resurgence by presenting responding for each peak trial in which resurgence was observed. Figure 2 is composed of three groups of cumulative records, one for each rat. More specifically, for Rat L9, the response rate for the last five minutes of extinction was 1.63 resp/min; higher response rates occurred during sessions 1, and 4-10. Also, within each session, resurgence was obtained during individual peak trials; for Rat L9, within-session resurgence was obtained during the first peak trials of the corresponding sessions mentioned before. During Sessions 6-8, as shown in Figure 2, within-session resurgence was obtained in peak trials 1-4.

For Rat L10, the response rate during the last five minutes of extinction was 2.73 resp/min. As shown on Figure 2, higher response rates than the corresponding local response rates, were exhibited during sessions 1, 3, and 5-10. Within each these sessions in which within-session resurgence was obtained in trial 1 of each corresponding session; during session 6 and 8, resurgence was obtained in three peak trials, and in session 5, 7, 9, 10 in two of such trials.

In line with this analysis, for Rat L11 the local response rate during extinction was 2.33 resp/min. Following Figure 2, resurgence was obtained in sessions 2-10. In sessions 3-8 resurgence was obtained in two peak trials, and in session 9 and 10, it was obtained in three of such trials.

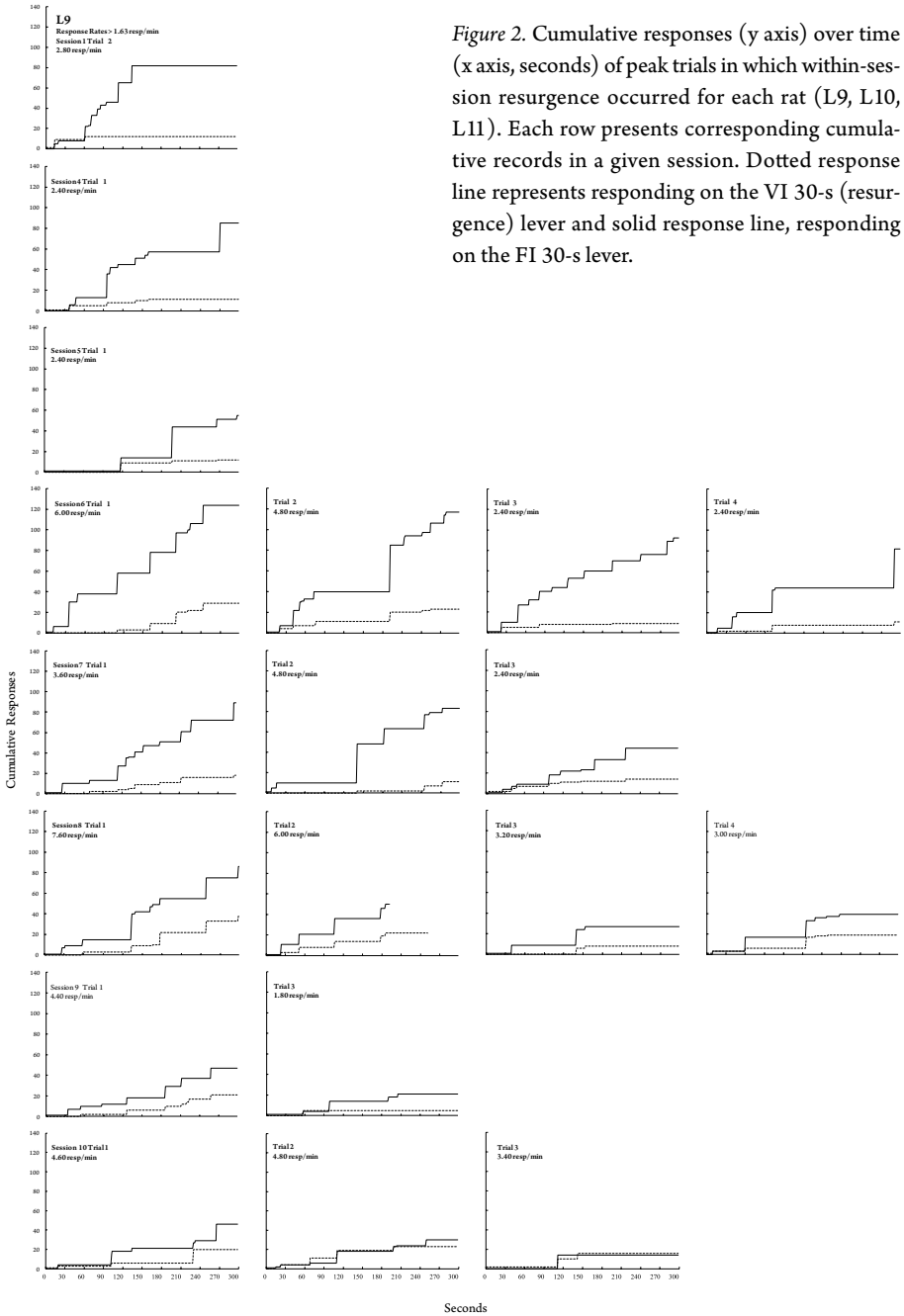
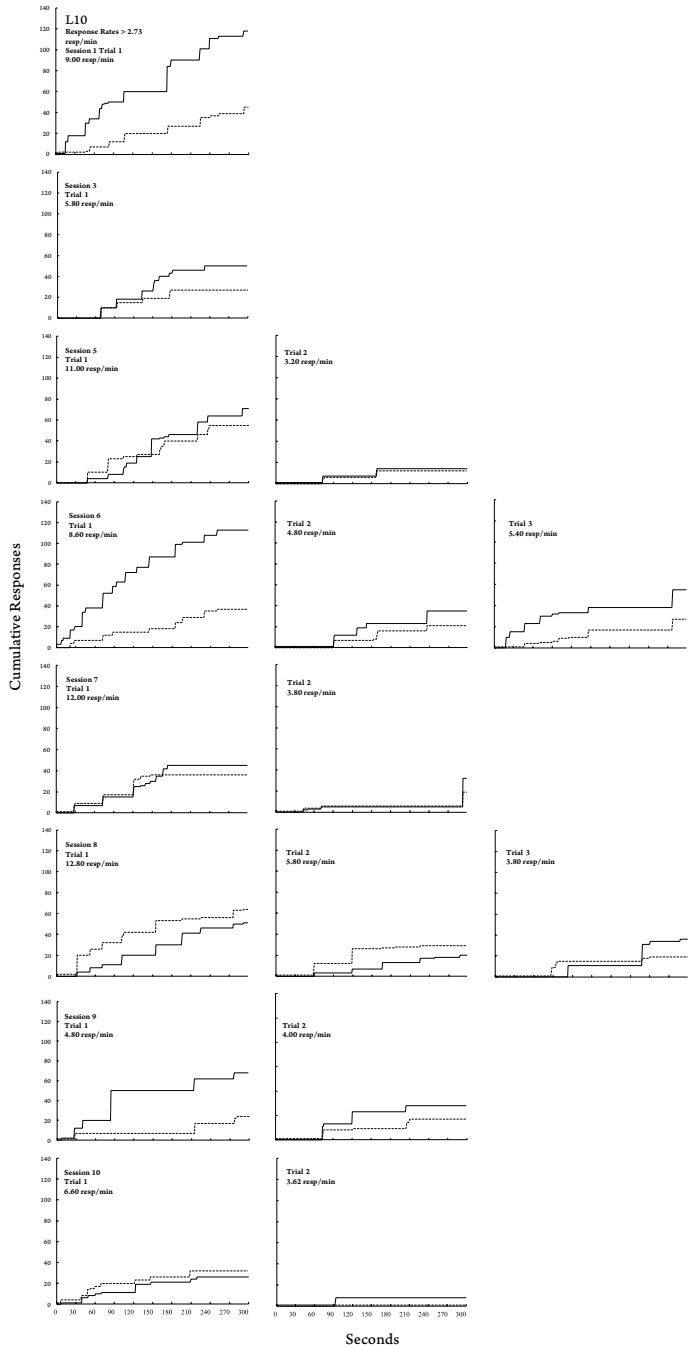
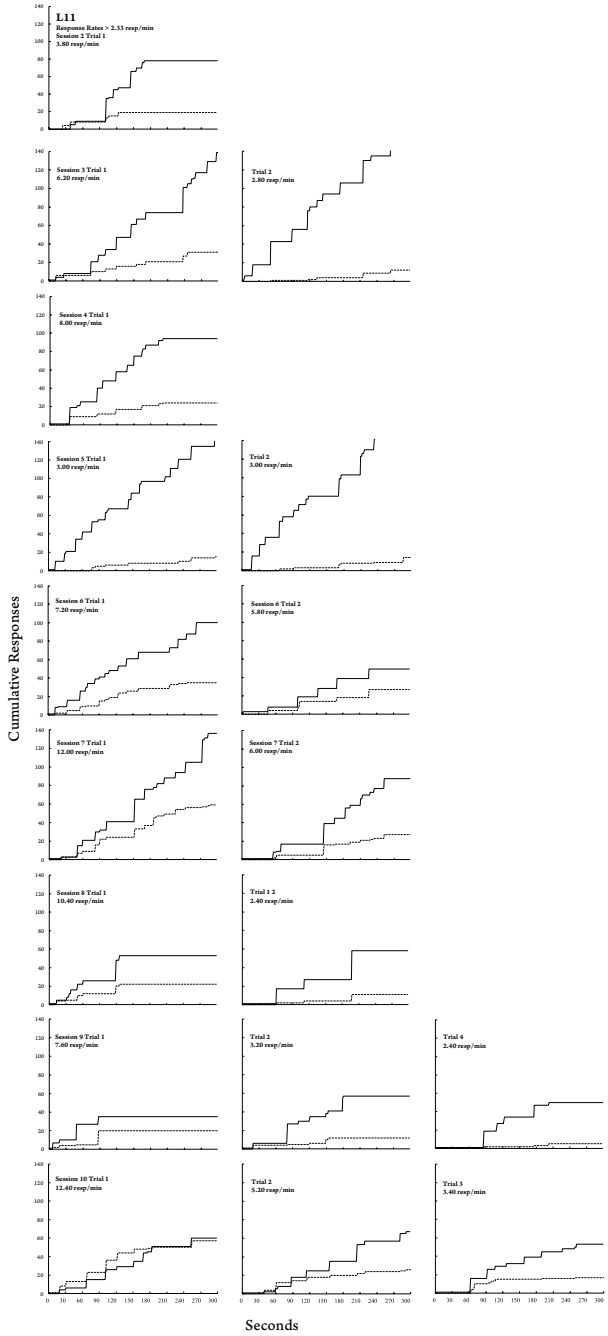


Figure 2. Cumulative responses (y axis) over time (x axis, seconds) of peak trials in which within-session resurgence occurred for each rat (L9, L10, L11). Each row presents corresponding cumulative records in a given session. Dotted response line represents responding on the VI 30-s (resurgence) lever and solid response line, responding on the FI 30-s lever.


L10
Response Rates > 2.73 resp/min
Session 1 Trial 1
9.00 resp/min
Session 3
Trial 1
5.80 resp/min
Session 5
Trial 1
11.00 resp/min
Trial 2
3.20 resp/min
Session 6
Trial 1
8.60 resp/min
Trial 2
4.80 resp/min
Trial 3
5.40 resp/min
Session 7
Trial 1
12.00 resp/min
Trial 2
3.80 resp/min
Session 8
Trial 1
12.80 resp/min
Trial 2
5.80 resp/min
Trial 3
3.80 resp/min
Session 9
Trial 1
4.80 resp/min
Trial 2
4.00 resp/min
Session 10
Trial 1
6.60 resp/min
Trial 2
3.62 resp/min
Cumulative Responses
Seconds


L11
Response Rates > 2.33 resp/min
Session 2 Trial 1
3.80 resp/min
Session 3 Trial 1
6.20 resp/min
Trial 2
2.80 resp/min
Session 4 Trial 1
8.00 resp/min
Session 5 Trial 1
3.00 resp/min
Trial 2
3.00 resp/min
Session 6 Trial 1
7.20 resp/min
Session 6 Trial 2
5.80 resp/min
Session 7 Trial 1
12.00 resp/min
Session 7 Trial 2
6.00 resp/min
Session 8 Trial 1
10.40 resp/min
Trial 1 2
2.40 resp/min
Session 9 Trial 1
7.60 resp/min
Trial 2
3.20 resp/min
Trial 4
2.40 resp/min
Session 10 Trial 1
12.40 resp/min
Trial 2
5.20 resp/min
Trial 3
3.40 resp/min
Cumulative Responses
Seconds

The cumulative records in Figure 2 allow for a local analysis of resurgence. This analysis also allows for the visualization of temporal aspects of resurgence and sustainability of responding as a function of time (300 s). Generally, in the three rats, when resurgence was observed in more than one peak trial within a session, response rates on the VI 30-s lever decreased across peak trials.

A continued examination of within-session responding was conducted by focusing on the times when switches of responding between levers occurred. As mentioned before, temporal aspects of resurgence may be visualized in Figure 2. Although the focus of the present study was on resurgence of operant responding, not on temporal control, it is worth examining the switch times from the FI to the VI lever during the resurgence test as shown in Figure 3.

To better capture this temporal aspect and to expand the analysis of within-session resurgence, the switch times (in seconds) from the FI lever to the VI (resurgence) lever, were identified for sessions in which resurgence occurred in three or more peak trials. The average switch times across trials were calculated in the following way; the first switch time across peak trials was averaged (e.g., for Rat L9, the first switch time was averaged across trials 1-4, and that is the first data point represented as an unfilled circle) for a given session, then the second switch time was averaged across peak trials, and so on. Each rat switched a different number of times per session, thus the different maximum values in the x axis of each graph in Figure 3.

The average switch times in Figure 3 were compared against 30-s intervals given that those were the interval values used in each component of the concurrent schedule used during the baseline phase. Following Figure 3, these average switch times were close to 30-s intervals for the first five to seven switches. After the fifth to seventh switches, the switch times occurred at times more removed from those 30-s intervals. It is worth mentioning that in some trials, initial responding during the peak trial occurred on the resurgence lever.

To examine resurgence across sessions, Figure 4 shows the change in probability of resurgence as the sessions of the resurgence test progressed. In this analysis, for each session, the number of peak trials in which resurgence occurred was divided by the number of opportunities for resurgence to take place, that is, the total number of peak trials in that session. Cançado, Abreu-Rodrigues, and Aló (2015) proposed number of instances of resurgence (i.e., frequency of resurgence) as one of several ways to measure resurgence. Such analytical approach served as the foundation of the present analysis; more specifically the primary source for the calculation of these probabilities comes from identifying the frequency of resurgence in

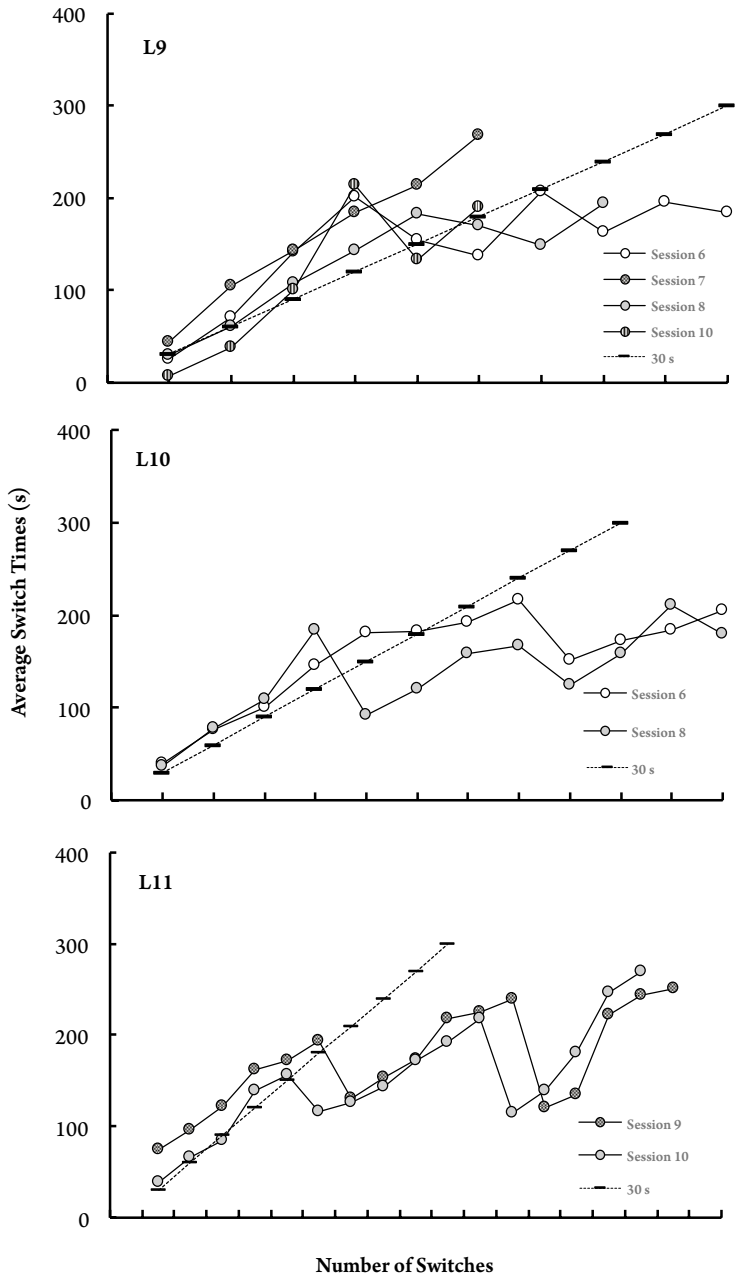


Figure 3. Average switch times (seconds) from peak trials, for sessions in which resurgence occurred in three or more peak trials.

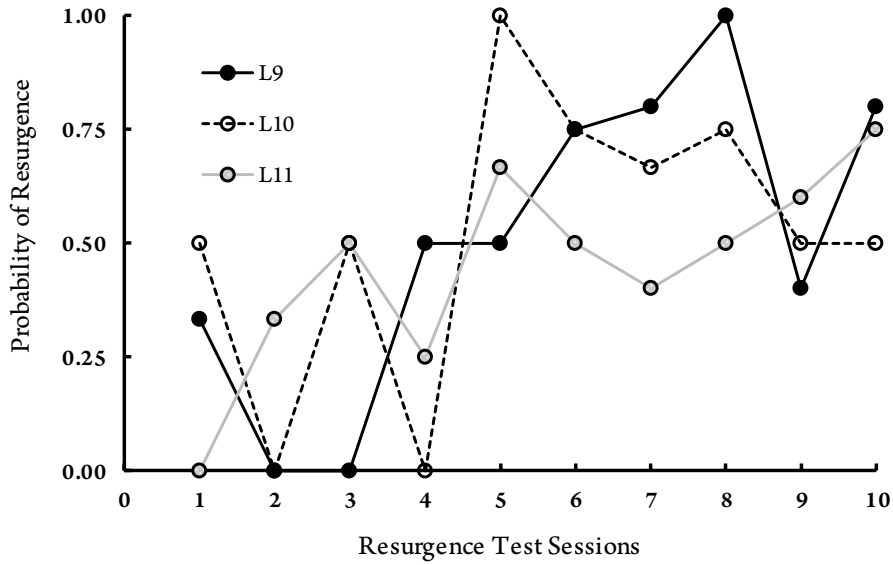


Figure 4. Probability of resurgence per session of the resurgence test for each rat (L9, L10, L11).

each session. Figure 4 reveals that, as the sessions of the resurgence test progressed, the probability of resurgence consistently increased. The average probability for resurgence during the first four sessions was 0.24 (SD = 0.21). Such probability increased to an average probability of 0.66 (SD = 0.13) for the last six sessions of the resurgence test.

The analysis across sessions included calculating overall response rates for the last six sessions of the concurrent VI 30-s FI 30-s schedule, last six sessions of extinction of the VI 30-s (while maintaining responding on the FI 30-s lever) and each of the resurgence test sessions are shown on the left of Figure 5. On the right of Figure 5, the proportions of responding from the average overall responding during the last three sessions of the extinction phase, were determined for each session of the resurgence of the test. Resurgence is indicated by bars that surpass the level of responding above the average of the last three sessions of extinction (represented by horizontal dashed line). Resurgence across sessions, as previously defined, occurred in six sessions for Rats L9 and L11, in seven sessions for L10 (Cançado et al., 2015).

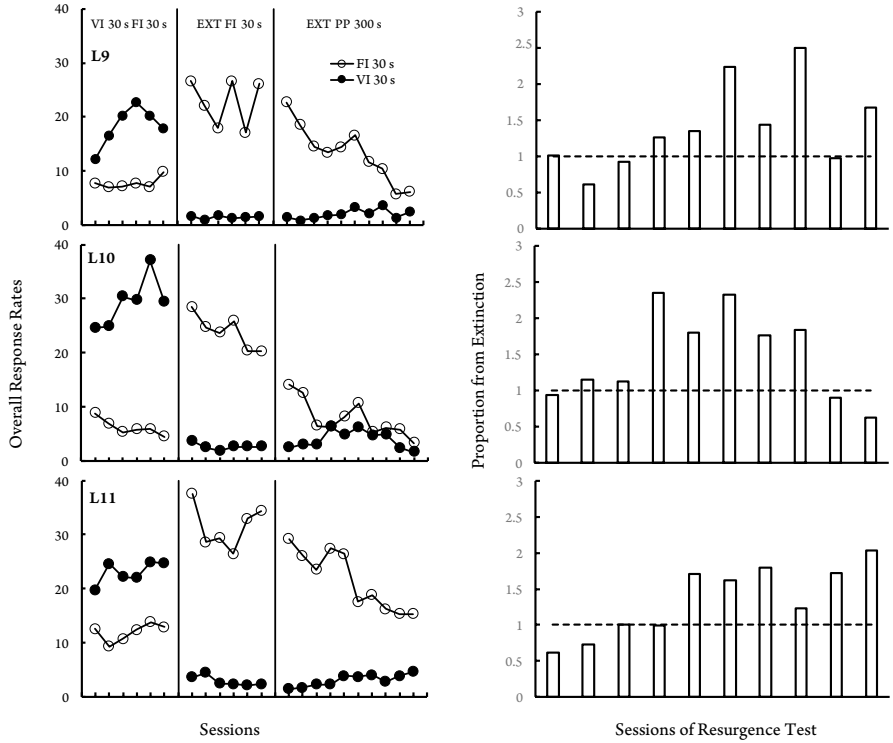


Figure 5. On the left, overall response rates for each lever across conditions for each rat (L9, L10, L11). On the right, proportion from average response rates of the last three sessions of extinction, for sessions of the resurgence test.

Discussion

The primary goal of this experiment was to explore the possibility of using a peak-interval procedure to generate reliable, repeatable within-session resurgence of operant responding. The proposed procedure to study resurgence was conducted as follows: (a) a baseline using a concurrent VI 30-s FI 30-s was established, (b) responding on the VI 30 s schedule was extinguished while maintaining responding in the FI 30-s schedule, (c) responding under the VI 30-s schedule remained under extinction and a peak-interval procedure using instances of FI 30-s trials and 300 s peak trials was implemented on the lever where the FI 30-s schedule responding

was previously established. Repeated resurgence was demonstrated within individual sessions of the resurgence test and was replicated across sessions.

Although resurgence was obtained reliably within and across sessions, it did not occur for all rats in all sessions, nor in all peak trials. After the fourth session of the resurgence test, the probability of resurgence increased consistently for the three rats (see Figure 4). According to these findings, the development of resurgence took a few sessions of exposure to the peak-interval procedure.

Two aspects of the peak-interval procedure may have contributed to the delayed appearance of the resurgence effects. First, the arrangement of the peak-interval procedure involved a variable number of peak trials (one to four, as described on the Method section) that were unsignaled in each session. Second, the presence of reinforcement during the resurgence test may have contributed to the weakening of the resurgence effects (Lattal & St. Peter Pipkin, 2009; Lieving & Lattal, 2003). After the fourth session of the resurgence test, the probability of within-session resurgence increased by more than double.

Other procedures to study temporal control such as the FOPP have been used to examine resurgence (Bai et al., 2017) but, as previously mentioned, the peak-interval procedure has not yet been reported to have been used for such purpose, thus making the present study, a novel approach to the study of resurgence. The FOPP, as implemented by Bai et al. (2017) shares some similarities with the three-condition procedure commonly used to study resurgence.

One of the modifications to adapt the FOPP to the study of resurgence made by Bai et al. (2017) was extending the duration of probe trials to double their conventional time (i.e., from 50 to 100 s). Similarly, in the present procedure, the duration of the peak trials was extended (300 s) compared to other studies that employ the peak-interval procedure that use peak-trial durations double or triple the duration of the corresponding FI portion of the procedure (i.e., peak-interval procedure with FI 30 s usually will have peak trials of 90 or 180 s).

The procedural modification of extending the duration of probe trials (in the case of the peak-interval procedure, the probe trial is also referred to as a peak trial) in both Bai et al.'s (2017) and the present study, served the common goal of generating resurgence. This is consistent with previous studies within the temporal control literature by Church et al. (1991) and Sanabria and Killeen (2007) that show that the duration of peak trials determines whether there is reoccurrence of behavior within the peak trial; the longer the duration, the higher the probability of such

reoccurrence. By the same token, extending probe trial duration contributes to the generation of resurgence.

Two intertwined methodological contributions of the present study are, as previously established, the incorporation of the peak-interval procedure to test resurgence, and including novel data analysis to examine within- and between-session resurgence and the examination of some temporal aspects of resurgence. Focusing on within-session responding by visualizing cumulative records (see Figure 2) is an accurate means to examine responding in real time and deciphering trends in resurgence effects. This analysis also led to further characterization of within-session resurgence.

Extracting switch times (i.e., times when switches from the FI 30-s lever to the VI 30-s lever occurred during the peak trials) allowed for the examination of the temporal dynamics of resurgence (Figure 3). As the number of switches progressed within a session, which is tantamount to time elapsing during the peak trials, it could be said that there is deterioration of temporal control. In other words, as the peak trial elapses, the switches happen at more distant times than 30 s.

The 30-s intervals included in the analysis presented in Figure 3 were based on findings from temporal control studies by Taylor et al. (2002) and Sanabria and Killeen (2007). In these studies, responding in a peak-interval procedure with prolonged peak trials reoccurred at about the time of the corresponding FI trial. In the present study, at the beginning of the peak trials, resurgence of responding occurred at times close to 30-s, suggesting that, in this procedure, resurgence tends to occur around the time when a reinforcer would have been scheduled. The peak trial is functionally an extinction trial that promoted resurgence (responding on the VI 30-s lever) at relatively precise times, at least at the beginning of the session.

The deterioration of temporal control during the resurgence test may be partly due to how the peak-interval procedure was arranged in the present experiment. In the present procedure, if there was no responding (during the FI trials of the peak procedure), then the procedure did not advance. This procedural aspect most likely contributed to low levels of responding as the peak-interval procedure elapsed and the deterioration of temporal control.

Overall rates of responding during the resurgence test (see Figure 5) revealed resurgence in 60-70% of the resurgence test sessions. Part of the rationale for using the peak-interval procedure in the study of resurgence was that intermittent peak trials (extinction) intermixed with FI 30-s trials, would generate sustained resurgence within and across sessions. This arrangement for a resurgence test is different

than the more frequently used pure extinction during a resurgence test (e.g., Exps. 1 & 2, Lieving & Lattal 2003).

Similar to the present procedure, Lieving and Lattal (2003) also examined alternative ways of arranging a resurgence test that included intermittent access to food. In Experiment 3 these authors used variable-time schedules and in Experiment 4, VI schedules to test for resurgence. Resurgence was not observed with the delivery of response-independent food and lower magnitude resurgence (compared to pure extinction during Exps. 1 & 2) was obtained when a VI schedule was used to test for resurgence.

The present procedure allowed for the characterization of trends of resurgence effects within and across sessions. Repeated within-session resurgence was obtained. Similar to results by Cook and Lattal (2019) a decreasing trend of magnitude of resurgence was evidenced in the decreasing local response rates within individual peak trials within a session for all rats. Such within-session resurgence was renovated after exposure to peak trials with each session. Consistent resurgence across sessions was also evidenced and the trend of such effects was variable and sustained across rats (see right panel of Figure 5). Thus, resurgence effects within and across sessions was renovated with the opportunity presented in each session of the resurgence test. The present procedure generated sustained within and across resurgence effects and may be worth exploring further.

One potential way to further examine the sustainability of resurgence effects generated by the present procedure is increasing the number of sessions of the resurgence test. In the present procedure, the resurgence test consistent of 10 sessions as in Lieving and Lattal (2003), while Bai et al. conducted 23 sessions. Future research iterations of the present experiment could include increasing the number of resurgence test sessions. An additional procedural variable that may be worth exploring, based on previous experiments within the temporal control literature (e.g., Sanabria & Killeen, 2007) is varying the peak-trial duration and examining whether such duration affects the magnitude of resurgence.

Resurgence is a multifaceted behavioral phenomenon that has been related to mechanisms such as response strength, contextual control, and temporal control, among others. Blending procedures from different areas of research allows for novel explorations of behavioral phenomena such as resurgence. Such novel procedural approaches also yield alternative ways of analyzing data that may contribute to advancing the knowledge about the variables that that contribute to resurgence.

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