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# Effects of Brief-Signal Number and Location on Responding Maintained by Delay of Reinforcement

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# Effects of Brief-Signal Number and Location on Responding Maintained by Delay of Reinforcement

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ABSTRACT

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The purpose of the present series of experiments was to examine the effects of the number, type, and location of brief signal(s) occurring during, but not throughout, a delay period, on responding maintained by the delay of reinforcement. In each experiment, a tandem variable time (VT) 60-s fixed interval (FI) 9-s schedule was used as a baseline condition of an immediate reinforcement against which delay conditions were examined. For the delay conditions, a chained variable interval (VI) 60-s fixed time (FT) 9-s (delay period) schedule was used, and the imposition of the brief signal (blackout) during the delay period was manipulated. In Experiment 1, when a brief signal(s) was imposed at the fixed temporal location during the delay period, the VI component response rate was maintained at a comparable level to the baseline. Conversely, when a brief signal was imposed at the variable temporal locations during the delay period, the VI component response rate diminished to low levels compared to the baseline. In Experiment 2, when a brief signal was imposed at the beginning of the delay period, the VI response rate was maintained at a higher level compared to when the brief signal was imposed at the middle or end of the delay period. In both Experiment 1 and 2, when the brief signal was contingent and temporally contiguous with the required response (a keypeck that completed the VI component and started the delay period), the VI response rate was maintained at a higher level compared to when there was a disruption in temporal contiguity between the required response and brief signal presentation. To examine this observation, in Experiment 3, a brief signal was imposed at the variable temporal location during the delay period, however, a contingency was imposed where an additional response after the elapse of the signal timer was required to produce the brief signal. In this procedure, the VI response rate was maintained at a higher level compared to when the brief signal was presented at the variable temporal location without an additional response requirement for the brief signal presentation. These results underline the importance of response-brief signal contingency and temporal contiguity in maintaining responding by partially signaled delay of reinforcement.

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# Effects of Brief-Signal Number and Location on Responding Maintained by Delay of Reinforcement

The disruption in response-reinforcer temporal contiguity is a conspicuous occurrence in the natural world. Such temporal disruption, which has been studied extensively under the rubric of delay of reinforcement (Catania, 2007), in turn, affects the potency of a stimulus as a reinforcer. Delay of reinforcement has been investigated from the earliest times of psychology as an independent science. When examining parameters of the law of effect, for example, Thorndike (1911, as cited in Renner, 1964) noted that the disruption of temporal contiguity between response and reinforcer negatively impacted the rate of learning.

Renner (1964), who traced the early history of research in this domain, suggested that the systematic analysis of delay of reinforcement as an independent variable can be traced to Watson`s (1917) experiment that examined the effects of delayed feeding on a digging response. Watson (1917) assigned twelve rats randomly to two groups. The first group received immediate access to food, whereas the second group received a delay of 30 s before being allowed to access food. Although he did not find any systematic difference in acquiring digging response between the groups, Watson showed that learning was possible with delays of reinforcement. To date, a substantial research literature has been accumulated concerning variables that impact the effects of delays of reinforcement (see Lattal, 2010; Renner, 1964; Tarpy & Sawabini, 1974). One such variable was identified by Roberts (1930) as "cues" or signals that can be programmed to occur during the delay period.

Stimulus changes of the latter sort that are imposed during a delay of reinforcement mitigate the adverse impact of temporal disruption between the response and the reinforcer. Investigators typically find that responding can be maintained at a higher level with the imposition of a signal as opposed to when no such signal is presented (Lattal, 1984; Richards, 1981; Schaal & Branch, 1988). In turn, different parameters of the signal, such as its duration, differentially impact the behavioral effect of the delay (Schaal & Branch, 1988, 1990). The purpose of the present series of experiments was to examine the effects of the number, type, and location of brief signals occurring during, but not throughout, a delay of reinforcement period, on responding maintained when reinforcement is delayed from the response that produces it.

## Literature Review

Ferster (1953) examined the effects of delay of reinforcement on responding maintained by a variable-interval (VI) 60-s schedule (immediate-reinforcement condition). After the response (key pecking) stabilized, a 60-s delay was imposed, thereby creating what was in essence a chained VI 60-s fixed time (FT) 60-s schedule. The operant chamber was darkened (blackout) throughout the delay period to prevent further responding. Once the delay period elapsed, access to grain was provided without any further response required for its delivery. With the imposition of the signaled delay, response rate declined to one-sixth of that maintained by the baseline VI 60-s schedule. However, rather than being introduced abruptly at full duration, when the delay duration was incrementally increased over several sessions to the terminal delay value of 60 s, response rate remained comparable to the initial VI 60-s condition (Experiment 2).

In a subsequent experiment, Ferster (1953) examined whether response maintenance under delays of reinforcement was a function of adventitiously reinforced “superstitious” behavior that might have occurred during the delay period (Experiment 4). Key pecking was maintained under a VI 60-s schedule. Once the responding stabilized under the VI 60-s schedule, a 60-s delay period was imposed. Unlike the previous experiment, however, a keylight color change was used instead of a blackout throughout the delay period. Each response to the key during the delay period was programmed to postpone reinforcer presentation for an additional 60 s. This ensured that a key peck would not occur in the 60 s before reinforcer delivery. Observation through a one-way screen indicated that each pigeon had acquired a characteristic response, such as "turning in a circle with the head stretched high" (p. 279), during the delay period. These findings suggested that some form of "superstitious" behavior was strengthened during the delay period, behavior which then presumably bridged the gap introduced by the delay.

Ferster's (1953) experiments invite two observations about delay of reinforcement. First, a 60-s interval was used as a terminal delay value in both Experiments 1 and 2, yet responding was maintained at a comparable level to that maintained by the immediate-reinforcement baseline condition in the latter experiment, but not the former. One explanation concerns the procedural difference between these two experiments. Specifically, the delay period was incrementally increased to 60 s in Experiment 2, while this was not the case in Experiment 1. Furthermore, the decline in VI-maintained responses in Experiment 1 cannot be attributed solely to the imposition of the delay, because imposing the delay period altered the frequency and distribution of reinforcement, thereby precluding a direct comparison between the immediate reinforcement and delay conditions. Additionally, in Ferster's Experiment 4, key pecking during the delay period reset the delay timer, which likely also increased the actual inter-reinforcer interval (IRI). The above analysis of Ferster's research suggests that schedules of reinforcement, reinforcement frequency, and distribution, and presence or absence of consequence for responding during the delay period all must be considered when examining the effects of delay of reinforcement on responding.

The second point to be made about Ferster`s (1953) experiments is that in each a distinct stimulus was correlated with the entire delay period. This raises a question as to whether responding would be maintained by delayed reinforcement in the absence of such a stimulus during the delay period. Furthermore, Ferster used, in different experiments, either a chamber blackout and keylight change to signal the delay period. Because these accompanying events were not directly compared, it is not clear whether these different types of signals similarly impact delay of reinforcement effects. Lastly, both the blackouts and keylight changes, in different experiments, were presented throughout the delay period, prompting questions about the effects of presenting a signal for only a portion of the delay period. Thus, the role of the presence or absence of a signal, types of signal, and whether it is imposed fully or partially must be considered as well in discussions of delay of reinforcement effects on behavior.

### *Schedules of Reinforcement and Reinforcement Frequency and Distribution*

Morgan (1972; cf. Azzi, Fix, Keller, & Rocha e Silva, 1964; Skinner, 1938) maintained rats' lever pressing under a fixed-ratio (FR) 9 schedule. Once lever pressing was stable, delays of .75 s, 3 s, or 12 s were imposed in different conditions. On completion of the FR requirement, the chamber houselight was dimmed throughout the delay period and reinforcer was delivered when the delay period elapsed. Lever pressing decreased as a function of the duration of the delay period. Morgan's results subsequently were confirmed by others using other schedules of reinforcement (Gonzalez & Newlin, 1976; Holtyn & Lattal, 2013; Jarmolowicz & Lattal, 2011; Williams, 1976).

As noted above, Morgan (1972) used FR 9 as a baseline against which the effects of delay of reinforcement were examined. When the delay period was imposed on FR 9, the underlying structure of the schedule changed to a chained FR 9 FT .75 s (or 3 s, or 12 s, when the longer delays were studied). In the baseline, lever presses were reinforced after every ninth response. When the delay period was imposed, a reinforcer was presented after the required number of responses were made and the delay period timed out. Thus, reduction in response rate in the delay condition might reflect the lengthening of post-reinforcement pause (PRP), either instead of or in addition to the delay of reinforcement. An additional challenge in attributing the response rate reductions exclusively to the delay stems from the reduction in the rate of reinforcement engendered by imposing the delay condition. This discrepancy in the rate of reinforcement between immediate the reinforcement condition (FR 9) and subsequent delay conditions was especially pronounced when the delay duration was longest (chain FR 9 FT 12-s schedule). Thus, the effects of frequency and distribution of reinforcement must be disentangled to discern behavioral effects attributable specifically to delay of reinforcement.

One possibility for addressing this issue is to employ a baseline condition of immediate reinforcement that has reinforcement frequency and distribution comparable to the inquired delay condition (cf. Lattal, 1987). Ferster (1953), as was discussed previously, used VI 60-s as an immediate reinforcement condition against which the delay condition amounting to a chained VI 60-s FT 60-s schedule was compared (Experiment 1). In this case, using a tandem variable time (VT) 60-s FI 60-s schedule as a baseline condition could have mitigated the discrepancy in reinforcement rate between immediate reinforcement and delay conditions. This method of keeping reinforcement frequency and distribution constant, however, is not without its flaws. Consider an experiment where delay duration is incrementally increased from 1 s to 10 s, 20 s, and 30 s. In this case, each delay value must be preceded and followed by a comparable immediate reinforcement condition (cf. Sizemore & Lattal, 1978), making this approach useful when assessing the effects of a single delay value, but cumbersome when examining multiple delay values. Lastly, this way of arranging the baseline does not account for discrepancies that might result from changes in temporal location and/or a number of response-reinforcer dependencies between baseline and delay conditions that could themselves impact responding in different ways (Lattal, 1987).

***Resetting and Nonresetting Delays of Reinforcement***

Depending on the type of delay implemented, following the response required to initiate the delay period, responding may continue during the delay period. Such responding can be a confounding variable that influences delay of reinforcement effects. For instance, it is plausible that the response closest to the elapse of the delay period is being adventitiously reinforced, thus making the obtained delays less than the nominal delays (obtained delay refers to the actual time elapsed between the last target response and reinforcer presentation, while nominal delay refers to the programmed delay). To address this issue, Ferster (1953, Experiment 4), for instance, imposed a contingency during the delay period to prevent key pecking from occurring in close proximity to the reinforcer delivery. Such a contingency has been labeled a resetting delay. By contrast, a nonresetting delay is in place when responses during the delay have no programmed consequence (Lattal, 2010).

Elcoro and Lattal (2011, cf. Dews, 1981) compared the effects of nonresetting and resetting delays on fixed-interval (FI) maintained responding. A nonresetting delay was examined using a tandem FI 60-s FT .5-s (or 1-s, or 10-s) schedule while a resetting delay was examined using a tandem FI 60-s differential-reinforcement-of-other-behavior (DRO) .5-s (or 1-s, or 10-s) schedule. Each delay condition was preceded and followed by a baseline FI 61-s schedule of immediate reinforcement. A stimulus change did not accompany the delay period in either of the conditions, that is, the delays were unsignaled. With delay durations of 1 and 10 s, response rates decreased relative to the baseline. By comparison, with a .5 s delay response rates in both conditions were higher relative to those during the baseline. Nominal and obtained delays were, by definition, identical in the resetting delay condition, while obtained delays were briefer than nominal delays in the nonresetting delay condition. Thus, the imposition of a contingency to prevent the occurrence of a target response (e.g., key pecking) during the delay can help to keep nominal and obtained delays constant and prevent the adventitious reinforcement of intervening target responses. It must be noted that this approach, however, would not prevent the adventitious reinforcement of nontarget responses (Ferster, 1953).

### *Signaled and Unsignaled Delays of Reinforcement*

In Elcoro and Lattal's (2011) experiment, a stimulus change did not accompany the delay period. This manner of arranging the delay period has been labeled an unsignaled delay of reinforcement. In conventional schedule nomenclature (Ferster & Skinner, 1957), such an unsignaled delay can be regarded as a tandem schedule of reinforcement (Lattal, 2010). Sizemore and Lattal (1978) used a tandem VI FT schedule to examine the effects of unsignaled delays of reinforcement. The VI component of the tandem schedule was considered a nondelay period, while the FT component was the delay period. The first response after the elapse of the VI 60-s inter-reinforcer interval initiated, in different conditions, FT schedules (delays) of .5 s, 1 s, 2 s, 4 s, and 10 s. Each delay condition was preceded and followed by a baseline condition consisting of a VI schedule with the nominal reinforcement rate equivalent to the associated tandem schedules. The reinforcer was delivered at the end of the delay period independently of any further responding. With brief unsignaled delays of .5 s, the rate of VI responding was higher compared to responding in the corresponding baseline (VI 61 s) condition. By contrast, with delay durations of 2 s, 4 s, and 10 s, rates of responding decreased substantially, and proportionally, relative to the corresponding baseline conditions.

In other experiments, a stimulus change has been imposed during the delay period, which is referred to as signaled delay of reinforcement (Ferster, 1953; Morgan, 1972; Pierce, Hanford, & Zimmerman, 1972). Richards (1981) compared the effects of signaled and unsignaled delays on responding maintained by VI reinforcement schedules. Following training on a VI 60-s schedule of immediate reinforcement, pigeons were exposed to reinforcement delays in the following order: 10 s, 5 s, 2.5 s, 1 s, and .5 s. In the signaled delay condition, the keylight and the houselight were turned off. In the unsignaled delay condition, both the keylight and houselight remained on as they were during the VI component. Delays of 5 and 10 s markedly decreased the response rate during the unsignaled delay condition, while only a moderate reduction in response rate occurred during the signaled delay condition. With delay durations of .5 s and 1 s, however, VI responding was higher in the unsignaled delay condition relative to the signaled delay condition. This outcome suggests that responding can be maintained at a higher level with signaled relative to unsignaled delays at longer delay durations. By contrast, higher responding was obtained with the unsignaled delay relative to the signaled delay when the delay period was brief (e.g., .5 s). The latter, however, had more to do with schedule dynamics than with the delay of reinforcement *per se* (Lattal & Ziegler, 1982).

### *Signal Types*

Researchers have used a variety of signals when investigating the delay of reinforcement (Ferster, 1953; Carlson & Wielkiewicz, 1972; Pierce et al., 1972). For instance, investigators using pigeons as subjects commonly relied on blackouts and key-color changes. Because blackouts are not particularly useful in restricting responding of rats, lever retraction has been used as a comparable alternative. When using a blackout or lever retraction as a signal, the target response can be substantially reduced, especially with the latter, during the delay period. By contrast, when a keylight change or auditory stimuli are used to signal the delay period, the opportunity to engage in the target response during the delay period remains. Because blackout and lever retraction minimize responding during the delay period, it is much more likely that nominal and obtained delays are in alignment when such signals occur during the delay period. By contrast, nominal delays and obtained delays might be misaligned when a keylight color change or auditory signal are used and the operandum remains available for responding. Thus, different signal types (e.g., blackout or keylight color change) might exert different effects on responding.

Pierce et al., (1972) compared the effects of lever retraction, nonresetting, and resetting delays on lever pressing of rats under delay of reinforcement. Lever pressing was maintained with a chained VI 60-s FT .5-s schedule that served as a baseline condition. Once responding stabilized, the delay duration was varied in different conditions from 10 s to 30 s to 100 s. For all the conditions, the VI schedule was followed by a delay period that ended with reinforcer delivery. A stimulus light accompanied each delay period in all conditions. In the first condition, the lever was retracted during the delay period. In the second condition, the lever was not retracted, but, responding during the delay period had no programmed consequences. In the third condition, a DRO schedule was imposed during the delay period. Thus, responding during the delay reset the delay period in this condition. In all conditions, response rate decreased relative to the baseline as a function of increasing delay duration. Furthermore, no systematic differences in response rate or PRP were found between the conditions. Thus, both keylight color change and lever retraction during the delay exerted similar effects on response rate and PRP. Because information about the obtained delay was not provided, it is not known how these arrangements impacted the concordance between obtained and nominal delays.

***Completely Signaled and Partially Signaled Delays of Reinforcement***

When delay periods are signaled, it is most common to present them continuously throughout the delay period (Ferster 1953; Lattal, 1984; Pierce et al. 1972). In the natural environment, however, behavior does not necessarily always produce a lasting stimulus change that is correlated with the delay of reinforcement. Many reinforced responses produce a momentary change in the environment that is maintained by a delayed consequence (e.g., the call bell at the customer-service counter). Schaal and Branch (1988) examined how a brief keylight-color change imposed during a portion of the delay period affected VI-maintained responding. Following an immediate reinforcement condition, they imposed, during separate conditions, unsignaled, and briefly signaled delays to reinforcement. The unsignaled delay condition was a tandem VI 60-s FT 1-s schedule. Under this schedule, the first response after the lapse of the IRI initiated a 1-s unsignaled nonresetting delay. The reinforcer was delivered at the end of the delay period independently of further responses. In the briefly signaled condition, a 0.5-s keylight color change followed the peck that initiated the 1-s delay period. Subsequently, the delay duration was increased to 3 s, 9 s, and 27 s, each with the 0.5-s keylight color change at the onset of the delay. Response rates during the VI declined in the 1-s unsignaled delay condition relative to those rates during the immediate reinforcement condition. However, VI response rates increased when the 0.5-s keylight change was imposed at the onset of the delay period relative to the unsignaled delay condition. Responding remained near or above the baseline level for briefly signaled delays of 3 s and 9 s, but declined to low levels when the delay was 27 s.

Schaal and Branch (1988) then compared unsignaled, briefly, and completely signaled delays of reinforcement. A multiple schedule was in effect during the baseline, with briefly and continuously signaled delays in either of its two components. Components alternated after variable lengths of time (6, 10, or 14 min; M = 10 min), excluding reinforcement and delay periods. Components were separated by a 60-s blackout, and sessions ended when each component was presented three times. During baseline, a multiple VI 60-s VI 60-s schedule was in effect. In the unsignaled delay condition, a 3-s nonresetting delay was imposed, resulting in a multiple tandem VI 60-s FT 3-s (Component 1) tandem VI 60-s FT 3-s (Component 2). On stabilizing responding in the unsignaled delay condition, briefly signaled and completely signaled conditions were implemented in either component. In one component, a 0.5-s change in key color occurred following the key peck that initiated each delay period. In the other component, the response that initiated the delay changed the key color for the entire delay period, a completely signaled delay condition. Both briefly signaled and completely signaled delay conditions were nonresetting. During the first condition, the delay duration was 3 s, increasing to 9 s and then to 27 s in subsequent conditions. Responding was maintained at a higher level in both components relative to the unsignaled delay conditions. Furthermore, VI responding was maintained at a comparable level by both briefly and completely signaled 9 s delays. When the delay period was lengthened to 27 s, however, VI response rates were higher during the completely signaled compared to the briefly signaled condition. These results suggest that the proportion of the delay period that is signaled affects the response rate in the delays of reinforcement.

## Statement of Problem

When examining partially signaled delay effects, Schaal and Branch (1988) imposed a brief signal at the start of the delay. The imposition of a brief signal maintained higher VI response rates than were maintained when the delay period was unsignaled. In this investigation, the brief signal was always presented at the start of the delay period. It is not known how a variable-location presentation of a brief signal would impact response maintenance when the reinforcer is delayed from the response that produces it. Unlike the continuously signaled delay, it also is possible to investigate the number and types (e.g., keylight color change, blackout, etc.) of brief signals imposed during the delay period, however, such manipulations remain uninvestigated. Lastly, in Schaal and Branch's experiment, it was not clear whether the response rate changes were the result of the brief signal alone, irrespective of the temporal location in the delay period, or whether the brief-signal location was also a relevant variable. Thus, the purpose of the present series of experiments was to examine the effects of brief signal number, type, and temporal location on responding maintained by partially signaled delay of reinforcement.

## Experiment 1

The purpose of Experiment 1 was to compare the effects of fixed/variable and multiple brief signal presentations during the delay period in maintaining responding by partially signaled delay of reinforcement. When examining multiple brief signals, the impact of the signal type imposed during the delay period was also examined.

### Subjects

Four mature male White Carneau pigeons were maintained at approximately 80% of their free-feeding weights. Supplemental feeding was provided after daily sessions to maintain a constant weight. The pigeons were housed in separate cages with a 12:12 hour light/dark cycle in the vivarium. Continuous water was available in their cages. Three of the pigeons were naïve and the remaining had a history of key pecking on different schedules of reinforcement. All procedures conformed to the National Research Council`s *Guide for the Care and Use of Laboratory Animals* (8$^{th}$ Edition) and were approved by the Institutional Animal Care and Use Committee at West Virginia University.

**Apparatus**

Sessions were conducted in two operant chambers, each with a work area 32 cm long by 30 cm high by 30 cm wide. An aluminum work panel, comprising one wall of the chamber, displayed two 2.5-cm diameter response keys, each operated by a force of approximately 0.15N. Each key could be transilluminated by different colored 28 v DC lamps. Reinforcement was 3-s access to mixed grain from a hopper located behind a 4.5 cm square feeder aperture located on the midline of the work panel 9 cm from the floor. During reinforcement, the hopper was raised into the aperture, which was illuminated by a white light. General chamber illumination was provided by a house light, illuminated throughout the sessions, excluding delay signals and reinforcement periods. White noise and a ventilation fan masked extraneous sounds. A Dell desktop computer operating MED-PC 7 software controlled the experiment.

**Procedure**

Key pecking by the three naïve pigeons was shaped manually. Then, the key pecking of each pigeon was maintained on an FR schedule. The value of the FR was increased from 1 to 10 over several sessions. The schedule then was changed to VI 10 s, the mean IRI of which was increased in 10-s steps to a terminal value of 60 s. All VI IRI distributions were constructed using 10 intervals based on Fleshler and Hoffman`s (1962) algorithm. A minimum of 30 responses per minute over three consecutive sessions constituted the criterion for increasing the

IRI during the training period. Once the IRI was 60 s, the first baseline condition was implemented.

Sessions occurred 7 days a week, with each session lasting until 60 reinforcers were delivered. Each session began after a 3-min blackout following the placement of the pigeon in the chamber. Each condition remained in effect for a minimum of 13 sessions and response rates were stable. The stability criterion was based on an analysis of response rates during the VT component of the baseline and VI component of the delay conditions during the last six sessions of each condition. Stability was attained when the mean difference in responding was at or below 5% between the last six sessions and the means of the first and last three sessions during the six-session period (Schoenfeld, Cumming, & Hearst, 1956). When the response rate decreased substantially to low levels in the VI component of the delay conditions, the stability criterion was adjusted where the low scores were normalized by adding a constant derived from the average response rate during the VT component of the preceding baseline to the low scores.

A baseline and several delay of reinforcement conditions were studied. Each was separated from the other by the immediate reinforcement baseline condition. Order of conditions, reinforcers per minute during the last six sessions of each condition, and the number of sessions for each condition are shown in Table 1.

***Baseline***

As was indicated in the literature review, one method for better-equating reinforcement frequency and distribution between immediate and delayed reinforcement conditions is to employ a tandem schedule in the baseline. A tandem VT 60-s FI 9-s schedule was used as the baseline condition against which delay conditions were examined. During the baseline condition, the keylight was red at all times except during reinforcement. The first response following the lapse of the FI was reinforced.

### *General Procedure for Delay Conditions*

For each delay of reinforcement condition, a chained VI 60-s FT 9-s schedule was in effect. The response key was red during the VI 60-s and FT 9-s components in all delay conditions, except during the brief signal presentation (delay period, hereafter, would be interchangeably used to refer to the FT component of the delay conditions). Responses occurring during the delay were recorded, but no programmed contingency was in effect; thus, the delay was nonresetting.

#### Single Stationary Signal (SINGLE).

After the elapse of the VI IRI, the first response produced a 2-s blackout, after which the red keylight was reinstated for the remaining 7 s of the delay period. At the end of the 7 s, the reinforcer occurred independently of any further responses.

#### Single Variable Signal (VARIABLE).

After the elapse of the VI IRI, the next response initiated both the FT component and signal timer. The duration of the signal timer was selected from a list containing numbers 1 - 9. For instance, if number 6 was selected from the list, the signal timer elapsed when the delay period reached 6 s. Once the signal timer elapsed, a 2-s blackout was presented independently of any response, concurrently, an integer was selected randomly without a replacement from the list for the signal timer. Excluding the 2-s blackout, the red key was in effect throughout the delay period. At the end of the delay period, the reinforcer was presented independently of any further responses.

**Nonoverlapping-Single-Variable Signal (NONOVERLAPPING).**

Because the list for the signal timer contained numbers 8 and 9, the 2-s blackout overlapped with the reinforcer presentation when the signal was presented at the delay period of 8 s and 9 s. To ensure that the signal overlap with reinforcer presentation did not account for the effects obtained under the VARIABLE condition, a condition was included during which the list for signal timer contained only numbers 1 - 7.

**Double Stationary Signals (DOUBLE).**

After the elapse of the VI IRI, the next response produced a 1-s blackout, after which the red keylight was reinstated. The second 1-s blackout was presented when the FT component reached 7-s, after which the red keylight was reinstated for the remainder of the delay period. At the end of the delay period, the reinforcer was presented independently of any further responses. In this condition, the total signal duration thus was 2 s, while the signal itself was divided into two 1-s blackout signals occurring at the start and end of the delay period.

**Double Different Stationary Signals (DOUBLE DIFFERENT).**

This condition was identical to the Double Stationary Signals condition, except the first signal presented after the elapse VI IRI produced a 1-s keylight color change from red to blue instead of a blackout.

***Measurement***

Response rates were computed separately for the VI and FT components in the delay conditions and for the VT and FI components of the baseline. The postreinforcement pause (PRP) duration (time from the end of reinforcer until the next response), and reinforcement rate (reinforcers per min) also were measured for each condition. Responses in successive 1-s periods of both the VI and FT components during the delay conditions and during the VT and FI components of the baseline conditions were recorded to examine the distribution of responses across the baseline and delay conditions.

## Results

Cumulative records for the last session of the first baseline and the last session of the delay conditions for each pigeon are shown in Figure 1. For each pigeon, a steady, relatively high rate of key pecking developed in the baseline, SINGLE, and DOUBLE DIFFERENT conditions. Due to a programming error, a substantial portion of the real-time data for constructing cumulative records was lost in the DOUBLE condition for 14482, 22595, and 25670. The remaining data, however, suggest that steady, high rate key pecking developed in this condition as well. Each pigeon developed a steady but lower rate of key pecking in the VARIABLE condition.

Key-peck responses per minute for each pigeon during the last six sessions of the baseline conditions and delay conditions are shown in Figure 2. For 14482, 22595, and 32647, response rates during the VI component of the SINGLE, DOUBLE and DOUBLE DIFFERENT condition decreased somewhat compared to the VT component of the respective preceding baseline condition. For 25670, response rate in the VI component of these delay conditions were comparable to VT component of the respective preceding baseline condition. For each pigeon, the VI response rates decreased to low levels in the VARIABLE condition compared to those occurring during the VT component of the preceding baseline condition. This effect was also replicated in the NONOVERLAPPING condition, which suggested that it was not the overlap between some instances of brief signal presentation with reinforcer delivery that was responsible for the reduction in the rate of responding in both VI and FT components of this condition. Although response rates in the VI component of the SINGLE, DOUBLE, and DOUBLE

DIFFERENT conditions were lower than VT component of the respective baseline conditions, response rates in these conditions were substantially higher than the VI component of the VARIABLE signal condition. These findings also were confirmed in the replication conditions, where response rates in the VI component of the delay conditions were maintained at a comparable level to their original iteration.

Response rates in the VT and FI components of the baseline conditions were comparable for each pigeon. However, delay conditions had differential effects on response rate during the delay period of the delay conditions (see Figure 2). Response rates were substantially lower in the delay period of the DOUBLE condition compared to response rates in the VI component of the same condition for each pigeon. Conversely, response rates were low but comparable in both delay and VI components of the VARIABLE condition for each pigeon. When 14482 was exposed to the SINGLE condition, response rates were substantially higher in the delay period compared to the VI component of this delay condition. Conversely, when 22595, 25670, and 32647 were exposed to SINGLE condition, response rates were substantially lower in the delay period compared to VI component of this delay condition. These discrepancies might have risen due to the impact of order effect impacting primarily SINGLE and DOUBLE DIFFERENT condition. When the first iteration of the DOUBLE DIFFERENT condition was preceded by the SINGLE condition with 14482, response rate was higher in the delay period compared to the VI component of this condition. When the second iteration of the DOUBLE DIFFERENT condition (replication) was preceded by DOUBLE condition, however, response rates were substantially lower in the delay period compared to the VI component of this condition. Thus, when the SINGLE condition was preceded by either the DOUBLE or DOUBLE DIFFERENT conditions, which was the case for 22595, 25670, and 32647, response rates in the delay period were substantially lower than those in the VI component of this condition.

The mean number of responses across successive 1 s periods of the FI component of the first baseline and the FT component of the delay conditions computed from the last six sessions of the baseline and delay conditions are shown in Figure 3. This number was more or less constant across the FI 9-s during the baseline condition for each pigeon. For 14482 and 25670, the mean number of responses increased after the signal presentation and thereafter declined until the end of the delay period for SINGLE condition. For 22595, 25670 and 32647, the mean number of responses declined to low levels after initial pick at the 1-s mark of the delay period in the VARIABLE, DOUBLE and DOUBLE DIFFERENT conditions. A SINGLE condition like pattern of mean number of responses were obtained in the DOUBLE DIFFERENT condition for the 14482, which can be attributed to the order effect described above.

The mean obtained delays during the last six sessions of the delay conditions are shown in Figure 4. There was no systematic relation between obtained delays and delay conditions, however, obtained and programmed delays were most convergent under DOUBLE condition for most pigeons. The mean PRP during the last six sessions of the first baseline condition and the last six days of each delay conditions are shown in Figure 5. Mean PRPs varied as a function of the brief signal arrangement. The longest PRPs occurred under VARIABLE compared to SINGLE, DOUBLE and DOUBLE DIFFERENT conditions. The mean PRPs occurring in the SINGLE, DOUBLE, and DOUBLE DIFFERENT conditions, in turn, were comparable to the PRP occurring in the baseline condition for each pigeon.

## Discussion

In general, VI response rates in the SINGLE, DOUBLE, and DOUBLE DIFFERENT conditions were maintained near or slightly below those during the VT component of their respective baseline conditions, replicating the effects of partially signaled 9-s delays reported by Schaal and Branch (1988). By contrast, response rates decreased to low levels in the VI component of the VARIABLE condition relative to those during the VT component of the preceding baseline. Thus, how the brief signal was arranged during the delay period determined the effect of delay on VI responding.

Even though the signal duration was constant, delay-period response rates and patterns differed as a function of how the brief signal presentation was arranged during the delay period. Response rates were low, for instance, during the delay period in the DOUBLE condition, while the VI component response rate was comparable to the levels obtained in the baseline of immediate reinforcement. Thus, functionally, imposing two brief signals, one at the beginning and another at the end of the delay period can modulate delay-period responding equivalent to that maintained by resetting or fully signaled delays (i.e., blackout) (cf. Elcoro and Lattal, 2011; Ferster, 1953).

Schaal and Branch (1988), demonstrated that response rates can be maintained with briefly signaled delay of reinforcement, albeit only up to a certain total delay duration. The outcome of the present experiment, in turn, further qualifies response-rate maintaining effects of brief signal by highlighting the importance of how brief signal is arranged during the delay period. Response-rate maintaining effects of a brief signal were enhanced when brief signal was imposed at a fixed temporal location (s), as was the case in the SINGLE, DOUBLE and DOUBLE DIFFERENT conditions. Conversely, when a brief signal was imposed at variable temporal locations, response-rate maintaining effects of brief signal deteriorated, as was the case in the VARIABLE condition.

The deterioration of VI response rates during the VARIABLE condition, however, cannot be solely attributed to brief signal presentation in variable temporal locations during the delay period. In this condition, the brief signal was arranged so that in some instances it overlapped with reinforcer presentation which might have reduced response rates. This possibility, however, was ruled out by arranging a condition (i.e., NONOVERLAPPING) during which the brief signal presentations did not overlap with reinforcer presentation.

## Experiment 2

In Experiment 1, in the SINGLE condition a brief signal occurred at the beginning, while in the DOUBLE and DOUBLE DIFFERENT conditions brief signals occurred at the beginning and end of the delay period. Conversely, in the VARIABLE condition, a brief signal occurred at different temporal locations (averaging to 5 s) throughout the delay period. It is not clear, however, why the VARIABLE condition reduced responding substantially compared to the reductions that occurred during the other delay conditions. One explanation might be the location of the brief signal occurring during the delay period. Thus, the purpose of Experiment 2 was to examine the effects of a brief signal occurring at different, that is, variable, temporal locations during delay period on responding maintained when delays of reinforcement are partially signaled.

# Method

## Subjects

Three, mature male White Carneau pigeons, different from those used in the first experiment, with a history of responding on different schedules of reinforcement were maintained as described in Experiment 1.

## Apparatus

As described in Experiment 1.

## Procedure

Training was as described in the Experiment 1, except that shaping of the key peck was not required.

General procedure was as described in the Experiment 1.

The three delay-of-reinforcement conditions are described below. Exposure to each was separated by an immediate reinforcement baseline condition. Order of conditions, reinforcers per minute during the last six sessions of each condition and the number of sessions for each condition are shown in Table 2.

### *Baseline*

As described in Experiment 1.

### *General Procedure for Delay Conditions*

As described in Experiment 1.

#### Signal at the Start of the Delay Period (START).

This condition was identical to the SINGLE condition of Experiment 1.

**Signal in the Middle of the Delay Period (MIDDLE).**

After the elapse of the VI IRI, the next response initiated the delay period with the response key remaining red. A 2-s blackout was imposed, independent of any further response, when the delay period timer reached 4 s, after which the red keylight was reinstated for the remaining 3 s of the delay period. At the end of the latter 3 s, the reinforcer was presented independently of further responses.

**Signal at the End of the Delay Period (END).**

After the elapse of the VI interval, the next response initiated the delay period with the response key remaining red. A 2-s blackout was imposed, independent of any further response, when the delay period timer reached 7 s, after which the reinforcer was presented independently of any further responses.

***Measurement***

As described in Experiment 1.

## Results

Cumulative records for the last session of the first baseline and the last session of the three delay conditions for each pigeon are shown in Figure 6. Steady, high-rate key pecking occurred in the baseline and START condition with each pigeon. A steady but low rate of key pecking occurred in the END condition. For 9553 and 35223, steady, low-rate key pecking occurred in the MIDDLE condition that was comparable to the results obtained in the END condition for these pigeons. Conversely, for 29321 a steady pattern of responding more similar to the START condition occurred in the MIDDLE condition.

Responses per minute for each pigeon during the last six sessions of the baseline conditions and delay conditions are shown in Figure 7. For each pigeon, response rates in the VI component of the START condition were close to the rates obtained during the VT component of the proceeding baseline condition. For each pigeon, response rates in the VI component declined substantially during both the MIDDLE and END conditions compared to those occurring during the respective VT components of the preceding baseline conditions. These results also were obtained in the replication conditions, where response rates in the VI component were higher in the START condition compared to those occurring during the MIDDLE and END conditions.

Response rates in the VT and delay period of the baseline conditions were comparable for each pigeon, thus replicating the effects of the baseline condition of Experiment 1. Conversely, rates of responding were higher in the delay period of the initial iteration of the START condition compared to the VI component of the same condition for each pigeon. For 29321 and 35223, response rates were higher in the delay period of the initial iteration of the MIDDLE condition compared to the VI component of the same condition. For 9553, however, rates of responding were comparable for both the VI and delay period in the initial iteration of the MIDDLE condition. For each pigeon, response rates were comparable in VI and delay period during the END condition.

There was an order effect that affected responding during the delay period in the delay conditions. For instance, for 29321 and 35223, the START condition preceded the MIDDLE condition, which resulted in higher response rates during the delay period compared to the VI component of the latter condition. Conversely, when the MIDDLE condition was the first condition, for 9553, response rates were comparable in the delay and VI components. For this pigeon, when the START condition preceded the subsequent replication of the MIDDLE condition, however, response rates were higher in the delay period compared to the VI component.

The mean number of responses across successive 1 s periods of the FI component of the first baseline and the FT component of each delay condition computed from the last six sessions of the baseline and delay conditions are shown in Figure 8. The mean number of responses was steady across the 9-s interval of the FI component of the baseline condition for each pigeon. During the delay period of the START condition, the mean number of responses increased steadily after the brief-signal presentation and continued until the end of the delay period. For 29321 and 35223, in the MIDDLE condition, the mean number of responses was relatively steady from the first through the sixth second of the delay period. After the termination of the brief signal, the mean number of responses progressively increased during the last 3 s of the delay period. Conversely, for 9553, the mean number of responses was highest in the first 2 s of the delay period and low but steady in the subsequent intervals. In the END condition, responding was low and steady across the 9 s of the delay period for each pigeon.

The mean obtained delays during the last six sessions of the delay conditions are shown in Figure 9. For each pigeon, the obtained delays were longest in the END condition, and shortest for two out of three pigeons in the START condition. The mean PRP during the last six sessions of the first baseline and the delay conditions are shown in Figure 10. The shortest PRP was obtained under the START condition compared to both baseline and END conditions. The data for obtained delays and PRP were unsystematic in the MIDDLE condition.

**Discussion**

Response rates in the VI component of the START condition were maintained close to those observed during the VT component of the preceding baseline condition, thereby replicating the effects of SINGLE, DOUBLE, and DOUBLE DIFFERENT conditions in Experiment 1 and those of the delay condition of similar duration in Schaal and Branch (1988). Response rates in the VI component of the MIDDLE and END conditions, however, declined to low levels compared to those maintained in the VT component of their respective preceding baseline conditions. These results were not only comparable to the outcome of the VARIABLE condition investigated in Experiment 1, but also further suggest the temporal location of the brief signal during the delay period affects the maintenance of operant behavior.

Response rates also were differentially affected during the delay period as a function of the location of the brief signal imposed during the delay period. Response rates were higher in the delay compared to the VI component in the START condition. This finding can be contrasted with DOUBLE condition of the Experiment 1, where response rates were substantially lower in the delay compared to the VI component. Response rates and patterns in the delay period of the END condition were low and comparable to VI component, which was a similar outcome to the VARIABLE condition of Experiment 1.

In all the delay conditions of Experiment 2, the brief signal presentation was contingent on the response that completed VI component requirement and initiated the delay period. When the brief signal, however, was presented at the beginning of the delay period, as was the case in the START condition, VI response rates were higher compared to those maintained during the MIDDLE and END conditions, where the brief signal was imposed at locations other than the beginning of the delay period. That is, in the START condition, the brief signal presentation was not only contingent on but also temporally contiguous with the response that initiated the delay period (henceforward, referred to as response-signal contingency and temporal contiguity). By contrast, in the MIDDLE and END conditions, the brief signal presentation was contingent on but not temporally contiguous with the response that initiated the delay period.

## Experiment 3

When there was both a contingency and temporal contiguity between brief signal presentation and the response that initiated delay period, VI response rates were higher, relative to when there was a contingency but no temporal contiguity between the response that initiated the delay period and the subsequent brief signal presentation. To further examine this observation, a brief signal that is contingent but not temporally contiguous with the response that initiates delay period can be made contingent on an additional response (i.e., a key peck) that immediately precedes it. If the disruption in temporal contiguity contributes to the decline in response rate, adding a response requirement for the brief signal presentation should mitigate this response-reducing effect. The purpose of the Experiment 3 was to examine this possibility.

## Method

### Subjects

Three, mature male White Carneau pigeons, different from those used in the first two experiments, with a history of responding on different schedules of reinforcement were maintained as described in Experiment 1.

### Apparatus

As described in Experiment 1.

### Procedure

Training was as described in the Experiment 1, except that shaping of the key peck was not required.

General procedure was as described in the Experiment 1, except each session lasted until 56 reinforcers were delivered.

The baseline and two delay of reinforcement conditions are described below. Conditions, reinforcers per minute during the last six sessions of each condition and the number of sessions for each condition are shown in Table 3.

### *Baseline*

As described in Experiment 1.

### *General Procedure for Delay Conditions*

As described in Experiment 1.

#### **VI Signal Presentation (VI SIGNAL).**

After the elapse of the VI IRI, the first response initiated both the FT component and the signal timer. The duration of the signal timer was selected from a list containing numbers 1 through 7. The first response after the elapse of the signal timer initiated a 1-s blackout (brief signal). Concurrently, one number from the list was selected randomly without replacement to assign the signal location during that delay. If no response was made after the elapse of the signal timer, the signal was not presented during that FT component. Except during the 1-s blackout, the same red key color remained on throughout the delay period. At the end of the delay period, the reinforcer was presented independently of any further responses.

#### **VT Signal Presentation (VT SIGNAL).**

This condition was identical to the VI signal presentation condition, except that the 1-s blackout was presented after the elapse of the signal timer independently of any response.

### *Measurement*

As described in Experiment 1.

# Results

Cumulative records for the last session of the first baseline and the last session of the delay conditions for each pigeon are shown in Figure 11. Steady, high-rate key pecking occurred in the baseline and VI SIGNAL condition with each pigeon. A steady but low rate of key pecking occurred in the VT SIGNAL condition.

Responses per minute for each pigeon during the last six sessions of the baseline conditions and delay conditions are shown in Figure 12. For 10028 and 10247, response rates in the VI component of the VI SIGNAL condition were comparable to the levels obtained to the VT component of the proceeding baseline condition. For 20542, response rates declined in the VI component of this condition compared to VT component of the preceding baseline condition. Conversely, response rates in the VT SIGNAL condition declined substantially compared to the response rates during VT component of the preceding baseline conditions for each pigeon. These results also were confirmed in the replication conditions, where response rates in the VI component were higher in the VI SIGNAL condition relative to those during the VT SIGNAL condition.

Response rates in the VT and FI components of the baseline conditions were comparable for each pigeon. Conversely, rates of responding were lower in the delay period of the initial iteration of the VI SIGNAL and VT SIGNAL conditions compared to the VI component of the same condition for 10028 and 10247. For 20542, response rates were lower in the delay period of the initial iteration of the VI SIGNAL condition compared to those during the VI component of that condition. For the VT SIGNAL condition, however, response rates were higher in the delay period of the VT SIGNAL condition compared to VI component of that condition for this pigeon.

The mean number of responses across successive 1 s periods of the FI component of the first baseline and the FT component of the delay conditions during the last six sessions of the baseline and delay conditions are shown in Figure 13. During the delay period of the VI SIGNAL condition, the mean number of responses typically were higher and remained relatively steady during the first 4 s of the delay period, and, subsequently, the number of responses decreased steadily over the remainder of the delay period. Conversely, during the VT SIGNAL condition, the mean number of responses sharply declined after the first second of the delay period and remained low during the remaining delay period.

The mean number of brief signals presented in each condition during the last six sessions of the delay conditions are shown in the Figure 14. Out of 56 possible brief signal presentation within a session, a mean of 56 brief signals were presented in each session of the VT SIGNAL condition for each pigeon. Conversely, in the VI SIGNAL condition, less than 56 instances of brief signal presentation was obtained across the last six session for each pigeon. These results can be attributed to how brief signals were arranged in VI and VT SIGNAL conditions, where in the former additional response was required for the brief signal presentation while in the latter the brief signal occurred irrespective of a response once the delay period began.

The mean obtained delays during the last six sessions of the delay conditions are shown in the Figure 15. Obtained delay was highest in the VT SIGNAL condition compared to VI SIGNAL condition for each pigeon. The mean PRP during the last six sessions of the first baseline and the delay conditions are shown in the Figure 16. Mean PRP was lowest in the VI SIGNAL condition compared to VT SIGNAL condition for each pigeon.

## Discussion

Response rates during the VI component of the VI SIGNAL condition were similar to those during the VT component of the preceding baseline condition, replicating the effects of the SINGLE, DOUBLE, and DOUBLE DIFFERENT conditions of Experiment 1, the START condition of Experiment 2, and the outcome of the similar-duration delay condition of Schaal and Branch (1988). Conversely, response rates in the VI component of the VT SIGNAL condition decreased relative to those during the VT component of the preceding baseline. This effect replicates those obtained during the VARIABLE condition of Experiment 1, and the MIDDLE and END conditions of Experiment 2.

The presence and absence of a response requirement for presentation of the brief signal resulted in, respectively, higher and lower response rates during the delay period. During the VI SIGNAL condition, the mean number of responses declined steadily to low levels by the end of the delay period, while during the VT SIGNAL condition responding was low throughout the delay period.

Thus, when a brief signal was both contingent on and temporally contiguous with a response, VI response rates were higher relative to those when the same signal was contingent but not temporally contiguous to a response. This observation also is relevant to the outcome of the SINGLE, DOUBLE and DOUBLE DIFFERENT conditions of Experiment 1 and the START condition of Experiment 2. In all of these conditions, there was both contingency and temporal contiguity between the response that initiated the delay period and the brief signal presentation. Conversely, in the VARIABLE condition of Experiment 1, MIDDLE and END conditions of Experiment 2, there was a contingency between the response and the signal, but the signal presentation was not temporally contiguous with the response. It is, therefore, not only the temporal location of a brief signal during the delay period that determined response rate maintenance, but also the response-brief signal contingency and temporal contiguity.

There is, however, a limitation in attributing response rate maintenance in the VI SIGNAL condition of Experiment 3 solely to response-brief signal contingency and temporal contiguity. In the VT SIGNAL condition, the brief signal was presented following a delay from the required response that began the delay period. In the VI SIGNAL condition, however, the brief signal was presented following some delay from the required response that began the delay period and an additional response to produce the brief signal. Thus, in the VI SIGNAL condition, two responses were required to produce a brief signal, which might have resulted in higher VI component response rate maintenance in this condition compared to those maintained during the VT SIGNAL condition, where only one response was required. It therefore is necessary to account for the number of responses required for a brief-signal presentation to determine whether response-brief signal contingency and temporal contiguity were only necessary conditions to enhance the response maintenance in the partially signaled delay of reinforcement.

## General Discussion

When delay of reinforcement intervals are only partially signaled, only a segment of the delay period is accompanied by a stimulus change, while the remaining segment of the delay period remains unsignaled. Hence, procedurally, partially signaled delay of reinforcement represents a middle ground between unsignaled and completely signaled delay of reinforcement. In the present series of experiments, for instance, when a brief signal was imposed at a fixed location of the delay period, the VI component response rate were maintained at levels similar to those maintained by immediate reinforcement. Conversely, when a brief signal was imposed at a variable location during the delay period, the VI component response rate declined to low levels compared to those maintained by immediate reinforcement (Experiment 1). A partially signaled delay of reinforcement, therefore, can have both a response-rate-reducing effect and a response-rate-maintaining effect depending on how a partial signal is arranged during the delay period.

Because only a segment of the delay period is signaled in partially signaled delay, various parameters of signal can be manipulated with this delay of reinforcement arrangement. In the present series of experiments, for instance, the impact of brief signal number, type and temporal location during the delay period were examined. Other potentially pertinent parameters of partially signaled delay, however, such as proportion of delay period briefly signaled, that might impact response-rate-maintaining effects of partially signaled delay of reinforcement were not addressed. Each of the preceding issues will be discussed in the sections that follows.

**Beyond Schaal and Branch**

In Schaal and Branch's (1988) investigation, a single brief signal was arranged to occur only at the beginning of the delay period. This arrangement of the partially signaled delay of reinforcement is only the tip of the iceberg. Such a procedure does not address the effect of imposing multiple brief signals, type of signal, and temporal locations of the brief signal during the delay period. To address these questions, in the present series of experiments, the delay period and signal duration were kept constant while different parameters of signal (s) were manipulated. When brief signals were imposed at both the beginning and end of the delay period, for instance, response rates were reduced to low levels during the delay period only. Conversely, arranging a brief signal at the beginning of the delay period resulted in substantial responding during the delay period. The VI component responding, however, remained unchanged from the immediate-reinforcement baseline condition for both of these brief signal (s) conditions. Thus, a differential impact on responding during the delay period was obtained as a function of the number of signals used, while maintaining baseline of immediate level of responding in the VI component (Experiment 1 and 2).

**Brief Signal Type**

When examining signaled delay of reinforcement, researchers have primarily relied on keylight color change or blackout as a signal to accompany the delay period (Ferster, 1953; Morgan, 1972; Richards, 1981). Different signal types, in turn, have been shown to exert similar effects on the VI component response rate (Pierce et al., 1972). When using pigeons as experimental subjects, however, imposing a continuous blackout prevents keypecking during the delay period, while the use of keylight color change does not. Thus, signal types might differentially impact the delay period responding. In the present series of experiments, a blackout was primarily used as a brief signal, which can be contrasted with Schaal and Branch`s (1988) experiment, where keylight color change was used instead. When a single brief signal was imposed at the beginning of the delay period, irrespective of signal type, similar impact on the delay period responding was obtained in both Schaal and Branch`s investigation and current experiments (Experiment 1 and 2). Likewise, there was no systematic difference in response rate maintenance when two identical (i.e., blackouts) or two different brief signals (i.e., blackout and keylight color change) were used, except the order effect impacted responding during the delay period in the latter much more so compared to the former brief signals arrangement..

**Brief Signal Temporal Location**

Unlike the continuously signaled delay, the temporal location of a signal imposed during a delay period can be manipulated in the partially signaled delay of reinforcement. When Schaal and Branch (1988), for instance, imposed a brief signal at the beginning of the delay period, the VI response rate was maintained at a much higher level compared to an unsignaled delay of reinforcement. In the present experiments, however, a brief signal of the same duration imposed at different temporal locations during the delay period differentially affected VI response rate maintenance. That is, response rates were substantially higher when the brief signal was imposed at the beginning of the delay period, compared to its imposition in the middle or at the end of the delay period (Experiment 2). These results show that the temporal location of a brief signal imposed during the delay period is another variable that impacts response rate maintained by partially signaled delay of reinforcement.

**Delay and Signal Duration Effects**

Apart from number, type, and temporal location of brief signal, there are other potentially pertinent parameters of partially signaled delay of reinforcement that might impact its response-rate-maintaining effects. When sequentially increasing delay duration, Schaal and Branch (1988) found that more responding can be maintained with completely as compared to partially signaled delay when the delay duration was 27 s. This suggests that delay duration also affects the response-rate maintaining effects of partially signaled delay of reinforcement. In this investigation, however, a VI 60-s schedule was used as the baseline of immediate reinforcement condition against which lengthening of delay duration was compared against. Increasing delay duration, however, changes the structure of the schedule which alters frequency and distribution of reinforcer, therefore, precluding direct comparison between immediate reinforcement and delay conditions (especially when delay duration was increased to 27 s). Hence, posing a challenge in attributing the response-rate reduction in partially signaled delay condition solely to increase in delay duration to 27 s.

The delay duration in Schaal and Branch (1988) also was increased progressively from 0 s (no delay) to 3 s, 9 s and 27 s. When Ferster (1953), for instance, incrementally increased the delay duration to 60 s, response rate in the delay condition was maintained at baseline level of immediate reinforcement. Conversely, when a 60 s delay was introduced abruptly, response rate maintenance deteriorated substantially. The response rate maintained with both completely and partially signaled delay in Schaal and Branch`s investigation, therefore, could also have been affected by the sequential increases in delay duration.

The signal duration in the partially signaled delay condition, moreover, was constant across different delay durations, which resulted in situations where different proportions of the delay period were signaled depending on length of the delay imposed. A 0.5 s keylight color change used in Schaal and Branch as a brief signal, for instance, accompanied 5.6 % of 9 s delay period, while the same brief signal duration only accompanied 1.9 % of the 27 s delay period. In the completely signaled delay condition, conversely, entire delay period was signaled irrespective of length of the delay period. Thus, the relatively small proportion of 27 s delay period briefly signaled compared to 9 s delay might have resulted in low response rates maintained by the former delay condition compared to the latter.

**Briefly Signaled Delays and Delay Reduction Theory**

To account for the effects of signaled delay of reinforcement, Schaal and Branch (1988) suggested that both complete and brief signals imposed during the delay period function as a conditioned reinforcer that reduces the delay to reinforcement (cf. delay reduction theory (DRT), Fantino, 1993). Because a completely signaled delay reduces the delay to reinforcement more than does a briefly signaled delay, response rate maintained by the former is higher compared to latter delay condition. According to DRT the effectiveness of a stimulus as a conditioned reinforcer can be predicted by calculating the reduction in the length of time to primary reinforcement measured from the onset of the preceding stimulus (Fantino, 1993). Thus, DRT predicts that a brief signal that is temporally closer to reinforcement should maintain higher responding as compared to a brief signal that is temporally furthest away from reinforcement.

In the SINGLE condition of Experiment 1, however, when the brief signal was imposed at the beginning of the delay period, VI response rates were higher relative to those maintained when the brief signal was imposed at variable locations during the delay period, averaging out to the middle of the delay period in the VARIABLE condition. Similarly, in Experiment 2, VI response rates were higher in the START as compared to MIDDLE and END delay conditions. Contrary to the DRT prediction, in Experiment 1 and 2, responding during the nondelay period was maintained at a higher level when the brief signal was temporally furthest from reinforcer delivery. Conversely, in Experiment 3, when the brief signal was imposed at variable locations that averaged out to middle of the delay period for both VI SIGNAL and VT SIGNAL delay conditions, VI response rates were higher in the VI SIGNAL compared to VT SIGNAL condition. In this instance, because the brief signal presented in both VI SIGNAL and VT SIGNAL delay conditions were, on average, in equivalent temporal proximity to the reinforcer, DRT predicts comparable response rates in these delay conditions, which was not the case.

The discrepancy between the brief signal location predicted by DRT to maintain responding most efficaciously and the results of the present series of experiments may be attributable to the different procedures for arranging the brief signal presentations in the different delay conditions. Response rates during the VI schedule remained unchanged from the immediate reinforcement baseline conditions when the brief signal was contingent on and temporally contiguous to the response that initiated the delay period, as was the case in the SINGLE, DOUBLE, DOUBLE DIFFERENT, START, and VI SIGNAL conditions. Conversely, VI responding decreased from immediate baseline reinforcement levels during the VARIABLE, MIDDLE, END, and VT SIGNAL conditions because, although the contingency remained in place (i.e., no response, no brief signal), the requirement of temporal contiguity between the response that initiated the delay period and the subsequent brief signal presentation was absent. Thus, a brief signal imposed in close temporal proximity to the reinforcer seems to maintain responding only if the brief signal is both contingent and temporally contiguous to the response.

**Limitations and Future Directions**

There are some methodological issues that may limit the interpretation of the present experiments. Many investigations of autoshaping show that the presentation of a response-independent stimulus change in close temporal proximity to a reinforcer elicits keypecking (Brown & Jenkins, 1968), a finding contrary to the findings in Experiment 2, where responding diminished to low level when a brief signal was presented in close temporal proximity to reinforcer delivery. This difference could be because a blackout in Experiment 2 served as the brief stimulus, as opposed to the use of a change in keylight color in autoshaping experiments. The present findings, therefore, might apply in circumstances where a diffuse stimulus (e.g., blackout, tone, etc.) is used, and may not be applicable when a localized stimulus (e.g., keylight color change) is used.

In these current experiments, when the brief signal presentation was contingent on and temporally contiguous to keypecking, keypecking was maintained at an equivalent level to that maintained during the immediate reinforcement baseline. It is, however, not known whether keypecking also would be maintained at a level equivalent to that during baseline if a response other than the reinforced (in this case, keypeck) response produced the brief signal. Iversen (1981), for instance, suggested that frequency of responding (i.e., food-tray entry) acquired through adventitious reinforcement during the signaled delay can increase during no-signal period (i.e., VI component of the schedule). Thus, it might be that in the VARIABLE condition of Experiment 1, MIDDLE and END conditions of Experiment 2, and VT SIGNAL condition of Experiment 3, a response other than keypecking was adventitiously reinforced which competed with keypecking. Conversely, in the SINGLE, DOUBLE, and DOUBLE DIFFERENT conditions of Experiment 1, START condition of Experiment 2, and VI SIGNAL condition of Experiment 3, not only keypecking was strengthened as a result of its contingency to reinforcer delivery, but also its temporal contiguity with the brief signal presentation.

**Concluding Remarks**

Skinner (1948) asserted that response-reinforcer temporal contiguity is one of the defining features of operant conditioning. This assertion has been supported in the context of both unsignaled (Sizemore & Lattal, 1977, 1978; Williams, 1976) and completely signaled delay of reinforcement (Ferster, 1953; Richards, 1981). In the latter case, response-rate maintaining effect is achieved when a contingent and temporally contiguous signal accompanies the entire delay period. Conversely, in the present series of experiments, when contingency between response-brief signal was in place but response-brief signal temporal contiguity was disrupted, partially signaled delay of reinforcement had response-reducing effect. When both contingency and temporal contiguity between response-brief signal presentation were in effect, however, response-rate-maintaining effect of partially signaled delay of reinforcement was preserved. Thus, the outcome of the present investigation not only affirms the importance of response-signal contingency and temporal contiguity impacting response-rate maintaining effect of completely signaled delay of reinforcement, but also extends this finding to partially signaled delay of reinforcement.

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**Table 1**

*Conditions, Number of Sessions, and Reinforcer per Minute of Experiment 1*

| | Pigeons | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 14482 | | 22595 | | 25670 | | 32647 | |
| Conditions | Reinforcers per minute | Sessions (Condition order) | Reinforcers per minute | Sessions (Condition order) | Reinforcers per minute | Sessions (Condition order) | Reinforcers per minute | Sessions (Condition order) |
| Baseline | .86 | 14(1) | .87 | 16(7) | .87 | 14(3) | .86 | 13(5) |
| Single | .83 | 13(2) | .86 | 20(8) | .86 | 13(4) | .82 | 14(6) |
| Baseline | .87 | 13(3) | .87 | 14(5) | .87 | 15(7) | .85 | 13(1) |
| Variable | .69 | 21(4) | .79 | 15(6) | .81 | 23(8) | .61 | 6(2)* |
| Baseline | .87 | 17(7) | .81 | 13(1) | .87 | 13(5) | .87 | 13(3) |
| Double | .85 | 14(8) | .83 | 13(2) | .86 | 13(6) | .83 | 16(4) |
| Baseline | .88 | 14(5) | .87 | 20(3) | .87 | 13(1) | .86 | 13(7) |
| Double Different | .84 | 13(6) | .86 | 18(4) | .86 | 13(2) | .83 | 14(8) |
| Baseline | .87 | 13(9) | .86 | 13(11) | .87 | 13(11) | .86 | 16(9) |
| Replication | .86 | 17(10) | .86 | 15(12) | .85 | 14(12) | .69 | 14(10) |
| Baseline | .87 | 17(11) | .88 | 13(9) | .87 | 26(9) | .87 | 14(11) |
| Nonoverlapping | .64 | 14(12) | .81 | 18(10) | .81 | 19(10) | .72 | 13(12) |
| Baseline | .86 | 16(13) | .87 | 21(13) | .86 | 16(13) | .86 | 13(13) |

*Note.* Summary of conditions, number of sessions per condition, and reinforcers per minute obtained during the final six sessions of each condition.

*When the Variable condition was imposed as the first delay condition for Pigeon 32647, responding stopped for 3 consecutive sessions after 6$^{th}$ session. Therefore, it was decided to switch the condition for this pigeon to baseline of immediate reinforcement to examine other delay conditions for this pigeon.

**Table 2**

*Conditions, Number of Sessions, and Reinforcer per Minute of Experiment 2*

| | Pigeons | | | | | |
|---|---|---|---|---|---|---|
| | 9553 | | 29321 | | 35223 | |
| Conditions | Reinforcers per minute | Sessions (Condition order) | Reinforcers per minute | Sessions (Condition order) | Reinforcers per minute | Sessions (Condition order) |
| Baseline | .86 | 22(5) | .87 | 13(3) | .87 | 13(1) |
| Start | .85 | 27(6) | .85 | 19(4) | .85 | 13(2) |
| Baseline | .86 | 16(1) | .87 | 16(5) | .87 | 13(3) |
| Middle | .76 | 21(2) | .85 | 18(6) | .77 | 14(4) |
| Baseline | .87 | 14(3) | .87 | 13(1) | .88 | 14(5) |
| End | .75 | 14(4) | .78 | 22(2) | .79 | 13(6) |
| Baseline | .86 | 22(7) | .87 | 13(7) | .88 | 14(7) |
| Replication | .81 | 17(8) | .70 | 13(8) | .85 | 13(8) |
| Baseline | .87 | 20(9) | .86 | 13(9) | .89 | 13(9) |

*Note.* Summary of conditions, number of sessions per condition, and reinforcers per minute obtained during the final six sessions of each condition.

**Table 3**

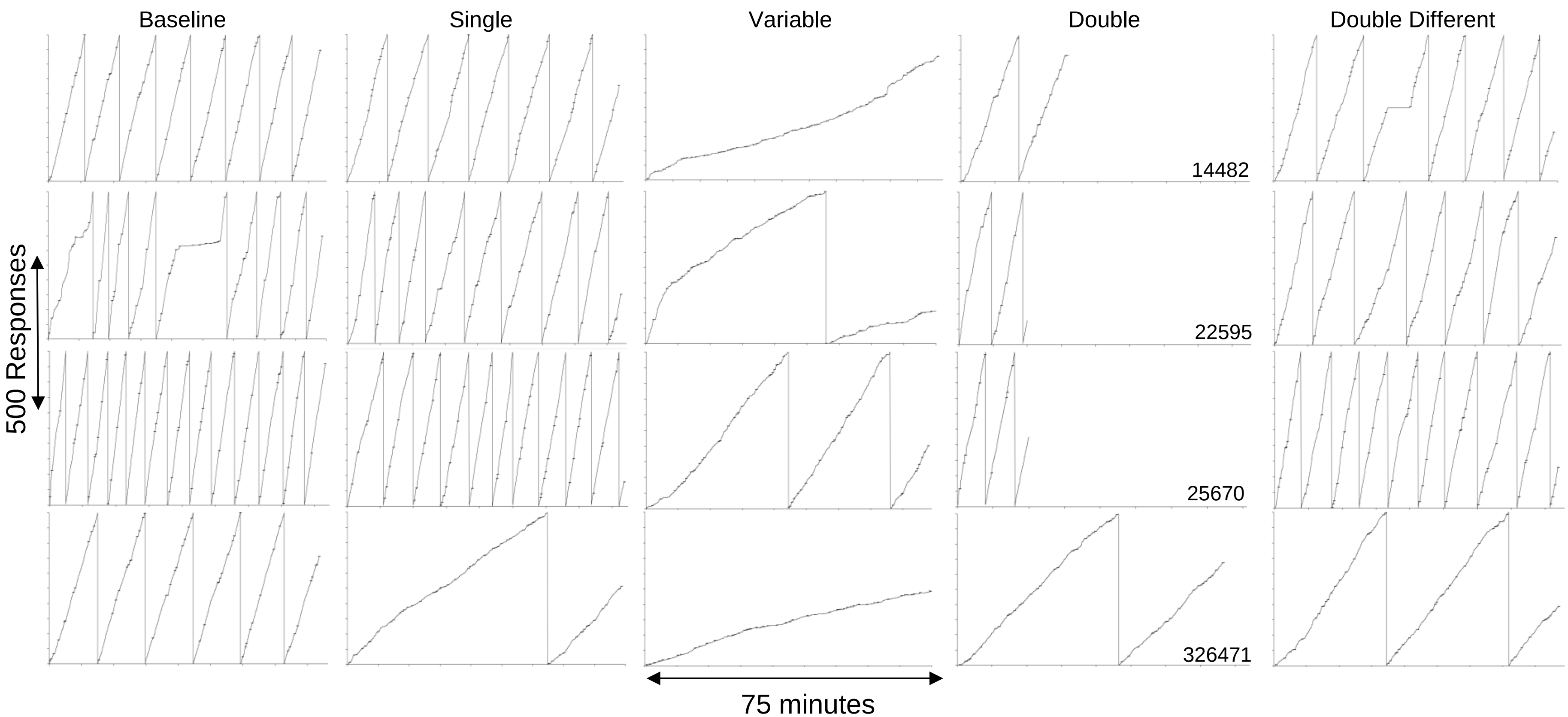
*Conditions, Number of Sessions, and Reinforcer per Minute of Experiment 3*

| | Pigeons | | | | | |
|---|---|---|---|---|---|---|
| | 10028 | | 10247 | | 20542 | |
| Conditions | Reinforcers per minute | Sessions (Condition order) | Reinforcers per minute | Sessions (Condition order) | Reinforcers per minute | Sessions (Condition order) |
| Baseline | .86 | 22(1) | .85 | 13(3) | .86 | 13(1) |
| VI Signal | .85 | 14(2) | .85 | 14(4) | .82 | 14(2) |
| Baseline | .85 | 12(3) | .86 | 16(1) | .86 | 16(3) |
| VT Signal | .81 | 17(4) | .75 | 13(2) | .68 | 21(4) |
| Baseline | .86 | 23(5) | .86 | 13(5) | .86 | 15(5) |
| Replication | .85 | 16(6) | .73 | 13(6) | .78 | 23(6) |
| Baseline | .86 | 16(7) | .85 | 17(7) | .86 | 15(7) |

*Note.* Summary of conditions, number of sessions per condition, and reinforcers per minute obtained during the final six sessions of each condition.

**Figure 1**

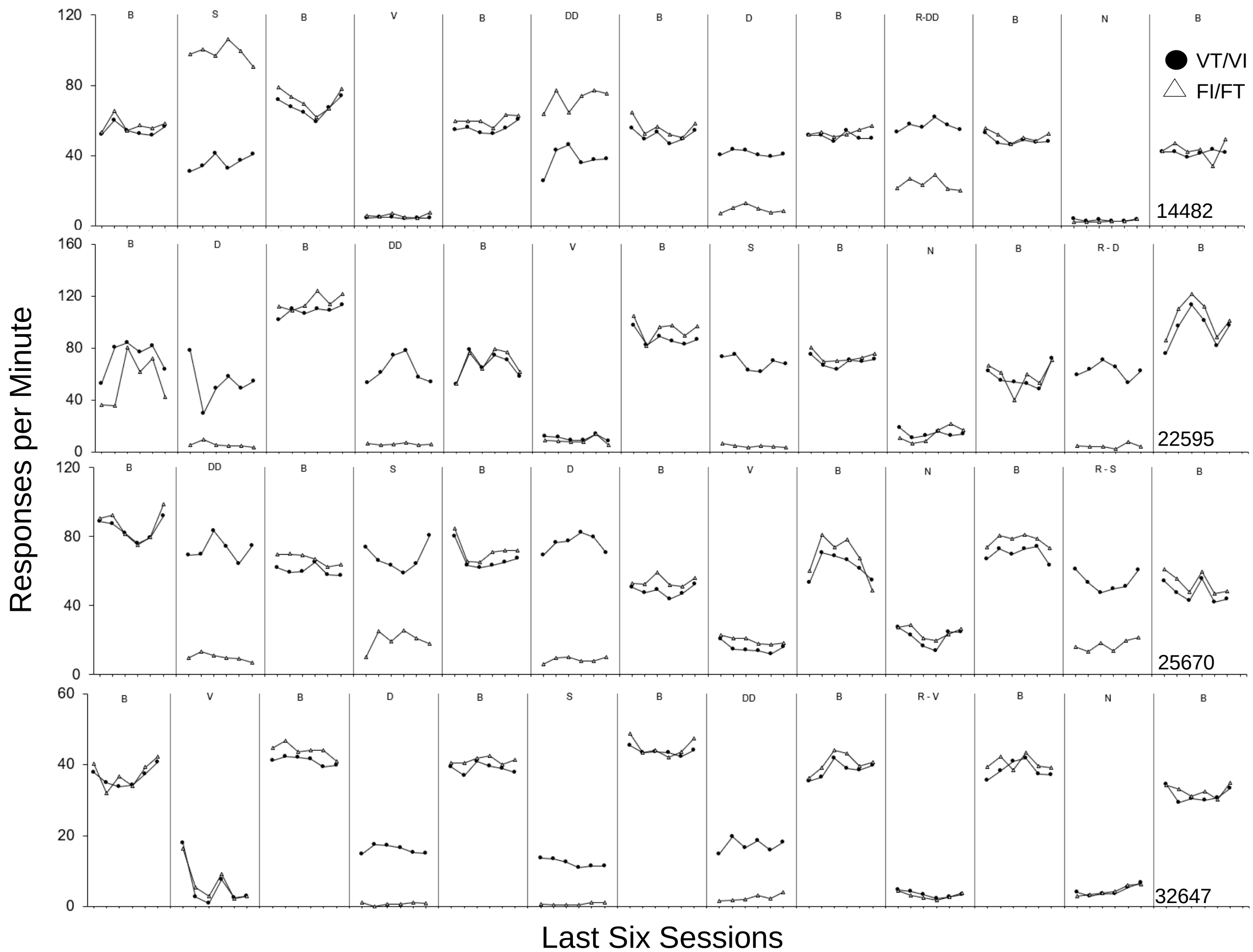
*Cumulative Records of the Baseline and Delay Conditions of Experiment 1*




*Note.* Cumulative records show the last session of the baseline and delay conditions. The number of responses is on the y-axis and the session duration on the x-axis. Each reset of the response pen occurs at 500 responses and downward deflections in the response line represent reinforcer delivery. Sessions across baseline and delay conditions lasted, on average, for 75 minutes.

**Figure 2**

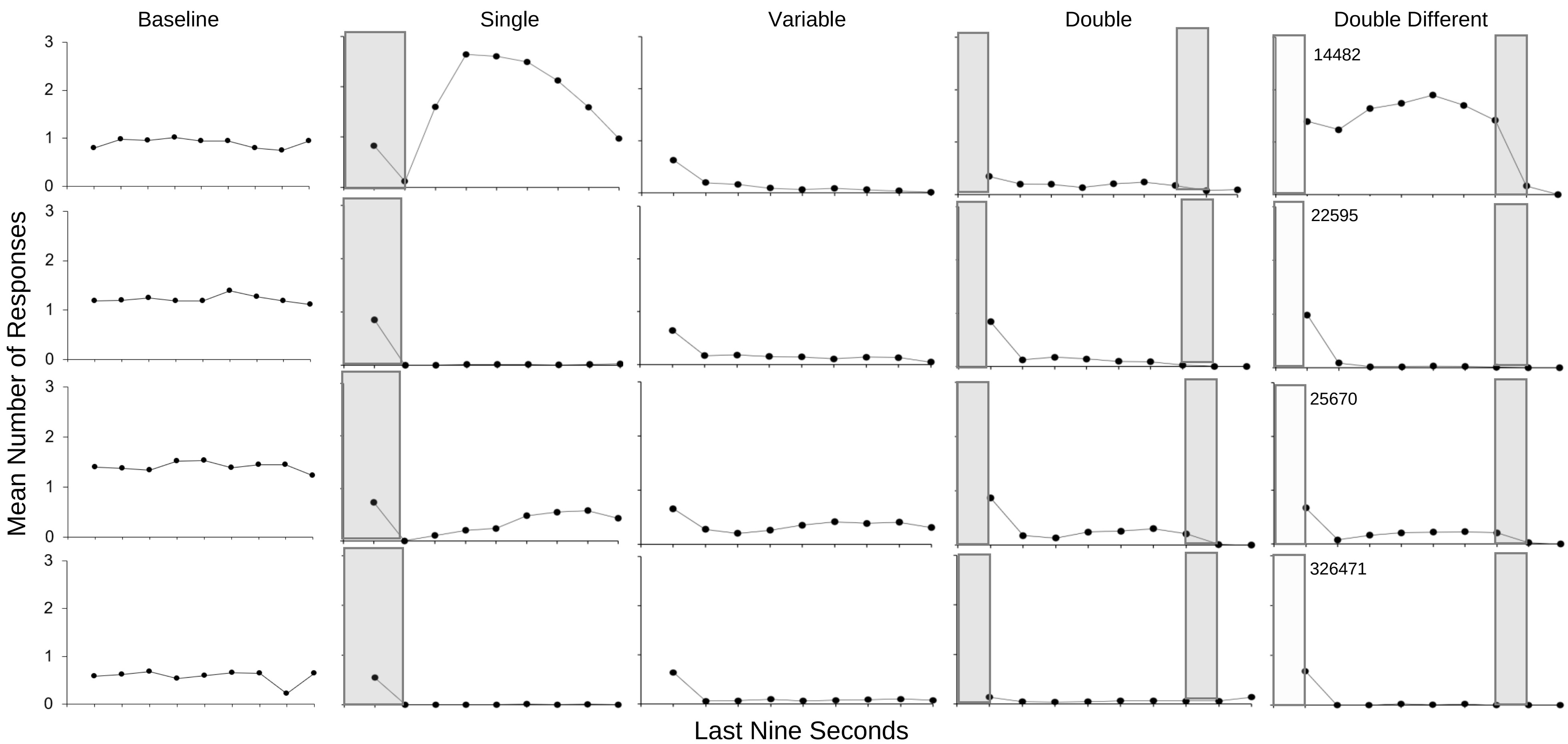
*Responses per Minute During Baseline and Delay Conditions of Experiment 1*




*Note.* Responses per minute during VT and FI component of the baseline conditions and VI and FT component of the delay conditions for the last 6 sessions of each condition. Order of conditions for each pigeon are labeled in each respective pigeon`s figure. Baseline and delay conditions are abbreviated as follows: Baseline (B), Single (S), Variable (V), Double (D), Double Different (DD), and Nonoveralpping (N). Conversely, abbreviation R refers to the replication of a delay condition. The y-axis shows responses per minute, while the x-axis shows the sessions (Please note different scale on Y-axis). The rate of responding during the VT component of the baseline and VI component of the delay conditions are indicated with a closed circle, while the FI component of the baseline and FT component of the delay conditions are indicated with an open triangle.

**Figure 3**

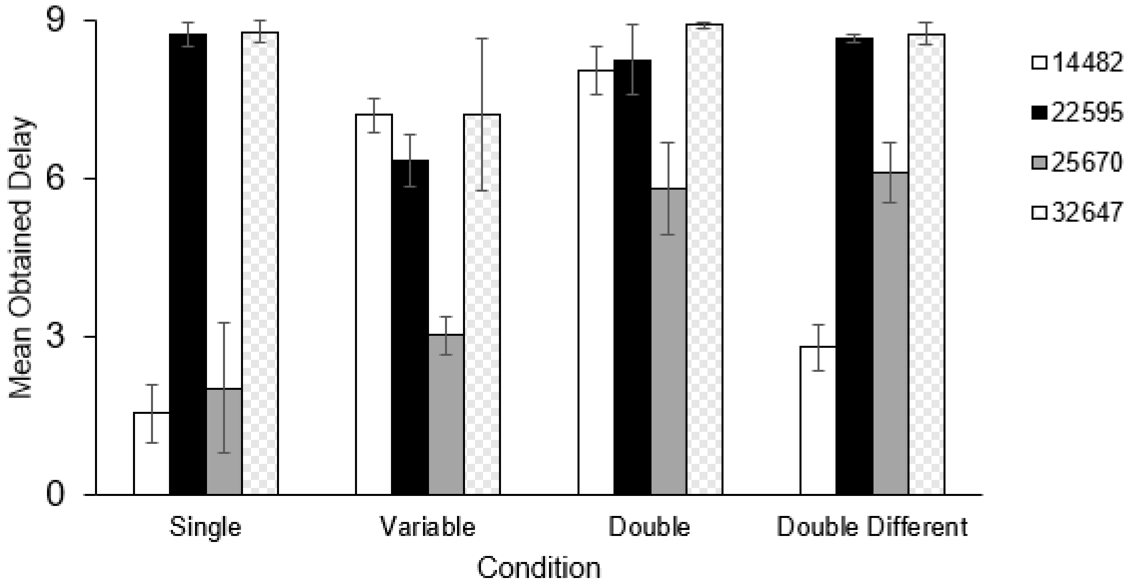
*Mean Number of Responses Across the Last Nine Seconds of the Baseline and Delay Conditions of Experiment 1*




*Note.* The mean number of responses are on the y-axis and the last nine second of the FI component of the baseline and FT component of the delay conditions are on the x-axis. The mean number of responses in each 1-s interval bin was computed from the last six sessions of the baseline and delay conditions. Transparent grey bars represent signal presentation duration during the FT component across the delay conditions. The widths of the transparent bars represent the duration of the signal in the respective delay condition. In the Variable delay condition, a 2-s signal was presented at the variable temporal location that averaged 5 s during the delay period. In the Double Different condition, the transparent light grey bar represents keylight change at the beginning of the FT component, while the darker grey bar represents a blackout at the end of the FT component.

**Figure 4**

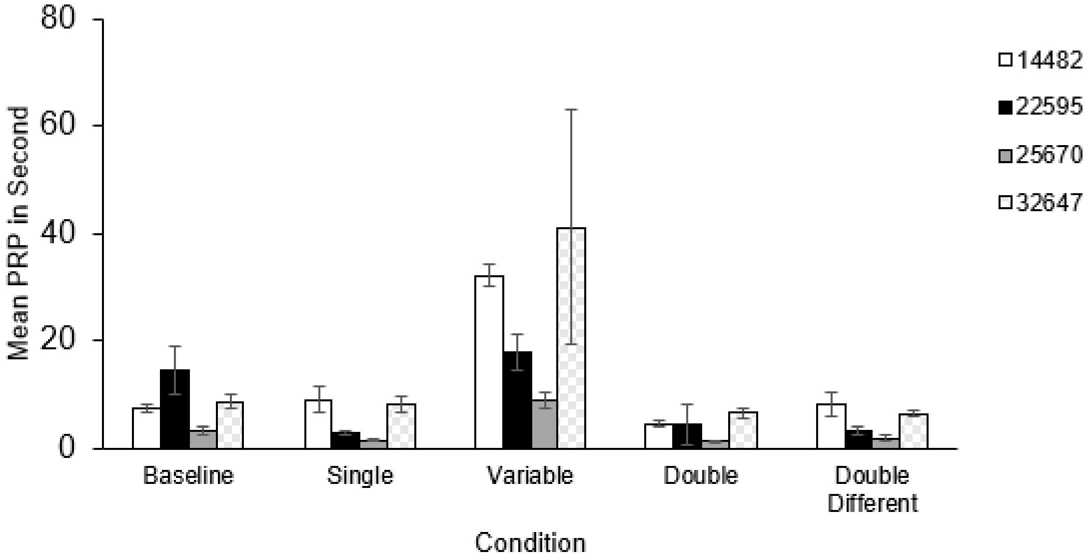
*Mean Obtained Delay for Each Delay Condition of Experiment 1*




*Note.* Mean obtained delay, shown on the y-axis, while conditions are shown on the x-axis. Mean obtained delay was computed from the last six sessions of the delay conditions. The error bars represent the standard deviation from the mean obtained in each delay condition.

**Figure 5**

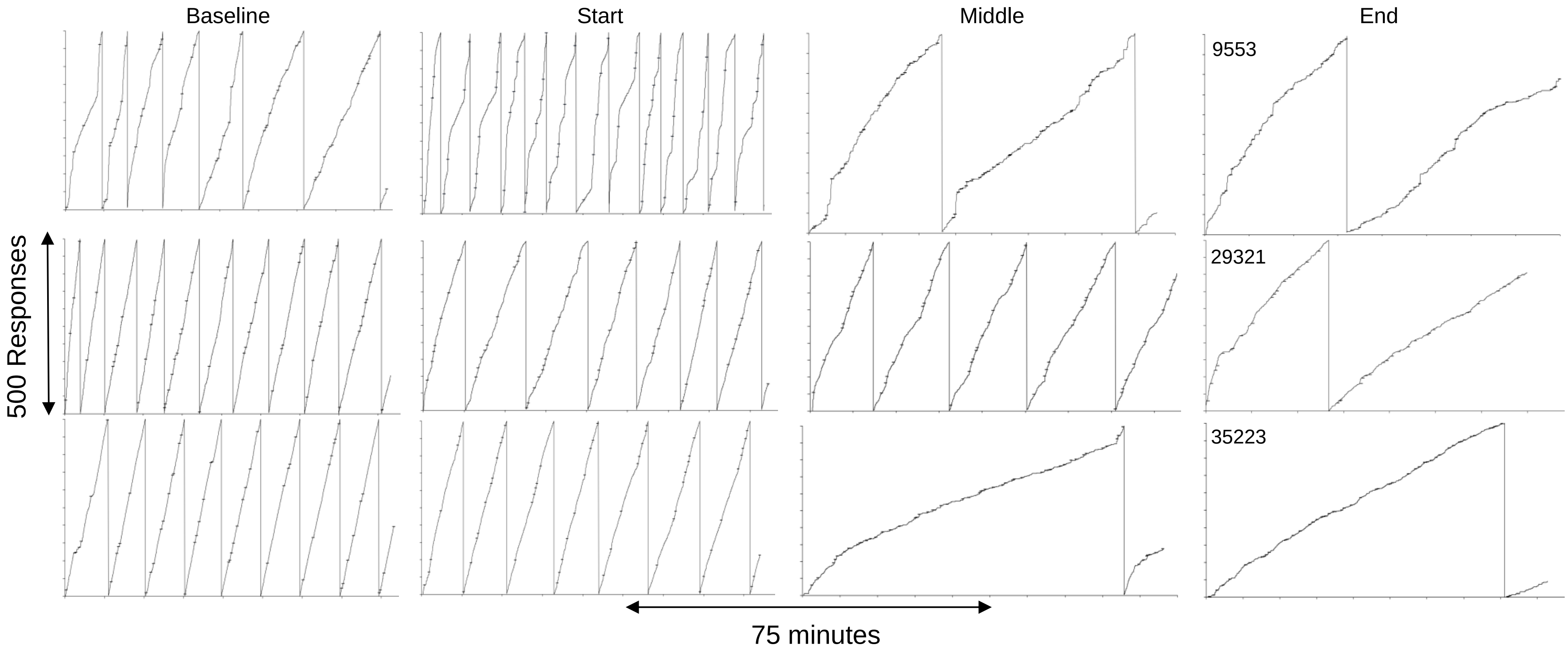
*Mean PRP in the Baseline and Delay Conditions of Experiment 1*




*Note.* Mean post-reinforcement pause shown on the y-axis and conditions are shown on the x-axis. Data represent the last six days of the first baseline condition and the last six days of each delay conditions. The error bars represent the standard deviation from the mean obtained in each condition.

**Figure 6**

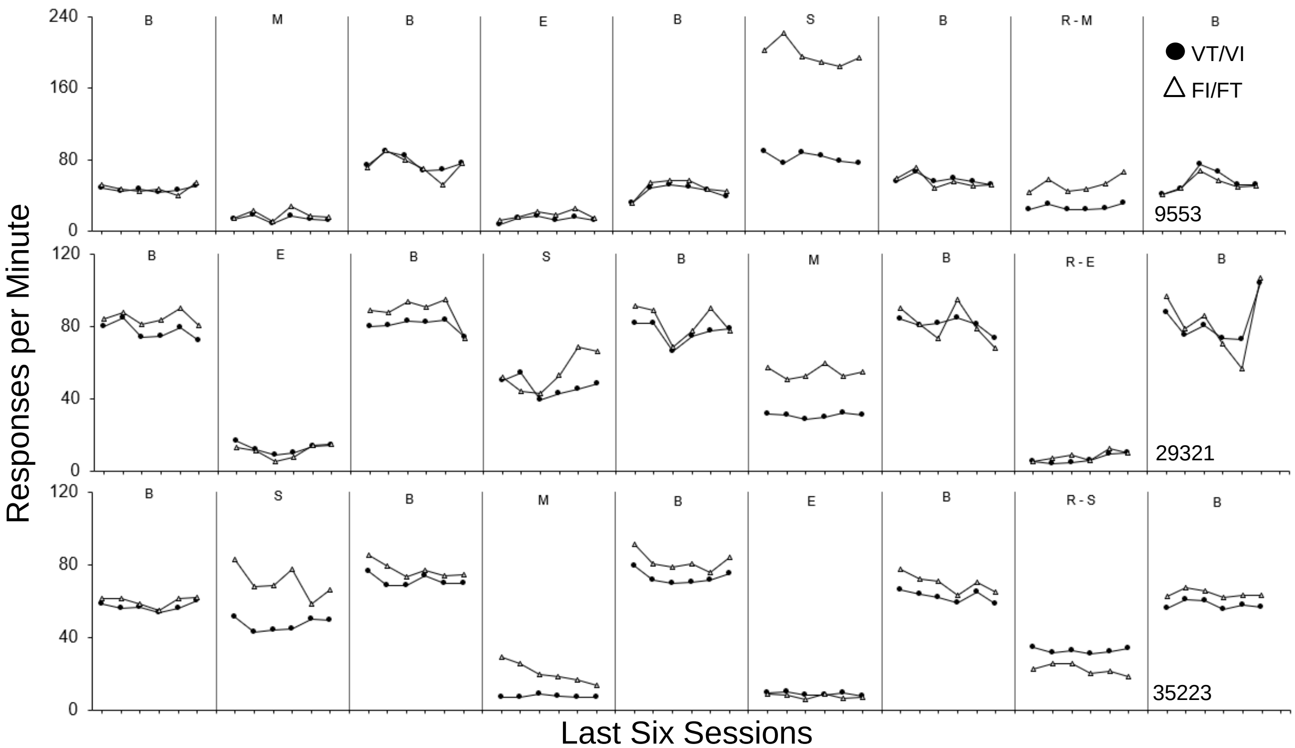
*Cumulative Records of the Baseline and Delay Conditions of Experiment 2*




*Note.* Cumulative records of the last session of the baseline and delay conditions. The number of responses is on the y-axis and the session duration is on the x-axis. Each reset of the response pen occurs at 500 responses and downward deflections in the response line represent reinforcer delivery. Sessions across baseline and delay conditions lasted, on average, for 75 minutes.

**Figure 7**

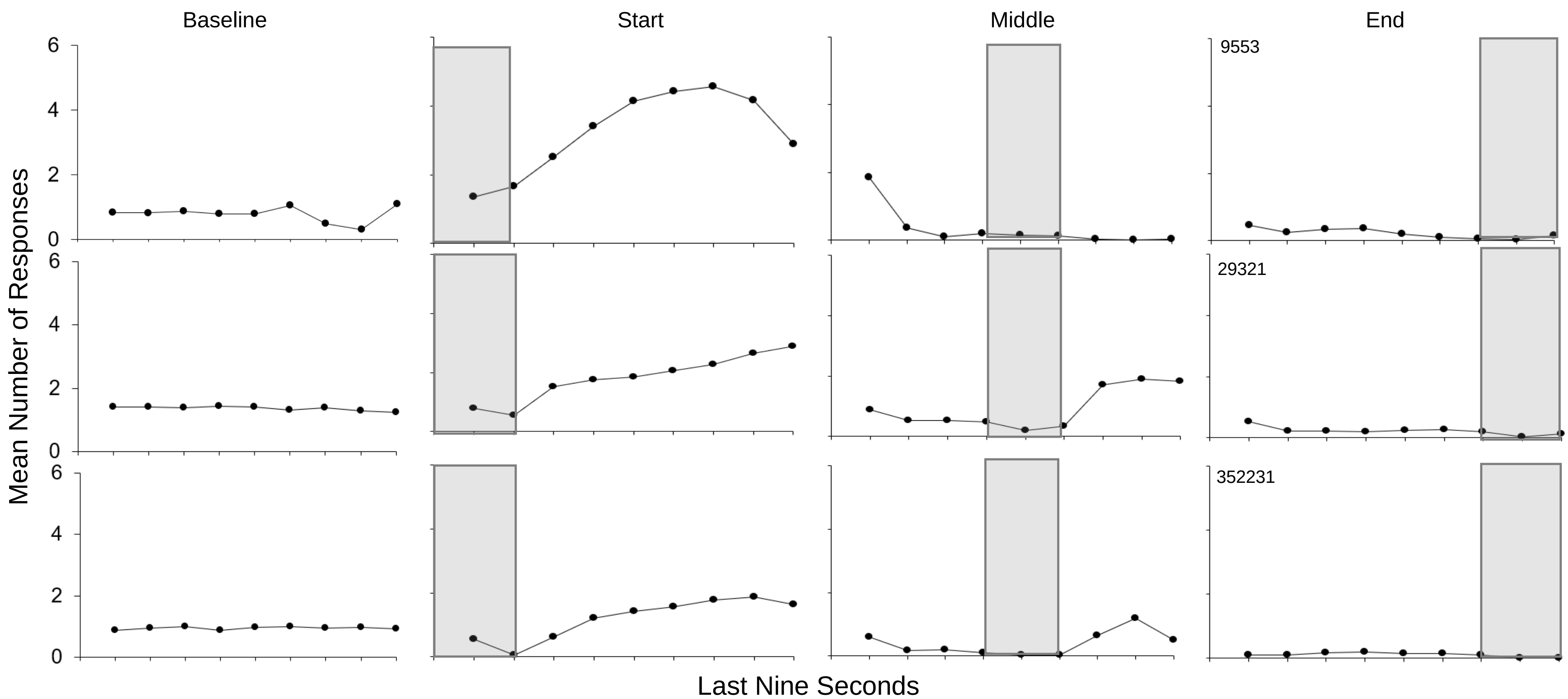
*Responses per Minute During Baseline and Delay Conditions of Experiment 2*




*Note.* Rates of responding during VT and FI component of the baseline conditions and VI and FT component of the delay conditions for the last 6 sessions of each condition. Order of conditions for each pigeon are labeled in each respective pigeon`s figure. Baseline and delay conditions are abbreviated as follows: Baseline (B), Start (S), Middle (M), and End (E). Conversely, abbreviation R refers to the replication of a delay condition. The y-axis represents responses per minute, while the x-axis represents the sessions (Please note different scale on Y-axis). The rate of responding during the VT component of the baseline and VI component of the delay conditions are indicated with a closed circle, while the FI component of the baseline and FT component of the delay conditions are indicated with an open triangle.

**Figure 8**

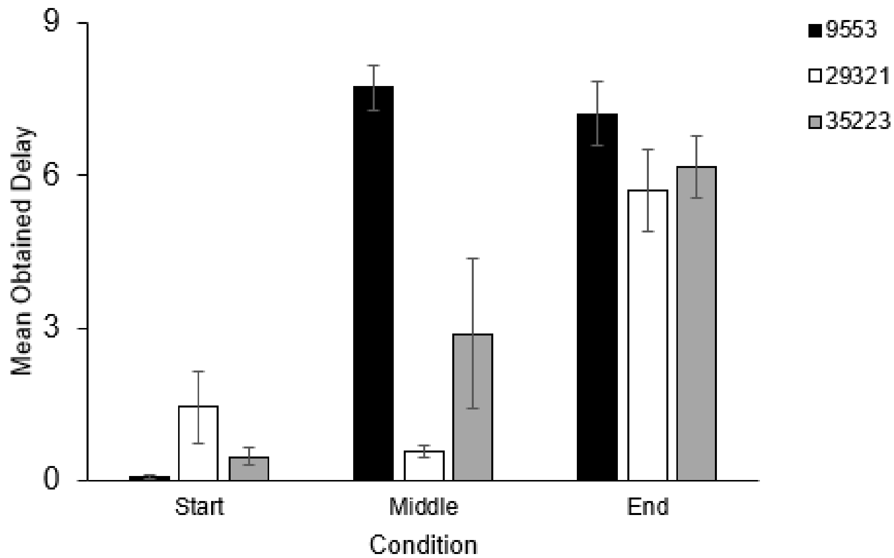
*Mean Number of Responses Across the Last Nine Seconds of the Baseline and Delay Conditions of Experiment 2*




*Note.* The mean number of responses are on the y-axis and the last nine second of the FI component of the baseline and FT component of the delay conditions are on the x-axis. The mean number of responses in each 1-s interval bin was computed from the last six sessions of the baseline and delay conditions. Transparent grey bars represent signal presentation duration during the delay period across the delay conditions.

**Figure 9**

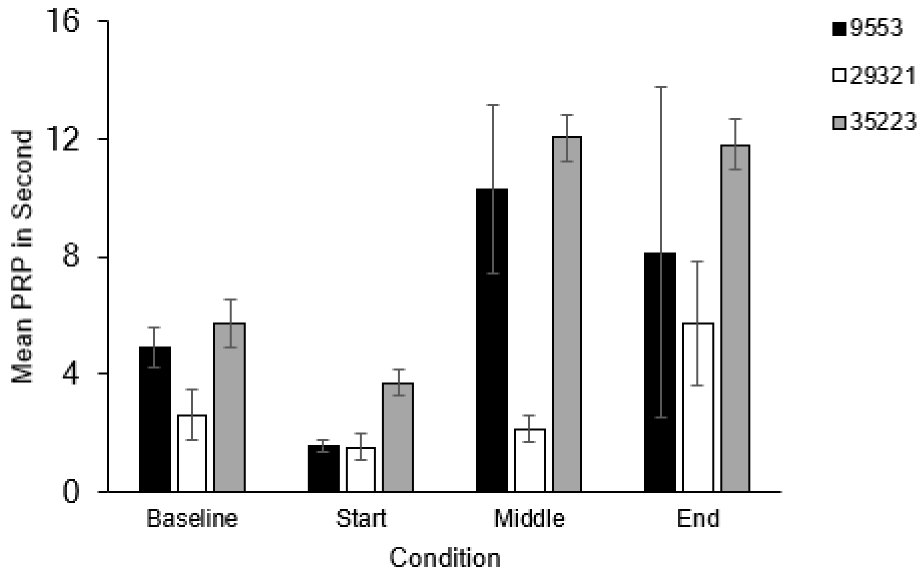
*Mean Obtained Delay Across Delay Conditions of Experiment 2*




*Note.* Mean obtained delay, shown on the y-axis, while conditions are shown on the x-axis. Mean obtained delay was computed from the last six sessions of the delay conditions. The error bars represent the standard deviation from the mean obtained in each delay condition.

**Figure 10**

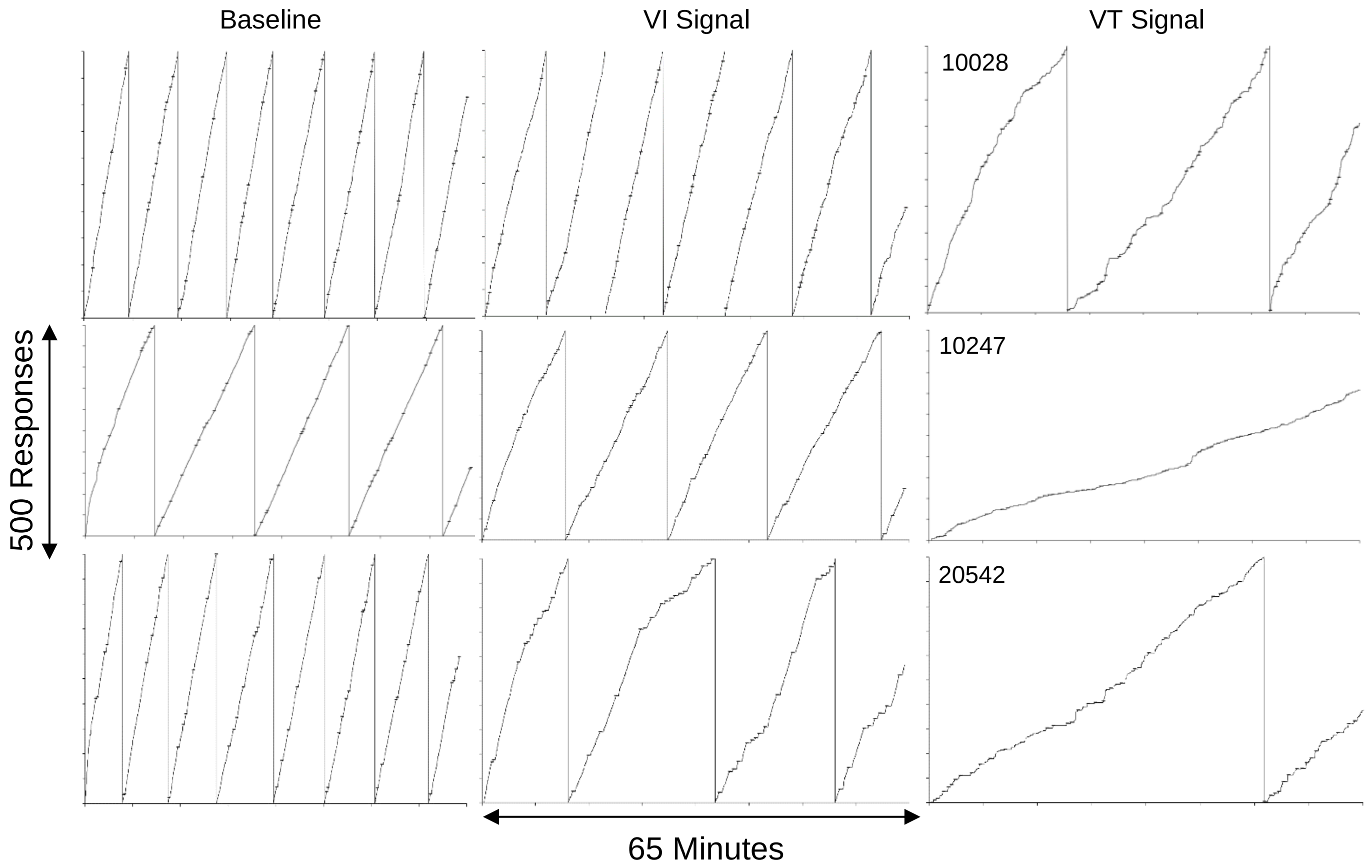
*Mean PRP in the Baseline and Delay Conditions of Experiment 2*




*Note.* Mean post-reinforcement pause shown on the y-axis and conditions are shown on the x-axis. Data represent the last six sessions of the first baseline condition and the last six sessions of each delay conditions. The error bars represent the standard deviation from the mean obtained in each condition.

**Figure 11**

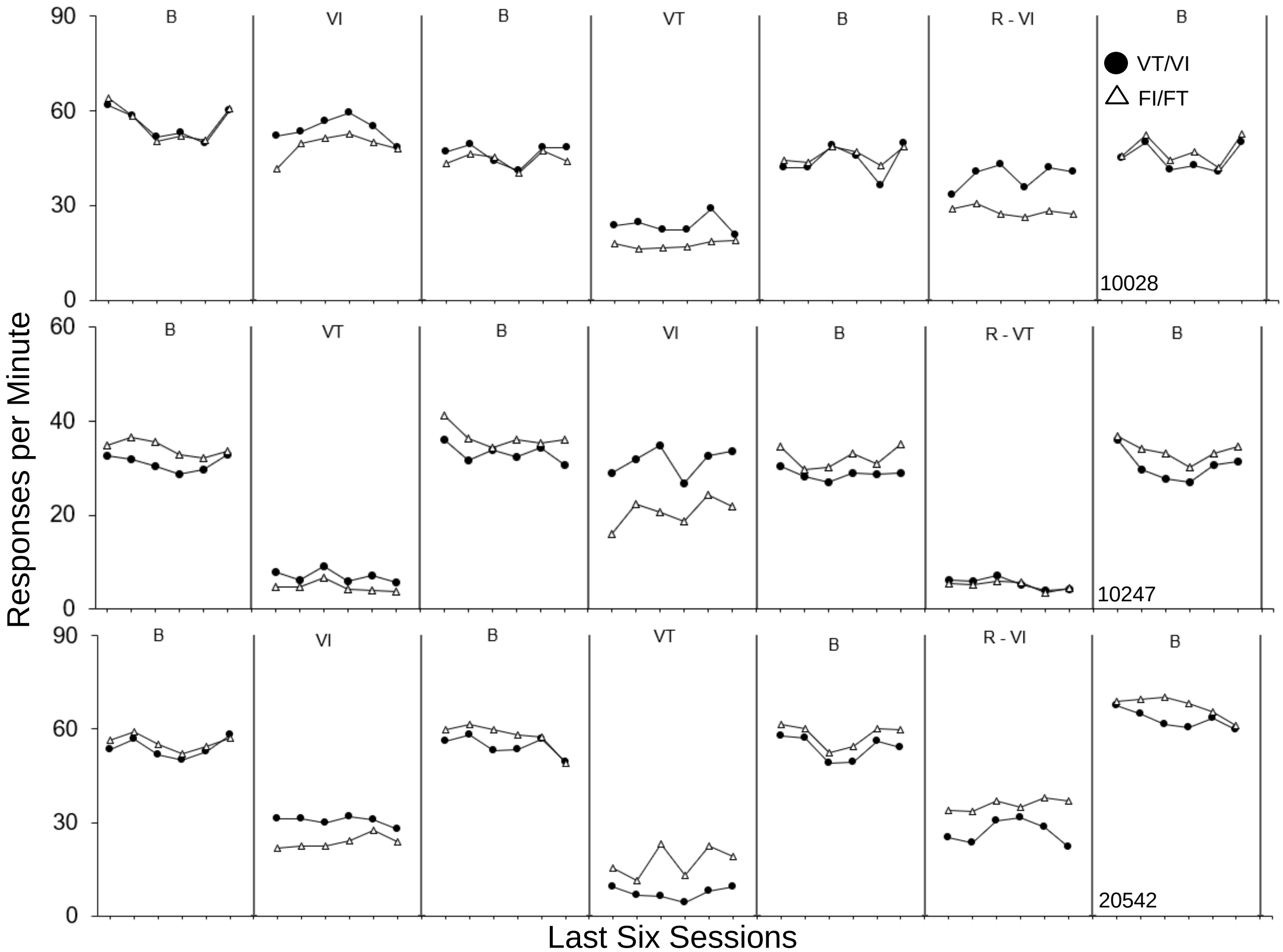
*Cumulative Records of the Baseline and Delay Conditions of Experiment 3*




*Note.* Cumulative records of the last session of the baseline and delay conditions. The number of responses is on the y-axis and the session duration is on the x-axis. Each reset of the response pen occurs at 500 responses and downward deflections in the response line represent reinforcer delivery. Sessions across baseline and delay conditions lasted, on average, for 65 minutes.

**Figure 12**

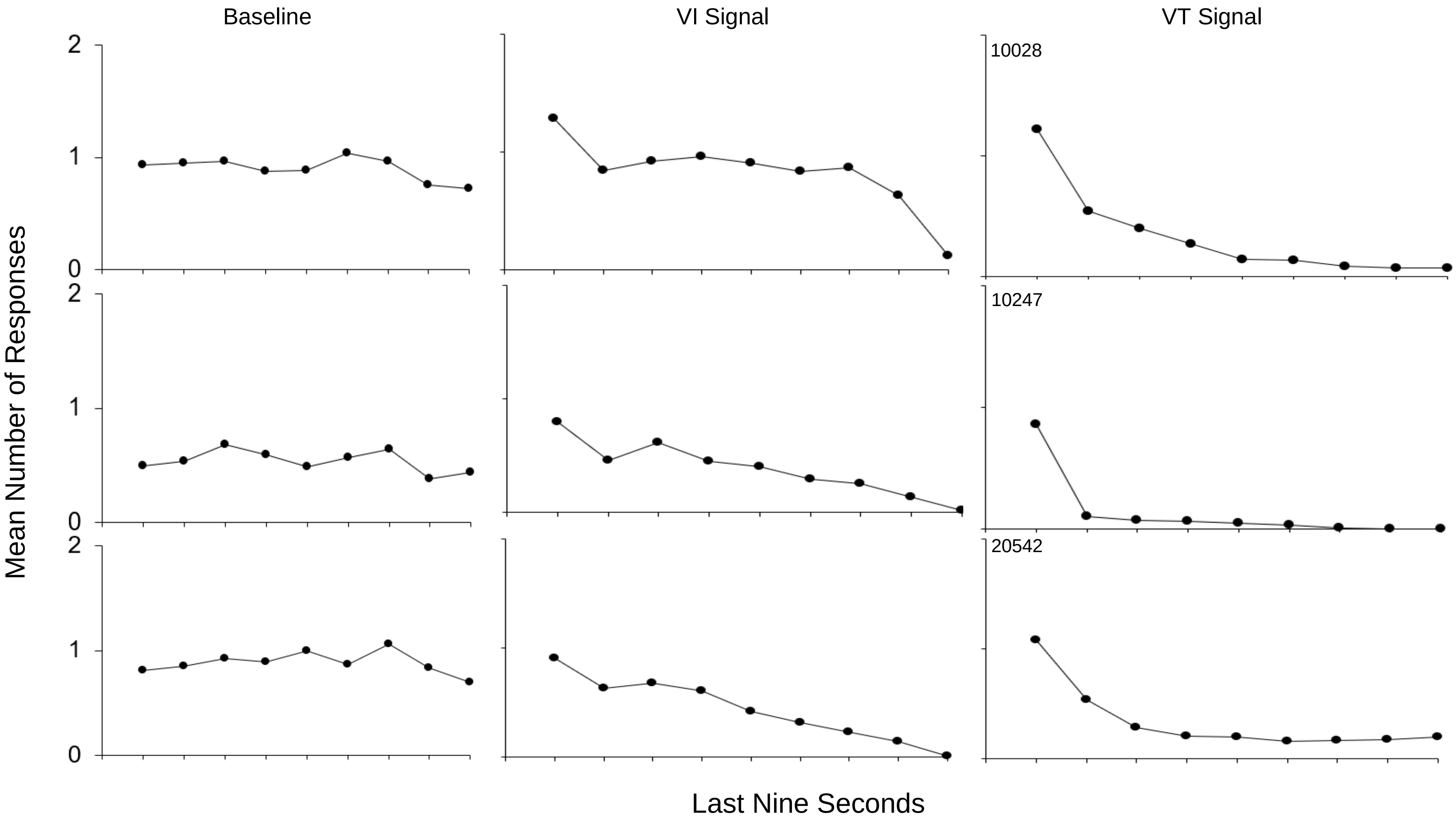
*Responses per Minute During Baseline and Delay Conditions of Experiment 3*




*Note.* Responses per Minute during VT and FI component of the baseline conditions and VI and FT component of the delay conditions for the last 6 sessions of each condition. Order of conditions for each pigeon are labeled in each respective pigeon`s figure. Baseline and delay conditions are abbreviated as follows: Baseline (B), VI Signal (VI), and VT Signal (VT) Conversely, abbreviation R refers to the replication of a delay condition. The y-axis represents responses per minute, while the x-axis represents the sessions (Please note different scale on Y-axis). The rate of responding during the VT component of the baseline and VI component of the delay conditions are indicated with a closed circle, while the FI component of the baseline and FT component of the delay conditions are indicated with an open triangle.

**Figure 13**

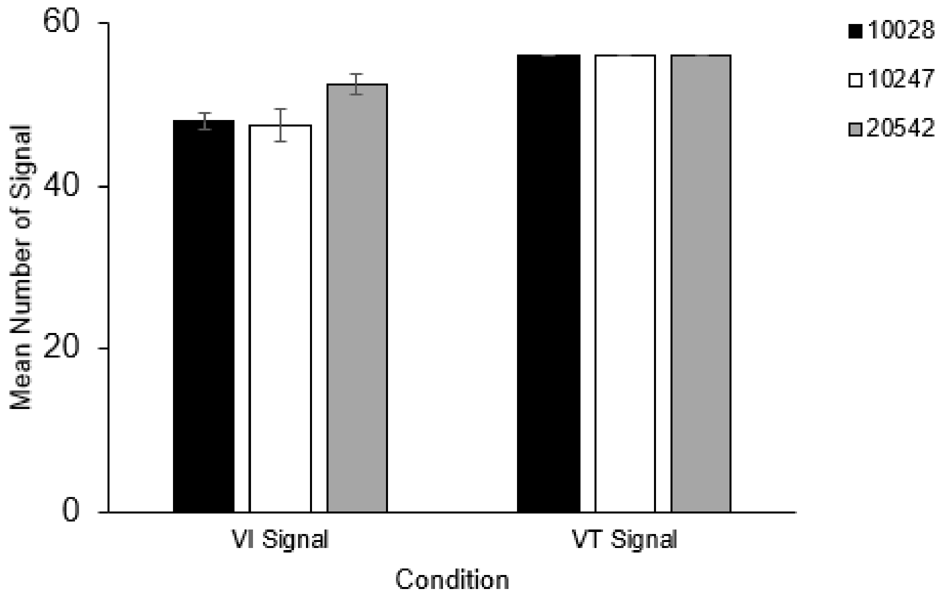
*Mean Number of Responses Across the Last Nine Seconds of the Baseline and the Delay Conditions of Experiment 3*




*Note.* The mean number of responses are on the y-axis and the last nine second of the FI component of the baseline and FT component of the delay conditions are on the x-axis. The mean number of responses in each 1-s interval bin was computed from the last six sessions of the baseline and delay conditions. In both delay conditions, a 1-s signal was presented at the variable temporal location that averaged to 4 s during the delay period.

**Figure 14**

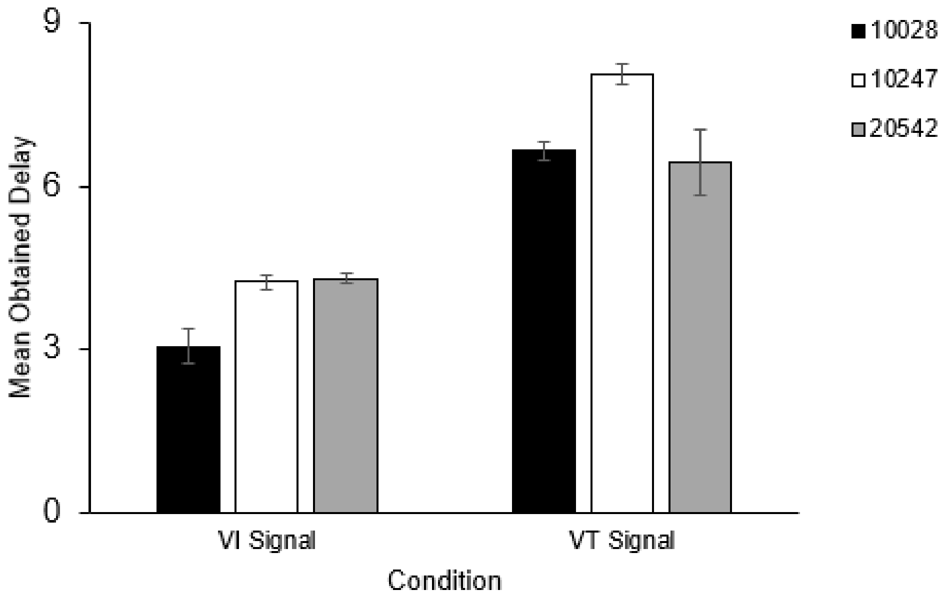
*Mean Number of Signals Presented in Each Delay Condition of Experiment 3*




*Note.* Mean number of signals are shown on the y-axis and conditions are shown on the x-axis. Data represent the mean number of signals presented in the last six days of each delay condition. The error bars represent the standard deviation from the mean obtained in each condition.

**Figure 15**

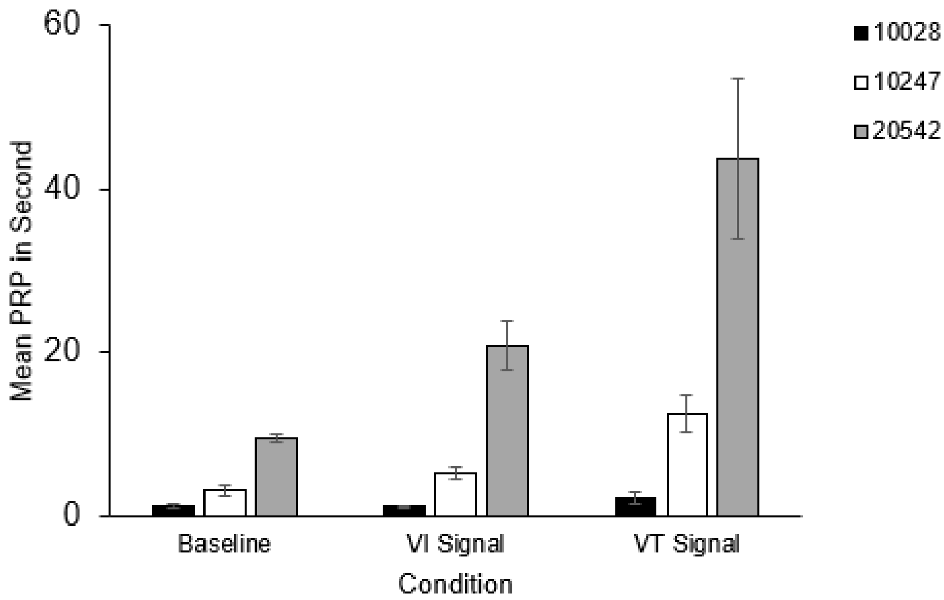
*Mean Obtained Delays Across Delay Conditions of Experiment 3*




*Note.* Mean obtained delay, shown on the y-axis, and conditions are shown on the x-axis. Mean obtained delay was computed from the last six sessions of the delay conditions. The error bars represent the standard deviation from the mean obtained in each condition.

**Figure 16**

*Mean PRP Obtained in the Baseline and Delay Conditions of Experiment 3*




*Note.* Mean post-reinforcement pause are shown on the y-axis and conditions are shown on the x-axis. Data represent the last six days of the first baseline condition and the last six days of each delay condition. The error bars represent the standard deviation from the mean obtained in each condition.