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Abstract	Preference pulses are defined as a tendency in choice for relative response rate to decline with time since receipt of the just-reinforced alternative. McLean, Grace, Pitts, and Hughes (2014) suggested preference pulses may not be solely a local reinforcement effect, but rather may include an artifact due to run structure of responding. If so, pulses after reinforcement should also appear if reinforcement is omitted. To evaluate whether occasional reinforcer omission leaves run structure unaffected, seven food-deprived rats responded for food pellets on a two-component multiple schedule of concurrent schedules. In both components, the assignment of reinforcement to a left or right lever varied randomly following each reinforcer. One of the components was a concurrent Variable-Interval (VI) 30-s Extinction (EXT) schedule. A stimulus light above the lever identified its association with the VI schedule. The second component was a concurrent VI 30-s VI 30-s schedule. In this component, the stimulus light above each lever was illuminated, and reinforcement was sometimes omitted randomly after the VI requirement was met. In the first component, preference pulses were reliably observed after reinforcement and its omission when the just-reinforced lever was the now-EXT lever ; however, when the just-reinforced lever was the VI lever again, and its next reinforcer was omitted, pulsing was not in evidence. Instead, an "antipulse" : a tendency for relative response rate to increase to the just-omitted lever, obtained. Additional analyses showed the initial choices after reinforcer omission were (1) more variable than the choices thereafter, (2) more variable than the first several choices after reinforcement, and (3) faster than the choices thereafter. These features suggest the manipulation of reinforcer omission has specific effects on choices that follow,

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Do Preference Pulses after Reinforcer Omission Occur due to its *a priori* run Structure or to its Own Local Effects?

Yosuke Hachiga[*]

Preference pulses are defined as a tendency in choice for relative response rate to decline with time since receipt of the just-reinforced alternative. McLean, Grace, Pitts, and Hughes (2014) suggested preference pulses may not be solely a local reinforcement effect, but rather may include an artifact due to run structure of responding. If so, pulses after reinforcement should also appear if reinforcement is omitted. To evaluate whether occasional reinforcer omission leaves run structure unaffected, seven food-deprived rats responded for food pellets on a two-component multiple schedule of concurrent schedules. In both components, the assignment of reinforcement to a left or right lever varied randomly following each reinforcer. One of the components was a concurrent Variable-Interval (VI) 30-s Extinction (EXT) schedule. A stimulus light above the lever identified its association with the VI schedule. The second component was a concurrent VI 30-s VI 30-s schedule. In this component, the stimulus light above each lever was illuminated, and reinforcement was sometimes omitted randomly after the VI requirement was met. In the first component, preference pulses were reliably observed after reinforcement and its omission when the just-reinforced lever was the now-EXT lever; however, when the just-reinforced lever was the VI lever again, and its next reinforcer was omitted, pulsing was not in evidence. Instead, an "antipulse"—a tendency for relative response rate to increase to the just-omitted lever, obtained. Additional analyses showed the initial choices after reinforcer omission were (1)

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more variable than the choices thereafter, (2) more variable than the first several choices after reinforcement, and (3) faster than the choices thereafter. These features suggest the manipulation of reinforcer omission has specific effects on choices that follow, resulting in the occurrence of preference pulses to the EXT lever and anti-pulses to the VI lever.

Key words: preference pulses, reinforcer omission, residual pulses, artifact, choice, lever press, rat

For decades, the local properties of choice performances under two-alternative concurrent schedules have been a topic of study. One aspect of interest has been the occurrence of *preference pulses* (Davison & Baum, 2002)—a tendency immediately after reinforcement for preferences to the just-reinforced alternative to be briefly elevated and then diminish over time, stabilizing at levels approximating session-wide means.

Subsequent work has tried to determine why preference pulses occur. Davison and colleagues have attributed this outcome primarily to the signaling effect of reinforcement rather than its strengthening effect (e.g., Boutros, Elliffe, & Davison, 2011; Cowie, Davison, & Elliffe, 2011; Davison & Baum, 2006). Hachiga, Sakagami, & Silberberg (2014) raised a different possibility: Perhaps preference pulses occur due to response induction (e.g., Killeen, Hanson, & Osborne, 1978) based on their finding that pulsing can occur even if a choice alternative signals Extinction (EXT) instead of imminent reinforcement. Both accounts argue a local effect of reinforcement—either discrimination or induction—contributes to preference pulsing; however, neither account views its contribution as absolute. The reason each account advances a multi-factorial explanation for pulsing is that McLean, Grace, Pitts, and Hughes (2014) have provided simulated evidence that pulsing also contains an artifactual component.

In their simulations, McLean et al. (2014) generated response runs sampled from two gamma distributions and switched between them to create a two-alternative choice sequence. The choices were occasionally tagged as “reinforced” when they satisfied the reinforcement requirement of a simulated concurrent Variable-Interval (VI) VI schedule. Even though the simulated runs could not be affected by reinforcement, McLean et al. nevertheless found pulses occurred.

McLean et al. (2014) attributed pulses without reinforcement to the fact that switching between alternatives is much less frequent than response continuation to an alternative. This characteristic of run structure could elevate preference to an alternative immediately after a simulated reinforcement. They additionally proposed that preference pulses in which responding has no local effects of reinforcement should be viewed as "null hypothesis preference pulses" (NHPPs). Furthermore, residual pulses, defined as the difference between pulses from real subjects and their corresponding NHPPs, could be used to evaluate any genuine local effect of reinforcement due to, say, the signaling or inductive effects of reinforcement.

Hachiga, Sakagami, and Silberberg (2014, 2015) collected data from two groups of rats—one group run on concurrent Variable Ratio (VR) 20 EXT schedules and the other on concurrent VI 27-s EXT schedules. In both groups, assignments of reinforcement to a left or right lever was cued by illumination of a stimulus light above the lever and changed randomly following each reinforcement. They found in both concurrent schedules that preference pulses were reliably observed to the reinforced lever that switched to the now-EXT lever, but no systematic change appeared in the case that the reinforced lever was again either a VR or VI lever. In keeping with McLean et al.'s (2014) simulation technique, Hachiga et al. (2014) ran several simulations under concurrent VR EXT schedules with a constant ratio of mean response runs to the VR and EXT levers (the ratio also matched the ratio of mean choice proportion to the VR and EXT levers obtained from the actual subjects) while the changeover rates were varied. The result they found was what they called an "antipulse" —instead of an EXT preference pulse to the now-EXT lever, preferences to the not-just-reinforced lever but now-VR lever were briefly elevated immediately after reinforcement. The difference between the actual and simulated data was large and qualitatively distinguishable in terms of the slopes of the pulse function. The same result appeared in the simulations on concurrent VI EXT schedules in Hachiga et al. (2015).

Why does the antipulse emerge in their simulations? It is because the stat rat switches levers (follows the light) and completes the current run on the now-cued-lever. For example, suppose twenty consecutive responses are selected as a current run, of which the fifth response is followed by reinforcement and the schedules assigned to the levers are switched. Thereafter, the remaining 15 responses are emitted on the now-VR lever that was the EXT lever before the last reinforcement occurred. That makes a strong preference to the now-reinforced lever, not to the now-EXT lever. The difference in the shapes of the actual pulsing and the simulated one is so large, it casts doubt on the application of the artifact argument to the concurrent VR (or VI) EXT schedules used by Hachiga et al.

Hachiga et al.'s simulations presumed perfect cue-light stimulus control of choice by the stat rat. The stat rat unmistakably responded to the reinforced alternative after reinforcement. If, on the other hand, the stat rat ignored the lights completely, the pulse curves to both the VR lever and the EXT lever merged into one (Hachiga et al., 2014). Given the discriminative perfection achieved by the stat-rats was not matched by actual subjects, the relevance of simulated performance as a model for actual performance is called into question. After all, the original simulation method McLean et al. (2014) provided could not apply to the choice situation Hachiga et al. (2014, 2015) used. A different method for conducting an artifact analysis is needed.

Indeed, McLean (personal communication, March 2014) argued that a simulation method should not be used with concurrent schedules when schedule location, cued by the lights, was switched frequently. Instead of using simulations for making NHPPs, he suggested making them from the actual data by occasionally omitting scheduled reinforcers. The idea behind this approach is that the usual analysis of preference pulses used reinforcer presentation as initiating recording time since reinforcement; but what if the starting position of the analysis was the occurrence of reinforcer omission? If pulsing occurred after reinforcer omission like pulsing after reinforcer presentation, the account attributing it to the local reinforcer effect would be unable to interpret it. The advantage of using rat's actual response sequences is that no assumptions are needed about the degree of discriminative control by the cue light.

Apparently, in the view of McLean (personal communication), that is a better way to evaluate the artifactual content in preference pulses. However, it is true only if reinforcer omission has no unique effect on choice. Azrin, Hutchinson, and Hake (1966) used a procedure that alternated periods of reinforcement presentation with periods of reinforcement omission. Their pigeon subjects showed aggressive behavior at the onset of the reinforcer-omitted period. They interpreted the transition from reinforcement period to the omitted period as aversive, leading to the aggressive behavior obtained. Staddon and Innis (1969) observed rats and pigeons under Fixed-Interval schedules where 25% of the intervals ended in the omission of food. In the interval following food omission, response rates increased. Antonitis (1951) reinforced rat nose-poking responses to anywhere along a 50-cm horizontal opening. With continued training, responses became limited a few locations on the strip. Thereafter, subjects were exposed to a period of reinforcement omission, resulting in increased variability in choice locations. These previous studies raise the possibility that an omission procedure would have some effects on choice, even though they may not be readily identifiable in a typical concurrent schedule. If so, a reinforcer-omission procedure would not be a valid way to make an NHPP.

The present experiment addresses this problem. To compare preference pulses after reinforcement and after reinforcer omission, a multiple schedule of concurrent schedules was used. A session consisted of repeated cycles of two successive concurrent VI 30-s EXT schedules followed by a concurrent VI 30-s VI 30-s schedule. In the last concurrent schedule, either reinforcer presentation or reinforcer omission occurred with equal probability. This procedure permits comparing preference pulses after reinforcement (post-delivered reinforcers or PDRs) and of post-omitted reinforcement (POR) once the multiple schedule of concurrent schedules returns to the first multiple-schedule component, concurrent VI EXT.

Method

Subjects

Seven experimentally naïve, 30-week-old, male Wistar rats (Subjects D9 through D15), maintained at 80% of their free-feeding weights, served as subjects. Water was continuously available in their home cages where a 12-h dark-light cycle was in effect (lights off at 8 AM). The experiment was conducted during the late morning, and supplemental feeding, when it was required, occurred after all subjects finished their daily experimental session.

Apparatus

Each of three experimental chambers, 21 cm long by 28 cm wide by 28 cm high, was housed in a sound-attenuating box. The ceiling and sidewalls of the chambers consisted of Plexiglas, and the front and back walls consisted of metal plates. The floor was made of parallel 1-mm thick stainless-steel bars that were 15 mm apart, center to center. The front wall contained two shielded white stimulus lights (24-V bulbs). They were 12 cm above the floor, 10 cm apart and directly over the two response levers. The levers required a force of approximately 0.15 N to operate. They were 7 cm above the floor and 8 cm apart, measured center to center, and were equally spaced from the middle of the front wall. A tray that could receive 45-mg food pellets was centered between the levers, 2 cm above the floor. A shielded 24-V white house light was located at the top of the back wall. A speaker that produced white noise and a ventilation fan were attached to the outside of the chamber. All experimental events and data recording from all chambers were controlled by a computer programmed in Visual Basic 2010 Express Edition.

Procedure

Rats were trained to press both levers by successive approximation to the desired response. Once responding appeared to be stable for 10 min, all rats were exposed to a concurrent schedule of continuous reinforcement. Each of the daily pretraining sessions ended after 80 reinforcers or 30 min had elapsed, whichever occurred first.

In subsequent pretraining, a session began with the illumination of a randomly selected stimulus light above its associated lever. A VI schedule composed of 20 intervals from the Fleshler-Hoffman sequence (Fleshler & Hoffman, 1962) assigned a single-pellet reinforcer for a response to the lever below the illuminated stimulus light that met the VI-schedule criterion. A 2-s blackout accompanied food delivery. Responding during a blackout had no programmed consequences. Immediately following the blackout, a new stimulus light was randomly chosen and illuminated. Only a press to the light-cued lever could deliver the next food pellet. The mean VI interval changed with stepwise increments of 10, 20, and 30 s over six sessions. The number of VI intervals increased to 40 to create a final VI 30-s schedule. No changeover delay (COD) was in force. Each daily session ended after 80 reinforcers or 50 min, whichever occurred first.

Once pretraining was complete, the main experimental condition began. The condition started with the contingencies at the end of pretraining–that is, one randomly selected stimulus light was illuminated, and its associated VI 30-s schedule was operative. An EXT schedule was associated with the unilluminated lever. Responses to it were recorded but had no programmed consequences. When the VI requirement was met, the response was followed by reinforcement and a 2-s blackout. The contingencies of concurrent VI EXT schedule were maintained until two reinforcer presentations occurred. After the second reinforcer, the next multiple-schedule compoonent began with illumination of both stimulus lights and a VI 30-s schedule was randomly assigned to a lever, while an EXT schedule was assigned to the other lever. When a response to the current VI lever met the VI requirement, reinforcement was presented with $p=0.5$; otherwise, reinforcement was omitted. After the 2-s blackout, the contingencies returned to the concurrent VI EXT schedule, where one stimulus light was lit. The experimental condition continued for 60 sessions and all analyses here are based on the last 20 sessions.

Results

Preference pulses and residual pulses:

Figure 1 presents, for two representative subjects, the log of the ratio of responses on the just-reinforced lever (P or “productive” lever) to responses on the other lever (N or “not just productive” lever) as a function of time since reinforcement in 2-s bins. Responses that occurred 30 s after reinforcement are not included. P and N designations are based on the location of the previously earned reinforcer, or the occurrence of its omission. Thus, if responding to the left lever produced reinforcement (or its omission), the lever is designated as the P lever, regardless of the whether the discriminative stimulus for the next reinforcer remained the same or shifted to the right lever.

When the P lever was in EXT in the concurrent VI EXT schedule, preferences for the lever decreased with time since reinforcement, whereas there is little evidence of systematic change when the P lever was again in VI. In the cases where reinforcement was omitted, changes in preference for the P lever were like those after reinforcement presentation when it was the now-EXT lever; however, in the case when it was now the VI lever, it showed an increasing function with time since reinforcement omission. When the multiple-schedule component consisted

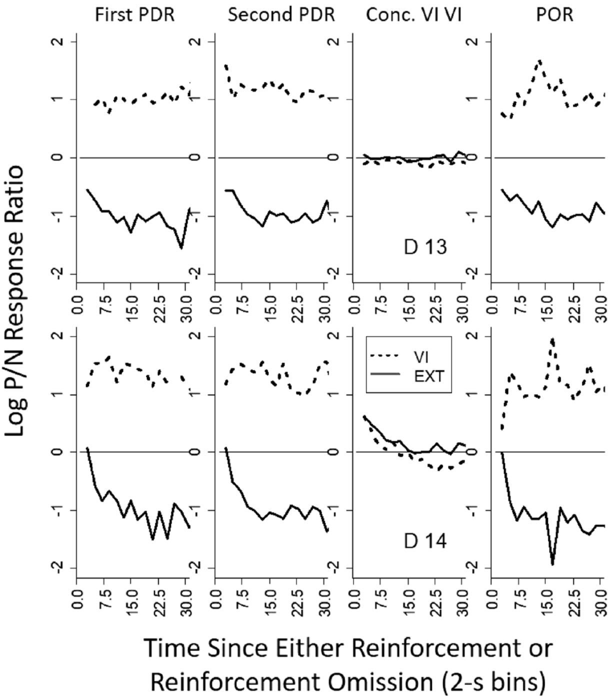

Figure 1. Log of the ratio of just-reinforced lever responses to responses on the other lever as a function of time since reinforcement or its omission in 2-s bins for two representative individuals in the experiment. The three left columns present data after reinforcement presentation in first and second concurrent VI EXT and concurrent VI VI schedules, respectively. The rightmost column presents data after reinforcement omission. Dashed and solid lines identify either the previous reinforced lever is now associated with VI or with EXT, respectively. The horizontal line at zero on the Y axis defines indifference in choice.

of a concurrent VI VI schedule, both functions merged into one and the changes in preference were not consistent across subjects. Generally, the preference changes were sharp up to about 10 s since reinforcement presentation or omission and stabilized thereafter.

Figure 2 presents for each subject the mean difference in the log P/N ratios between 2 to 10 s and 12 to 40 s across all components. If the dif-

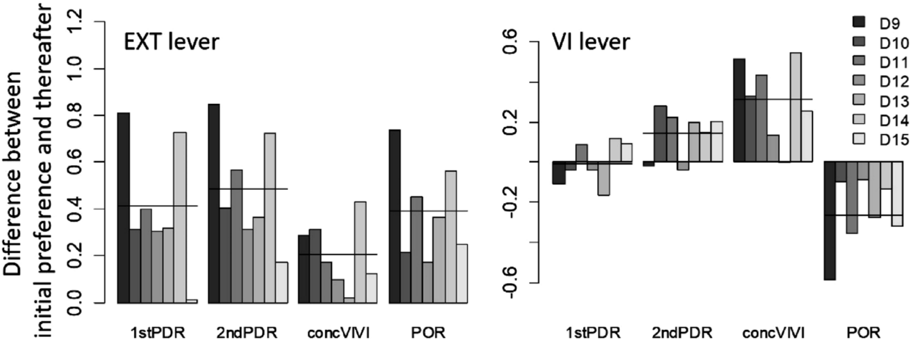

Figure 2. Difference of mean preference between 2 to 10 s and 12 to 40 s since reinforcement or reinforcement omission. The horizontal line in each component indicates mean difference across subjects.

ference was positive, it means the initial preference to the P lever was elevated relative to the preference thereafter—in other words, preference pulses were evident. All components in EXT showed preference pulses, while those in the VI pulsing occurred in the components of second PDR and concurrent VI VI. Remarkably, the component POR showed anti-pulsing to the N lever that was the now-EXT lever.

One-way, repeated-measures ANOVAs were conducted based on the components when the now-EXT lever was pulsing (the left panel) and when the now-VI lever was pulsing (the right panel), separately. Both of the ANOVAs to the EXT pulses and the VI pulses showed components were significantly different ($F(3, 6)=8.24$, $p=.001$; $F(3, 6)=18.65$, $p<.0001$, respectively). In the EXT pulses, post analyses showed the second PDR was larger than the difference in the first PDR ($t(6)=2.82$, $p=.03$), the concurrent VI VI ($t(6)=4.12$, $p=.006$), and the POR ($t(6)=2.55$, $p=.04$), and the difference of the concurrent VI VI was smaller than those of the first PDR ($t(6)=2.59$, $p=.04$) and the POR ($t(6)=2.67$, $p=.03$). The difference between the first PDR and the POR was not significant ($t(6)=0.35$, $p=$n.s.). In the VI pulses, the POR was smaller than the first PDR ($t(6)=3.64$, $p=.01$), the second PDR ($t(6)=5.67$, $p=.001$), and the concur-

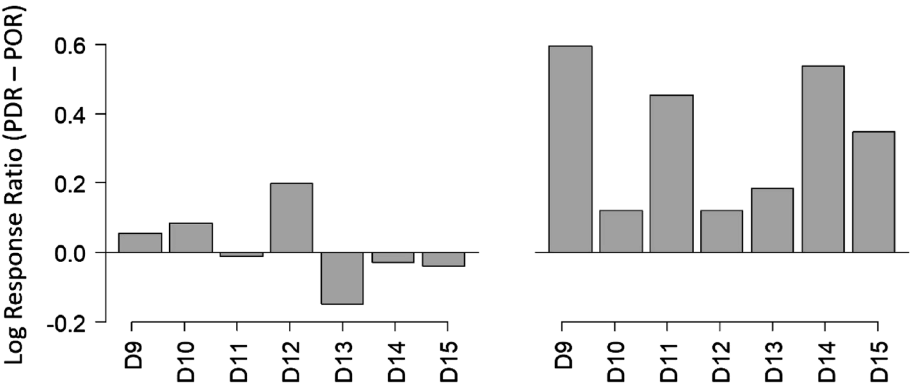

Figure 3. Difference of preference between first PDR and POR during the first 8 s since either event.

rent VI VI ($t(6)=4.99$, $p=.003$). The first PDR was smaller than the second PDR ($t(6)=2.85$, $p=.02$) and the concurrent VI VI ($t(6)=4.97$, $p=.003$).

These post analyses of ANOVAs showed no significant difference between the first PDR and POR in pulsing to the EXT lever, but a significant difference does appear to the VI lever. Figure 3 shows these results. Given the POR pulses are NHPPs, the residual pulses are, according to McLean et al.'s (2014)'s interpretation, the true local effects of reinforcer after removing artifactual effects.

Local performances after reinforcement presentation and omission:

The analyses so far show that pulses to the EXT lever seem artifactual whereas pulses to the VI lever appear real. This conclusion would be sensible if the manipulation of reinforcer omission was neutral in effect on subject's performances like the simulated NHPPs. However, if the manipulations' effects were not neutral, this interpretation would be in doubt.

As noted, reinforcement omission might make subject's behavior more variable temporarily in choice (Antonitis, 1951). *U* statistics are used to evaluate variability in local choice performances (see Attneave, 1959;

Page & Neuringer, 1985). The measure of variability takes the form:

$$U = -\frac{\sum_{1}^{2} p_i Log_2 p_i}{Log_2(2)}$$

where p_i equals the relative frequencies of response to the EXT lever and the VI lever. The U value approaches 1.0 when both relative frequencies are equal (that is the highest variability) and approaches 0.0 when responses are emitted only to one lever.

The left panel of Figure 4 presents U values in the first PDR and the POR across subjects. The values are shown separately based on responses up to 10 s (initial performances) and those of 12 to 40 s (performances thereafter) since reinforcement or its omission.

In both the PDR and the POR, the initial behavioral variability was higher than thereafter ($t(6)=4.04$, $p=.007$, and $t(6)=5.67$, $p=.001$, respectively, by paired t test). The right panel of Figure 4 presents the difference of U values between PDR and POR. It shows initial choices in POR were more variable than in PDR ($t(6)=-2.50$, $p=.05$), but no difference in choices thereafter ($t(6)=0.74$, $p=$n.s.).

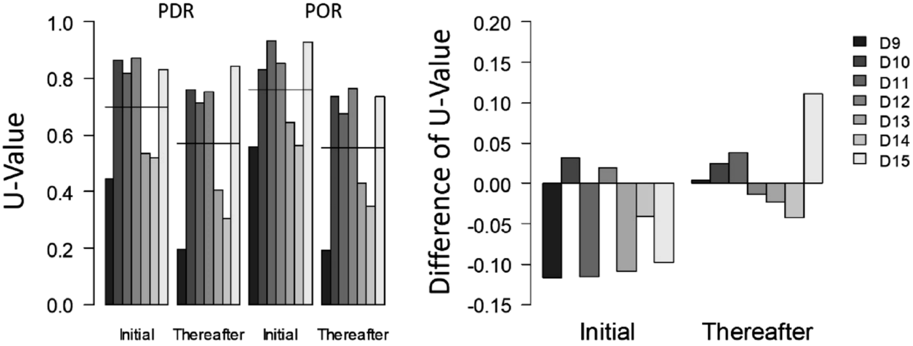

Figure 4. Left panel: U value based on responses up to 10 s (initial) and 12 to 40 s (thereafter) since reinforcement or its omission in case of the first PDR and the POR. Each horizontal line presents the average across subjects in each condition. Right panel: the difference of U values between PDR and POR. See text for further details.

Another possible effect of reinforcement omission was to increase response rate temporarily (Staddon & Innis, 1969). To evaluate this possibility, one-way, repeated-measures ANOVAs were conducted based on the mean absolute response rate in the first 8-s interval (2 to 10 s) and the following 8-s interval (12 to 20 s) in both the first PDR and the POR. Absolute response rates were significantly different ($F(3, 6)=4.03$, $p=.02$). Post analyses showed only the initial response rate in the POR was higher than that in the following rate ($t(6)=10.19$, $p=.0001$). The other comparisons showed no significant differences.

Discussion

In the first component of the multiple schedule in this study, one of two levers selected at random and cued by a stimulus light provided the next reinforcer according to a VI schedule; the other lever was in EXT. After reinforcers were delivered twice in that component, the component shifted to a concurrent VI VI schedule, where one of the two levers was selected at random to provide the outcome, either a food reinforcer or reinforcer omission. Both lights above the two levers were illuminated

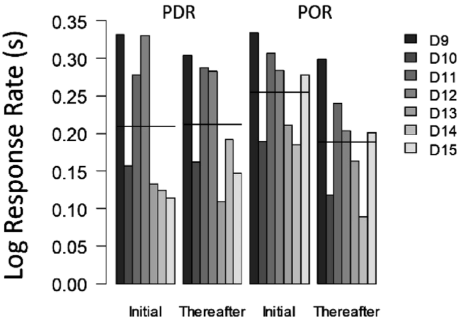

Figure 5. Log of the absolute response rate of the first PDR and the POR. The initial response rate and thereafter derived from the first (2 to 10 s) and second (12 to 20 s) interval since reinforcement or its omission. Each horizontal line indicates the average across subjects in each condition.

during this component.

The results successfully replicated two characteristics of preference pulses (Figures 1 and 2): (1) In the concurrent VI EXT component, preference pulses were reliably observed to the reinforced lever that switched to the now-EXT lever, but weak or no pulses occurred when the reinforced lever was the now-VI lever again (Hachiga et al., 2015), and (2) In the concurrent VI VI component, preference pulses occurred but were weak without the presence of a COD (see Krägeloh & Davison, 2003).

In addition, this study found preference pulses occurred to the omitted-reinforcer lever that was now-EXT lever as well, while antipulses occurred to the omitted-reinforcer lever that was the now-VI lever again (Figure 2). The effect size of residual pulses of the EXT pulsing approached zero, whereas that of the VI pulsing was more positive than the original effect size of the VI pulsing in Figure 3. According to the argument of McLean et al. (2014), the now-VI lever showed reliable pulsing but the now-EXT lever did not. However, this interpretation hypothesizes that preference pulses should occur after reinforcer omission even where the following choices were not affected by the experimental manipulation of reinforcer omission.

Further analyses of the data from the first concurrent VI EXT schedule made the McLean et al. (2014) hypothesis doubtful in some respects. First, initial choices since POR were more variable than the choices thereafter (Figure 4, left). It suggests the manipulation of the omission affected the following structure of choice temporarily. Second, the initial choices since POR were more dispersed than since PDR (Figure 4, right). It is compatible with Antonitis' (1951) finding that behavior was more variable after reinforcer omission. Finally, the initial absolute response rate since POR was significantly faster than the following rate (Figure 5). Six of seven subjects showed initial response rates in POR that were higher than those in PDR; however, this tendency approached but did not reach statistical significance. These results are compatible with the those of Staddon and Innis (1969).

Originally, the artifact account stood on the basis that response allocation occurs in engagement bouts (Shull, Gaynor & Grimes, 2001); and reinforcer presentation or omission is likely to occur at the middle of the bout run, resulting in leading preference to the P lever that would be necessarily high. However, the response runs to the EXT lever is usually short; that would suppress an artifactual effect on run structure. Moreover, choice runs were likely interrupted by rat's leaving the lever to check the pellet tray during 2-s blackouts and by switches in the location of the cued-lever. These features and the observed results, taken together, indicate that the observed pulses are phenomena specific to reinforcer omission rather than being an artifact of run structure.

The initial increased behavioral variability in both the PDR and the POR is due to the preference pulses. In the EXT pulsing, the preference to the now-VI lever was opposed by the preference to the P lever at first and overcame it by about 10 s since reinforcement or its omission. It means the occurrence of preference shift in the 2 to 10-s initial interval made the initial behavioral variability increase. Similarly, antipulses that occurred after POR in the VI pulsing worked to further increase behavioral variability, as the N lever had some preferences first since reinforcer omission and diminished later. These interactions did not occur in VI pulsing after PDR.

How does one explain the pulsing in POR? If the preference pulses immediately after reinforcement presentation were induced, as argued by Hachiga et al. (2014), POR pulsing and antipulsing might be also due to an induction process. However, it is not clear induction processes affect PDR and POR pulsing in the same manner. Effects of introducing a reinforcer omission period may be attributable to an induction process; however, the literature suggests there may be several varieties of induction processes: EXT-induced aggression (e.g., Azrin, Hutchinson, and Hake, 1966; Rilling & Caplan, 1975), EXT-induced variability (e.g., Galbicka, 1988; Galizio, Frye, Haynes, Friedel, Smith, & Odum, 2018), and EXT-induced resurgence (e.g., Bachá-Méndez, Reid, & Mendoza-Soylovna, 2007; Reed & Morgan, 2006).

Should one wish to explain the occurrence of POR pulsing and antipulsing in terms of the induction accounts presented above, two possibilities come to mind. One possibility is omission is aversive. In consequence, subjects avoided to choosing the now-cued lever for a while. Another possibility is that they sampled both levers to determine reinforcer availability or omission. Such a behavioral pursuit would increase response variability. In any case, we cannot be sure these possibly separable induction processes were independent from each other or just reflections of different aspects of the same process. Answers to this question awaits further research.

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Footnote

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