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ABSTRACT

Title of Document: **FURTHER INVESTIGATION OF DIFFERENTIAL-REINFORCEMENT-OF-LOW-RATE BEHAVIOR PROCEDURES**

Jessica L. Becraft, Doctor of Philosophy, 2017

Directed By: John C. Borrero
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Differential-reinforcement-of-low-rate (DRL) schedules are designed to decrease the rate of a target response without eliminating the response. There are at least two variations of DRL schedules: spaced-responding and full-session. However, it is unclear whether the two variations work in the same way. In fact, there is some evidence that a full-session DRL may eliminate target responding, which may be problematic if it is used for responses where elimination is not ideal (e.g., hand-raising). In the current set of three studies, we systematically compared the DRL types. In Study 1, 19 college students and 10 preschoolers played a computer game in which they earned points based on the two DRL schedules with or without signals indicating reinforcer availability. Results indicated that both DRL schedules reduced, but did not eliminate, target responding as long as signals were present for most participants. In Study 2, we compared the DRL schedules on reducing excessive requests for teacher attention with 3 preschoolers. For all participants, responding was similar and near the optimal criterion (i.e., not eliminated) in both DRL conditions. In Study 3, we conducted a multi-level meta-analysis of published studies and dissertations using DRL schedules with humans. Results indicated that both DRL schedules reduced target responding relative to baseline, but there were no significant differences between DRL types. There were moderating

effects of whether the target response was applied or arbitrary, whether the reinforcer was functional, and the type of signals used. In total, these three studies generally found little to no difference between the DRL types in both experimental preparations and a synthesis of the literature. As such, the use of a full-session DRL in application to reduce, but not eliminate, behavior was supported.

Further Investigation of Differential-Reinforcement-of-Low-Rate Behavior Procedures

Jessica L. Becraft

Dissertation submitted to the Faculty of the Graduate School of the University of Maryland, Baltimore County, in partial fulfillment of the requirements for the degree of Doctor of Philosophy, 2017

Dedication

For my three children: With hard work, patience, perseverance, passion, and the love of family and friends, anything is possible. I know you will do great things.

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General Introduction

Differential-reinforcement-of-low-rate (DRL) schedules may be used to decrease a behavior that occurs too frequently. However, unlike other response-reducing procedures, the goal of a DRL is not to eliminate the behavior; rather, it is to reduce the behavior to a more manageable rate. DRL schedules are useful for responses such as rapid eating (Anglesea, Hoch, & Taylor, 2008) or excessive hand-raising in a classroom (Austin & Bevan, 2011).

There are at least two types of DRL schedules (Deitz, 1977). The first, the spaced-responding DRL, is most frequently studied in the nonhuman animal laboratory. In a spaced-responding DRL, a reinforcer is presented if the amount of time since the last response is greater than a specified value. The second, the full-session DRL, is more frequently studied in applied contexts. In a full-session DRL, a reinforcer is presented if a certain number of responses or less occur within a specified time period. Although both procedures are called DRL schedules, there is some evidence that they may affect behavior differently. Specifically, the full-session DRL has the potential to eliminate a response because reinforcers are provided even in the absence of the response (Jessel & Borrero, 2014). This may be problematic because clinicians may inadvertently eliminate a response that is appropriate at a low level (e.g., hand-raising). Thus, because practitioners are more likely to use full-session DRLs in application, it is important to understand exactly how they affect behavior.

Thus, the purpose of the following three studies was to systematically and comprehensively compare the DRL procedures. The first study examined the two types of DRL procedures in a human operant laboratory setting with college and preschool students. In addition to the comparison of DRL types, we investigated the role of signals in DRL schedules. In the context of a DRL schedule, signals are stimuli that indicate when responses would and would not be reinforced. In the second study, we directly compared the two DRL procedures in an applied context to reduce excessive bids for teacher attention of preschool students. Finally, in the third study, we reviewed and meta-analyzed all studies that used a DRL schedule with humans. We explored several moderators that may affect the DRL schedules including age, whether the individual was diagnosed with a developmental disability, whether the target response was applied or arbitrary, whether the contingency was for a group or an individual, and whether signals were used.

A common theme to this set of studies is to be found in the translational approach used across studies. All studies were essentially asking the same question: do the effects of a spaced-responding and full-session DRL vary? Each study took a different angle to address this question. The first study may be considered a more basic investigation. We used an arbitrary response to ask, at a very simplistic level, if the two procedures varied. The second study was closer to application. It addressed a socially meaningful problem while comparing the DRL procedures. In the third study, we compared already published data on DRL schedules. In addition to evaluating the effects of the DRL schedules on target response rates, we also could identify descriptive information about how each type of schedule is typically arranged. By investigating and comparing DRL schedules from multiple angles, we hope to be able to make better recommendations for when and how to arrange DRL schedules.

A second theme that may be less apparent is the role of development and the outcomes of DRL applications. DRL schedules, particularly spaced-responding DRLs, require the organism to pace responding and may be related to impulsivity and self-control. In fact, several studies use DRL performance as an index of impulsivity. For instance, Cheng, MacDonald, and Meck (2006) injected rats with cocaine and ketamine and measured inter-response times in a spaced-responding DRL. Inter-response times were shorted after cocaine injections than with no drug or with ketamine injections, consistent with more impulsive responding. Avila, Cuenca, Félix, Parcet, and Miranda (2004) used spaced-responding DRL performance to investigate attention deficit hyperactivity disorder of school-aged boys. In a factor analysis, DRL performance loaded on other tasks related to impulsivity including the Stroop task and perseverative errors from the Wisconsin Card Sorting Test. In behavior analysis, impulsivity is defined as the selection of a smaller, sooner reward over a larger, later reward (Catania, 2013). In other words, someone who is impulsive has difficulty delaying gratification. Impulsivity generally decreases with age (Mischel & Metzner, 1962; Scheres, Tontsch, Thoeny, & Sumiya, 2014). Thus, we would expect children to be more impulsive than adults. In the current series of studies, we addressed development in several ways. In the first study, we compared DRL schedules with both preschool students and college-aged students. Although measures of impulsivity were outside the scope of this study, we investigated whether DRL performance varied between these samples. The second study did not compare or investigate age. However, it does extend prior work on DRL schedules to reduce excessive requests for teacher attention to a younger, and presumably more impulsive, age group. Austin and Bevan (2011) used a full-session DRL to reduce requests of third-grade students, whereas our study investigated preschool students (age 4). In the third study, we investigated development by including age as a moderator.

Finally, these studies demonstrate methods to combine inferential statistical analyses with single-case designs. DRL schedules are most commonly used in behavior analytic studies that employ a single-case design rather than a group design. Typically, single-case design studies are analyzed visually rather than statistically. In the first study, in addition to visual analysis, we used a repeated measures analysis of variance to determine whether there was an effect of DRL type and signals. We conducted these analyses because we had a sufficient sample size ($N = 19$) of college students, which is uncommon in single-case design research. One primary purpose of the third study was to advance analysis methods for single-case design research by using a multi-level model meta-analysis. Although a meta-analysis of single-case design studies is necessarily complex, there are several benefits (Shadish, Kyse, & Rindskopf, 2013). First, it can comprehensively and succinctly summarize data from multiple studies with multiple participants. Second, researchers unfamiliar with single-case design methodology may be more likely to contact and appreciate research that is analyzed statistically. Third, it provides a model for other single-case design researchers and may ultimately advance single-case design research.

In summary, the following three studies investigated the central questions of the extent to which the full-session DRL and spaced-responding DRL function similarly or differently. We employed multiple methods and analytic techniques to answer these questions for a comprehensive comparison of DRL schedules.

Slow Down: Translational Investigation of Signaled Differential-Reinforcement-of-Low-Rate Procedures (Study 1)

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Abstract

Differential reinforcement of low rates of responding (DRL) is used to decrease the overall rate, but not eliminate a target response. Two variations of DRL, spaced-responding and full-session, exist, but whether the schedules function similarly is unclear. Signals may also impact responding in DRL arrangements. In the current study, we compared response rates under two DRL variations with and without signals. In Experiment 1, 19 college students played a game in which points served as reinforcers under DRL schedules. In some sessions, a stimulus signaled when responses would be reinforced (S+) or not reinforced (S-). In other sessions, only an S- was present. In Experiment 2, we replicated Experiment 1 with 5 preschool students. In Experiment 3, we modified the signals and repeated the procedure with 5 preschoolers. Instead of an S-only, we did not present any signals. Signals (S+/S-) maintained responding in both types of DRL schedules. Elimination and high variability of the target response was observed with the S- only and absence of S+/S-, respectively. Data were more variable for the full-session DRL than the spaced-responding DRL. Signaled DRL schedules are recommended for use in application.

Keywords: differential reinforcement of low rates, stimulus control, signals, translational, mouse clicks, humans

Slow Down: Translational Investigation of Signaled Differential-Reinforcement-of-Low-Rate Procedures (Study 1)

Differential reinforcement describes a set of procedures in which one class of responses is reinforced and another class of responses is not (Catania, 2013). Contingencies can be arranged in a variety of ways to increase or decrease target responses. One procedure, differential reinforcement of low rates of responding (DRL), has generally been shown to decrease but not eliminate the rate of a target response. DRL schedules have been studied extensively in the nonhuman literature (e.g., Doughty & Richards, 2002; Farmer & Schoenfield, 1964; Kapostins, 1963; LeFrancois & Metzger, 1993; Zimmerman & Schuster, 1962). In addition, DRL schedules have been used to decrease socially-meaningful responses such as rapid eating (e.g., Anglesea, Hoch, & Taylor, 2008; Lennox, Miltenberger, & Donnelly, 1987; Wright & Vollmer, 2002) and excessive requests for attention (e.g., Austin & Bevan, 2011).

Traditionally in a DRL, a response is reinforced only if a predetermined inter-response time (IRT) has elapsed (Deitz, 1977). It is for this reason that some prefer IRT > *t* as the descriptor of this type of arrangement. For example, if the IRT is 30 s, a reinforcer will be provided if the organism makes a response at least 30 s after the last response. If the organism responds before the predetermined IRT, the interval is reset and the reinforcer is withheld. This DRL arrangement, termed *spaced-responding DRL*, is the typical arrangement of a DRL schedule in nonhuman laboratory research. In a spaced-responding DRL schedule, the overall rate of responding decreases but is not eliminated because a reinforcer is only provided if a response occurs. In nonhuman behavioral research, spaced-responding DRL schedules are often used to assess stimulus control and impulsivity. For instance, Wiley, Compton, and Golden (2000) compared performance in signaled and unsignaled spaced-responding DRL schedules when rats were injected with different drugs (e.g., diazepam, amphetamine, pimozode). All drugs tested disrupted response timing by either decreasing IRTs (e.g., diazepam) or increasing IRTs (e.g., pizmozode). Some drugs disrupted timing in the unsignaled DRL but not in the signaled DRL (e.g., amphetamine). Thus, the DRL schedules were used as a way to study impulsivity, timing, and stimulus control. In application, Lennox et al. (1987) utilized a spaced-responding DRL to reduce the rate of eating for three individuals with intellectual disabilities. If 15 s elapsed since the last bite of food, participants were permitted to take a bite. Attempts to take a bite of food were blocked, and the DRL interval was reset if at least 15 s had not elapsed since the last bite. Mean IRTs increased for all participants, thereby decreasing response rate, in the DRL condition as compared to a baseline and a fixed-interval 15-s condition.

In contrast to the spaced-responding DRL, in a *full-session DRL*, a reinforcer is provided if a predetermined number of target responses or less (i.e., *tolerance*) occur in a given amount of time[1] (Deitz, 1977). For instance, if the tolerance is two responses and the interval is 60 s, a reinforcer will be provided every 60 s as long as the organism does not engage in more than two target responses in each 60-s interval. Like the spaced-responding DRL, responding in the full-session DRL should be reduced because the

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[1] Deitz (1977) describes the interval in a full-session DRL as the entire session duration. Alternatively, he describes another DRL variation called an interval DRL. According to Deitz, an interval DRL breaks the session into smaller intervals, and the reinforcer is provided for engaging in the tolerated number of responses or less in each interval. Conceptually, one may view the interval and full-session DRL as the same procedure in which there is only one interval in the full-session DRL. To avoid confusion, we will only use the term full-session DRL to describe both procedures. However, whether the different arrangements produce functionally similar response patterns is unknown.

tolerance level is some proportion of baseline response rate; unlike the spaced-responding DRL, the contingencies support reinforcer provision given zero responses. Austin and Bevan (2011) applied a full-session DRL to decrease excessive requests for attention displayed by three elementary-school-aged students. Participants could earn points exchangeable for a choice of back-up reinforcers if they requested attention fewer than a target number of times (i.e., the teacher-prescribed tolerance level) in each academic period. Under the full-session DRL, requests for help decreased for all children.

Full-session DRLs are more common in applied settings than spaced-responding DRLs, possibly because they are easier to implement. In a spaced-responding DRL, a teacher or clinician would have to (a) keep a constant timer to ensure that the interval had elapsed before provision of the reinforcer and (b) reset the timer following each instance of the target response that occurred before each interval had elapsed. By contrast, in a full-session DRL, the interventionist need only record whether the number of responses exceeded tolerance at the end of each specified interval. However, a potential limitation of full-session DRLs is that behavior may be eliminated because a reinforcer can be earned even if a response is not made. In Austin and Bevan (2011), behavior was eliminated (zero) for all participants in over half of DRL sessions. Elimination of the target response may not be desirable. Requesting help and attention in an academic context is adaptive when it occurs at a reasonable rate. Therefore, a full-session DRL contingency may be contraindicated if maintenance of a response is desired.

The spaced-responding DRL procedure was born in the nonhuman animal laboratory to focus on the temporal control of responding (Ferster & Skinner, 1957). Ferster and Skinner (1957), however, also mention the possibility of arranging a DRL based on engaging in *n* responses or less in a specified amount of time (i.e., a full-session DRL). To our knowledge, there are no nonhuman laboratory studies that utilize a full-session DRL. According to Ferster and Skinner, this alternative arrangement was not typically studied because DRL schedules are “easiest to arrange in terms of a single inter-response time” (p. 459). Nowhere else in *Schedules of Reinforcement* do Ferster and Skinner describe or allude to a full-session DRL. The procedure was not utilized in application until Deitz and Repp (1973), in which the researchers applied a full-session DRL to reduce excessive talking-out in class. Later, Deitz (1977) termed the procedure a full-session DRL. The goal was to reduce responding in the absence of extinction (i.e., when extinction was not possible; Deitz & Repp, 1973). Often, it was not only acceptable, but desirable, to eliminate the responses targeted by a full-session DRL (e.g., aggression, Alderman & Knight, 1997).

In the absence of a comparative analysis between the two DRL procedures, it is reasonable to predict functional differences in performance based solely on the contingencies programmed in each arrangement. Jessel and Borrero (2014) compared the two DRL procedures in a human-operant preparation with college students. The target response was clicking on a colored square on a computer screen. Optimal responding in the spaced-responding DRL was set to 50% of the response rate in the reinforcement condition. Allowable responding in the full-session condition was one fourth of the response rate in the reinforcement condition. In general, participants responded near optimal levels in the spaced-responding DRL and at near zero levels in the full-session DRL. This preliminary study suggests that full-session DRLs may function more similarly to differential-reinforcement-of-other-behavior (DRO) schedules in that behavior is eliminated rather than just reduced. In the context of clinical practice, this suggests that desirable behavior could be eliminated, and as a result, the authors urged against the use of a full-session DRL in such circumstances. However, the task (i.e., clicking on colored squares) was very simple, and results therefore may not translate well to clinical applications. In addition, there were no signals to indicate to participants when responses would and would not be reinforced. Clinical applications of DRLs often use signals. For example, Lennox et al. (1987) prompted the participants when they were permitted to take a bite in a spaced-responding DRL. In Austin and Bevan (2011), boxes on an index card indicated how many more requests for attention would be permitted in the academic interval. Therefore, to fully realize the applied potential of these two DRL procedures, their effects should be assessed using conditions that best emulate those that are likely to occur in applied contexts (e.g., with signals).

Much is known about the value of signals in promoting schedule control in multiple-schedule arrangements (e.g., Hanley, Iwata, & Thompson, 2001; Hursh & Fantino, 1974; Lattal, 1973; Tiger & Hanley, 2004). Discriminative stimuli (SDs) signal the availability of reinforcement. However, in a DRL schedule, signals are programmed differently than SDs in a multiple schedule. In a multiple schedule, a unique stimulus is associated with each component schedule. Thus, a DRL schedule may be correlated with one stimulus and a ratio schedule may be correlated with a different stimulus. For example, Jessel and Borrero (2014) correlated yellow squares with the spaced-responding DRL and red squares with the full-session DRL. Although schedule-correlated stimuli may help the participants distinguish between the two conditions, they do not provide specific information about the dynamic contingencies within a DRL schedule. In a DRL, availability of reinforcement changes within the component schedule. That is, reinforcement for a response becomes temporarily unavailable after a response. Thus, signals can also change within the component. For example, a green stimulus might signal when the organism should respond. After a response occurs, the stimulus may change to red, which would signal that the organism should wait (i.e., not respond). The green stimulus could be termed an S+ and the red an S-.

Although many applications of DRLs use signals, very few studies have specifically evaluated the effect of those signals within DRL schedules. Marcucella (1974) compared signaled and unsignaled spaced-responding DRL schedules in a basic laboratory preparation with rats. In the signaled condition, a clicking sound on the right side of the operant chamber indicated that a response would be reinforced (i.e., S+). A clicking sound on the left side of the chamber indicated that a response would not be reinforced (i.e., responding was extinguished) and responses would reset the interval (i.e., S-). In the unsignaled condition, there were no stimuli indicating when responses would or would not be reinforced. In general, the subjects earned a higher proportion of potential reinforcers in the signaled DRL. Similarly, Wiley et al. (2000) compared the effects of drugs on signaled and unsignaled DRL schedules. Although all drugs disrupted timing, rats were significantly more efficient at earning reinforcers in the signaled DRL than the unsignaled DRL. These results suggest that signals may enhance responding in the spaced-responding DRL, however, Marcucella and Wiley et al. did not evaluate the full-session DRL.

The purpose of the current study was to replicate the work of Jessel and Borrero (2014) by investigating the spaced-responding and full-session DRL procedures with college and preschool students using a more complex operant. In addition, we sought to understand the role of signals in the two DRL arrangements so that we could identify the conditions under which these procedures would meet the clinical objectives of (a) suppressing or (b) maintaining responding.

Experiment 1

Method

Participants. Participants consisted of 30 (60% female) undergraduate students from a medium-sized mid-Atlantic public university. An institutional review board approved all study procedures. Participants were recruited from lower-level psychology classes and earned extra credit for participation. Participants were also eligible to win \$50, \$40, or \$10 for earning the first, second, and third most points, respectively, in the study. Participants were between the ages of 18 and 25 (M = 20.5 years). There were no exclusionary criteria for participation.

Apparatus and setting. Participants were seated at a desk with a computer and mouse in a quiet room (3m x 3m). The computer displayed a game programmed in Visual Basic™. Four background screens, each associated with a different condition, served as schedule-correlated stimuli. The variable ratio (VR) condition depicted a park scene, the extinction condition depicted a desert scene, the spaced-responding condition depicted a playground scene, and the full-session condition depicted a classroom scene (see Appendix A for screenshots of the scenes). In a random location on the screen was a waste receptacle. In the VR and extinction conditions, the receptacle was labeled with the word “trash” in black font. In the spaced-responding condition, the receptacle was labeled with the word “bottle” in red font. In the full-session condition, the receptacle was labeled with the word “paper” in blue font. The word on the receptacle indicated what the target response was for a given condition. In some conditions or portions of conditions, the waste receptacle had a closed bag and in others there was no bag (i.e., open receptacle; see Figure 1), which indicated reinforcement availability (described in further detail in the procedure). The color of the receptacle bag corresponded to the color of the font (e.g., the bag was blue in the full-session DRL). Trash, bottles, and paper stimuli moved in set paths across the screen. Table 1 presents a summary and depiction of stimuli used in each condition. In all conditions there was a small rectangular box at the top center of the screen that depicted the cumulative number of points (i.e., reinforcers) earned. The computer program automatically recorded the time and frequency of responses (defined below).

Response measurement. The primary dependent variable was the number of waste items dropped in the receptacle expressed as responses per min (rpm). To drop an item in a receptacle, participants clicked on the item, dragged it across the screen, and released it into the receptacle. This was calculated for each waste type (i.e., trash, paper, and bottles).

Experimental design. We used a combination of single-subject designs. The initial reinforcer assessment was conducted in a reversal design with VR (A) and extinction (B) phases. Next, a multi-element design was used to compare the spaced-responding (C) and full-session (D) DRL procedures with S+/S-. The spaced-responding (E) and full-session (F) procedures were then compared in a multi-element design with only an S-. Finally, a reversal to the DRL schedules with S+/S- was implemented. Some participants also experienced a second extinction phase at the end of the experiment due to undifferentiated responding in the DRL comparison. The design can be summarized as follows:

$$A - B - A - \frac{C}{D} - \frac{E}{F} - \frac{C}{D}$$

Procedure. Sessions were approximately 60 to 90 min and consisted of sequential 5-min blocks. Points were delivered for placing the corresponding waste in the receptacle based on the reinforcement schedule in place for each condition. For example, in the spaced-responding condition, points were earned for placing bottles in the bottle receptacle (see Table 1). No points were earned for placing other items in the receptacle (e.g., the banana in the spaced-responding condition). The following written instructions about the game appeared on the computer screen prior to session:

> Thank you for your participation in this study. You will be competing with other students for a monetary award. Your goal is to earn as many points as possible before time is up. There are different ways to earn points. All of your earnings will be visible throughout the experiment at the top of the screen, and a tone will sound with each distribution. Your time here will approximate one and a half hours with a minute break every five minutes. Here are some of the rules. Trash goes in the trash bin. Paper goes in the paper bin. Bottles go in the bottle bin. If the bin is full, the trash will not go in and you cannot earn points. Click the start button when you are ready. Remember that you are free to leave at any point during this study; however, you will only be eligible for the monetary reward following completion of your participation. Good luck!

Accompanying the instructions were pictures depicting which items should be thrown away in each receptacle and an image of a "full" receptacle.

Reinforcer assessment. The purpose of the reinforcer assessment was to demonstrate that points functioned as reinforcers. We evaluated two conditions: VR and extinction.

VR. A receptacle labeled "trash" was present on the screen. The receptacle was open (i.e., no bag was present). Participants earned points on a VR 15 ± 5 schedule for placing the trash items in the receptacle. Incorrect responses (i.e., throwing away bottle or paper items) reset the VR schedule.

Extinction. A receptacle labeled “trash” was present on the screen. The trash receptacle displayed a closed bag. Participants did not earn points for placing items in the trash receptacle, but could still make responses.

DRL comparison. Following the reinforcer assessment, participants began the comparison of the DRL conditions with S+/S- and with only S-. The purpose of the DRL comparison was to assess response rates in the two DRL conditions when unique signals were and were not present.

Spaced-responding DRL with S+/S-. A receptacle labeled “bottle” was present on the screen. Initially, the receptacle was open. The open bottle receptacle was an S+ that signaled a response would be reinforced. After a participant placed a bottle into the receptacle, a point was awarded and the bag closed. The closed bag was an S- that signaled a response would *not* be reinforced. After the DRL interval elapsed, the bottle receptacle reopened and the sequence was repeated. If the participant placed an item in the receptacle before the receptacle opened, the interval reset and the bag remained closed until the interval elapsed. The DRL interval was calculated as twice the mean IRT in the last phase of the VR condition (*cf.* Jessel & Borrero, 2014). Thus, to maximize earnings, optimal response rate was 50% of the last phase of the VR condition.

Full-session DRL with S+/S-. A receptacle labeled “paper” was present on the screen. Like the spaced-responding DRL with S+/S-, the paper receptacle was initially open (S+), which signaled that responses would be tolerated or allowed. When the participant placed the allowable number of pieces of paper in the receptacle, the bag closed (S-), which signaled that responses would not be tolerated or allowed. In other words, a response when the receptacle was closed reset the DRL interval. When the interval elapsed, a point was awarded, and the receptacle reopened. If the participant put fewer than the allowable number of items in the receptacle in a given interval, a point was awarded at the end of the interval and the receptacle remained open. Thus, points were earned if the participant placed the number of allowable items or fewer (including zero) in the receptacle within each interval. The DRL interval was calculated as four times the IRT of the last phase of the VR condition (*cf.* Jessel & Borrero, 2014). In other words, the full-session DRL interval was twice that of the spaced-responding DRL interval. To equate allowable response rates in the full-session DRL to the optimal response rate in the spaced-responding DRL, two responses were allowed in each interval. We did not make the interval sizes the same in the two DRL conditions for two reasons. First, we were systematically replicating Jessel and Borrero (2014), which calculated intervals in the same way as described here. Second, in clinical practice, it is common to use larger interval sizes.

Spaced-responding DRL with S- only. The spaced-responding DRL with S- only condition was identical to the spaced-responding DRL with S+/S- condition except that the bottle receptacle bag remained closed throughout the entire session, regardless of whether reinforcement was available. That is, there were no unique signals to indicate when a participant should or should not respond. Rather, the closed bag, which served as the S- in the spaced-responding DRL with signals, was present for the entire session. We chose the closed bag over the open receptacle as a comparison to the signal phase because one goal of DRL schedules is to reduce the rate of a target response. Thus, it was more appropriate to use an extinction-correlated stimulus than a reinforcement stimulus. The S- only condition was conceptualized as a test of stimulus control. If prior experience with the S- effectively eliminated responding when alternated with an S+, the S- only condition would allow us to assess the durability of stimulus control.

Full-session DRL with S- only. The full-session DRL with S- only condition was identical to the full-session DRL with S+/S- condition except that the paper bag remained closed throughout the entire block. Again, like the spaced-responding DRL with S- condition, this condition served as a test of the durability of stimulus control.

Data analysis. After initiating the study, we excluded participants from further analysis if (a) he or she failed to demonstrate a reinforcement effect in the reinforcer assessment or (b) data were unstable. Failure to demonstrate a reinforcement effect was defined as having a lower or equal rate of target responses in the VR condition as the extinction condition. If points did not function as reinforcers, we could not meaningfully compare DRL schedules. Further, we received approval to conduct three 1.5-hr sessions from our institutional review board. Therefore, we dropped participant from the study if the data were highly variable such that within the last three data points of a DRL condition and phase, the difference between the highest and lowest data point was more than 50% of the rate of responding in the VR condition. For example, if mean response rate in the VR condition was 10 rpm, 50% would be 5 rpm. Further, if the rate of responding in the last three spaced-responding DRL with S+/S- sessions was 7.3, 1.8, and 5.5 rpm, the participant was dropped from the study because the difference between the highest (7.3) and lowest (1.8) data point was 5.5 rpm. Of the 30 participants, we excluded six due to highly variable data, four because points did not appear to function as reinforcers in the reinforcer assessment, and one due to a computer malfunction. The final sample consisted of 19 participants.

Data were primarily analyzed using visual analysis, which included inspection of the mean rate of responding, trend, and stability in each condition. However, as noted previously, we excluded participants who displayed highly unstable data. Data were then categorized based on whether the rate of responding was eliminated, nearly eliminated, or maintained in the S- only and second S+/S- phases for each participant. Elimination of a response was defined as a participant engaging in zero responses in the last three sessions of the phase. Near elimination of a response was defined as either (a) a mean reduction of 90% or greater (but less than 100%) from the optimal or allowable rate of responding that was determined for that participant or (b) a mean reduction of 70% or greater from the optimal or allowable rate with a decreasing trend. The near-elimination category accounted for participants who displayed high levels of responding in the first session that subsequently decreased in rate. For simplicity in describing the results, we will consider both elimination and near elimination as “elimination.” Maintenance of responding was defined as response rates that were between 0 and 69.9% reduction of the optimal or allowable rate of responding. The optimal response rate was the rate of responding required for the participant to earn the maximum number of reinforcers in the spaced-responding DRL condition. The allowable response rate was the rate of responding that was permitted while still earning the maximum number of reinforcers in the full-session DRL. Both the optimal and allowable response rates were set at 50% of responding in the VR condition of the reinforcer assessment.

In addition to visual analysis, overall differences between conditions for all participants were analyzed using a repeated measures analysis of variance (RM ANOVA). The analysis included two within-group factors: DRL condition (spaced-responding or full-session) and signal condition (S+/S- phase 1, S+/S- phase 2, or S-only).

Results and Discussion

Figure 2 presents data for four participants, which represent the four patterns of responding. Table 2 (spaced-responding DRL) and Table 3 (full-session DRL) present the mean rate of target responding in the last three sessions per phase for all participants in all phases.

Collectively, results in Table 2 show that all participants responded near the optimal criterion in the spaced-responding DRL with S+/S-. Roughly half of the participants (47%) maintained responding when signals were removed in the S- only condition. P24 and P07 (top and bottom left of Figure 2, respectively) are representative of this pattern of responding. The remaining participants responded near zero (e.g., P03 and P14, Figure 2). Thus, responding was eliminated for slightly more than half of participants with the S- only.

Four patterns of responding were observed in the full-session DRL (see Table 3). Most (89%) participants responded near the allowable criterion in the full-session DRL during the first phase with S+/S- (e.g., P03, P07, and P14, Figure 2). With the S- only (i.e., the bag was closed the entire time), 79% responded near zero (e.g., P03, P14, P24, Figure 2). When the S+/S- was reintroduced, 68% of participants maintained responding near allowed levels (e.g., P03, P07, Figure 2). Thus, for most participants, responding was maintained near allowable levels with signals but was eliminated when the S- only was present. Eight participants displayed this modal pattern (Pattern 1) of responding including P03 (top right of Figure 2). Five participants responded at near zero levels in the S- only and second S+/S- phases, but not in the initial S+/S- phase (Pattern 2; e.g., P14, bottom right of Figure 2), suggesting a potential history effect of the S- only condition. That is, following experience with not responding in the S- only condition, some participants continued to not responding when S+/S- was reintroduced. Conversely, four participants demonstrated response maintenance in all signal phases (Pattern 3; e.g., P07, bottom left of Figure 2). It should be noted that maintenance of the target response was weak for P16 (see Pattern 3 in Table 3); however, the response did not meet our definition of near elimination. Finally, two participants stopped responding in the full-session DRL during all signal phases (Pattern 4; e.g., P24, top left of Figure 2). Mean response rate in the first signal phase for P24 was slightly higher than the S- only or second S+/S- phases. Nonetheless, visual inspection of the data indicates that the first data point in the initial S+/S- is driving the rate up. Despite four distinct response patterns, our summative conclusion is that signals can facilitate responding in a full-session DRL for the majority of individuals.

To support the overall patterns observed via visual analysis, we also conducted an RM ANOVA with two within-subject factors. The first factor, DRL type, had two levels (spaced-responding and full-session DRL). The second factor, signal type, had three levels (S+/S- phase 1, S- only phase, S+/S- phase 2). Mauchly's test revealed no violations of the sphericity assumption for signal type ($\chi^2(2) = 5.62$, p =.060) or the interaction of signals and DRL type ($\chi^2(2) = 0.33$, p =.847). First, there was a significant interaction of DRL condition and signal phase ($F(2, 36) = 3.26$, $p = .050$, partial $\eta^2 = .15$). Figure 3 depicts the aggregated mean response rate in each signal phase by DRL. To adjust for Type 1 error, we applied a Bonferroni correction such that *p*-values less than .008 are considered significant. In the full-session DRL, there was a significant difference between the S- Only phase and the first ($p < .001$) and second ($p = .001$) S+/S- phases, such that response rate was higher in the S+/S- phases than in the S-Only phase. There was also a significant difference between the two S+/S- phases such that response rate was higher in the first S+/S- phase than the second ($p = .002$). In the spaced-responding DRL, there was also a significant difference between the S- Only phase and the two S+/S- phases (*p*s < .001). However, there was no difference between first and second S+/S- phase in the spaced-responding-DRL condition ($p = .010$). This is consistent with the somewhat mixed results that we found for the DRL conditions based on visual analysis.

Results indicate that, overall, there was not a significant effect of DRL condition ($F(1, 18) = 2.46$, $p = .134$, partial $\eta^2 = .12$). That is, there was no statistical difference between response rates in the two DRL conditions. There was a significant effect of signal condition ($F(2, 36) = 43.28$, $p < .001$, partial $\eta^2 = .71$), but the interaction shows that the effect of signals depended on the DRL condition. Therefore, we do not interpret the main effect of signals.

Although there was not a significant difference between the DRL conditions, visual analysis indicates that responding in the spaced-responding condition was consistently lower than the full-session condition in the S+/S- phases. In the spaced-responding DRL, each response reset the DRL interval. Therefore, when the interval elapsed, even a short delay to respond could delay the start of next interval. This pattern, over the course of a 5-min session, could have a cumulative effect and drive down response rate. For instance, if the interval size were 10 s, perfectly optimal responding would result in a rate of 6 rpm. However, if a participant took 2 s on average to engage in or begin a response when the signal indicated that responding would be reinforced, response rate would decrease to 5 rpm. Because interval start-times in the spaced-responding DRL are response-dependent, response rate is driven down. Interval start times are not response-dependent in a full-session DRL (i.e., the interval start times were fixed and participants could respond anywhere within the interval), so a reduction in response rate was not a concern in the full-session DRL.

Prior research comparing DRL schedules indicated that responding might be eliminated in a full-session DRL (Jessel & Borrero, 2014). Indeed, for two participants in Experiment 1, we observed no or very low levels of responding in the full-session DRL in the first signal phase. Another four participants engaged in near zero levels of responding in the second signal phase. Jessel and Borrero (2014) did not use signals, and we do not know whether we would have obtained results like those of Jessel and Borrero if we had included an unsignaled DRL. However, most applications of DRL schedules use signals, and the current study suggests that signals support optimal responding relative to an extinction-correlated stimulus only. Thus, comparisons of the DRL schedules with signals may have more ecological validity.

To reiterate, as is common in behavioral research, there was some variability in response to the DRL conditions. However, on a molar level, visual and statistical analyses indicate three primary findings. First, there is little difference between DRL conditions, particularly when signals (S+/S-) are in place. Second, for most participants, responding maintained in both DRL conditions when signals were present. Third, responding tended to be eliminated in the presence of an S- only, particularly in the full-session DRL.

Experiment 2

In Experiment 1, we demonstrated that signals might facilitate responding in both types of DRL schedules with college students. Experiment 1 demonstrated proof of concept. In other words, findings from Experiment 1 suggested that the vehicle (computer game) was sufficient and appropriate to test the effects of signals in the contexts of the two DRL procedures. However, our objective with this research was to determine the applicability and utility of these procedures for the behavior of school-aged children. Frequently in applied contexts, DRL schedules are used with preschool and school-aged children, and in applied contexts, signals are often included. Therefore, in Experiment 2 we sought to take one translational step closer to application, by replicating Experiment 1 with preschoolers.

Method

Participants. Five children from a local preschool participated in Experiment 2. Participants were between 4 and 5 years old. We recruited participants by approaching parents at pick-up and drop-off times and asking parents if they would be interested in a research study. We described the study procedures to parents, and if they agreed, parents signed consent forms. An institutional review board approved recruitment and study procedures. Prior to each experimental session, the participant provided verbal assent to participate. If the participant requested to terminate sessions, we honored the request.

Teachers and parents reported no developmental or intellectual delays or disabilities and no behavioral problems. There were no exclusion criteria.

Setting, apparatus, measurement, and experimental design. Participants were seated at a desk with a computer and mouse in a quiet room in the preschool. The computer program was identical to the program used in Experiment 1.The dependent variables were the target response rates and number of reinforcers earned. Target response rate was measured as in Experiment 1. We converted the number of reinforcers earned to the proportion of possible reinforcers in each condition.

Like Experiment 1, we used a combination of single subject designs. We conducted the initial reinforcer assessment in a reversal design (one participant) or a multi-element design (four participants). For the DRL comparison, we used a combined multi-element and reversal design for the DRL comparison as in Experiment 1.

Procedure. Sessions were approximately 20 to 40 min. We made minor changes to the procedure due to the developmental age of the participants. First, the VR schedule in the reinforcer assessment was decreased from a VR 15±5 to a VR 3±2. In addition, the experimenter read the instructions to the participant and asked comprehension questions. The instructions and questions were as follows:

> It is time to a play a recycling game! Your goal is to earn points. The more points you earn, the more prizes you can get including the chance to become an Earth Protector for the day with a badge you can wear in your classroom. Here are some of the rules. Trash goes in the trash bin. Paper goes in the paper bin. Bottles go in the bottle bin. If the bin is full, the trash will not go in and you cannot earn points. Click the start button when you are ready and remember to let an adult know if you do not want to play anymore. Good luck!
> (1) What goes in the trash bin?
> (2) What goes in the bottle bin?
> (3) What goes in the paper bin?
> (4) What does it mean when the bag is on the bin?

The correct answers were (1) trash, (2) bottles, (3) paper, and (4) the trash will not go in and I cannot earn points. If participants answered incorrectly, we repeated the instruction relevant to the question. Further, we ran sessions out to stability rather than running a fixed number of sessions. Finally, for some participants, we conducted additional phases to demonstrate experimental control. Namely, for Eliza and Bryce, we repeated the reinforcer assessment and DRL comparison with S+/S- at the end of the experiment. All other aspects of the procedure were identical to Experiment 1. Following the study, we gave participants a small prize from a treasure box (e.g., pencils, stickers) and an “Earth Protector Badge” for participation.

Results and Discussion

Figure 4 depicts target response rates for all children. In the reinforcer assessment, all participants responded at a higher rate in the VR condition relative to the extinction condition, regardless of the design. These data affirmed that points functioned as reinforcers for all participants. In addition, all participants responded near optimal levels in both DRL conditions with S+/S-. Further, like Experiment 1, response rate was slightly higher in the full-session DRL than in the spaced-responding DRL for all participants. With the S- only, Miguel and Teagan (top and middle left panels) responded near zero. When signals were reintroduced, Miguel and Teagan again responded near optimal, indicating that signals facilitated responding. These data are consistent with the modal patterns observed in Experiment 1.

Eliza and Bryce (top and middle right panels) also responded near zero with the S- only. When signals were reintroduced, response rate for Eliza and Bryce increased. However, target response rate in the full-session DRL decreased slightly from and was more variable than the first S+/S- phase for both participants. Therefore, we replicated the reinforcer assessment and the DRL comparison with S+/S-. For both Eliza and Bryce, response rate was high in the reinforcement condition and zero in the extinction condition of the second reinforcer assessment. In the third DRL comparison with S+/S-, response rate stabilized for Bryce and was similar to responding in the first DRL comparison with signals. For Eliza, response rate continued to be somewhat variable; however, results replicated the second S+/S- phase. Importantly, response rate in the full-session DRL condition was not eliminated for either participant. Thus, Eliza and Bryce's data are consistent with Miguel and Teagan. Signals helped to facilitate and maintain responding whereas the S- only eliminated responding.

One participant (Harrison, bottom left panel) responded near optimal levels in the spaced-responding DRL but near zero in the full-session DRL with the S- only. When signals (S+/S-) were reintroduced, response rate in both conditions was near optimal or allowable. The same pattern was observed with one participant in Experiment 1 (P26; see Tables 2 and 3).

These results suggest that, like with college students, signals may facilitate responding during DRL schedules with young children. Fewer patterns of responding emerged with the preschool students. This may be due to the difference in sample size or developmental differences. Results of Experiment 2 predict a highly desirable side effect of using signals to indicate when responses will and will not be reinforced. Namely, the majority of children completely stopped responding in the presence of the S- only. From the perspective of a classroom teacher, these findings may be ideal because they can have a high degree of control over student responses by presenting appropriate signals.

Nonetheless, lack of signals, and particularly presenting only an S-, may actually eliminate responding in both types of DRL arrangements. That is, if there is no stimulus to signal when it is appropriate or acceptable to engage in a response, it is possible that a socially-desirable response (e.g., hand-raising) may be eliminated.

Experiment 3

Based on the results of Experiments 1 and 2, it appears that signals facilitate responding in the context of these two DRL arrangements. However, it is unclear how the lack of unique signals impacted responding. When unique signals (an S+ and S-) were not programmed, only an S- was present, which may explain why response rate was so low for the majority of participants. The purpose of Experiment 3 was to better understand the effect of the S+/S- by also evaluating the complete absence of S+/S- in a similar experimental preparation.

Method

Participants. Four different preschool students from the same preschool as Experiment 2 (Phoebe, Luca, Emily, and Evan) and one kindergartner (Oliver) from a different school participated in Experiment 3. Participants were between the ages of 4 and 5. The recruitment procedures were identical to Experiment 2 for the preschoolers. The kindergarten student was recruited by word of mouth at the university. The parent volunteered her child to participate, signed the consent form, and coordinated permission for experimenters to conduct sessions during the child’s after-school program. The institutional review board approved this alternative recruitment method. The kindergarten student also provided daily assent for sessions. Teachers and parents reported no developmental or intellectual delays or disabilities and no behavioral problems. There were no exclusion criteria.

Setting, apparatus, measurement, and experimental design. Participants were seated at a desk with a computer and mouse in a quiet room in the preschool or school. The computer program was nearly identical to the program used in Experiment 2, except that the signals were different colors on the inside of the receptacles. The dependent variables were identical to Experiment 2. The design was nearly identical to Experiment 2 except that a no S+/S- phase replaced the S- only phase. For several participants, due to variability in responding, we conducted portions of the DRL comparison in a reversal design. In addition, we replicated the reinforcer assessment with some participants.

Procedure. The procedure was identical to Experiment 2 with the exception of the signals. As in Experiment 2, we began with a reinforcer assessment in which a VR3 condition was compared to an extinction condition. The oval area of the receptacle (i.e., the inside) was green during the VR condition and red during the extinction condition Next, we conducted the DRL comparison. As in Experiment 2, we began with a comparison of the spaced-responding and whole-session DRL conditions with S+/S-. However, the S+ was a green color on the inside of the waste receptacle and the S- was a red color on the inside of the receptacle (See Appendix B for visuals). Rather than the S-only phase, we compared the DRL conditions without an S+ or S-. The inside of the receptacle was neither red nor green during the no S+/S- phase. Thus, the no S+/S- phase was similar to Jessel and Borrero (2014) in which there were no unique signals. Finally, we returned to the DRL comparison with S+/S-.

Results and Discussion

Figures 5 and 6 present data for all participants. Results of the reinforcer assessment (first phase of all figures) indicate that points functioned as reinforcers for all participants. As in Experiments 1 and 2, all participants responded near optimal or allowable in the S+/S- phases.

Four participants (Phoebe, Luca, Oliver, and Emily) exhibited highly variable responding without S+/S-. To rule out treatment interference from the multi-element design, we conducted repeated consecutive sessions of each DRL type separately in a reversal design. After repeated sessions in both DRL conditions, responding did not stabilize for Phoebe or Luca (Figure 5). That is, responding was variable and there appeared to be no difference between the DRL conditions. Therefore, we returned to the DRL comparison with S+/S-. Response rate was somewhat variable in the second signal phase for Phoebe, but stabilized, replicating responding we observed in the first signal phase. Luca also responded near optimal and allowable levels in the second signal phase. Due to the considerable variability observed in the DRL comparison, we replicated the reinforcer assessment for Phoebe and Luca. For both participants, points still appeared to function as reinforcers.

For Oliver (Figure 6, top), it originally appeared as though responding was slightly higher in the spaced-responding DRL condition than the full-session DRL condition without S+/S-. In both conditions, response rate was somewhat variable. In addition, he tended to earn more reinforcers in the full-session DRL condition, likely because response rate was so low and a reinforcer would be earned for two or fewer responses in each interval. Therefore, we attempted to replicate the spaced-responding

DRL and full-session DRL phases without S+/S-. Although there is considerable overlap between the data paths, the proportion of possible reinforcers earned in the full-session DRL condition continued to be higher (*M* = .81) than the spaced-responding DRL condition (*M* = .20). Nonetheless, because response rate was highly variable in both conditions with overlap across conditions, it is difficult to draw definitive conclusions. Therefore, like Phoebe and Luca, absence of signals evoked variable responding. We returned to the S+/S- phase and response rate became more stable in both DRL conditions.

When repeated sessions of the spaced-responding DRL without S+/S- were conducted with Emily (Figure 6, middle), she displayed variable responding similar to other participants. However, in the full-session DRL, responding was eliminated. In the first session of each day, response rate was high; subsequently, response rate decreased to zero. This effect was replicated. Notably, response rate in the spaced-responding DRL was less variable in the replication, but Emily earned a similarly low number of reinforcers. Within-session patterns indicate that responding occurred in bouts followed by long pauses rather than the steady-step pattern that was observed with signals (data available from the first author). With the return to S+/S-, response rate increased to near optimal and allowable levels. In the replication of the reinforcer assessment, points still appeared to function as reinforcers.

Evan (Figure 6, bottom) responded near zero in both DRL conditions without S+/S-. Thus, like participants in Experiment 2, responding did not maintain in either DRL condition. When signals were reintroduced, responding returned to optimal and allowable levels.

Four of five participants exhibited highly variable responding without S+/S-, at least initially. Inspection of within-session patterns without S+/S- suggested that participants were responding variably and inefficiently even when response rate was similar to that observed when we presented S+/S- were used. For example, Figure 7 depicts cumulative records for four sessions for Luca. Sessions 12 and 53 are full-session DRL sessions in which response rate was 2.2 rpm. Session 12 (top left) is with S+/S- and session 53 (bottom left) is without S+/S-. Sessions 13 and 38 are spaced-responding DRL sessions in which the response rate was 1.4 rpm. Session 13 (top right) is with S+/S- and session 38 (bottom right) is without S+/S-. With S+/S-, the temporal spacing of responses was fairly orderly and even. Without S+/S-, responding occurred in bouts followed by long pauses. Thus, even when response rate without S+/S- was comparable to response rate with S+/S-, participants were not responding efficiently.

Additional evidence of inefficient responding is presented in Figure 8. Figure 8 displays the mean proportion of reinforcers earned in both DRL conditions with S+/S- and either with S- only (Experiment 2, left side) or without S+/S- (Experiment 3, right side). All participants in Experiments 2 and 3 earned the majority of reinforcers in the full-session DRL regardless of whether there were unique signals (i.e., S+/S-) or not (i.e., S- only or no S+/S-). In addition, participants earned a lesser proportion of reinforcers in the spaced-responding condition than the full-session condition in both experiments. Because response rate was eliminated for most participants in the S- only phases of Experiment 2, the proportion of reinforcers earned in the spaced-responding condition was also near zero. In Experiment 3, four out of five participants earned some reinforcers in the spaced-responding DRL without S+/S-. In addition, the proportion of reinforcers earned in both DRL conditions without S+/S- was highly variable as evidenced by large standard deviations (error bars) in comparison to both the S+/S- phase for both Experiments 2 and 3 and the S- only phase of Experiment 2 (see left side of Figure 8).

In light of a plethora of research on the importance of discriminative stimuli in reinforcement schedules (e.g., Hanley et al., 2001; Hursh & Fantino, 1974; Stagner, Laude, & Zentall, 2012), it is no surprise that variability in response rate and temporal pattern of responding (e.g., Luca's cumulative records, Figure 7) was observed without S+/S-. The S+ and S- provided participants with guidelines. Thus, when no guidelines were present, participants had to guess. Anecdotally, it did not appear as though participants were "aware" that the contingency in the sessions without S+/S- was the same as the S+/S- phase. Oliver was the only participant to make an explicit connection between the S+/S- and no S+/S- conditions. When he threw a target item away and earned a point without the S+/S-, he said, "maybe it is actually green right now." In addition, he occasionally commented that he needed to wait longer if he did not earn a point after a response. Other participants only expressed uncertainty about the contingencies (e.g., "I don't know what to do.").

Although there were some differences across participants, there were several commonalities. First, all participants responded near optimal and allowable levels when signals were present. Similarly, when signals were reinstated, all participants eventually responded near optimal and allowable levels again in both conditions. In addition, like in Experiments 1 and 2, response rate was slightly lower in the spaced-responding DRL condition relative to that observed in the full-session DRL condition. Furthermore, for most participants, response rate was highly variable and the proportion of reinforcers earned was generally lower without S+/S-, suggesting that signals are important in maintaining responding and maximizing reinforcement. Results of Experiment 3 are consistent with the first two experiments. That is, target response rate in the DRL schedules was maintained when signals were used but were either eliminated or highly variable without signals. The absence of signals had a highly disruptive effect on what was otherwise very orderly responding in the two DRL arrangements.

General Discussion

Results of all three experiments underscore the importance of signals in decreasing but not eliminating responses in DRL schedules. Both S- only and the absence of S+/S- may lead to undesirable patterns of behavior—elimination and variability, respectively. Moreover, we saw few little differences between the two DRL types. That is, response rates were similar in the two conditions for the majority of participants, and the signals appeared to exert more control over responding than the type of DRL schedule. We observed the largest difference between the DRL types in Experiment 1 with college students. For about half of college students, responding in the full-session DRL was eliminated in one or both S+/S- phases; responding in the spaced-responding condition, however, was near optimal in both S+/S- phases for all participants.

Overall, these experiments have prescriptive implications for the use of DRL schedules in applied settings. Behavior in the spaced-responding DRL was fairly consistent and near optimal across studies when both an S+ and an S- were present. Response patterns in the full-session DRL were more variable, particularly in Experiment 1, with some participants responding near zero even with S+/S-. Although we recognize that the generality of our suppositions will need to be tested explicitly in an applied setting, we cautiously offer the following recommendations for application. First, when the clinical or practical objective is to maintain responding, a spaced-responding DRL with S+/S- may be most appropriate because it produces stable and near optimal levels of responding. Still, S+/S- did maintain responding in the full-session DRL for most participants. Thus, second, when the clinical or practical objective is to maintain responding, a full-session DRL with signals may also be acceptable. Third, it is clear from the current study that the use of S+/S- is important in either type of DRL schedule. Further research comparing the DRL conditions with signals in an applied context such as a classroom is warranted.

Before lauding or vilifying the outcomes of the signal arrangements or DRL type, one should consider the goal or purpose of applying the DRL intervention. The goal of the DRL intervention will have implications for how the DRL contingencies and signals are arranged. If the goal of the intervention is to maintain some level of responding (i.e., not completely eliminate a response), practitioners may consider using a spaced-responding DRL or modifying the full-session DRL because of the potential for elimination of responding in a full-session DRL. Recall that in a spaced-responding DRL, the interventionist must constantly keep track of when in time responses occur and only provide a reinforcer if IRTs are greater than a specified value. Thus, modifications to a full-session DRL may be preferable due to the challenges of implementing the spaced-responding DRL in application. Rather than earning a reinforcer if a certain number of responses or less occurs in each interval, reinforcers may be earned if (a) an exact number of responses occur or (b) between a lower and upper limit number of responses occur. Both solutions (a) and (b) can be arranged to decrease the rate of a response while still requiring a response to produce a reinforcer. Future research may study alternative methods to design full-session DRL schedules.

Alternatively, in some instances, the elimination of responding may not be a concern. In which case, the current study suggests that a full-session DRL is effective at reducing the target response by at least 50%, although reductions may also exceed a 50% reduction from baseline. For example, a teacher may want to reduce unsolicited call outs in class. The teacher may prefer that call outs never happen, but may be able to tolerate some call outs. In such a scenario, either a reduction or an elimination of call outs is acceptable. Thus, the current study supports the use of either of spaced-responding or a full-session DRL for this purpose.

Finally, some practitioners may use a full-session DRL to eliminate a problematic behavior. In fact, a full-session DRL may be an attractive alternative to DRO for reducing problem behavior because the individual may be more likely to contact reinforcement. If, over time in a full-session DRL, more reinforcers are earned for the absence of problem behavior than reinforcers earned for occasionally engaging in the target response, we may expect an elimination of problem behavior. For instance, Shaw and Simms (2009) used a full-session DRL to reduce screaming, profanity, and disruptive behaviors displayed by three boys. Over the course of the intervention, the criterion or tolerance of the DRL schedule decreased until the boys displayed near zero levels of problem behavior. If elimination is a goal as in Shaw and Simms, results of the current study suggest that presentation of an S- only stimulus throughout the full-session DRL may be suitable.

One consistent finding that we identified via visual analysis in all three experiments was that response rate in the full-session DRL was slightly higher than response rate in the spaced-responding DRL when signals were present. The difference in response rates between the conditions is likely trivial, as was evidenced by non-statistically significant results in Experiment 1. However, a lower response rate in the spaced-responding DRL may also result in fewer reinforcers that can be earned. Thus, it is important to consider whether a lower response rate and proportion of reinforcers earned is contraindicated. Such features may make the intervention less effective or less preferred. Additional research may investigate preference for the DRL procedures when the total number of reinforcers possible is equated.

We observed variability in responding across participants, particularly in Experiment 1. Experiments 1 and 2 were nearly identical, yet most of the preschoolers in Experiment 2 responded similarly whereas we saw four distinct patterns in Experiment 1. One possibility is that preschool students are more likely to follow rules than college students. Rule following is heavily emphasized for young children by parents and teachers (Demirkasimoglu, Aydin, Erdogan, & Akin, 2012). Indirect evidence supports the notion that participants may have been following the rule rather than responding based on the contingency in place. All but one participant in Experiment 2 never responded in the extinction condition of the reinforcer assessment. Therefore, the majority of participants never contacted the contingency that throwing items away when the S- was present did not produce points. Harrison was the only participant to make any responses in the S- only condition. He was also the only participant for whom responding maintained in the DRL conditions with the S- only. The college students, conversely, were more likely to track the contingencies. Most participants in Experiment 1 engaged in at least some responding in the extinction condition of the reinforcer assessment, suggesting they were testing the contingencies. This may be why the behavior of college students was more sensitive to contingencies in the DRL comparison with the S- only.

Rule governance may also explain why response rate was maintained in the full-session DRL. We did not tell participants anything about the contingencies that were in place during each condition. That is, we did not tell participants how fast to respond, how many responses to make, or similar information about the reinforcement schedules. Rather, we instructed participants to throw items away when one stimulus was present (open bag or green color; S+) and to not throw items away when another stimulus was present (closed bag or red color; S-). If we had provided more specific information about the schedules, responding may have been different even with signals. For example, it is possible that responding may have been lower in the full-session DRL with S+/S- if we told the participants that they could engage in two or fewer responses while the can was open (or green). In application, individuals may be told that a reinforcer can be earned without engaging in a response. For example, Austin and Bevan (2011) provided students with an index card with boxes. The boxes represented the number of times each student could request attention plus one. That is, if the student could request attention two times, there were three boxes. Prior to implementing the DRL, the researchers explained the rules to the students. Thus, unlike the current study, the students in the study by Austin and Bevan were given explicit rules about and a visual indication of how many responses would be allowed. This may explain why requests for help were zero in the majority of DRL sessions in the study by Austin and Bevan. Future research could examine whether an indication of how many responses are tolerated affect responding in a full-session DRL, which could inform the types of rules and signals that are provided in application.

Additionally, the DRL comparison with S+/S- was always presented before the S- only or no S+/S- phases. Pilot data from 10 college student participants indicated that response patterns were similar even when the S- only was presented first. That is, most participants engaged in near zero responses with the S- only and near optimal with signals in both DRL conditions, with similar variability in response patterns as in Experiment 1 across participants. Nonetheless, to fully compare the effect of the order of conditions, it would be necessary to have more participants. Further, each exposure to the signal phases was relatively brief. We suggested that responding in the full-session DRL was likely not eliminated because participants were following the rules. If participants had longer exposures to the DRL conditions with signals, they may have learned that no responses were required in the full-session DRL, and responding would be eliminated. Thus, further investigation of the order of conditions and the duration of exposure is an area for future research.

In summary, DRL schedules may be a useful tool for decreasing responses that occur in excess. The current study was a human-operant comparison of DRL schedule variations with and without unique signals. Translational investigations have the advantage of being able to isolate features of an intervention or procedure. To that end, we were able to demonstrate that unique signals that indicate when responses would and would not be reinforced were most likely to produce stable and near optimal reductions in response rate in both types of DRL schedules. Future research should continue to evaluate and compare DRL schedules in applied contexts to determine the best way to arrange these schedules.

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Table 1

Summary of Stimuli Used

Condition	Target stimuli	Receptacle color	Background scene
VR		Black	Park
Extinction		Black	Desert
DRL-*s* – S+/S-		Red	Playground
DRL-*f* – S+/S-		Blue	Classroom
DRL-*s* – S- Only		Red	Playground
DRL-*f* – S- Only		Blue	Classroom

Note. VR = variable-ratio condition of reinforcer assessment; Extinction = extinction condition of reinforcer assessment; DRL-*s* = spaced-responding differential reinforcement of low rates (DRL); DRL-*f* = full-session DRL; S+/S- = unique within-schedule signals; S- Only = only a stimulus correlated with extinction present throughout the entire session.

Table 2

Experiment 1 Target Response Phase Means in Spaced-Responding DRL

Participant	*Optimal*	*S+/S- 1*	*S- Only*	*S+/S- 2*	*% Reduction in S-*
Pattern 1: Eliminated/Near Eliminated in S- Only (*N* = 10)					
P03	13.56	8.47	0.00	8.47	100.00
		(3.25)	(0.00)	(1.81)	
P02	14.23	12.27	0.00	12.13	100.00
		(0.12)	(0.00)	(0.23)	
P01	17.20	15.17	0.00	9.67	100.00
		(0.32)	(0.00)	(3.69)	
P19	17.40	13.27	0.00	14.13	100.00
		(0.12)	(0.00)	(0.12)	
P28	18.27	14.87	0.00	13.67	100.00
		(1.29)	(0.00)	(1.10)	
P10	18.47	15.20	0.00	15.67	100.00
		(0.20)	(0.00)	(0.12)	
P12	20.37	17.53	0.00	17.67	100.00
		(0.12)	(0.00)	(0.31)	
P14	23.00	17.60	0.07	18.67	99.70
		(1.06)	(0.12)	(0.76)	
P23	21.53*	18.40	0.07	13.93	99.67
		(0.20)	(0.12)	(0.12)	

P20	19.10	15.60	0.47	10.86	97.54
		(0.72)	(0.81)	(2.12)	

Participant	*Optimal*	*S+/S- 1*	*S- Only*	*S+/S- 2*	*% Reduction in S-*
Pattern 2: Maintained All Phases (N = 9)					
P08	15.87	13.26	8.67	11.80	45.37
		(0.64)	(1.81)	(2.12)	
P16	14.47	12.85	8.07	12.07	44.23
		(0.32)	(4.75)	(0.42)	
P09	10.80	7.80	7.00	8.33	35.19
		(0.20)	(1.22)	(0.70)	
P06	26.27	19.60	18.07	17.07	31.21
		(0.60)	(1.86)	(0.70)	
P11	30.37	26.07	21.60	22.80	28.88
		(0.12)	(7.63)	(5.56)	
P25	15.60	10.53	11.67	13.20	25.19
		(2.02)	(1.14)	(0.20)	
P26	20.83	20.93	16.20	17.33	22.23
		(6.47)	(1.78)	(0.50)	
P24	28.67	24.27	24.20	24.20	15.59
		(0.12)	(1.06)	(0.20)	
P07	8.40	7.73	7.47	7.27	11.07
		(1.47)	(2.04)	(0.31)	

Note. Optimal = response rate required to produce the maximum number of reinforcers; S+/S- 1 = mean responses per min (rpm) of first signal phase; S- Only = rpm in S- only phase; S+/S- 2 = rpm in second signal phase. Percentage reduction is calculated as the proportional decrease observed in the S- only phase relative to the optimal response rate. Data are sorted based on the percentage reduction from highest to lowest within each pattern type. Mean values for each condition were calculated based on the last three sessions of each phase. Standard deviations are reported in parentheses.
*Optimal rate was incorrectly set at 15.60 in the second signal phase.

Table 3

Experiment 1 Target Response Phase Means in Full-session DRL

Participant	*Allowed*	*S+/S- 1*	*S- Only*	*S+/S- 2*	*% Reduction in S-*
Pattern 1: Eliminated/Near Eliminated S- Only (*N* = 8)					
3	13.56	11.93	0.00	11.40	100.00
		(1.42)	(0.00)	(1.64)	
1	17.20	17.13	0.00	11.07	100.00
		(0.12)	(0.00)	(4.29)	
19	17.40	16.60	0.00	17.20	100.00
		(1.04)	(0.00)	(0.00)	
28	18.27	18.20	0.00	17.80	100.00
		(0.53)	(0.00)	(0.53)	
20	19.10	19.06	0.00	16.27	100.00
		(0.12)	(0.00)	(3.04)	
2	14.23	13.93	0.07	13.80	99.51
		(0.64)	(0.12)	(0.20)	
23	21.53*	21.27	0.20	15.40	99.07
		(0.12)	(0.35)	(0.20)	
26	20.80	21.53	1.87	20.60	91.01
		(2.39)	(0.95)	(0.00)	
Pattern 2: Eliminated/Near Eliminated S- Only and S+/S- 2 (*N* = 5)					

14	23.00	11.67	0.00	0.00	100.00
		(0.31)	(0.00)	(0.00)	
10	18.47	18.27	0.00	2.20	100.00
		(0.12)	(0.00)	(2.69)	

Participant	*Optimal*	*S+/S- 1*	*S- Only*	*S+/S- 2*	*% Reduction in S-*
25	15.60	14.33	0.60	1.40	96.15
		(2.02)	(1.04)	(1.31)	
6	26.27	25.53	3.67	0.13	86.03
		(0.83)	(6.18)	(0.23)	
8	15.87	15.87	2.73	1.67	82.80
		(0.31)	(3.74)	(1.42)	
Pattern 3: Maintained All Phases (*N* = 4)					
16	14.47	14.33	4.84	6.73	66.55
		(0.12)	(4.09)	(0.31)	
9	10.80	10.87	6.67	9.73	38.24
		(0.12)	(5.15)	(1.68)	
7	8.40	9.53	5.67	8.27	32.50
		(1.47)	(0.61)	(0.23)	
11	30.37	29.73	29.80	29.73	1.88
		(0.12)	(0.20)	(0.31)	
Pattern 4: Eliminated/Near Eliminated All Phases (*N* = 2)					
12	20.37	1.07	0.13	0.67	99.36

		(0.46)	(0.23)	(0.83)	
24	28.67	8.47	1.27	2.53	95.57
		(11.38)	(0.31)	(2.72)	

Note. Allowed = response rate permitted while still earning the maximum number of reinforcers; S+/S- 1 = mean responses per min (rpm) of first signal phase; S- Only = rpm in S- only phase; S+/S- 2 = rpm in second signal phase. Percentage reduction is calculated as the proportional decrease observed in the S- only phase relative to the optimal response rate. Data are sorted based on the percentage reduction from highest to lowest within each pattern type. Mean values for each condition were calculated based on the last three sessions of each phase. Standard deviations are reported in parentheses. *Allowable rate was incorrectly set at 15.60 in the second signal phase.

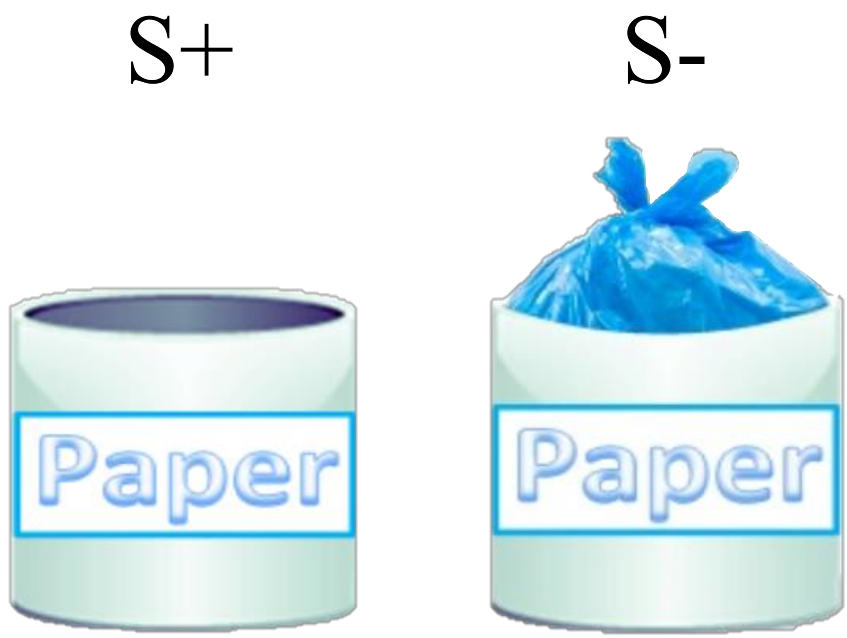

Figure 1. Example of S+ and S- used in Experiments 1 and 2. A receptacle without a bag, or an “open” receptacle, was the signal used to indicate that responses would be reinforced or could occur (S+). A receptacle with a bag, or a “closed” receptacle, was the signal used to indicate that responses would not be reinforced or could not occur (S-).

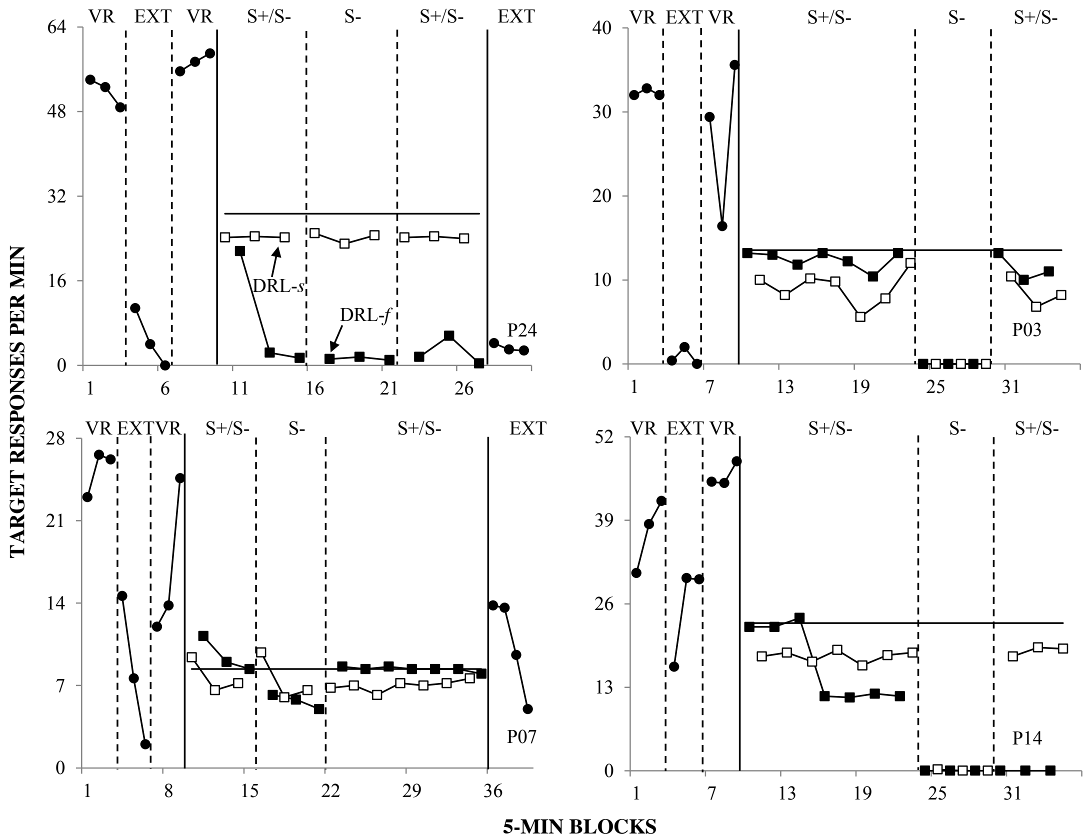

Figure 2. Representative data from Experiment 1. The first three phases are the reinforcer assessment comparing reinforcement (VR) to extinction (EXT). The next three phases are the comparison of the differential-reinforcement-of-low-rate (DRL) conditions (full-session is filled squares and spaced-responding in open squares) with S+/S- and with S-only. P24 and P07 also experienced an additional extinction phase. The dashed horizontal line is 50% of responding in the reinforcer assessment or the optimal/allowable response rate. Panels are individually scaled.

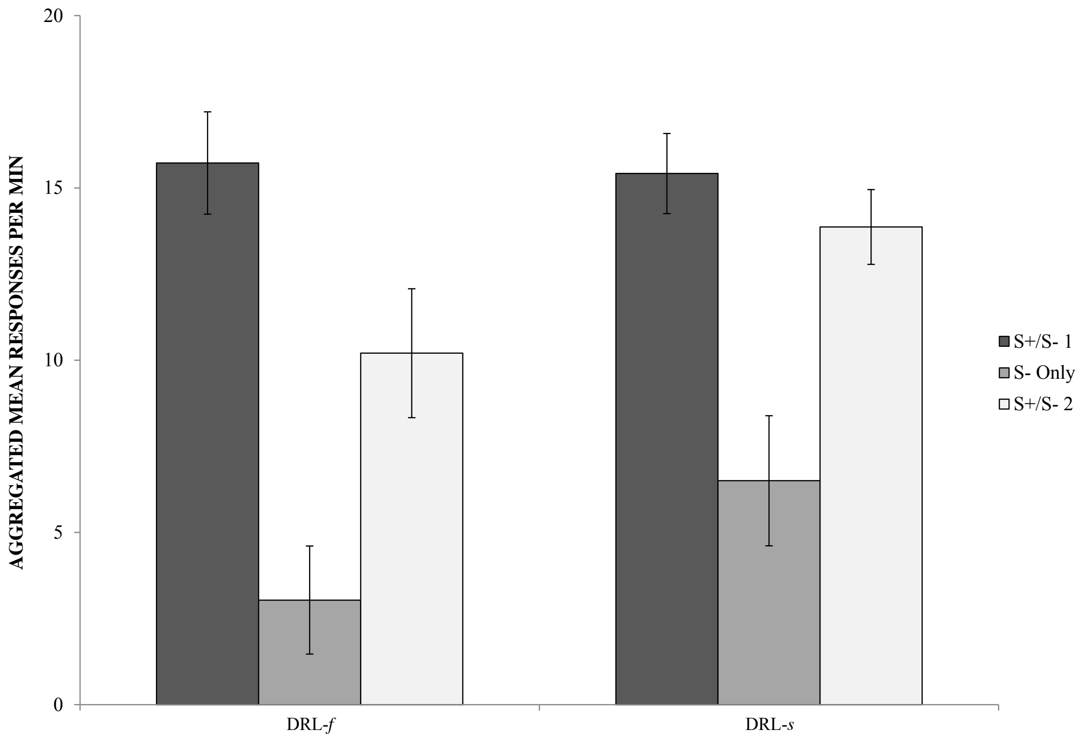

Figure 3. Aggregated mean response rate for all participants in Experiment 1. Error bars indicate standard error. Dark gray bars depict response rate in the first S+/S- phase, light gray bars depict response rate in the S- only phase, and white bars depict response rate in the second S+/S- phase.

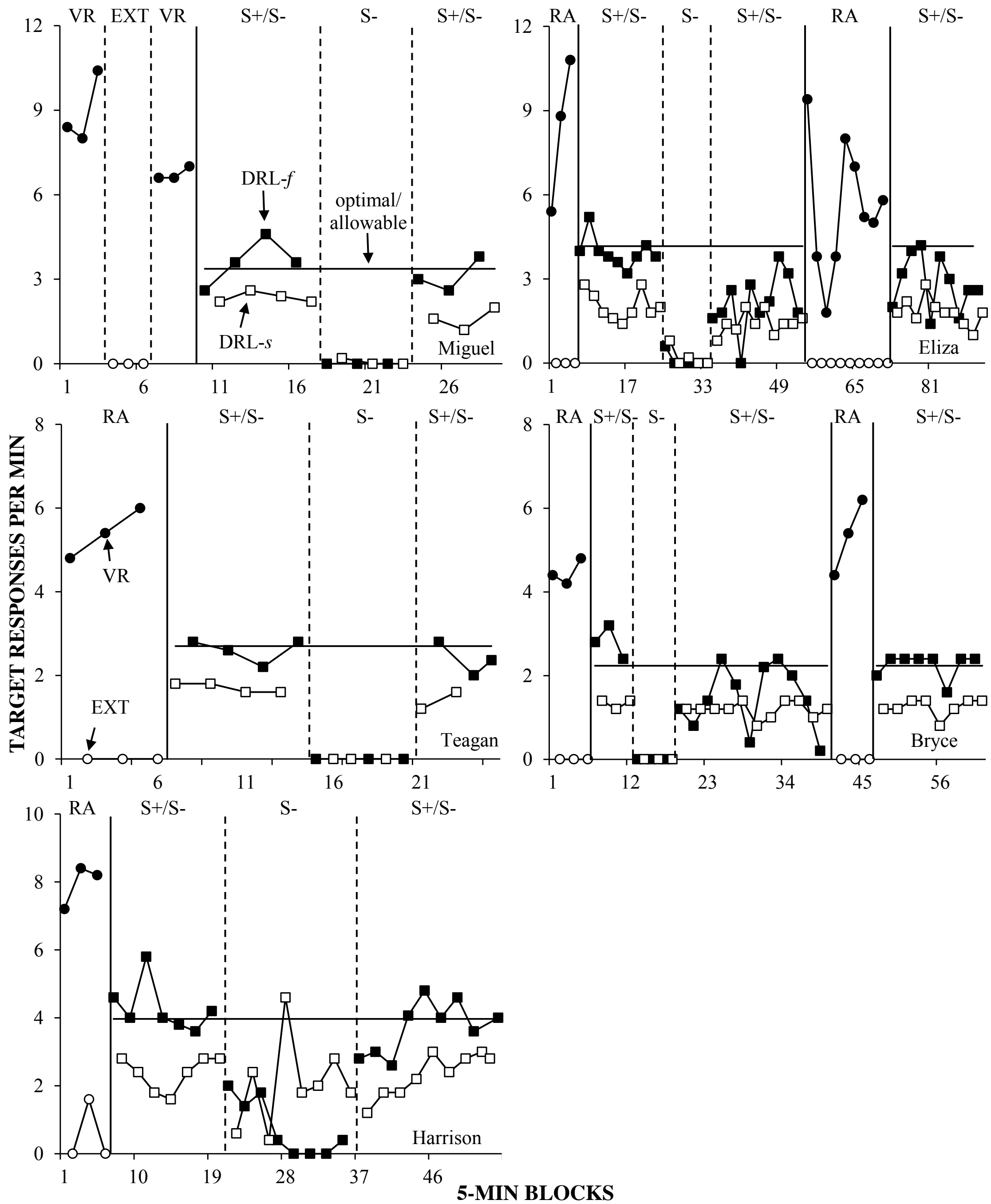

Figure 4. Target responses per min for all participants in Experiment 2. Reinforcement (VR) sessions are closed circles, extinction (EXT) are open circles, full-session differential reinforcement of low rates (DRL) are closed squares, and spaced-responding DRL are open squares. Sessions prior to the solid vertical line are the reinforcer

assessment and sessions after the solid vertical line are the DRL comparison. The black horizontal line is the optimal or allowable response rate. Panels are individually scaled.

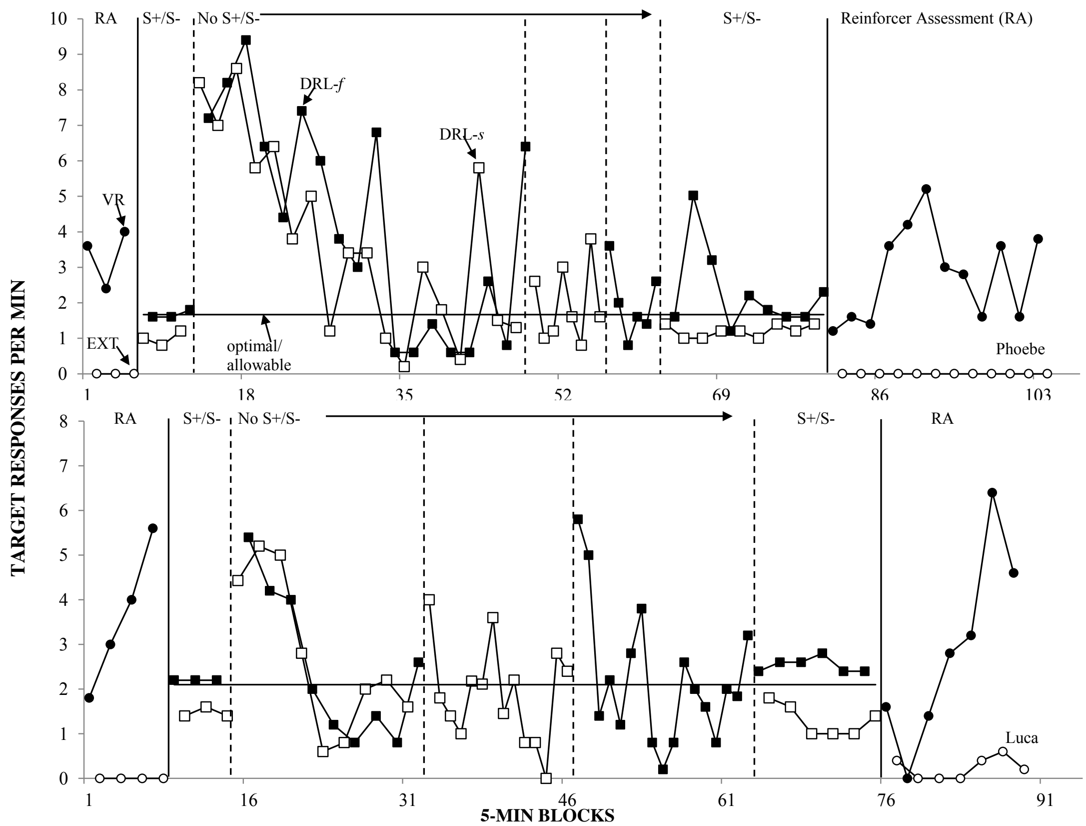

Figure 5. Target responses per min for Phoebe (top) and Luca (bottom) in Experiment 3. Reinforcement (VR) sessions are closed circles, extinction (EXT) are open circles, full-session differential reinforcement of low rates (DRL) are closed squares, and spaced-responding DRL are open squares. Sessions prior to the solid vertical line are the reinforcer assessment and sessions after the solid vertical line are the DRL comparison. The black horizontal line is the optimal or allowable response rate. Panels are individually scaled.

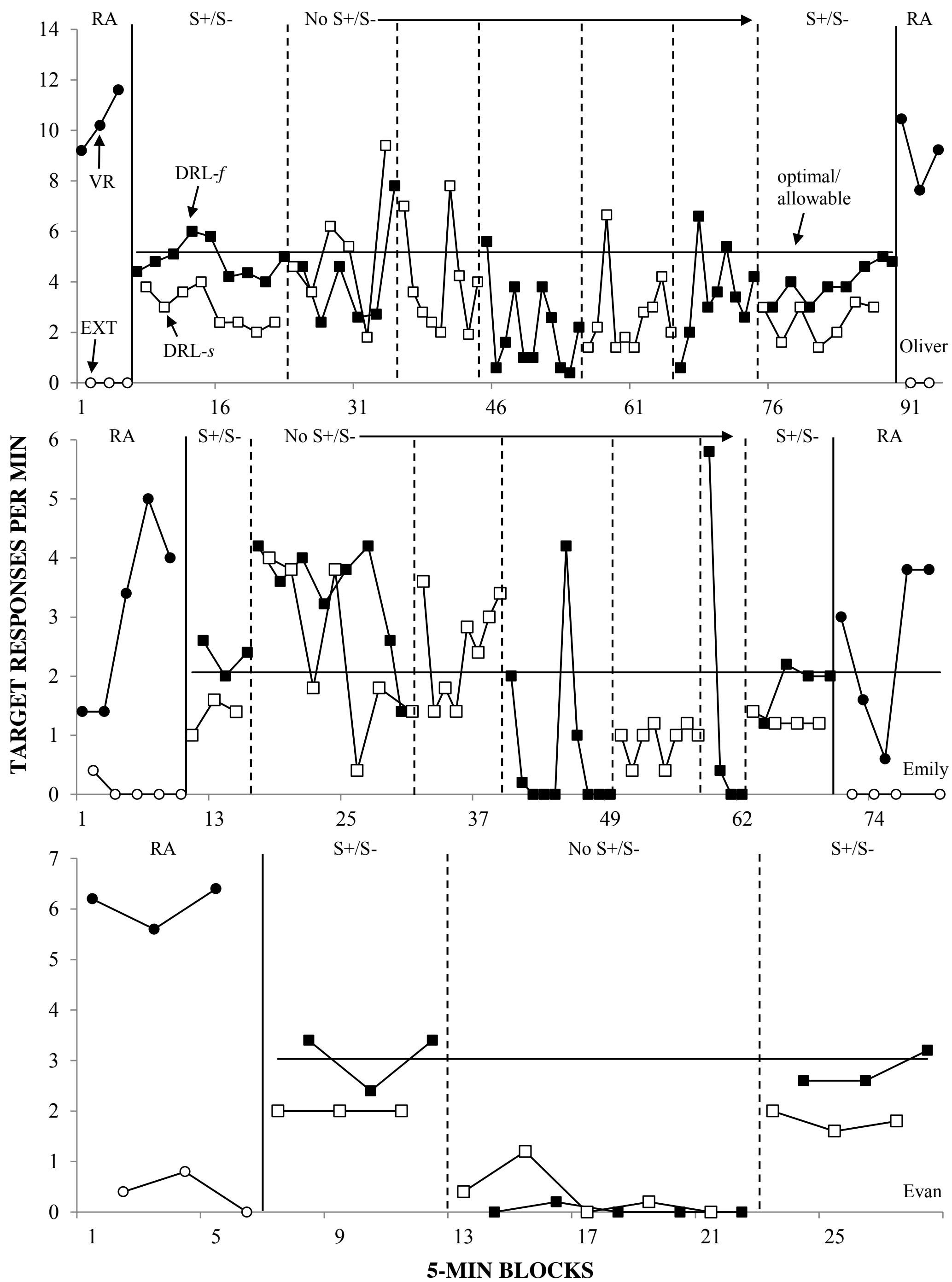

Figure 6. Target responses per min for Oliver (top), Emily (middle), and Evan (bottom) in Experiment 3. Reinforcement (VR) sessions are closed circles, extinction (EXT) are

open circles, full-session differential reinforcement of low rates (DRL) are closed squares, and spaced-responding DRL are open squares. Sessions prior to the solid vertical line are the reinforcer assessment and sessions after the solid vertical line are the DRL comparison. The black horizontal line is the optimal or allowable response rate. Panels are individually scaled.

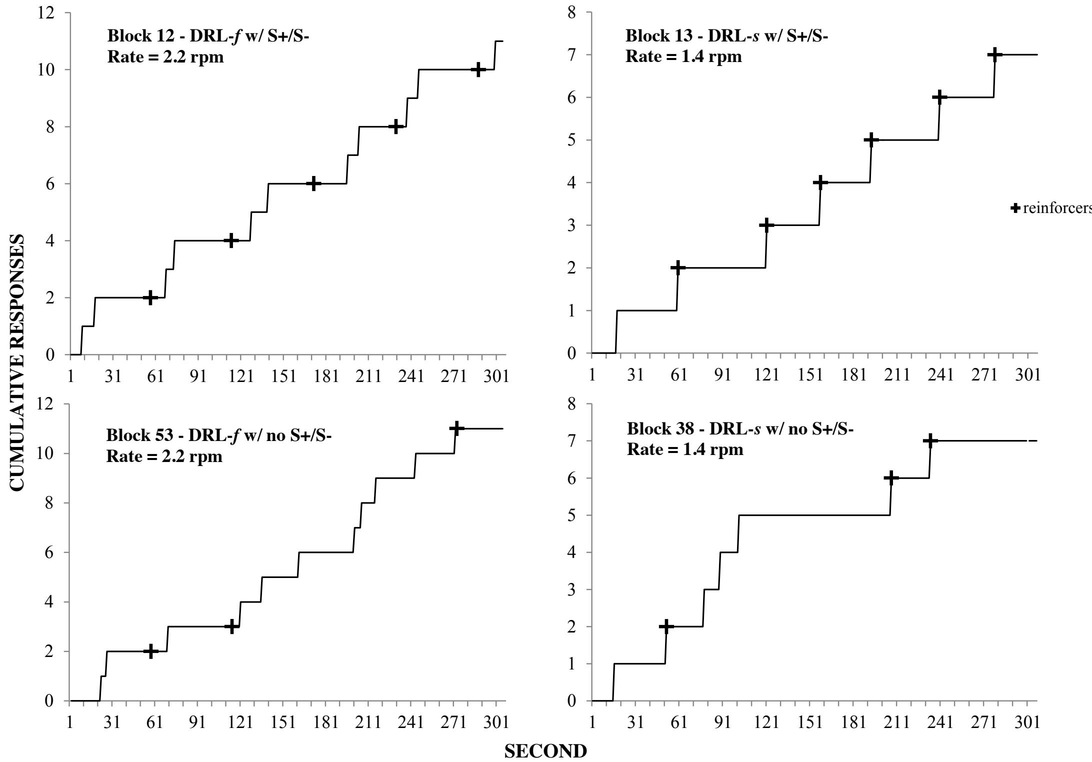

Figure 7. Cumulative records for select blocks with S+/S- (top panels) and with no S+/S- (bottom panels) for Luca. The full-session differential-reinforcement-of-low-rates (DRL) blcoks are depicted on the left side and spaced-responding DRL blocks on the right side. The plus sign indicates when a reinforcer was earned.

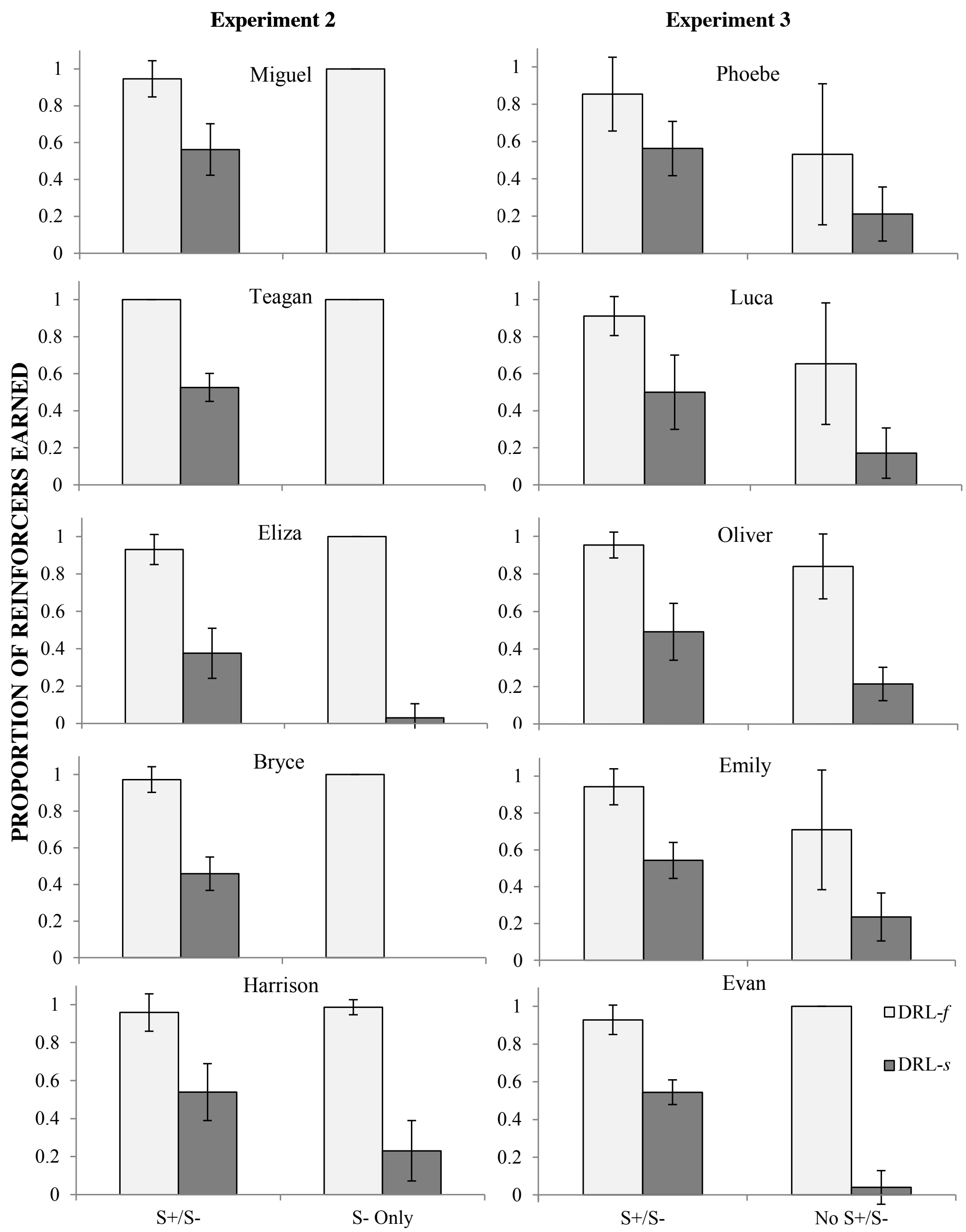

Figure 8. Mean proportion of reinforcers earned in Experiments 2 (left panels) and 3 (right panels). Light bars depict the full-session differential-reinforcement-of-low-rates (DRL) condition and dark bars depict the spaced-responding DRL. Reinforcers earned in

the S+/S- phases are averaged across all S+/S- phases and are displayed on the left side of each panel. Reinforcers earned in the S- only and no S+/S- are on the right of each panel.

Decreasing Excessive Bids for Attention in an Early Education Classroom (Study 2)

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Authors' Note

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Abstract

Differential-reinforcement-of-low-rate (DRL) schedules can be used to decrease, but not eliminate, excessive bids for teacher attention in a classroom. There are two primary methods of implementing a DRL: full-session and spaced-responding. Some research suggests that the full-session DRL may eliminate target responding. The purpose of the current study was to compare the effectiveness of and preference for the two DRL methods in a simulated preschool classroom. Three participants completed difficult puzzles in baseline, both DRL, and differential reinforcement of other behavior (DRO) conditions. In the spaced-responding and full-session DRL conditions, the optimal rate of bids for attention was approximately 75% (2 participants) or 50% (1 participant) of baseline responding. All participants bid for attention near the optimal criterion in both DRL conditions and at a lower rate (near zero) in the DRO condition. Treatment preference of the students was assessed in a concurrent-chain arrangement. All participants preferred both types of DRL conditions to DRO, and 2 participants showed a preference for the full-session DRL. A teacher social validity survey indicated slightly higher acceptability for the full-session DRL. Results suggest that either DRL procedure may be suitable for a preschool classroom, but a full-session DRL may be ideal.

Decreasing Excessive Bids for Attention in an Early Education Classroom (Study 2)

In early education classrooms teachers must often deal with the competing needs of multiple students. In the United States, teacher to child ratios for typical preschool classrooms (age 4) range from 1:8 to 1:20 (Administration for Children and Families, 2013). In kindergarten, the number of students to a single teacher can be as high as 25. With a lean teacher to student ratio, it may be difficult to provide individualized attention to many students. However, there are times when students do need teacher attention or help. For instance, a child may not understand or hear the group instructions. Children are taught from a very early age to request teacher assistance by raising their hands. Although hand raising is an appropriate and adaptive classroom behavior, there are several reasons for which excessive bids for attention may become troublesome (Vargo, Heal, Epperly, &Kooistra, 2014). First, the teacher may be concerned that the student is relying on individualized support rather than listening to group instructions or attempting to solve a problem on his or her own. Second, students who frequently request teacher attention and help may take teacher attention away from other students in need of assistance. Third, if excessive hand raising occurs during group instruction such as circle time, the teacher has to frequently stop the lesson to attend to the student, which can be disruptive to other students.

One way to address frequent bids for attention in a classroom may be to teach students when they can or cannot raise their hand using multiple schedules. A multiple schedule involves two or more component schedules, each of which is presented with a unique stimulus. For example, in a multiple schedule, one stimulus could be associated with reinforcement of hand raises whereas another stimulus could be associated with extinction. Tiger and Hanley (2004) presented different colored floral leis that were associated with either reinforcement or extinction of requests for attention for three typically-developing preschoolers. For one child, a blue lei signaled that requests would be reinforced on a fixed ratio (FR) 1 schedule. A red lei signaled reinforcement for the second child, and a white lei signaled reinforcement for the third child. Thus, for each child, one color signaled reinforcement and the other two colors signaled extinction (e.g., for the first child, blue signaled reinforcement, and red and white signaled extinction). The multiple schedule with stated rules about the contingencies resulted in near zero requests in the presence of the two extinction-correlated stimuli and higher requests in the presence of the reinforcement stimulus. Multiple schedules have also been applied to entire classrooms in which reinforcement is available for all students when one stimulus is present and not when a different stimulus is present (e.g., Cammilleri, Tiger, & Hanley, 2008; Vargo et al., 2014). However, an inherent limitation of multiple schedules that signal teacher availability is that requests for attention may occur at a very high rate when reinforcement is available (Hanley, Iwata, & Thompson, 2001). Although this may suggest good stimulus control, a very high rate of requests for attention may not be manageable for a teacher. When multiple schedules are applied to an entire classroom as in Cammilleri et al. (2008), it is possible that multiple students may need help at the same time, and it may not be possible to reinforce every request for attention.

An alternative strategy to reduce the rate of appropriate behavior is differential reinforcement of low-rate behavior (DRL). In a DRL schedule, a reinforcer is provided if the rate of responding is reduced. Three variations of a DRL exist: spaced-responding, full-session, and interval DRL (Deitz, 1977). In a spaced-responding DRL, a reinforcer is provided if the inter-response time, or the amount of time that elapses between responses, is greater than or equal to a specific value. For instance, if the desired minimum inter-response time is 5 min, a teacher may call on a student who has raised her hand if at least 5 min has elapsed since the last time he or she raised his or her hand. In a full-session DRL, a reinforcer is provided if a specified number of responses or less occurs during the session or observation. For example, the teacher may specify that a reinforcer will be provided (e.g., a token) if a child raises his or her hand four times or fewer during a 20-min session. An interval DRL is similar to the full-session DRL except that the session is divided into smaller intervals, and the reinforcer can be earned in each interval if fewer than a specified number of responses occur. For example, the student may earn a reinforcer if he or she engages in one or fewer hand raises every five minutes in a 20-min session. Because of the procedural similarities between a full-session DRL and an interval DRL, we consider the full-session DRL to be an interval DRL in which the interval size is the entire session duration. For simplicity, we will use the term full-session DRL to refer to both full-session and interval DRL procedures.

Full-session DRLs have been studied in classroom settings for several decades. Deitz and Repp (1973) applied a full-session DRL to reduce talking out displayed by a boy with intellectual disability. In baseline, the child engaged in a talk-out approximately 6 times per 50-min session. In the DRL treatment, talk-outs reduced to a mean of less than 1 talk-out per session. More recently, Austin and Bevan (2011) reduced requests for attention displayed by three girls in an elementary school classroom. Prior to the intervention, the researchers examined baseline rates of requests for attention and consulted with the teachers to identify the target number of responses that would be tolerated in the DRL. During the DRL intervention, each student had an index card on her desk with boxes that corresponded to the number of times she could request attention plus one. For instance, if a student could request attention two times during the 20-min instructional period, there were three boxes on her card. Each time the student requested teacher attention the teacher initialed a box and provided attention if there was at least one box remaining. At the end of the instructional period, the student earned a point toward the class-wide token economy if she had at least one box that was not initialed (i.e., she requested attention fewer than the allotted number of times). Requests for attention reduced below the tolerated rate determined for each participant.

Despite several studies examining the effect of full-session DRLs in classroom settings, we are not aware of any research on the spaced-responding DRL in a classroom context. Spaced-responding DRLs have been studied extensively in basic nonhuman animal research (e.g., Doughty & Richards, 2002; Farmer & Schoenfeld, 1964; Kapostins, 1963; LeFrancois & Metzger, 1993; Zimmerman & Schuster, 1962). In addition, a few studies have applied a spaced-responding DRL to reduce rapid eating (e.g., Anglesea, Hoch, & Taylor, 2008; Lennox, Miltenberger, & Donnelly, 1987; Wright & Vollmer, 2002) and stereotypy (e.g., Singh, Dawson, & Manning, 1983). There is a practical reason why a spaced-responding DRL may not be used in a classroom. A spaced-responding DRL requires that the teacher keep track of the time between every response. Thus, the teacher must continuously monitor the time at which each response of each student occurred and whether or not it met the criterion for reinforcement. A full-session DRL as used in Austin and Bevan (2005) may be easier for teachers to implement because they can simply check off that a response occurred.

Notwithstanding the practical advantages of the full-session DRL, there is some evidence that responses could be eliminated in a full-session DRL. Procedurally, a reinforcer may be provided even if the individual engages in zero responses. Thus, a full-session DRL may function similarly to a differential reinforcement of other behavior (DRO) contingency. All three students in the study by Austin and Bevan (2011) engaged in zero requests for attention in more than half of DRL sessions. Austin and Bevan noted that the elimination of requests for help did not appear to affect the quantity or quality of the students' work, but did not collect formal data on on-task behavior. Thus, it remains possible that other appropriate responses were also eliminated. Further, in one application of the full-session DRL, Alderman and Knight (1997) decreased dangerous aggressive behavior to near zero levels. Thus, the data from Alderman and Knight support the use of the full-session DRL when the clinical goal is response elimination. In a human-operant comparison of spaced-responding and full-session DRL schedules with college students, Jessel and Borrero (2014) found that, for nearly all participants, response rates were near optimal in the spaced-responding DRL and near zero in the full-session DRL.

Becraft et al. (2016) extended the work of Jessel and Borrero (2014) by investigating the role of signals in DRL schedules with preschool-aged students. Stimuli that signal when responses will and will not be reinforced in a DRL schedule are typically used in a classroom setting. For example, the boxes on the index card in Austin and Bevan (2011) signaled how many more responses would be reinforced. Results of Becraft et al. showed that response rates may be maintained in both types of DRL schedules when signals are used. However, the response in Becraft et al. was moving trash items into a waste receptacle in the context of a computer game developed specifically for the study. Thus, it is unclear whether these results would translate to a classroom. The results of Austin and Bevan (2005) suggest that responding may be eliminated even with signals in a classroom setting. Therefore, a comparison of DRL schedules in an applied context is warranted.

The purpose of the current study was to compare the spaced-responding and full-session DRL schedules in an early education classroom context. Because most studies that utilize DRL schedules use signals and Becraft et al. (2016) suggest that both DRL types may function similarly when signals are used, we compared the DRL conditions with signals.

Method

Participants and Setting

Three preschool students (one female) participated in this study as "study participants." Children were recruited from two preschools in the Baltimore-Washington area. Both preschools were associated with the YMCA and followed the same curriculum. Tessa and Dexter were in the same classroom at one preschool. Bobby was a student at the other preschool. Study participants were identified through teacher and parent report as students that requested attention and help too frequently during instructional periods. For every study participant that was recruited, two "buddy participants" were also recruited from the same classroom. Buddy participants were selected based on teacher report of children that did not frequently request help or attention. Tessa's buddies were Julia and Drew. Dexter's buddies were Ian and Eli. Bobby's buddies were Madeline and Henry. All study and buddy participants were four years old and were in the four-year old classrooms at their respective schools at the start of the study.

After recruitment into the study, we conducted a behavioral observation to corroborate that the frequency with which each child requested attention was commensurate to teacher or parent report. The observation was conducted during an instructional period at the school with their teachers. Figure 9 displays the responses per min of bids for teacher attention (defined under Response Measurement, below) for study and buddy participants. The observations corroborated teacher report for study and buddy participants. There were no additional exclusion criteria for participants.

Sessions were conducted at the participants' school three to four days per week for approximately 30-45 min per day. The first several sessions were the preference assessment and only consisted of one study participant at a time. Participants were then pulled out into small groups (three students; one study and two buddy participants) for the remainder of the study. Pullout sessions were conducted in a quiet area of the school (e.g., an empty classroom, staff lounge) and were set up to simulate an independent work activity in a classroom. Students were seated at a table with chairs. Each child had a work activity (a puzzle) in front of his or her seat at the table. The first author served as the teacher in all sessions.

Response Measurement

The dependent variable in the preference assessment was selection of an item by pointing to or saying the name of the item. In baseline and the treatment conditions, the primary dependent variable was bids for attention. Bids were defined as raising a hand, saying the experimenter's name, asking for help (e.g., "I need help"), or speaking to the experimenter while making eye contact. Additionally, for Dexter, bids included the statement, "where does this go?" because initial observations indicated that Dexter typically asked for help by asking where to place a puzzle piece, but would not make eye contact with the experimenter while he said it. Observers scored the frequency of bids for attention within 30-s intervals. We also collected data on a secondary dependent variable during the treatment evaluation: on-task behavior. On-task behavior was defined as the participant directing his or her eye gaze at the task materials and physical contact with task materials that could result in completion of the task. Observers scored on-task behavior using momentary time sampling with 1-min intervals. Every minute, the observer recorded whether or not the child was on-task at that moment. The number of intervals in which the child was on-task was divided by the total number of intervals and multiplied by 100 to yield a percentage.

A second independent observer collected data for at least 30% of observations in each phase of the study (see Table 4). Interobserver agreement was calculated using the block-by-block method of agreement (Mudford, Martin, Hui, & Taylor, 2009). For the preference assessments, observers' records for each trial were compared. If observers scored the same selection, it counted as an agreement. The number of agreements was divided by the total number of trials and multiplied by 100. For bids for attention, the smaller number of bids was divided by the larger number of bids in each 30-s block. The quotients were averaged across blocks and multiplied by 100 to yield a percentage. For on-task behavior, an agreement was scored if the observers both scored that the child was or was not on-task. The number of agreements was divided by the total number of trials and multiplied by 100. Secondary data collectors (undergraduate students) were trained on the data collection method until agreement scores were above 80% for three consecutive observations with the primary data collector (the first author). Table 4 shows the mean agreement per study phase for each participant. Mean agreement was above 80% (range, 80% to 100%) for bids for attention for all participants. Mean agreement was also above 80% (range, 60% to 100%) for on-task behavior for all participants except one buddy participant (Drew). Drew frequently would have physical contact with the task (e.g., holding a puzzle piece), but would not attempt to complete the activity (e.g., talking to a peer). Thus, it was sometimes difficult to determine if he was on task, leading to lower agreement scores. After a low agreement score of 30%, the definition of on-task was reviewed with all data collectors, and improved to a mean of 86.7% in the last three sessions for Drew. Agreement for on-task was high for all other participants.

Procedure

Preference assessment. Prior to beginning the treatment evaluation, we conducted a paired stimulus preference assessment for each study participant with eight pictures of animals (Fisher et al., 1992). Each picture was presented with every other picture one time. Selection of an item resulted in access to the picture for 10 s. The preference assessment was conducted two times with each participant. Based on the animal preference assessment, we identified schedule-correlated stimuli to be used in the treatment conditions and treatment preference assessment. We selected four stimuli that were fairly evenly preferred for each participant such that responding in the different treatment conditions could not be attributed to a preference for the schedule-correlated stimuli (*cf*. Luczynski & Hanley, 2009). In addition, all animals that we selected were from the lower half of participants' hierarchies because we hypothesized that low-preference items would be less likely to exert less control over behavior independent of the contingencies.

Treatment evaluation. The treatment conditions were evaluated in a combined reversal and multi-element design to compare the effect of the DRL conditions to baseline and to one another. In addition, we compared the DRL conditions to a DRO condition to determine whether response rates would be similar to a DRO, as suggested by prior research (e.g., Jessel & Borrero, 2014). Following baseline, the three treatment conditions, spaced-responding DRL, full-session DRL, and DRO, were alternated for each study participant. After stability in each of the treatment conditions, we returned to baseline and then again to intervention. For each of the three treatment conditions, at the start of each session, the experimenter presented the participant with 3-5 sticker packets that were reported by teachers or parents as highly preferred (e.g., Mickey Mouse, Paw Patrol). The participant chose which stickers he or she wanted to earn for that session. All stickers earned in a single day of sessions were presented on the same index card. At the end of the day (typically three sessions), the participant counted the number of stickers he or she earned. For every three (Tessa and Bobby) or six (Dexter) stickers earned, participants could pick a prize from a treasure box. Dexter had to earn more stickers to get a prize because the interval sizes for Dexter allowed him to earn up to double the number of stickers than the other participants each session. The treasure box included small prizes such as pencils, balls, animal figures, and key chains. The index cards with stickers were stored in picture album. Participants kept the album at the end of the study.

During all treatment evaluation sessions for Tessa and Bobby, study participants and their two buddy participants worked a table in a quiet area or room of the school.

Two buddy participants initially joined Dexter for session as well. However, Dexter showed low on-task behavior, and it was hypothesized that the buddies were a distraction. Thus, for the remainder of the experiment, Dexter completed all sessions by himself. The experimenter provided each participant (study and buddy) with a puzzle. Each puzzle had at least 35 pieces and the manufacturer rated the difficulty of the puzzle as six years or older. The puzzles were identified in conference with the teachers as a task that was difficult for the children. The purpose of using a difficult task was to create a motivating operation to request help during the session in keeping with the logic used by Hall and Sundberg (1987). A picture of the completed puzzle was provided for Tessa and Bobby to serve as a guide for completing the puzzle. Dexter was unable to complete the puzzles with only a picture, so we gave Dexter tray puzzles. The tray puzzles had a cardboard surface with imprints of each puzzle piece to guide piece placement. In each session, a puzzle was randomly chosen for each participant. There were 24 puzzle options for Tessa and Bobby and seven tray puzzle options for Dexter.

Baseline. In baseline the experimenter responded to bids for attention of the study and buddy participants on an FR 1 schedule. Participants were told that they could request help or attention whenever they needed it. If participants requested attention at the same time, the experimenter assisted one student and told the other student that she would come to help shortly. After assisting the first student, the experimenter provided attention and help to the other student. Each session was 10 min. Buddy participants remained in baseline throughout the study. Following baseline for each study participant, in conjunction with the teachers, we identified an acceptable rate of responding on which to base the intervals in the intervention condition. For Tessa and Bobby, the acceptable level was set at 0.5 responses per min. For Dexter, we set the acceptable level to 1.0 response per min because our observations and teacher report suggested he was less capable of working independently. However, after demonstrating a treatment effect with an acceptable rate of one response per min for Dexter, we decreased the acceptable level to 0.5 responses per min. Details about the interval sizes and optimal response rates are presented in Table 6.

Spaced-responding DRL. One of the animal stimuli identified in the animal preference assessment was associated with the spaced-responding DRL. For example, for Bobby the spaced-responding condition was the "koala" condition. The background stimuli and signals in this condition included pictures of a koala. When a participant could make a bid for attention (e.g., raising a hand, calling out the teachers name), a green card with a picture of the schedule-correlated animal was presented. The session began with the green animal present. When responses would not be reinforced, the schedule-correlated animal picture was on a red card. Prior to the session, the experimenter explained what the signals meant. If a participant responded while the green animal was present, the experimenter immediately responded to the child's request. In addition, the experimenter placed a sticker from the chosen sticker pack on an index card. Then, the red animal was presented. After the specified DRL interval elapsed (see Table 6), the green animal was presented again. If the child requested attention when the red animal was presented, experimenter told the child, "You need to wait for the green animal" one time, did not respond to subsequent bids, and reset the interval.

Full-session DRL. Like the spaced-responding DRL, we associated another animal with the full-session DRL. For example, for Bobby, the full-session condition was the “eagle” condition. The background stimuli and signals in this condition included pictures of an eagle. The full-session DRL interval was twice that of the interval used in the spaced-responding condition (see Table 6). Participants could request attention or help two times *or less* per interval, thus equating optimal or allowable response rate in the two conditions. The schedule-correlated animal picture was presented on a green card when responses would be reinforced and on a red card when responses would not be reinforced. The session began with the green card. If a child requested attention or help while the green animal was present, the experimenter responded to the request. If the child responded a second time within the interval, the experimenter also responded to the request. Then, the red animal was presented. When the interval elapsed, the participant earned one sticker if he or she had engaged in two or fewer responses, and the green animal was represented. If the child engaged in a response when the red animal was present, attention was not provided and no sticker was presented at the end of the interval. After the first bid for attention with the red animal, the experimenter said, “I cannot help you right now. Wait until the green animal comes back.” Subsequent bids were ignored.

DRO. A different animal was associated with the DRO condition. For Bobby, the DRO condition was the “elephant” condition. Background stimuli and signals included pictures of an elephant. The DRO interval was the same as the full-session DRL condition because we wanted to directly compare the DRO to the full-session DRL based on prior suggestions that a full-session DRL may work similarly to a DRO (Jessel & Borrero, 2014). Throughout the interval, a red card with the schedule-correlated animal was present, which signaled to participants that responses should not be made. In each interval, if the child did not request help or attention, he or she earned a sticker. If a child engaged in one or more bids in an interval, no sticker was earned for that interval. After the first bid for attention with the red animal, the experimenter said, “I cannot help you right now. Wait until the green animal comes back.” Subsequent bids were ignored.

Treatment preference. Following the treatment evaluation, we evaluated preference for each of the treatment conditions using a procedure similar to that described by Luczynski and Hanley (2009). Prior to working on the puzzles, participants were presented with animal pictures corresponding to each intervention condition. A control choice, no reinforcement, was also presented. A different animal that was similarly preferred to the other three animals signaled the control choice. The purpose of the control choice was to help distinguish indifference for treatment conditions from not understanding the contingencies. That is, if participants selected the three treatment conditions fairly equally, but did not select the no reinforcement condition, we concluded that the participant preferred all three conditions equally. However, if the participant chose all four conditions equally, failure to discriminate between the contingencies was a possibility. We instructed participants to pick which one they wanted each session. After choice of a condition, sessions were 5 min in duration. During the session, contingencies were identical to the chosen treatment condition from the treatment evaluation. In the no reinforcement condition, the schedule-correlated animal (e.g., a penguin) was presented on a red card, the experimenter did not respond to any bids for attention, and no stickers were earned. Following each 5-min session, another choice was presented. There were a total of 20 choice trials.

Social Validity

Following the treatment preference assessment with the study participants, we evaluated the acceptability of the DRL conditions with four teachers at the two preschools. All teachers regularly interacted with at least one of the study participants. The survey included two vignettes. Both vignettes were about a hypothetical student, Caleb, who excessively asked for teacher attention and described a plan to reduce requests for attention. One vignette described a spaced-responding DRL intervention and the other described a full-session DRL intervention. Following each vignette, teachers rated how much they agreed with five statements on a 4-point scale (4 = strongly agree; 1 = strongly disagree). The statements measured likelihood to implement the plans, time it would take to implement, plan effectiveness, difficulty of implementation, and likelihood that teachers would recommend the plan to colleagues. Teachers could also provide comments about why they were or were not willing to implement the two plans. Finally, at the end of the survey, we asked teachers which of the two plans they preferred, and why. The full vignettes and surveys are presented in the Appendix.

Results

Preference Assessment

Figure 10 displays the mean percentage of trials in which each animal picture was selected in the animal preference assessment for Tessa (top), Bobby (middle), and Dexter (bottom). For Tessa, we selected the octopus, eagle, elephant, and polar bear as scheduled correlated stimuli. For Bobby, we selected the penguin, eagle, raccoon, and koala. For Dexter, we selected the cow, koala, eagle, and elephant. Table 5 indicates which animal picture was associated with each condition for each participant.

Treatment Evaluation

Figure 11 depicts the results of the treatment evaluation with Tessa. Responses per min (rpm) of bids for attention and percentage of intervals on-task are displayed on the top and bottom panels, respectively. All means reported are for the last three sessions in each phase. During the initial baseline, Tessa bid for attention 2.1 times per min. During intervention, the ideal rate of responding was set to 0.5 rpm. For both the spaced-responding and full-session DRL conditions, mean bids for attention were 0.5 rpm. Bids for attention in the DRO condition were initially similar to the DRL conditions, but eventually reduce to near zero (M < 0.1 rpm). In the second baseline phase, after several sessions, bids for attention increased and replicated the first baseline phase. In the return to intervention, results replicated the first intervention phase, with responding near optimal or allowable in the DRL conditions and near zero in the DRO condition. There appeared to be little difference across the conditions for on-task behavior. The mean percentage of intervals on-task (middle panel) was above 90% of intervals across all conditions. On-task was highest in baseline and lowest in DRO.

Figure 12 displays results of the treatment evaluation with Bobby. Initially, Bobby requested attention at a high rate in baseline. However, we hypothesized that the high rate was partially due to the novelty of the experimenter. Therefore, we continued baseline until response rate stabilized. In the final three sessions of baseline, Bobby bid for attention 2.3 times per min. In intervention, bids for attention decreased in all conditions, but was initially somewhat variable. In the final three sessions of each condition, the rate of bids for attention was near optimal or allowable (0.5 rpm) in the spaced-responding (M = 0.5 rpm) and full-session (M = 0.6 rpm) DRL conditions and lower in the DRO condition (*M* = 0.2 rpm). Although response rate was not zero in the DRO condition, it was lower than either DRL condition. These patterns were replicated in the second baseline and intervention phases. Mean on-task behavior was above 95% of intervals across all conditions.

Figure 13 displays results of the treatment evaluation for Dexter. As previously stated, Dexter began the treatment evaluation in a group with two buddy participants like the other study participants. However, bids for attention were variable and lower than expected based on teacher report. Furthermore, Dexter was on-task in less than 50% of intervals. It appeared that Dexter was distracted by the peers, and would interact with the peers instead of completing the task. Therefore, we ran the remainder of the evaluation without the buddy participants. In baseline without buddies, Dexter had a high and consistent rate of bids for attention (*M* = 2.1 rpm). During the first intervention phase, bids for attention decreased to near optimal or allowable (1.0 rpm) in the spaced-responding (*M* = 1.1 rpm) and full-session (*M* = 1.2 rpm) DRL conditions. In the DRO condition, similar to Bobby, response rate was lower (*M* = 0.4 rpm) but not zero. Results were replicated in the second baseline and intervention phases. We then reduced the optimal or allowable criterion for Dexter to 0.5 rpm. Response rates in the spaced-responding (*M* = 0.5 rpm) and full-session (*M* = 0.6 rpm) DRL decreased accordingly. Bids also decreased slightly in the DRO condition (*M* = 0.2 rpm). Dexter initially had low on-task behavior during the intervention conditions. Throughout the phase, on-task behavior increased and remained at 100% for the remainder of the study.

Figure 14 is the mean responses per min of bids for attention for all study and buddy participants in each condition. The means include the last three sessions of the first baseline phase and the last three sessions per condition of the final intervention phase. In baseline, all study participants bid for attention at more than twice the rate of the buddy participants. For all study participants, with intervention, mean rate of bids for attention decreased to a level similar to the buddy participants.

In summary, results suggest that both a full-session and spaced-responding DRL can maintain responding near a set criterion, whereas a DRO eliminates or nearly eliminates responding. In other words, our results indicate that a full-session DRL did not eliminate responding for any participant. Further, on-task behavior was fairly high in all conditions, indicating that the DRL conditions did not affect on-task behavior.

Treatment Preference

Figure 15 depicts the number of selections for each intervention condition in the treatment preference assessment for all participants. All study participants selected the DRL conditions more than the DRO and no reinforcement control conditions, suggesting preference for both DRL conditions. Tessa and Bobby appeared to prefer the full-session DRL to the spaced-responding DRL. Tessa selected the full-session DRL three more times than the spaced-responding DRL, indicating a slight preference. Bobby selected the full-session DRL eight more times than the spaced-responding DRL, indicating a fairly strong preference. Dexter appeared to prefer the DRL conditions equally. He selected the full-session DRL eight times and the spaced-responding DRL nine times. Within-session data patterns for Dexter show that he typically alternated his choices between the two DRL conditions.

Social Validity

Results of the social validity survey are presented in Figure 16. On average, teachers rated the full-session DRL more favorably than the spaced-responding DRL. Teachers were more willing to implement the full-session DRL, found the full-session DRL more effective, and were more likely to recommend the full-session DRL than the spaced-responding DRL. On average, they rated the procedures equally in terms of how time consuming and how difficult the interventions were. Because of the small sample size, it is unclear if these differences are meaningful. However, each individual teacher also rated the full-session DRL more favorably than the spaced-responding DRL. In addition, when asked which plan they preferred, two of three teachers said the full-session DRL (one teacher did not answer this question and one teacher said it depended on the specific child). In their description of why they chose the full-session DRL, all teachers mentioned something related to the feasibility of implementing a spaced-responding DRL in a classroom with many children. For example, one teacher said that the full-session DRL was a better approach because it is “not a never-ending 2 min plus 2 min in a classroom where 1:1 attention [cannot be] infused into the day. It makes it more achievable for success.” Despite a slight preference for the full-session DRL, ratings even for the full-session DRL were not extremely high. All teachers agreed, but did not strongly agree, that the full-session DRL would likely be effective, that they would be likely to implement it, and that they would recommend it to others. Comments on the survey pointed to the size of the intervals as a potential barrier. One teacher indicated that a four min interval for the full-session DRL may be a good starting point, but that "working up to more than four minutes and gradually increasing the…set time" would be ideal.

Discussion

Results of the current study indicate that, in a simulated classroom, bids for attention of preschool students can be reduced but not eliminated in either type of DRL schedule with the use of signals. Furthermore, we found a general preference for the full-session DRL over the spaced-responding DRL by the preschool students and teachers at their schools. These results are consistent with Becraft et al. (2016), which found that on an arbitrary task, preschool students responded near an optimal or allowable criterion in either type of DRL schedule as long as there were signals indicating when responding would and would not be reinforced. Our results further support this by extending the findings to a classroom-like context.

The study participants were students who were identified by teachers as disruptive because they frequently requested teacher attention. Teachers also identified buddy participants that were not disruptive. Our corroboration and baseline data support the teachers' recommendations, with study participants requesting attention by twice as much as buddy participants. With intervention, bids for attention of study participants reduced to a level similar to the buddies. These results suggest the interventions led to a clinically and socially meaningful reduction of bids for attention.

Importantly, nearly all applied studies that have used a DRL have used a full-session DRL. In our recent review of the literature, we characterized 35 studies as applied investigations of a DRL schedule. Of those, 30 were a full-session DRL. We, as well as other researchers, have hypothesized that practitioners may be more likely to implement a full-session DRL because of ease of implementation. The results of the social validity survey suggest that, based on a description of the procedures, teachers did not find the spaced-responding DRL any more time consuming or difficult than the full-session DRL. However, teachers generally did prefer the full-session DRL procedure. It is important to note, however, that the teachers did not implement the procedures, and results may have varied if they had direct experience with the interventions. Nonetheless, results of the treatment evaluation for each participant showed that the full-session DRL was just as effective as the spaced-responding DRL. Based on these findings, practitioners and educators may consider using either type of DRL schedule to reduce but not eliminate responding. Considering a historic empirical preference for the full-session DRL in application and the student preference and teacher social validity results of the current study, a full-session DRL may be more preferable and feasible in a group setting.

Although Jessel and Borrero (2014) suggested that the full-session DRL might eliminate responding, we did not find any evidence to support this in the current study. There are several key differences between the current study and Jessel and Borrero (2014). First, our sample was preschool-aged students whereas Jessel and Borrero used college students. It is possible that age may be a factor. Older individuals may be more likely to test the DRL contingency and, thus, may be more likely to experience earning a reinforcer in the absence of a response in the full-session DRL. Although possible, pilot data that we collected with undergraduate students indicated that when signals are presented, responding in the two DRL conditions are fairly similar. Second, the target response in the current study was socially meaningful whereas Jessel and Borrero used an arbitrary response (mouse clicks). However, Becraft et al. (2016) also used an arbitrary response and found that responding could be maintained in both DRL schedules. Third, we used signals whereas Jessel and Borrero did not. Consistent with Becraft et al., signals appear to facilitate responding near a certain criterion by indicating when responses would and would not be reinforced. Thus, the most likely reason for the difference in results between Jessel and Borrero and the current study was the use of signals.

However, other applied studies using full-session DRL schedules have also reported an elimination of responding. For instance, requests for attention for all participants in Austin and Bevan (2011) were eliminated in a majority of full-session DRL sessions. Although Austin and Bevan did not compare the full-session DRL to a spaced-responding DRL, an elimination of responding is still concerning. One possible explanation is simply sampling error. That is, it could have been chance that all three participants displayed zero or near zero responding. It may also be due to the age of participants. The participants were 7-8 years old whereas our participants were 4-5 years old. However, as previously stated, we have some evidence that responding in a full-session DRL can be maintained for adults. Another explanation may be the signals. Austin and Bevan did use signals. Participants were given a card with boxes on which the teacher marked off a box each time she asked for attention. Thus, each participant had a visual signal indicating how many more time she could ask for attention. However, the way we presented signals in the full-session DRL was different. We did not indicate how many more responses would be allowed. Instead, we changed the color of the card from green (bids for attention would be reinforced) to red (bids for attention will not be reinforced). We also did not give any rules about how many responses would be allowed; Austin and Bevan told participants they would earn the reinforcer if they engaged in a certain number of responses *or less*. These subtle procedural variants may account for the difference in results. In other words, the signals and rules in Austin and Bevan indicated that reinforcers could be earned for the absence of responding. As such, additional research investigating the DRL schedules with more explicit rules about the contingencies is warranted.

Some features of our data are noteworthy. Both Bobby and Dexter maintained responding at a low level in the DRO condition. One criticism of the full-session DRL is that responding may be eliminated, similar to a DRO. Although responding was lower in the DRO condition than the DRL conditions for both participants, it was never eliminated. However, even in other contexts, target responses are not always eliminated in a DRO. For example, Payne, Dozier, Briggs, and Newquist (2016) used a DRO in three different group-oriented contingency conditions to decrease problem behavior in a preschool classroom. Problem behavior was reduced, but not completely eliminated. Often, clinicians determine a percentage reduction for baseline that would be considered clinically meaningful (e.g., 80% reduction). Bids for attention for Bobby and Dexter were both decreased by more than 85%, consistent with a clinical reduction from baseline.

Regardless of the comparison to the DRO condition, responding in the full-session DRL was still maintained near the criterion we set and was similar to the spaced-responding DRL. Furthermore, Dexter's data demonstrate that when the criterion was changed, response rate in both DRL conditions adjusted accordingly. That is, in the final phase of the treatment evaluation for Dexter, we doubled the DRL interval sizes, which had the effect of reducing the optimal or allowable response rate by half. Bids for attention immediately tracked the change in the contingency. Thus, our results dampen the criticism that a full-session DRL could eliminate a response that one would prefer to see maintained. Instead, for all participants, the rate of responding was very close to optimal or allowable criterion.

Another notable finding was that there did not appear to be an effect of the intervention conditions on on-task behavior. In fact, for Tessa and Bobby, on-task behavior was slightly lower in the intervention conditions than it was in baseline. It is possible that the interventions actually disrupted on-task behavior. Crawford et al. (2012) found that food rewards disrupted engagement in a high-preference task for a boy with autism. Although we did not use food rewards, the presence of the signals and presentation of stickers potentially temporarily disrupted engagement with the puzzles. For example, when the experimented presented a sticker, participants occasionally stopped attending to the puzzle to look at the sticker or talk to the experimenter. The slight decrease may also be due to a ceiling effect. On-task behavior was rarely below 80% of intervals for Tessa or Bobby in all conditions. Thus, it could be chance that baseline sessions were higher, on average. In addition to being on-task, participants were completing the puzzles at a high rate across the study (data available from the first author). Thus, correct responding was not negatively impacted and, in some cases, improved.

Although this study evaluated DRL schedules in an applied context, the experimenter acted as the teacher in a small group setting. Further, Dexter's evaluation was conducted without a group. Though this study did not target the precise ecological conditions under which we would ultimately envision in application, we believe that these small, highly controlled, and incremental steps will lay the foundation upon which we can inform application on a larger scale. Thus, future research may investigate DRL schedules in a classroom led by a teacher. In addition, research may investigate using group rather than individual contingencies, which may be more manageable for teachers to implement in a large classroom (Payne et al., 2016). For example, under an interdependent group contingency, the entire class could earn potential reinforcers if the number of bids for attention for the entire class is less than a specified criterion. This DRL arrangement is frequently used in the Good Behavior Game (Barrish, Saunders, & Wolf, 1969; Sy, Gratz, & Donaldson, 2016). Additionally, future research may evaluate larger interval sizes, which may be more suitable to a classroom as suggested by one of the teachers that completed the social validity survey. DRL schedules may be a useful intervention tool for classroom management, and as such, continued investigations in application and practice are warranted.

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Table 4

Mean Interobserver Agreement Scores

Phase	**Response**	**% Sessions**	**Study Agree**	**Buddy A Agree**	**Buddy B Agree**
			Tessa	*Julia*	*Drew*
Animal Preference	Selection	100.0%	100.0%	N/A	N/A
	Bids	39.5%	96.5%	92.7%	95.2%
Treatment Eval.	On-task		95.3%	87.1%	74.6%
Treatment Pref.	Selection	30.0%	100.0%	N/A	N/A
			Bobby	*Henry*	*Madeline*
Animal Preference	Selection	100.0%	100.0%	N/A	N/A
Treatment Eval.	Bids	54.1%	92.3%	96.9%	98.1%
	On-task		99.1%	97.4%	98.3%
Treatment Pref.	Selection	60.0%	100.0%	N/A	N/A
			Dexter	*Ian*	*Eli*
Animal Preference	Selection	100.0%	97.0%	N/A	N/A
Treatment Eval.	Bids	47.3%	91.7%	97.8%	97.5%
	On-task		97.3%	80.0%	90.0%
Treatment Pref.	Selection	40.0%	100.0%	N/A	N/A

Table 5

Schedule Correlated Stimuli for Each Study Participant

Study Participant	**DRL-*s***	**DRL-*f***	**DRO**	**No SR**
Tessa	Octopus	Eagle	Elephant	Polar bear
Bobby	Koala	Eagle	Raccoon	Penguin
Dexter	Koala	Eagle	Elephant	Cow

Note. DRL-*s* = spaced-responding differential reinforcement of low-rates of behavior (DRL); DRL-*f* = full-session DRL; DRO = differential reinforcement of other behavior; No SR = no reinforcement.

Table 6

Parameters for Intervention Conditions

Study Part.	**DRL-*s* Interval**	**DRL-*f* Interval**	**DRL-*f* Tolerance**	**DRO**	**Optimal or Allowable Rate**	**% Reduction**
Tessa	2 min	4 min	2	4 min	0.5 rpm	76.5%
Bobby	2 min	4 min	2	4 min	0.5 rpm	76.1%
Dexter (initial)	1 min	2 min	2	2 min	1.0 rpm	55.9%
Dexter (final)	2 min	4 min	2	4 min	0.5 rpm	77.9%

Note. DRL-*s* interval = interval size in spaced-responding differential reinforcement of low-rates of behavior (DRL); DRL-*f* = interval size in full-session DRL; DRL-*f* tolerance = the number of responses allowed in each DRL-*f* interval; DRO = differential reinforcement of other behavior; optimal or allowable response rate = responses per min (rpm) that would result in earning the maximum number of reinforcers (DRL-*s*) or the maximum number of responses allowed to earn a reinforcer (DRL-*f)*; % reduction = the percentage reduction from the last three sessions of baseline if responding at optimal or allowable response rate

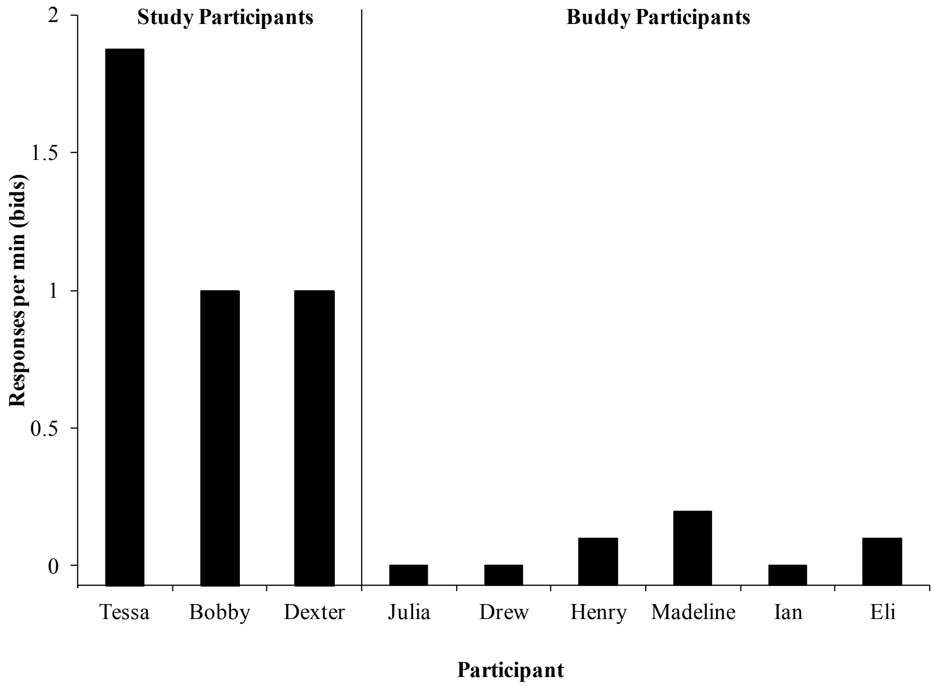

Figure 9. Responses per min of bids for attention during the corroboration screening for study and buddy participants.

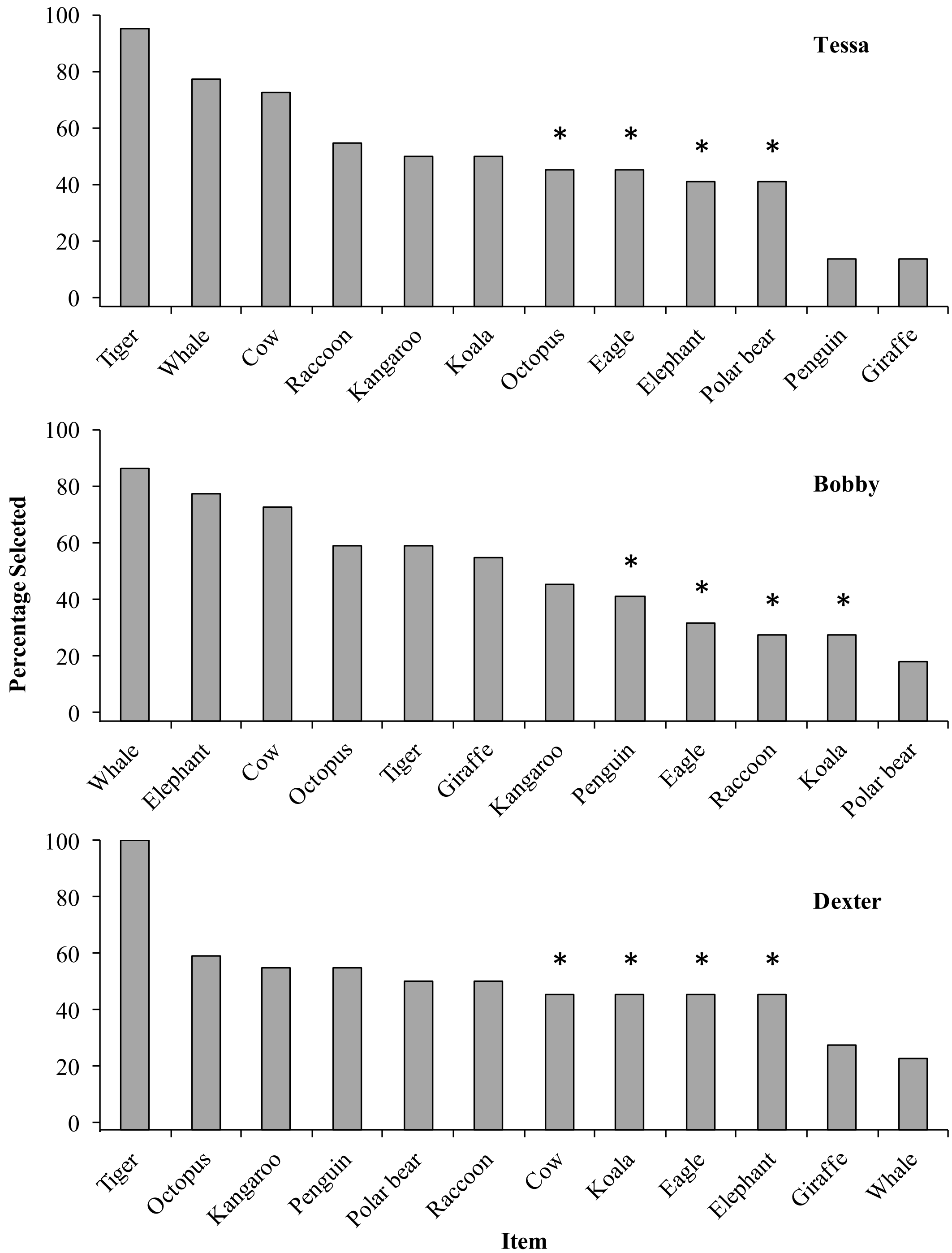

Figure 10. Percentage each picture item was selected in the animal preference assessment for Tessa (top), Bobby (middle), and Dexter (bottom). The asterisk indicates items chosen as schedule correlated stimuli.

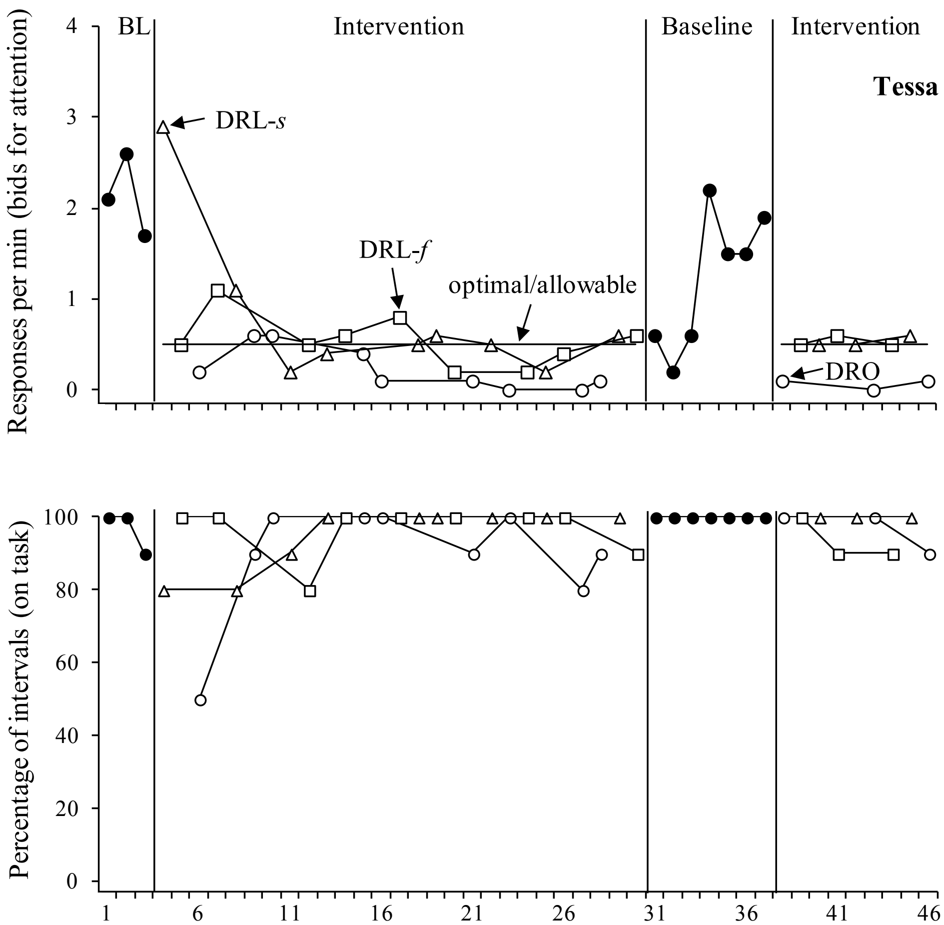

Figure 11. Responses per min of bids for attention (top) and percentage of intervals on-task (bottom) for Tessa during the treatment evaluation. Black circles are baseline, white triangles are spaced-responding differential reinforcement of low rates of responding (DRL-*s*), white squares are full-session DRL (DRL-*f*), and white circles are differential reinforcement of other behavior (DRO). The horizontal line in the top panel indicates the optimal or allowable criterion for the DRL conditions, which was set to 0.5 responses per min.

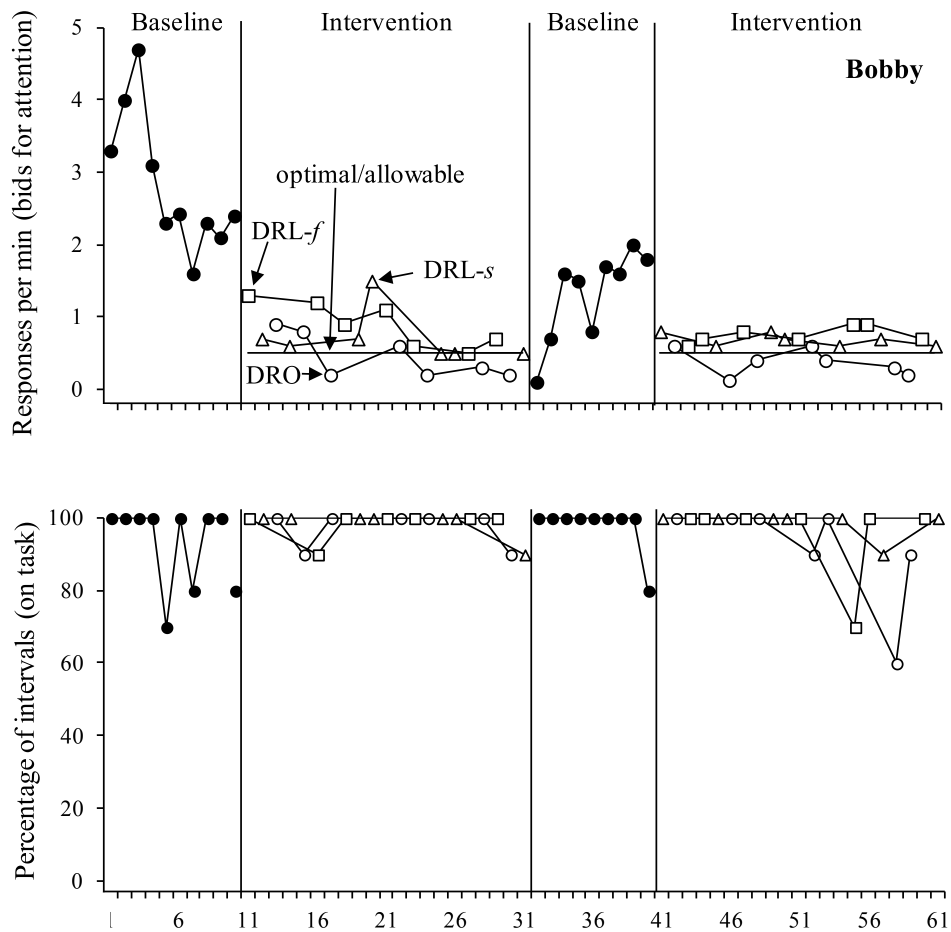

Figure 12. Responses per min of bids for attention (top) and percentage of intervals on-task (bottom) for Bobby during the treatment evaluation. Black circles are baseline, white triangles are spaced-responding differential reinforcement of low rates of responding (DRL-*s*), white squares are full-session DRL (DRL-*f*), and white circles are differential reinforcement of other behavior (DRO). The horizontal line in the top panel indicates the optimal or allowable criterion for the DRL conditions, which was set to 0.5 responses per min.

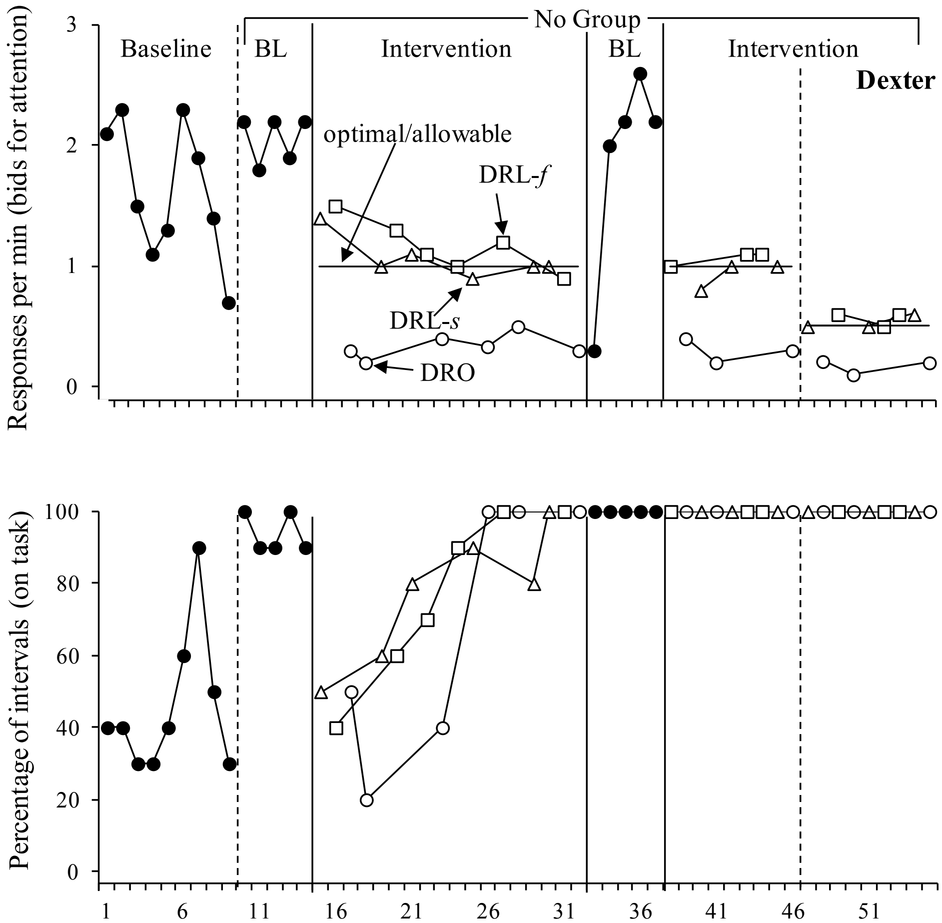

Figure 13. Responses per min of bids for attention (top) and percentage of intervals on-task (bottom) for Dexter during the treatment evaluation. Black circles are baseline, white triangles are spaced-responding differential reinforcement of low rates of responding (DRL-*s*), white squares are full-session DRL (DRL-*f*), and white circles are differential reinforcement of other behavior (DRO). The horizontal line in the top panel indicates the optimal or allowable criterion for the DRL conditions, which was initially set to 1.0 response per min. In the last phase of the second intervention, the criterion was reduced to 0.5 responses per min.

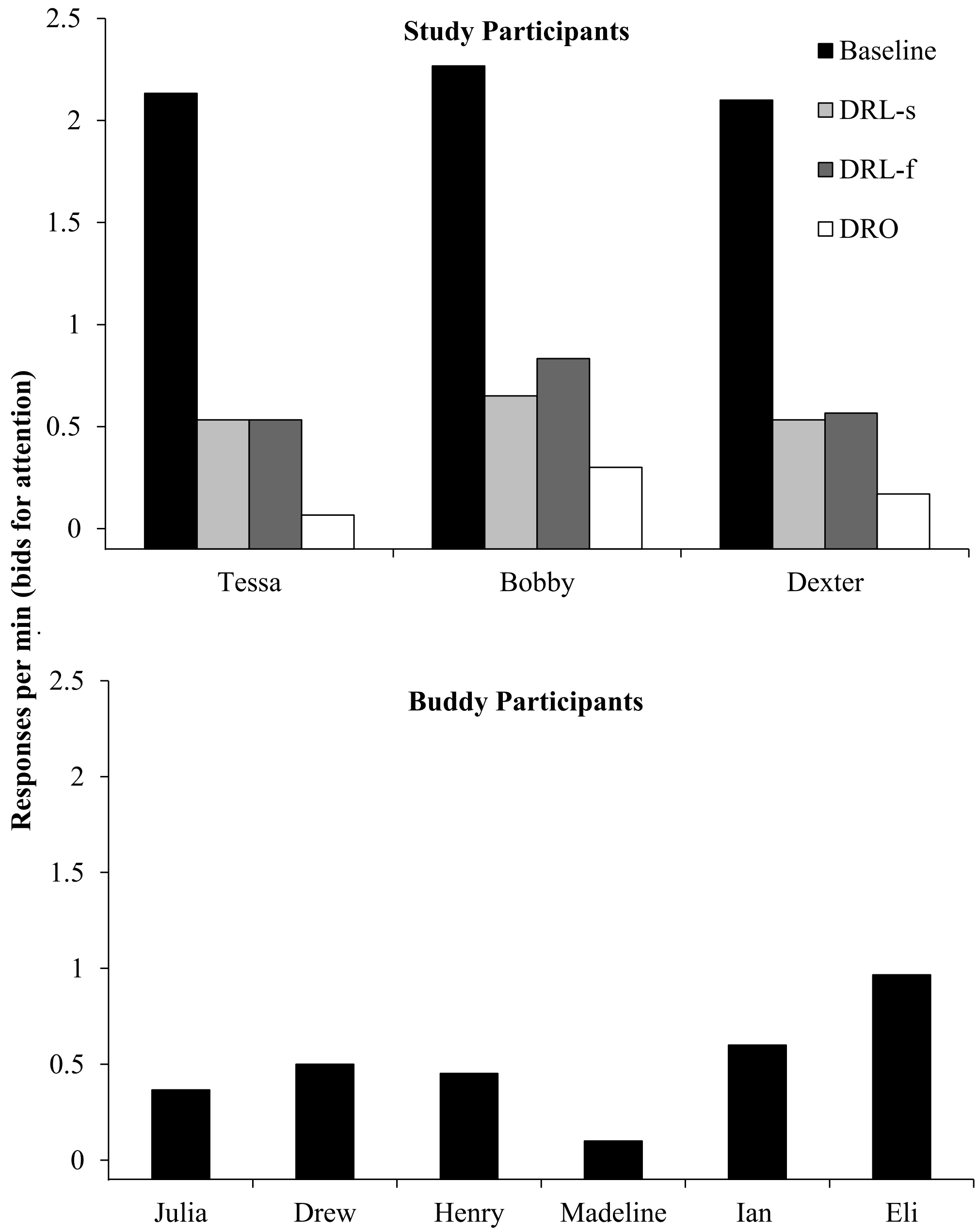

Figure 14. Mean responses per min of bids for attention for each study and buddy participant. Means include the last three session of the first baseline phase and the last three sessions per condition of the last intervention phase.

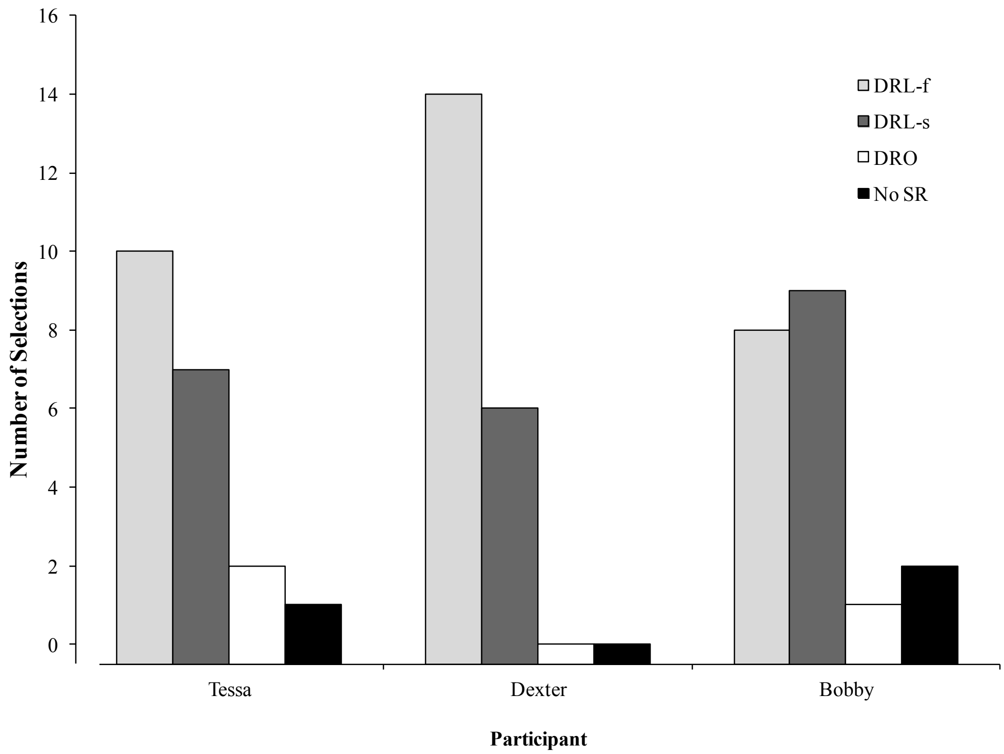

Figure 15. The number of selections for each intervention condition in the treatment preference assessment for all study participants. The full-session differential reinforcement of low rates of behavior (DRL-*f*) condition is light gray, the spaced-responding DRL (DRL-*s*) condition is dark gray, the differential reinforcement of other behavior (DRO) condition is white, and the no reinforcement control (No SR) condition is black.

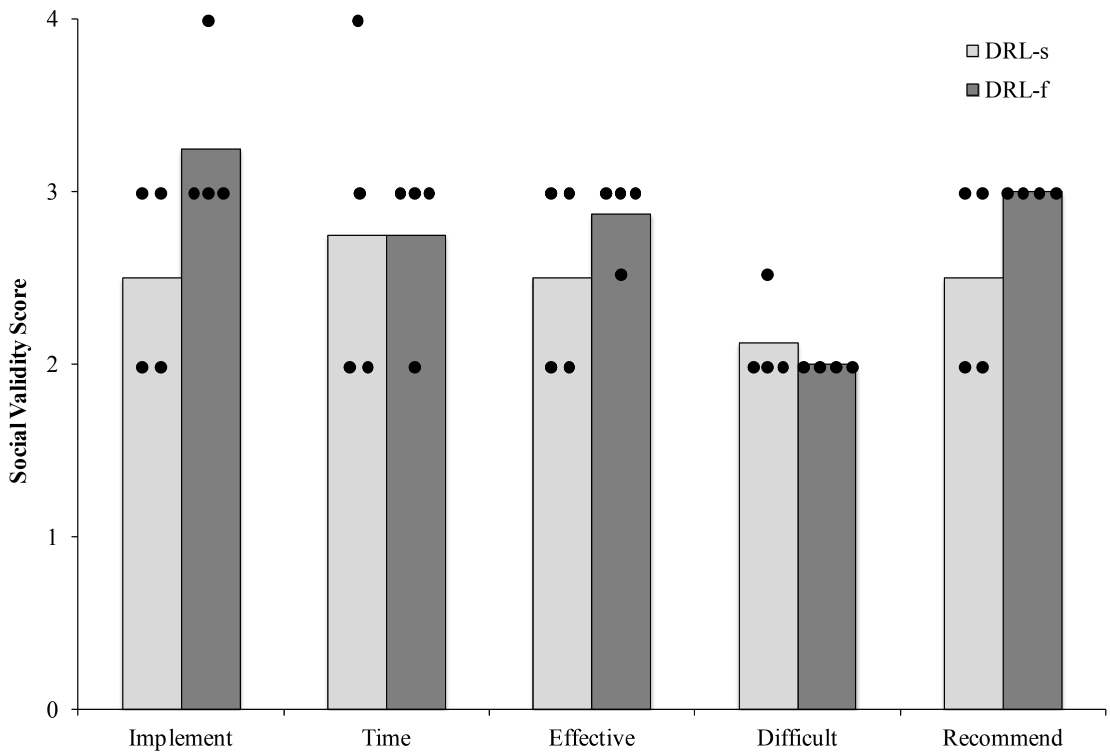

Figure 16. Mean teacher ratings on the social validity survey for the spaced-responding differential-reinforcement-of-low-rate (DRL) intervention (light gray bars) and full-session DRL intervention (dark gray bars). The dots indicate individual teacher responses. Implement is the teacher's willingness to implement the intervention. Time is if the intervention would take too much time to implement. Effectiveness is the teacher's perception of how effective the intervention will be. Difficult is if the intervention is too difficult to implement. Recommend is if the teacher would recommend the intervention to other teachers. Scores range from 1 (strongly disagree) to 4 (strongly agree).

Differential-Reinforcement-of-Low-Rate Schedules Effects on Human Behavior: A Meta-Analysis (Study 3)

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Authors' Note

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Abstract

Differential-reinforcement-of-low-rate (DRL) schedules can be used to decrease, but not eliminate target responding. However, there is some evidence that one type of DRL, the full-session DRL, may eliminate responding. The purpose of the current study was to synthesize and compare published data using full-session and spaced-responding DRL schedules with humans since 1970. The meta-analyses were conducted using multi-level modeling and included 32 studies and 187 datasets. Both DRL conditions significantly reduced responding relative to baseline, but the reductions across the DRL type were not significantly different. There was also significant variability across datasets for both DRL types. For the full-session DRL, there were greater reductions when the reinforcer was not the same reinforcer as baseline, when the target response was applied rather than arbitrary, and when signals with rules about the DRL contingency were used. For the spaced-responding DRL, reductions were greater when signals were used. These results indicate that the full-session DRL is no more likely to eliminate responding than the spaced-responding DRL. In application, a full-session DRL may be most successful at reducing, but not eliminating, responding if a functional reinforcer and signals without rules are used.

Key words: Differential-reinforcement-of-low-rates, meta-analysis, single-case design, multi-level models

Differential-Reinforcement-of-Low-Rate Schedules Effects on Human Behavior: A Meta-Analysis (Study 3)

Differential reinforcement schedules are frequently used to decrease undesirable behavior such as self-injury or aggression (e.g., Athens & Vollmer, 2010; Mazaleski, Iwata, Vollmer, Zarcone, & Smith, 1993; Rooker, Jessel, Kurtz, & Hagopian, 2013). In differential reinforcement of alternative behavior (DRA), a reinforcer is provided for the occurrence of an appropriate, alternative response while the inappropriate response is placed on extinction (Wallace & Najdowski, 2009). For instance, a child who typically engages in aggression when presented with challenging academic demands may be taught to ask for a break. Requests for a break can be reinforced with a break from work, whereas no break or escape would be provided contingent on aggression. In differential reinforcement of other behavior (DRO), a reinforcer is provided for the absence of a target response (i.e., the inappropriate behavior) within a specified interval (Jessel & Ingvarsson, 2016). Using the same scenario as the example for DRA, the child may be afforded a break from work for every 5 min that the child does not engage in aggression during academic demands. DRA and DRO boast wide support in behavioral literature for decreasing problematic behavior (Wallace & Najdowski, 2009). Both procedures are especially suited when the interventionist would like to eliminate the target response (e.g., self-injury) because both either reinforce a behavior that is expected to replace the unwanted behavior (DRA) or reinforce the absence of the unwanted behavior (DRO).

However, some behavior may be desirable when it occurs at a low rate but is considered problematic if it occurs at a very high rate. For example, raising one’s hand to request help with independent work in a classroom is a desirable behavior but excessive hand raising may be disruptive. Differential-reinforcement-of-low-rate behavior (DRL) schedules are useful for reducing, but not eliminating, behavior that occurs in excess (Catania, 2013). Two variations of a DRL schedule exist: spaced-responding and full-session.

In a spaced-responding DRL, a response is reinforced if the inter-response time is greater than or equal to a specified value. Extensive nonhuman animal research has been conducted with spaced-responding DRL schedules (Kramer & Rilling, 1970). Early work focused on understanding the functional properties of the schedule (e.g., characteristic response patterning). In the 1960s, investigators began to use DRL schedules to study other topics of interest (e.g., stimulus control, behavioral contrast; Kramer & Rilling, 1970). More recently, researchers have used spaced-responding DRL schedules to study impulsivity. For example, Cheng, MacDonald, and Meck (2006) investigated spaced-responding DRL schedule performance of rats that were injected with cocaine and ketamine. In all sessions, lever presses were reinforced if more than 12 s had elapsed since the last response. In cocaine sessions, inter-response times were shorter than baseline or ketamine sessions, suggesting higher impulsivity. The spaced-responding DRL has also been occasionally used in application. For example, several studies have used a spaced-responding DRL to reduce the rate of rapid eating among individuals with intellectual disabilities (e.g., Anglesea, Hoch, & Taylor, 2008; Lennox, Miltenberger, & Donnelly, 1987; Wright & Vollmer, 2002).

In a full-session DRL (Deitz, 1977), a reinforcer is provided if a certain number of responses or less occur in a specified time period. Jessel and Borrero (2014) have referred to this as tolerance, or the number of responses permitted, while still producing reinforcer access. As the name implies, the time period is the entire session or observation. However, a DRL can also be arranged for intervals within an observation period (sometimes called interval DRL; Deitz, 1977). For example, a teacher may decide that it is acceptable for a student to request help up to four times during a 60-min math instruction period (a full-session DRL). Alternatively, the teacher may arrange it such that the student may request help up to one time every 15 min (an interval DRL). Austin and Bevan (2011) arranged a full-session DRL in which participants earned a point toward a class-wide token economy if they requested teacher attention fewer than a specified number of times in a 20-min independent work period. All three participants demonstrated a decrease in requests for attention from baseline. In fact, full-session DRLs may be even more common than they appear; some interventions use a full-session DRL procedure but do not explicitly name it as such. For example, the Good Behavior Game (Barrish, Saunders, & Wolf, 1969; Leflot, van Lier, Onghena, & Colpin, 2015) is a classroom intervention in which teams of students are given a point when someone engages in inappropriate behavior. Teams that have fewer than a certain number of points earn a reward. Thus, the Good Behavior Game can be considered a full-session DRL contingency (Donaldson, Vollmer, Krous, Downs, & Berard, 2011).

The spaced-responding DRL, rooted in basic nonhuman research, has well-understood functional properties (Kramer & Rilling, 1970). Namely, it results in a reduction, but not elimination, of the target response. The full-session DRL and interval DRL procedures are based in application. That is, to our knowledge, there are no full-session DRL investigations in nonhuman laboratory research. Ferster and Skinner (1957) alluded to a variation of a DRL similar to the full-session DRL, but did not present data to illustrate the variation.

Several applications of full-session DRL schedules appear to target responses for which a complete suppression is not desired (e.g., requests for attention). However, because a reinforcer is provided even if zero responses occur, it is unclear whether the full-session DRL does reduce, but not eliminate, the target response. In the study by Austin and Bevan (2011), all three participants requested attention zero times in more than half of the observations in the full-session DRL treatment, which suggests that the full-session DRL schedule may eliminate the target response. Furthermore, full-session DRLs are sometimes used to treat problem behavior that an interventionist likely would want to eliminate. For instance, Shaw and Simms (2009) implemented a full-session DRL to reduce screaming, profanity, and disruptive behavior displayed by three individuals with intellectual disabilities. Initially, the number of responses that could occur while still earning a reinforcer was set to near or slightly below baseline levels of responding. The researchers then systematically decreased the number of tolerated responses until the problematic behaviors were virtually eliminated.

In light of the procedural and potentially functional differences between the spaced-responding DRL and full-session DRL arrangements, it seems reasonable to thoroughly compare the procedures. In Jessel and Borrero (2014), 10 college students earned points by clicking on a square on a computer screen according to either a spaced-responding DRL or full-session DRL[2] schedule. All participants maintained responding near optimal levels in the spaced-responding DRL condition. Conversely, 60% of

[2] The schedule was technically an interval DRL schedule.

participants engaged in zero responses by the last full-session DRL session. Results of Jessel and Borrero suggest that there are functional differences between the two DRL procedures and that the full-session DRL may lead to an elimination of the target response. Becraft, Borrero, Davis, Mendres-Smith, and Castillo (in press) conducted a systematic replication of the procedures reported by Jessel and Borrero and evaluated the role of signals in DRL schedules with 10 children between the ages of 4 and 5. When signals were used to indicate when reinforcers were or were not available for responding, all participants responded similarly (near the optimal rate) in both DRL conditions. However, when there were no unique signals, participants generally displayed a complete suppression of or high variability in the target response. Thus, the results of Becraft et al. suggest that the two DRL schedules may function similarly under certain stimulus conditions. Similarly, in an applied extension, Becraft, Borrero, Mendres-Smith, and Castillo (2016) reduced excessive requests to attention of three preschool children in a simulated classroom near an optimal criterion for both types of DRL schedules using signals.

Given somewhat mixed findings regarding response elimination, further investigation of the full-session DRL is important is warranted. The full-session DRL is more common in application than a spaced-responding DRL, potentially because it is easier for clinicians and practitioners to implement. However, whether or not it does eliminate behavior may provide guidelines for how clinicians use it in application. For example, if it does generally eliminate behavior, clinicians may avoid the full-session DRL for responses that they only want to reduce, but not eliminate (e.g., hand-raising).

However, if it generally does not eliminate behavior, the full-session DRL may be a viable alternative to the more time-consuming spaced-responding DRL.

Although experimental analogs are excellent ways to directly compare two treatment arrangements, other methods exist that can synthesize existing data. Research syntheses are not uncommon in behavior analytic literature (e.g., Carr, Severtson, & Lepper, 2009; Levy et al., 2016; Schlichenmeyer, Roscoe, Rooker, Wheeler, & Dube, 2013; Tiger, Hanley, & Bruzek, 2008). Such reviews often integrate findings quantitatively (e.g., summarizing the mean reduction in problem behavior across studies), but generally do not rely on inferential statistics. However, there are good reasons for behavior analysts to consider statistical methods to analyze and synthesize research findings.

Applying Statistics to Single Case Designs

Most behavior analytic studies use visual analysis rather than statistical analyses to determine functional relations between independent and dependent variables (Kahng et al., 2010). Despite a tradition of visual analysis in behavior analysis, there is increasing interest in applying statistical techniques to single-case designs (SCD) as evidenced by entire issues dedicated to this topic in journals such as *Journal of School Psychology* (Volume 52, Issue 2), *Journal of Behavioral Education* (Volume 21, Issue 3), and *Neuropsychological Rehabilitation* (Volume 24, Issue 3/4). Behavior analytic studies, particularly applied behavior analytic studies, rarely make use of statistical analyses largely due to the complex methods required for SCD (Parker & Vannest, 2012). Unfortunately, it seems unlikely that fields outside of behavior analysis will embrace SCD and visual analyses (Shadish et al., 2014), although some behavior analysts are have encouraged other disciplines to consider the merits of SCD (e.g., Dallery & Raiff, 2014). Most non-behavior analytic researchers are unfamiliar with the methods and analysis of SCD, and it is nearly impossible to integrate the results of SCD studies with group design studies. Furthermore, it can be reasonably expected that funding for SCD research will eventually require power and other statistical analyses (Shadish et al., 2014). Therefore, it is incumbent upon behavior analytic researchers to find a way to communicate results in a language that is common to the larger psychological and educational research communities.

Meta-analyses provide a quantitative, statistical method of summarizing data across multiple studies that is widely accepted by the scientific community (Shadish et al., 2014). Meta-analyses are frequently used in other social science fields to identify effective, evidenced-based treatments. To conduct a meta-analysis, one needs to calculate an effect size for each study (Lipsey & Wilson, 2000). The effect size then serves as the dependent variable in the meta-analysis. A common effect size measure reported in SCD research is the percentage of non-overlapping data (PND, Scruggs, Mastropieri, & Casto, 1987) between conditions. There are at least nine overlap calculation methods (for a review, see Parker, Vannest, & Davis, 2011). More recently, researchers have introduced effect size estimates that are comparable to Cohen's *d* in group-design research (Hedges, Pustejovsky, & Shadish, 2012; 2013). Another approach is to use standardized regression coefficients, which is particularly suited to multi-level models (Van Noortgate & Onghena, 2003).

Unfortunately, several problems arise when attempting to identify an appropriate effect size for SCD studies. First, with respect to overlap methods, the statistical properties (e.g., standard error, distribution) are unknown, which can result in biased estimates (Shadish et al., 2014). Second, due to repeated measurement of the dependent variable over time, any analysis of SCD must take into account autocorrelation of the data points over time. That is, individual data points would not be expected to be independent of one another (Shadish & Sullivan, 2011). Overlap effect sizes and some other proposed effect sizes fail to address autocorrelations (Shadish et al., 2014). Third, most effect size calculations do not account for trend in the data. Analysis of trend is an essential component of visual analysis of SCD data (Kratochwill et al., 2010). Two of the nine overlap methods discussed by Parker et al. (2011) account for trend. Statistical analyses can also take trend into account. However, it is usually necessary to specify the form of the trend (e.g., linear, quadratic) in advance. If the form of the trend is not specified correctly, estimates will not be accurate (Shadish et al., 2014). Fourth, the dependent variable in behavioral studies is often a count or percentage of intervals measure (Shadish & Sullivan, 2011). Many statistical methods assume that the data are normally distributed (e.g., Hedges et al., 2012; 2013). However, a Poisson and a binomial distribution better characterize count and percentage data, respectively (Shadish & Sullivan, 2011). Fortunately, count data can often be converted into rate (e.g., responses per min), which is generally assumed to follow a normal distribution (Rindskopf & Ferron, 2014). Fifth, measurement of the dependent variable may vary across studies and participants within a study. Thus, it is necessary to standardize the dependent variable such that meaningful comparisons can be made (Baek et al., 2014). Because of these problems, methods to statistically analyze SCDs are necessarily complex. Techniques range from Bayesian statistics (e.g., Swaminathan, Rogers, & Horner, 2014) to interrupted time-series analysis (e.g., Harrington & Velicer, 2015) to multi-level modeling (e.g., Moeyaert, Ferron, Beretvas, & Van den Noortgate, 2014; Shadish, Kyes, & Rindskopf, 2013).

There are no clear guidelines for which method is most appropriate. Statisticians generally agree that overlap effect sizes should not be used in a meta-analysis until their statistical properties are better understood (Shadish et al., 2014). Bayesian methods are attractive because they can better handle smaller samples sizes and may produce more accurate parameter estimates than other methods (Shadish, Rindskopf, Hedges, & Sullivan, 2013). However, Bayesian approaches to SCDs are still a work in progress, and additional research may be necessary before such approaches can be of practical utility (Shadish et al., 2014). Interrupted time-series analyses can be beneficial because they directly account for serial dependency, a type of autocorrelation in which each data point affects subsequent data points, in the data (Harrington & Velicer, 2015). However, most behavior analytic studies do not have enough data points to detect significant effects. Interrupted time-series is typically conducted with 40 or more data points, whereas most behavior analytic studies have fewer than 30 data points (Harrington & Velicer, 2015).

Alternatively, multi-level models may be able to address many of the concerns associated with SCDs. Recently, Richman, Barnard-Brak, Grubb, Bosch, and Abby (2015) conducted a meta-analysis of noncontingent reinforcement as a treatment for problem behavior using multi-level modeling and an effect size estimate similar to that described by Hedges et al. (2012). Noncontingent reinforcement is an intervention in which a known reinforcer is delivered without regard to target behavior, and typically results in the elimination of said behavior. Although this was not the first meta-analysis of SCD research, it is likely to be among the most influential for behavior analysts because it is the first to be published in the *Journal of Applied Behavior Analysis*. Multi-level modeling can indirectly deal with autocorrelations by specifying a random-effects model (Shadish, Kyse, & Rindskopf, 2013). In addition, it is possible for the researcher to model trend. Richman et al. modeled trend using a piecewise model, but noted that each meta-analytic study should examine the best model fit for the data. Multi-level modeling can also be used with non-normally distributed data such as count or percentage measures by transforming the data (Shadish, Kyse, et al., 2013). For instance, a Poisson model uses a log link function. Thus, although there are several methods of statistically analyzing SCD, the multi-level framework seems to address many of the difficulties of doing so. Despite its advantages, multi-level modeling with a small number of participants is likely to have low power, such that researchers may fail detect an effect that is present. However, SCD researchers may be willing to accept low power because (a) effect sizes in behavior analytic studies seem to be large (Shadish, Kyse, et al., 2013) and (b) a common argument supporting the use of visual analysis is that researchers are less likely to make Type I errors even at the expense of Type II errors (Baer, 1977).

The Current Study

In the current study, we employed a multi-level model to determine the effect of DRL schedules on reducing human responding in behavior analytic studies. Specifically, we compared the spaced-responding DRL and full-session DRL schedules. Moreover, because the full-session DRL appears to be more commonly used in application, potentially because it is easier to implement, the current study aimed to determine whether and under what conditions it is appropriate to use a full-session DRL. Our analyses were not limited to a particular type of response (e.g., hand-raising); however, we included moderators such as response topography in the model. Unlike other interventions such as noncontingent reinforcement (e.g., Richman et al., 2015), DRL schedules should not necessarily reduce the target response to zero. Rather, they reduce the rate of behavior to a specified, optimal level. For example, the optimal response rate in Becraft et al. (in press) was 50% of baseline responding in a variable ratio reinforcement condition. Thus, the effect size estimates must be sensitive to this unique feature of DRL schedules. We account for this by controlling for the expected reduction from baseline. In addition to the meta-analytic analysis, we also investigated an overlap statistic: percent of zero-data (PZD; Scotti, Evans, Meyer, & Walker, 1991). PZD quantifies the percentage of data points in a treatment phase that are at zero. PZD is a nuanced overlap method that is useful when one is interested in the elimination of a target response. As previously discussed, overlap statistics are not feasible for use in a meta-analysis. Nonetheless, PZD provides additional descriptive information to support the meta-analytic results. Specifically, because a concern with full-session DRL is that desired responses may be eliminated, PZD provides a measure of response elimination. If PZD is higher for full-session DRL than spaced-responding DRL, there is evidence that full-session DRL is more likely to eliminate rather than just reduce a response. In sum, the present study addressed the following questions:

1. What are the average effects of full-session DRL and spaced-responding DRL on reducing human behavior relative to a baseline phase?
2. Do the effects of full-session DRL and spaced-responding DRL differ?

3. Do the effects of the DRLs relative to baseline vary across datasets or studies? If so, how do they vary (i.e., what potential moderators account for variation across datasets or studies)?

Method

Article Identification

Articles utilizing SCD published in journals (e.g., *Journal of Applied Behavior Analysis*, *Journal of Behavioral Education*, *Behavioral Interventions*) between 1970 and 2016 were included in the search. We used PsycINFO, PubMed, and Academic Search Complete to identify appropriate published (including dissertations) articles using the following search terms: *differential reinforcement of low rate*, *DRL*, *differential reinforcement of other behavior*, *DRO*, *response reduction*, *low rate*, *reduce behavior, Good Behavior Game, bedtime pass*. The rationale for including studies starting in the 1970s is that the first series of studies using DRL procedures to address socially significant problems with humans began around that time (e.g., Deitz & Repp, 1973; Deitz & Repp, 1974; Deitz, 1977). We also included two manuscripts submitted for publication that were conducted by the first author. The initial search yielded 285 articles.

Inclusion and Exclusion Criteria

To be included in the study, (a) participants had to be human, (b) the study must have used a SCD (c) that met experimental standards for SCD outlined by the What Works Clearinghouse (WWC; Kratochwill et al., 2010), and (d) included at least one type of DRL procedure[3]. WWC specifies that standards for SCD designs include (a)

[3] Some studies may not use the term “DRL.” Therefore, we also reviewed studies that report using differential reinforcement of other behavior (DRO) or other response

manipulation of the independent variable, (b) repeated measurement over time by more than one data collector, and (c) a minimum of three data points per phase. WWC also indicates that a SCD should have three attempted demonstrations of experimental control. For example, for a reversal design, there should be at least three phase changes between baseline (A) to treatment (B) (e.g., ABAB). However, WWC states that there may be exceptions to the demonstration guideline. We believed this criterion would have unnecessarily restricted our sample size. Therefore, we did not exclude studies on the basis of number of attempted demonstrations of control. In addition, after coding articles, we further excluded studies that used multi-element designs or that measured the outcome as a percentage of intervals. Multi-element designs comparing a baseline and DRL condition could not be included in the same multi-level model as other designs because the model was based on a phase change from baseline to treatment. Articles using percentage of interval could not be included because percentage data fall on a different distribution than count or rate data. Any study that did not meet the other above specific criteria was excluded from further data analysis.

Coding Categories

Articles were coded for number of datasets, measurement procedures, target response, study purpose, study design, DRL type, signals, DRL parameters, consequence provided, and contingency type. We also coded basic demographic variables including age, sex, and diagnosis/developmental level of participants. The coding data sheet and instructions for data collectors are provided in Appendix A.

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reducing procedures. Regardless of the name, any procedure that described a DRL contingency satisfied this requirement.

Number of datasets. The number of datasets was scored as the number of SCD figures of the dependent variable that were included in the study. In some cases, this was equal to the number of participants. However, this number may have varied from the number of participants if only a subset of participant data were shown or the data were graphed as group data (e.g., an entire classroom). In addition, some participants experienced the intervention across multiple topographies of behavior or in multiple settings. However, for the datasets to be independent of one another, only one dataset per participant was permitted in the analysis. Therefore, we randomly selected one dataset per person. We also scored whether the dataset included individual (one person) or group scores. Because some datasets did include group scores, we refer to each set of data as a dataset as opposed to a participant or subject.

Measurement. Categories of measurement procedures for the dependent variable targeted in the DRL intervention were frequency, rate, inter-response time, percentage of intervals, duration, or percentage duration. Frequency was selected if the dependent variable was measured as a count (total number of responses). Rate was selected if it was measured as the number of responses per unit time (e.g., responses per min). Inter-response time was selected if it was measured as the mean amount of time in between target responses. Frequency, rate, and inter-response time data were converted into a common rate metric: responses per min. Percentage of intervals was selected if the dependent variable was measured using an interval (e.g., partial-interval recording) or time-sampling method, and it was graphed as the percentage of intervals in which the behavior was occurring. Duration was selected if the dependent variable was measured as the amount of time the behavior occurred. Percentage duration was selected if the dependent variable was measured as the percentage of time the behavior was happening per observation. No study used duration of percentage duration.

Target response. The target response was an open-ended description of the response topography of the dependent variable. Data collectors wrote-in the topography (e.g., hand-raising) based on the article's description. Because we expected some variability in the target responses, it was not possible to create *a priori* categories. After coding, we categorized the target responses as either applied (socially-meaningful, e.g., aggression) or arbitrary (not socially-meaningful, e.g., mouse clicks).

Study purpose. Study purpose was coded into one of four categories: to (a) eliminate the target response, (b) to reduce but *not* eliminate the target response, (c) to maintain baseline levels of the target response, and (d) or not enough information to determine. We did not include a category in which the purpose was to increase the target response because we did not find it plausible that one would use a DRL to increase behavior. Ultimately, very few studies explicitly described the study purpose in such a way that allowed for meaningful categorization. That is, most studies simply stated the purpose as to determine the effect of the DRL schedule. Thus, this variable was not used in any analyses.

Design. Designs were categorized as an AB design if there was one baseline (A) and one DRL (B) phase. Designs were considered a reversal design if a baseline phase alternated with a DRL phase at least one time with three or more data points in each phase (e.g., ABA). Designs were categorized as a multiple baseline if the introduction of the DRL phase was staggered across participants and/or settings and/or responses and there was no reversal to baseline. Designs were considered a multi-element if there was an alternation between a DRL condition and the baseline condition. The design category was based on the baseline and DRL phase(s) only. That is, the relevant comparison was the DRL condition(s) to the baseline phase. If the study included other conditions, those conditions were ignored in determining the design. If more than one design were used for the baseline and DRL phases, all designs were coded. Designs that did not meet any of the criteria above would have been categorized as other, but all studies met one of the above criteria.

DRL type. The DRL was coded as a spaced-responding DRL if every response reset the interval and reinforcers were provided only following a response that occurred after the inter-response time elapsed. A full-session DRL was recorded if a reinforcer was provided if a certain number of responses or fewer could occur in the entire session duration. An interval DRL was recorded if a reinforcer was provided if a certain number of responses or less could occur in distinct intervals within a session. Because only a handful of studies used an interval DRL, interval and full-session DRLs were collapsed into one category of full-session DRL. If more than one type of DRL was used, the study was coded as including all that were used as long as there were sufficient data points and the study met other inclusionary criteria for both DRL types. If only one DRL type met the criteria, then only that DRL type was selected.

Signals. Articles that included unique signals indicating when responses would and would not be reinforced during the DRL schedule(s) were coded as using signals. Signals could be visual stimuli like different colors that were associated with reinforcement and no reinforcement. Signals could also be verbal rules (e.g., “you may ask for my help two times”) or tactile stimuli (e.g., vibration) that were associated with a change in reinforcement contingencies. Those that did not use signals were coded as not using signals. If some parts of the study used signals and others did not, the study was coded as both as long as there were sufficient data points and the study met other inclusionary criterion for both signals and no signals. The type of signals was also specified. We created three categories based on the types of signals recorded: signals with rules, signals with no rules, and no signals. Signals that included rules involved specific information about the DRL schedule parameters (e.g., the interval size, the tolerance). For example, a specific rule might be, "You need to wait at least 1 min before asking for attention again." Signals without rules did not have specific parameter information, but could include more general rules (e.g., "you should wait before asking for attention again"). Dummy codes were created to analyze this categorical variable.

DRL parameters. The interval size used in the DRL procedure was recorded for both types of DRL procedures. In addition, for the full-session DRL condition, the number of responses permitted in each interval was recorded. The DRL parameters were used to calculate an optimal response rate for each dataset. In some interventions, the interval size or number of responses permitted changed as the reinforcement schedule was thinned. We recorded the initial schedule values selected for the intervention. In addition, we recorded the session number at which changes to the initial schedule began. When extracting the data (described below), data after the parameter change were not included in the data analysis because the changing values would likely cause a systematic change in the level of the target response. That is, if the interval size in a spaced-responding DRL was made larger, one would expect response rate to decrease. Thus, it would be difficult to determine the effect of the DRL intervention because it would depend on interval size. Although statistical techniques can model this interaction, the purpose of the current study was to compare the two DRL procedures more generally.

Consequence provided. The reinforcer earned in each DRL schedule was identified as functional if it was the same reinforcer provided in baseline. The reinforcer was identified as nonfunctional if it was not the same reinforcer provided in baseline. If both functional and nonfunctional reinforcers were used, the study was coded as both. For example, if participants earned points for responses in both baseline and the DRL, the study was coded as functional (e.g., Jessel & Borrero). If, however, the participant received escape for responses in baseline, but earned tokens that could be exchanged for a choice of back-up reinforcers in the DRL, the study was coded as nonfunctional (e.g., Alderman & Knight, 1997). If the participant received attention for responses in baseline, and both attention and a sticker in the DRL phase, the study was coded as both (e.g., Becraft, Borrero, Mendres-Smith et al., 2016). For analysis purposes, we included studies that used both as using the functional reinforcer.

Contingency type. The contingency was coded as an individual contingency if the intervention and reinforcers earned were only applied to one participant. A group contingency was coded if the intervention and/or the reinforcers provided were applied to more than one person. Group contingencies were further divided into independent, dependent, and interdependent contingencies. In an independent contingency, access to the reinforcer is dependent on each individual's behavior but the entire group has the same intervention in place. In a dependent contingency, group access to the reinforcer is dependent on the behavior of a subset of individuals. In an interdependent contingency, the entire group must meet some criterion as a group to earn a reinforcer. We also recorded whether or not the Good Behavior Game was studied, which uses a full-session DRL but does not typically name it as such.

Articles Included in Data Analysis

Of the initial 285 articles, 216 articles were excluded after the first screening (45 did not use a SCD, 169 did not use or isolate a DRL condition, and two were duplicate articles). After coding the remaining 69 articles, an additional 16 articles were excluded because the data were not graphed in a comparable format (e.g., displayed mean responding instead of individual session data points), six were excluded because the data could not be extracted from the study figures due to poor quality of the image, five were excluded for using a multi-element design, and 10 were excluded for measuring the outcome as percentage of intervals. The final number of included articles in the analyses was 32 for a total of 187 unique AB pairs for analysis.

Data Extraction

Data from each article that met the criteria for inclusion in the meta-analysis was exported into separate image files for each figure. The images were loaded into UnGraph (BioSoft, 2014). Once the images were imported into UnGraph, the data collector identified sets of known coordinates on the figure (e.g., 0 on the *y*-axis and 0 on the *x*-axis). When basic coordinates were identified, the program can then determine the coordinates of the remaining data paths on the figure. Shadish et al. (2009), which established the reliability and validity of this method, provide more details about the procedure for extracting data using UnGraph. Extracted data of the *x* (observation or session number) and *y* (dependent variable value) were imported into Excel. Data collectors transferred this information to a spreadsheet that included the other coded information about each particular case (e.g., DRL type). Because the *x* values are observation or session numbers, they should be whole numbers. Other researchers using this method have noted that the extraction process sometimes yields a value that is slightly higher or lower than a whole number (Richman et al., 2015). Therefore, data collectors rounded the *x* values to the nearest whole number. If the value was more than 0.1 above or below a whole number, the coordinates were re-identified in UnGraph and the data were extracted again. No such rounding was applied to the *y* values.

Interobserver Agreement

A second data collector independently coded 31.9% of the articles for all coding categories and independently extracted data from 21.3% of articles. Agreement was calculated on a point-by-point basis for coding the articles on the aforementioned coding categories. An agreement (value of 1) was scored if both observers assigned the exact same code within each category for an article. A disagreement (value of 0) was scored if they did not agree. The number of agreements was divided by the number of disagreements plus agreements and multiplied by 100 to yield a percentage. Initially, mean agreement across all categories was 80.0% (range, 33.3% to 100.0%). Due to low agreement on several key categories (DRL type, signals, consequence provided), we reviewed and clarified the definitions, and rescored the coding categories for all articles. Mean agreement increased to 92.8% (range, 83.3% to 100%) after recoding. For data extraction, the point-by-point method was also used to assess agreement of the *x*-values. To evaluate agreement for the *y*-values, we used proportional agreement. For each *y*-value, the two data collectors' recorded value was compared. If both observers recorded the same value, an agreement of 1 was recorded. For all other situations, the lower value was divided by the higher value. These proportions were averaged across *y*-values and multiplied by 100 to yield a percentage. Richman et al. (2015) used identical agreement methods. However, the authors noted that proportional agreement for the *y*-values may result in very low agreement when the level of behavior is low (e.g., one data collector extracts 0.1 and the other extract 0.2). Thus, we also compared *x* and *y* coordinates with a Pearson correlation. Mean agreement for the *x* values was 100% and for the *y* values was 90.7% ($r = .99$).

Data Analysis

Prior to the meta-analysis, all dependent variables from the studies needed to be measured on the same metric. As previously stated, we only included articles that measured the outcome as a rate or count, and we converted all data to responses per min. We converted all count data to rate by dividing each *y* value by its respective session duration in min. We converted inter-response time data to rate by dividing 60 by the inter-response time in seconds. Rate data that were not already measured as responses per min were also converted to responses per min (e.g., 60 responses per hr was converted to 1 response per min). We further standardized raw rate data to make them comparable across studies by following the procedure described below.

First, a regression model as shown in Equation 1 was analyzed for each individual:

$$\text{BEHAVIOR}_{tis} = \pi_{0is} + \pi_{1is}\text{TIME}_{tis} + \pi_{2is}\text{PHASE}_{tis} + \pi_{3is}\text{TIME}_{tis}\text{PHASE}_{tis} \quad (1)$$

BEHAVIOR is the predicted level of the target response for a given individual (*i*) at a given time point (*t*) in a given study (s). TIME is the observation or session number. For interpretative purposes, the time variable is centered at the last session of baseline before the DRL intervention began. Thus, the coefficient π_{0i} represents the value of the dependent variable during the last baseline session. The coefficient π_{1i} represents the rate of change over time during baseline. PHASE is a dummy-coded variable for the treatment phase (baseline = 0, DRL = 1). The coefficient π_{2i} represents the difference between baseline and DRL phases, which reflects the immediate effect of DRLs. The coefficient π_{3i} represents the difference in rates of change between baseline and DRL phases, which reflects the effect of DRLs on rate of change (i.e., the interaction of time and phase).

The slopes of interest are the immediate effect of phase (π_{2i}) and the effect on rate of change (π_{3i}). We then standardized the slopes and obtained their variances (Van den Noortgate & Onghena, 2003). Specifically, the standardized effect was obtained by using Equation 2:

$$g^* = \left(\frac{\pi}{\sqrt{MSE}}\right)\left(1 - \frac{3}{\left[4(o-2)-1\right]}\right), \tag{2}$$

where π is the slope of interest, s_π is the standard error of the slope, MSE is the mean squared error from the regression model in Equation 1, and o is the number of observations per individual. The variance of the standardized effect (v) was calculated using Equation 3:

$$v^* = \left(\frac{s_\pi^2}{MSE}\right)\left(1 - \frac{3}{\left[4(o-2)-1\right]}\right). \tag{3}$$

Once the effects of interests were standardized, a three-level model in metaSEM (Cheung, 2015) in R 3.3.2 was used to meta-analyze the immediate effect and the effect on rates of change, respectively. The level 1 model expressed each standardized effect per individual as the true effect plus its sampling error, as shown in Equation 4:

$$g^{*}_{is} = \beta_{is} + e_{is}, \tag{4}$$

in which g^{*}_{is} is the standardized effect (i.e., either immediate effect or effect on rates of change) for dataset (*i)* within study (*s)*, β_{is} is the true effect for each dataset, and e_{is} is the sampling error.

The second level of the model analyzed the degree of variance across individual datasets within each study using the standardized effects, as shown in Equation 5:

$$\beta_{is} = \theta_{0s} + u_{is}, \tag{5}$$

in which θ_{0s} is the average effect within each study and u_{is} is the residual term (i.e., random effect), which represents the deviation of each dataset's effect β_{is} from the average effect of study.

The third level analyzed the degree of variance across studies, as shown in Equation 6 below:

$$\theta_{0s} = \lambda_{00} + v_{0s}, \tag{6}$$

in which λ_{00} is the average effect of all included studies and v_{0s} is the residual term (i.e., random effect), which represents the deviation of each study's effect θ_{0s} from the average effect.

The above model was based on datasets that have two phases: a baseline (A phase) and DRL (B phase). Thus, we only included one AB pair from each dataset (Shadish et al., 2012). This included all data from a multiple-baseline design, but only included the first A and B phases from a reversal design. It is possible to include step-coded variables to account for additional A and B phases (Shadish et al., 2013); however, because not all studies included additional phases or the same number of phases, we could not include additional phases in the same model.

Separate meta-analyses were conducted for the spaced-responding DRL and full-session DRL. This allowed us to compare baseline to each DRL separately. Because some studies included more than one type of DRL schedule, we could not compare them in the same analysis. We then compared the effects obtained in the two meta-analyses. Because we used standardized effects, the estimates from the models of each DRL type were directly comparable. As a secondary analysis, we removed the three studies that used both types of DRL schedules, and ran one analysis of the remaining data using DRL type as a moderator to directly compare the DRL conditions in the same analysis.

In addition, to determine whether either DRL schedule reduced the target behavior more than what would be expected based the optimal response rate of the DRL schedule, we included the expected proportional reduction from baseline as a covariate. The optimal response rate was divided by the mean baseline rate of responding for each dataset. This value was subtracted from 1 to yield the expected proportional reduction. For example, if the baseline rate was 10 responses per min, and the optimal response rate was 1 responses per min, the expected reduction would be .90. If the effect of phase was significant after controlling for the expected reduction, this suggests that the DRL intervention reduces responding above and beyond what would be expected. Thus, it may suggest whether one or both types of DRL schedules are more likely to eliminate responding.

We also explored potential moderators in each analysis to determine if the effect of either type of DRL schedule varied across certain characteristics of datasets and studies. Age, diagnosis, and contingency type (dataset-level variables) were added to the second level. We also planned to investigate the moderating effect of sex, but a majority of studies either did not report sex or the dataset consisted of multiple participants of different sexes. Target response topography (applied or arbitrary), the type of signals (no signals, signals with rules, or signals without rules), and whether or not the reinforcer was functional (study level variables) were added to the third level of the model.

A second effect size estimate, PZD (Scotti et al., 1991) was also calculated. To calculate PZD, we (a) identified the first data point in an intervention at zero and (b) calculated the percentage of data points thereafter that were at zero. If no intervention data points were at zero, we assigned the PZD value as zero. PZD allowed us to compare whether a full-session DRL was more likely to eliminate responding than a spaced-responding DRL. Because the standard errors are unknown, PZD cannot be meta-analyzed. Nonetheless, it provides more descriptive information about whether a full-session DRL is more likely to eliminate the target response than a spaced-responding DRL.

Overall, the analyses identified and compared (a) the frequency with which each procedure was used, (b) characteristics of each procedure (e.g., response type), (c) mean effect sizes for reductions in the target response that are obtained using each procedure, (d) the degree to which effect sizes varied across datasets and studies, and (e) differences in effect sizes based on the characteristics of the dataset or study (e.g., age, diagnosis, signals, contingency type).

Results

Description of Included Articles

The final sample was 32 articles. Table 7 shows study-level information about each article, and Table 8 shows dataset-level information. The full-session DRL was more common (24 articles) than the spaced-responding DRL (12 articles). Four articles (Becraft et al., in press; Becraft, Borrero, Mendres-Smith et al., 2016; Deitz, 1977; Jessel & Borrero, 2014) used both types of DRL schedules. As displayed in Figure 17, there were several notable differences in study characteristics between the types of DRL schedules. The full-session DRL was more likely to target an applied response, use signals (specifically signals with rules), use a reinforcer different than the reinforcer during the intervention (nonfunctional reinforcer, and use a group contingency than the spaced-responding DRL. In addition, nearly all (11/13) full-session DRLs that used a group contingency involved the Good Behavior Game intervention. Furthermore, across both DRL types, of the 27 studies that targeted an applied response, 24 used signals. Overall, these initial descriptive data confirm that the full-session DRL is more common in application than the spaced-responding DRL and that signals are typically used in application.

PZD

PZD effect size estimates were calculated for all 187 datasets included in the final analysis. All spaced-responding DRL datasets had a PZD value of zero, indicating that it was highly unlikely to eliminate responding. There was more variability for the full-session DRL (M = 16.65%, SD = 33.83%). These results suggest that the full-session DRL is more likely to lead to response elimination than a spaced-responding DRL. Importantly, however, PZD was zero for 79 of 101 (78.22%) full-session DRL datasets, indicating that it frequently did not lead to response elimination. Figure 18 displays the percentage of datasets with PZD values that were zero, between 1-20, 21-40, 41-60, 61-

80, and 81-100. Thus, although it appears more likely to eliminate behavior than a spaced-responding DRL, it does not do so in the majority of cases.

Full-Session DRL

There were 24 studies consisting of 101 datasets using a full-session DRL. Results of the multi-level analysis are shown in Table 9. There was a significant immediate effect of phase (λ_{00} = -4.84, *z*= -5.20, *p* < .001), indicating that response rate was nearly 5 standard deviations lower in the full-session DRL phase than in baseline. This effect remained significant after controlling for the expected proportional reduction (λ_{00} = -4.82, *z*= -2.55, *p* = .01). There existed significant heterogeneity among immediate effects (*Q* = 4167.37, *df* = 100, *p* < .001). The immediate effects varied significantly across datasets (τ_2^2 = 41.97, *z*= 6.60, *p* < .001), which explain about 87% of the variation. However, the immediate effects did not vary across studies (τ_3^2 = 5.02, z = 1.63, *p* = .10), which explain only about 10% of the variation. Thus, these results show that there is a reduction from baseline to the full-session DRL that is independent of the expected reduction determined by the schedule parameters, and there is significant variability in the magnitude of that effect across datasets.

There was also a significant effect on rate of change (λ_{00} = -0.53, *z* = -2.93, *p* = .003) such that there was an increasing trend in response rate in baseline and a slight decreasing trend in the DRL phase. There was significant heterogeneity among the effects (*Q* = 1051.17, *df* = 100, *p* < .001). The effects varied significantly across datasets (τ_2^2 = 1.65, *z* = 5.41, *p* < .001), which explain about 90% of the variation. However, the effects on rate of change did not vary across studies (τ_3^2 = 0.16, z = 1.36, *p* = .17), which explain about 8% of the variation.

Moderator analyses were then conducted to explore dataset and study characteristics that may explain the variability of effect sizes. There was no significant interaction of age, disability, or contingency type on the effect of phase. There was a significant interaction of target response type, such that the effect of the DRL was 6.55 standard deviations greater when the target response was applied rather than arbitrary. There was also a significant interaction effect of whether the reinforcer was functional, such that the effect of phase was 5.59 standard deviations greater when the reinforcer was not the same reinforcer that was used in baseline. Furthermore, there was a significant effect of signal type. Signals with rules significantly reduced responding by 6.53 standard deviations more than signals without rules. No signals reduced responding more than signals without rules and less than with rules, but was not significantly different from either. These interaction effects remained significant and in the same direction after controlling for the expected percentage reduction.

Spaced-Responding DRL

There were 12 studies consisting of 86 datasets using a spaced-responding DRL that measured the outcome as a rate. Results are presented in Table 10. Similar to the full-session DRL, there was a significant immediate effect of phase (λ_{00} = -8.76, z = -2.39, p = .02), indicating a reduction of nearly 9 standard deviations from baseline to the DRL condition. After controlling for the expected proportional reduction from baseline, the immediate effect was not significant (λ_{00} = -5.83, z = -0.92, p = .36). There existed significant heterogeneity among immediate effects (Q = 29159.62, df = 85, p < .001). The immediate effect varied significantly across datasets (τ_2^2 = 546.46, z = 6.38, p < .001), which explains approximately 93% of the variation, but not across studies (τ_3^2 = 39.79, $z(83)$ = 1.14, p = .25), which explains about 7% of the variation.

The magnitude of the uncontrolled immediate effect was slightly larger for the spaced-responding DRL than it was for the full-session DRL, indicating a larger reduction for the spaced-responding DRL. However, after controlling for the expected percentage reduction from baseline, the magnitude of the effect was smaller than the full-session DRL and not significant. Thus, for the spaced-responding DRL, the reduction from baseline to the DRL condition can be explained by the specific parameter values that were arranged. Notably, because the confidence intervals of the effects for the spaced-responding and full-session DRL overlap (95% CIs [-8.52, -1.12] and [-18.25, 6.59], respectively), the difference between them is likely not significant.

There was also a significant effect on rate of change in which there was an increasing trend in baseline and a decreasing trend in the DRL phase (λ_{00} = -0.86, z = -2.87, p = .004). There was significant heterogeneity of the effects (Q = 1007.64, df = 85, p < .001). The effects of rate change varied significantly across datasets (τ_2^2 = 3.35, z = 5.56, p < .001), accounting for approximately 91% of the variation. The effects did not vary across studies (τ_3^2 = 0.27, z = 1.06, p = .29), accounting for 7% of the variation.

Moderators were also explored for the spaced-responding DRL. Several moderators (contingency type, functional) were constant across datasets and therefore not analyzed. Signal type was the only significant moderator. No study used signals with rules. The reduction from baseline was 14.75 standard deviations greater when no signals were used than when signals without rules were used in the spaced-responding DRL.

Comparison of DRL Types

To compare the DRL types in the same analysis, we excluded three articles[4] that included both types of DRL conditions for a total of 29 articles and 103 datasets. There was a significant overall immediate effect of phase across both DRL types (λ_{00} = -5.28, z = -3.16, p = .002). The immediate effects varied significantly across datasets (τ_2^2 = 15.09, z(199) = 6.01, p < .001), but not studies (τ_3^2 = 1.19, z(199) = 0.80, p = .424). However, there was no significant difference in the effect of the intervention between the DRL types (z = 0.82, p = .41). Thus, both DRL types reduced target responding by approximately the same amount, consistent with the separate analyses of each DRL type.

Discussion

We summarized and synthesized the effects of DRL schedules with humans during a nearly 50 year period. Although most studies involving DRL schedules only applied one type of DRL arrangement, a quantitative synthesis of the literature allowed us to make comparisons between the two procedures. Regarding our primary research questions, we found that, unsurprisingly, both DRL procedures significantly reduced target responding relative to baseline. Further, the effects of the DRL procedures did not appear to significantly vary from one another. In addition, we identified the type of response, the type of reinforcer, and the type of signals as potential study-level moderators.

Comparison of DRL Procedures

There were general differences in study characteristics across the DRL types. Importantly, the full-session DRL was more common than the spaced-responding DRL in

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[4] Deitz (1977) was not excluded because each participant only experienced one DRL type. The other articles using both types of DRL procedures were excluded because they used both DRL procedures with each participant. Thus, including those participants would violate the assumption that the dependent variable values were independent.

application. Thus, for practitioners, it is important to fully understand the full-session DRL and its effects on behavior. That is, practitioners should be aware of the conditions under which the full-session DRL may or may not eliminate behavior.

The overall meta-analytic results show little difference between the DRL procedures. Confidence intervals of the effects overlapped even when controlling for the expected reduction from baseline suggesting no difference between them, and there was no differences in the combined analysis of both procedures. Nonetheless, the full-session DRL may have reduced target responding more than the desired reduction from baseline as evidenced by a significant immediate effect after controlling for the expected proportional reduction, which was not found for the spaced-responding DRL. Moreover, the PZD results suggest that elimination was more common for the full-session DRL. A likely reason that no statistically significant difference was found between the two DRL procedures in spite of this evidence is the large amount of variability observed across datasets. There was no evidence of response elimination in a majority of full-session DRL datasets. However, for 11 datasets, PZD values were between 80 and 100%, indicating response elimination. In addition to statistical significance, interpretation of SCDs also should consider clinical significance (Dallery & Raiff, 2014). For these data, results may be clinically relevant for the 11 datasets for whom PZD values were 80% or higher. Further inspection of those data sets shows they came from four studies, three of which used signals with specific rules. Thus, if practitioners do not want to eliminate a response, we recommend that specific rules about DRL parameters not be provided.

Implications of Moderator Effects

For this initial review of DRL procedures, we wanted the inclusion criteria to be as broad as possible so that we could comprehensively compare the two DRL procedures. Results showed that the effects varied significantly across datasets but not across studies. As such, we accounted for some of the variability in datasets by including moderators to the extent possible.

Because one concern about the full-session DRL is that it may eliminate desirable behavior, it is useful to understand these moderating effects particularly for the full-session DRL. No data-set level moderators significantly impacted the effect of either DRL condition. In other words, specific characteristics of individual participants (or groups when graphed together) did not seem to impact the effect of the DRL. Thus, the DRL effects were consistent across age, whether or not there was a developmental disability diagnosis, and contingency type. However, several study-level moderators did have an effect. Specifically, whether the response was arbitrary or applied, whether the reinforcer was functional, and the type of signals moderated the effect of the full-session DRL. Applied responses had greater effect sizes than arbitrary responses. Although this does not necessarily indicate that applied responses are eliminated, the effect was still significant after controlling for the expected proportional reduction from baseline. Thus, responding is reduced by more than the desired criterion level in the full-session DRL. Unfortunately, this information does not provide useful guidelines for how to arrange the full-session DRL because practitioners will likely target an applied response. Rather, it may indicate that translational investigations of the full-session DRL schedule may not fully model the schedule as it is used in practice. If experimental analogs using arbitrary responses produce different effects than an applied studies, then the analogs may not be capturing something about how the schedule is operating in application.

The second moderating effect, whether the reinforcer was functional, may inform practice. The reductive effect was greater when a nonfunctional reinforcer was used. For example, in Alderman and Knight (1997), one participant (T.J.) engaged in problem behavior to escape a hygiene task. During the full-session DRL intervention, T.J. earned tokens that he could exchange for a variety of back-up reinforcers, including phone calls to his wife. Thus, the reinforcer for T.J. was not functional by our definition. For other datasets, when a functional reinforcer was used, there was less of an effect (i.e., responding was reduced by less than with a nonfunctional reinforcer). Thus, practitioners may consider using a functional reinforcer in the full-session DRL, particularly if response elimination is unwanted.

Similarly, the third moderating effect, types of signal, may have implications for practice. Results showed that signals that included specific rules about the DRL contingency (e.g., how many responses could be made in each interval) reduced behavior the most, no signals the second most, and signals without rules the least. These results are consistent with what we would expect. Specific rules in the full-session DRL may lead to lower rates of responding because the individual is told that he or she does not need to engage in any responses and will still earn the reinforcer. Further, with no signals at all, one may expect slightly lower rates of responding because responding resets the interval, thereby delaying reinforcement. Signals without specific rules may reduce behavior the least because the signals provide guidelines about when to respond and when not to respond and do not specifically tell individuals that zero responses are acceptable. These findings are also consistent with the spaced-responding DRL results in which no signals produced a greater reduction in behavior than signals without rules. In application, if a large reduction is not desired, this suggests that signals without specific rules should be used because they appear to maintain criterion-level responding the best. However, it is important to note that only two studies included signals without rules in the full-session DRL, both of which were conducted by the first author of this paper. Thus, independent corroboration of the effect of signals without rules is warranted.

Practitioners may also consider the use of the full-session DRL to eliminate an unwanted problem behavior. Several studies in this review targeted responses that clinicians would likely prefer to eliminate (e.g., aggression, swearing, talking out in class). If the goal is to eliminate the target response, the results of the current study suggest that using a nonfunctional reinforcer and specific rules about the DRL parameters (i.e., interval size and tolerance) may produce a larger reduction. However, importantly, we only included the initial treatment effect in our analyses. We did not include any reversals or scheduling thinning, which may show further suppression of behavior. For example, Watson and Heindl (1996) used a full-session DRL to reduce a psychogenic cough. The number of allowable responses per session was initially set fairly high (i.e., 30) and was systematically reduced. As the number of allowable responses per interval was decreased, behavior decreased, and eventually was eliminated. Thus, in this way, the full-session DRL can be thinned into a DRO schedule. Future research may further analyze schedule thinning for full-session DRLs to determine how quickly to thin the schedule and at what point in thinning there may be an elimination of the target response.

Other Methodological Considerations

Although we used broad search criteria we may still have omitted studies that procedurally used DRL schedules, but do not label them as such. Most notably, contingency management interventions (e.g., Dallery, Meredith, Jarvis, & Nuzzo, 2015; Silverman, Svikis, Robles, Stitzer, & Bigelow, 2001) could be characterized as full-session DRLs, at least initially. Typically, the aforementioned contingency management studies are described as DRO schedules because a reinforcer is provided for the absence of the target response (e.g., drug use, smoking). However, often, there is a tapering feature to the intervention. For instance, Dallery et al. (2015) had a 4-day tapering condition in which a monetary voucher was provided if a participant's CO_2 level was at or below the participant's goal. The goal was lowered each day until the CO_2 level was indicative of the absence of smoking. In the current study, we chose not to include contingency management studies as full-session DRLs because the reinforcer is provided based on a permanent product, rather than the observed response. Nonetheless, as our understanding of the DRL literature is established and refined, including contingency management research as a variant of the DRL may be advisable.

Because several studies used both DRL procedures with the same participants, we had to conduct one analysis for each DRL type. It would have been ideal to include all studies in a single analysis to compare the effects of the DRL types. However, standardized effects allowed us to directly compare the parameter values and confidence intervals across the analyses. Further, we excluded 15 studies that either measured the outcome as percentage of intervals or used a multi-element design but otherwise met the inclusion criteria. We conducted separate analyses for these two types of studies, and both indicated non-significant differences between the DRL types (see Appendix B).

Implications for Analysis of SCD

Overall, the current investigation not only provides a comprehensive comparison of DRL schedules with humans, but also advances analytic methods for single-case designs. Statistical analyses in general and meta-analyses specifically are uncommon in behavior analytic work. The current study is beneficial to behavior analysis in two ways. First, it provides a method to analyze SCDs that can be emulated in subsequent behavior analytic research syntheses. Second, because we used a method that is widely accepted by the scientific community to meta-analyze the data, researchers outside of behavior analysis may be more likely to contact this research and future research. Behavior analytic interventions, although highly effective based on SCD standards proposed by Kratochwill et al. (2010), are often not considered by non-behavior analysts because of unfamiliarity with SCDs and visual analysis. We may think of meta-analysis, broadly defined, as a common currency by which interventions grounded in behavioral principles may be interpreted and independently assessed by scientists beyond the behavior analysis research community.

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Table 7

Study-level information About Each Study Included in the Meta-Analysis

Article	Data sets	Data display	Target response	DRL type	Sig	Func	Cont. type
Alderman & Knight (1997)	2	IND	*Problem behavior*	F	Rul	No	IND
Anglesea, Hoch, & Taylor (2008)	3	IND	*Eating*	S	Oth	Yes	IND
Austin & Bevan (2011)	3	IND	*Attention bid*	F	Rul	Yes	IND
Becraft, Borrero, Davis, Mendres-Smith, & Castillo (in press)[a]	29	IND	Mouse clicks	F, S	Oth	Yes	IND
Becraft, Borrero, Mendres-Smith, & Castillo (2016)[b]	3	IND	*Attention bid*	F, S	Oth	Yes	IND

Article	Data sets	Data display	Target response	DRL type	Sig	Func	Cont. type
Bird, Hepburn, Rhodes, & Moniz (1991)	1	IND	*Inapprop. verbal behavior*	F	Rul	No	INT
Bostwick (1977)	1	IND	Key press	S	No	Yes	IND
Buskist & Morgan (1987)	4	IND	Lever presses	S	No	Yes	IND
Deitz (1977) Exp 1[c]	3	IND	*Disruptive behavior*	S	No	Yes	IND
Deitz (1977) Exp 2[c]	2	IND	*Disruptive behavior*	F	Rul	No	IND
Deitz & Repp (1973)	3	BOTH	*Disruptive behavior*	F	Rul	No	IND, INT
Deitz, Repp, & Deitz, (1976)	2	BOTH	*Disruptive behavior*	F	Rul	No	IND, INT
Donaldson, Wiskow, & Soto (2015)	5	GRO	*Disruptive behavior*	F	Rul	No	INT

Article	Data sets	Data display	Target response	DRL type	Sig	Func	Cont. type
Donaldson, Vollmer, Krous, Downs, & Berard (2011)	5	GRO	*Problem behavior*	F	Rul	No	INT
Echeverria & Miltenberger (2013)	2	IND	*Eating*	S	Rul	Yes	IND
Haas & Hayes (2006)	20	IND	Button presses	S	No	Yes	IND
Hagopian, Kuhn, & Strother (2009)	1	IND	*Inappropr comments*	F	Rul	No	IND
Hartman & Gresham (2016)	3	GRO	*Disruptive behavior*	F	Rul	No	INT
Jessel & Borrero (2014)	10	IND	Clicks	F, S	No	Yes	IND

Article	Data sets	Data display	Target response	DRL type	Sig	Func	Cont. type
Joslyn, Vollmer, & Hernandex (2014)	3	GRO	*Disruptive behavior*	F	Rul	No	INT
Kosiec, Czernicki, & McLaughlin (1986)	3	BOTH	*Inapprop. vocalization*	F	Rul	No	INT
Kostinas, Scandlen, & Luiselli (2001)	1	IND	*Inapprop. vocalizations*	F	Rul	No	IND
Kroger-Costa & Abreu-Rodrigues (2012)	7	IND	Key presses	S	No	Yes	IND
Lennox, Miltenberger, & Donnelly (1987)	3	IND	*Eating*	S	No	Yes	IND

Article	Data sets	Data display	Target response	DRL type	Sig	Func	Cont. type
McCurdy, Lannie, & Barnabas (2009)	3	GRO	*Disruptive behavior*	F	No	No	INT
Medland & Stachnik (1972)	8	BOTH	*Disruptive behavior*	F	Rul	No	INT
Ruiz-Olivares, Pino, & Herruzo (2010)	2	GRO	*Disruptive behavior*	F	Rul	No	INT
Salend, Reynolds, & Coyle (1989)	3	GRO	*Disruptive behavior*	F	Rul	No	INT
Shaw & Simms (2009)	3	IND	*Disruptive behavior*	F	Rul	No	IND
Sy, Gratz, & Donaldson (2016)	4	GRO	*Disruptive behavior*	F	Rul	No	INT

Article	Data sets	Data display	Target response	DRL type	Sig	Func	Cont. type
Turner, Green, & Baunling-McMorrow (1990)	1	IND	*Problem behavior*	F	Rul	No	IND
Watson & Heindl (1996)	1	IND	*Coughing*	F	No	No	IND
Wright & Vollmer (2002)	1	IND	*Eating*	S	Oth	Yes	IND

Note. Datasets = number of datasets meeting inclusion criteria, Data display = whether data are displayed as an individual person (IND) or group of people (GROUP), target response = the response targeted in the intervention (responses that are italicized were considered applied responses; non-italicized are arbitrary responses), DRL type = full-session DRL (F) or spaced-responding DRL (S), Sig = signals with rules (Rul), signals without rules (Oth), or no signals (No), Func = the reinforcer was the same as baseline (Yes) or not the same (No), Cont. type = individual (IND) or interdependent group (INT) contingency.

[a] 19 datasets were pilot data not included in the final manuscript submission

[b] Manuscript submitted for publication

[c] Separated into Experiment 1 and Experiment 2 because different DRL types across participants

Table 8

Dataset Characteristics

Category	N
DRL type	
Full-session	59
Spaced-responding	44
Both types	42
Age (M = 15.57)	
< 5 years	24
6 – 10 years	26
11 – 15 years	13
16 – 20 years	61
21 – 25 year	9
> 25 years	8
Not reported	4
Sex	
Male	34
Female	28
Not reported	83
Intellectual/Developmental Disability	
Yes	36
No	109

Category	N
Contingency type	
Individual	102
Group	43
Target response type	
Applied	74
Arbitrary	71
Reinforcer type	
Functional	89
Not functional	56
Signal type	
Signals with rules	55
Signals without rules	38
No signals	52

Table 9

Multi-level Analysis Results for Full-Session DRL

	Immediate Effect of Phase		Effect on Rate of Change	
Effect	**Estimate**	**CI**	**Estimate**	**CI**
Average Effect (λ)	-4.84***	-6.66, -3.01	-0.53**	-0.89, -0.18
Level 2 Variance (τ_2^2)	41.97***	29.50, 54.49	1.65***	1.05, 2.25
Level 3 Variance (τ_3^2)	5.02	-1.03, 11.08	0.16	-0.07, 0.38
Average Effect Controlling for EPR	-4.82*	-8.52, -1.12	-0.79*	-1.53, -0.06
Moderator Analyses[a]				
Age	-0.11	-0.29, 0.06	-0.00	-0.04, 0.03
IDD	-1.74	-5.29, 1.82	-0.34	-1.04, 0.35
Contingency	1.74	-1.90, 5.38	0.52	-0.19, 1.24
Target	-6.55***	-8.32, -4.78	-1.26***	-1.79, -7.21
Functional	5.59**	2.05, 9.13	N/A	N/A
No signals	-2.68	-6.47, 1.10	-0.73	-1.52, 0.06
Signals without rules	-6.53***	-8.78, -4.27	-1.13***	-1.57, -6.85

Note. EPR = expected proportional reduction from baseline, Age = age in years, IDD = intellectual or developmental disability (1) or no diagnosis (2), Contingency = whether contingency was individual (1) or group (2), Target = whether target response was applied (1) or arbitrary (2), Functional = whether reinforcer was the same as in baseline (1) or not (2), No signals = dummy coded variable comparing signals with rules (1) to no signals (2), Signals without rules = dummy coded variable comparing signals with rules (1) to signals without rules (2).

[a] Analyses were conducted for one moderator at a time

* < .05

** < .01

*** < .001

Table 10

Multi-level Analysis Results for Spaced-Responding DRL

	Immediate Effect of Phase		Effect on Rate of Change	
Effect	**Estimate**	**CI**	**Estimate**	**CI**
Average Effect (β)	-8.76*	-15.93, -1.58	-0.86**	-1.45, -0.27
Level 2 Variance (τ_2^2)	546.46***	378.61, 714.31	3.35***	0.60, 2.17
Level 3 Variance (τ_3^2)	39.79	-28.52, 108.09	0.27	-0.23, 0.76
Average Effect Controlling for EPR	-5.83	-18.25, 6.59	-0.64	-1.62, 0.35
Moderator Analyses[a]				
Age	-0.17	-0.88, 0.53	0.02	-0.03, 0.08
IDD	-3.82	-22.39, 14.76	-0.85	-2.29, 0.58
Target	-8.40	-23.28, 6.49	-1.04	-2.21, 0.12
Signals	14.75***	10.71, 18.79	0.89	-2.12, 3.90

Note. Time = session number, Age = age in years, IDD = intellectual or developmental disability (1) or no diagnosis (2), Target = whether target response was applied (1) or arbitrary (2), Signals = whether signals without rules were used (1) or no signals (2).

[a] Analyses were conducted for one moderator at a time. Several moderators were not tested for the spaced-responding DRL because there was no variation in the moderators across datasets.

* < .05

** < .01

*** < .001

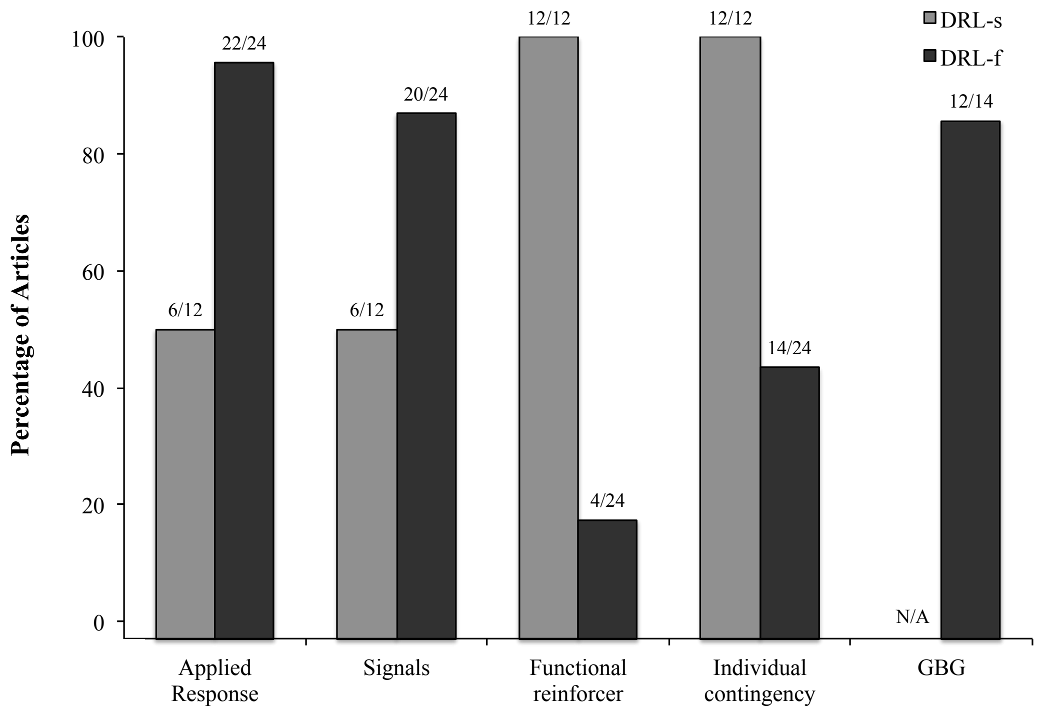

Figure 17. The percentage of articles for each differential-reinforcement-of-low-rate (DRL) type that targeted an applied response for reduction (applied), used signals (signals), used the same reinforcer in intervention as in baseline (functional), and used an individual contingency (individual). Of the articles that used a group contingency (full-session DRL only), GBG shows the percentage that used the Good Behavior Game as an intervention. Numbers above the bar show the study frequency for each category.

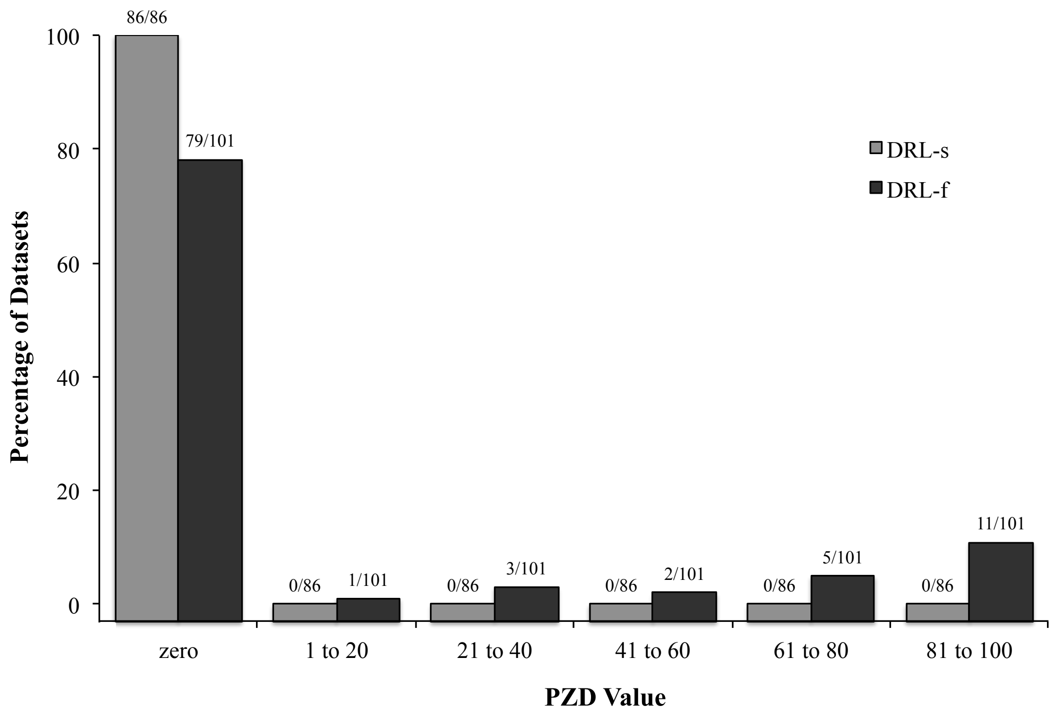

Figure 18. The percentage of datasets with percentage of zero data (PZD) values equal to zero, between 1-20, 21-40, 41-60, 61-80, and 81-100. The light gray bars are the spaced-responding DRL and the dark gray bars are the full-session DRL.

General Summary and Conclusions

These series of studies compared DRL schedules both experimentally (Studies 1 and 2) and through a meta-analytic synthesis (Study 3). In general, results were fairly consistent across studies. In the first study, the majority of college students and all preschoolers responded near an optimal criterion in both DRL conditions as long as there were signals. The absence of signals produced either an elimination or high variability across both DRL types for most participants. In the second study, all participants requested teacher attention near the optimal criterion in both DRL conditions. Finally, in the third study, no significant differences were observed between the DRL types across studies using DRL schedules with humans.

Another consistent finding was the impact of signals. In Study 1, signals appeared to be necessary to maintain responding in both DRL schedules, but particularly the full-session DRL. Furthermore, responding was maintained in Study 2 with the use of signals for both DRL types. Notably, signals in both Studies 1 and 2 were signals without specific rules about the contingencies. That is, participants were told that one signal indicated reinforcers were available and another indicated they were not available, but were not told how many responses to make or how long the intervals were. In Study 3, signals significantly moderate the effect of the spaced-responding DRL. Responding was generally lower without signals than with signals without rules. This result is consistent with Study 1 in that many participants responded near zero without signals. Similarly, there was a significant moderating effect of signals for the full-session DRL in which signals with rules reduced behavior the most, no signals the second most, and signals without rules the least. Importantly, however, the only two full-session studies to use signals without rules were conducted by the same research group. Thus, further investigation of signals with and without rules is warranted.

Despite these consistencies, there are several areas that warrant further consideration. In Study 1, the general findings were consistent with the other studies. However, for two college students, responding was eliminated in the full-session DRL regardless of whether or not there were signals. An additional five college students responded near optimal in the first signal phase, but near zero in the reversal to signals. No preschoolers displayed these patterns. Age or developmental level may be partially responsible for this difference, but the mechanism is unclear. Impulsivity may be related to both age and DRL performance, and thus may help to explain the differences across age groups. However, the differences in the current study were with the full-session DRL whereas the spaced-responding DRL is the schedule that is linked to impulsive behavior (Cheng et al., 2006). Another plausible explanation is that younger children may be more likely to follow rules than older individuals (Demirkasimoglu, Aydin, Erdogan, & Akin, 2012). In this study, participants were instructed to respond when a certain stimulus was present and not when another one was present. Thus, children may have continued to respond in the full-session DRL because of the rule. Further research investigating the absence of rules or the ways the rules are presented with children and adults are needed to clarify any potential age differences in DRL schedule performance.

Additionally, in contrast to a possible age effect in Study 1, there was not a significant moderating effect of age in Study 3. There are several reasons for this difference. First, the effect may simply not exist. That is, age may not impact responding in full-session DRL schedules, and Study 1 results are an anomaly. Second, there may not have been sufficient sample size or variation in ages in the studies that were included in the analysis. Although participants ranged in age from 4 to 58 years old, the modal age was 20. In fact, of the 268 datasets that we had information about age, over half (57%) were between the ages of 18 and 23 years. Thus, the majority were college-aged students, and there may not have been a sufficient sample size for other age categories. Third, age may have been confounded by another variable such as an intellectual or developmental disability. We did record whether a participant or set of participants had a developmental or intellectual disability, and there was no moderating effect of this variable. However, there may have been variability in the degree of the disability. Perhaps a better variable would be IQ or a similar metric that may capture the degree of impairment. Thus, research may further investigate age and development in DRL schedules.

Furthermore, maintenance or elimination of a response in a full-session DRL may depend on the motivation to engage in the response and the consequence for making a response. If there is a strong motivating operation for the response, it may be less likely to be eliminated. Such an effect is possible with punishment; in Azrin, Holz, and Hake (1963), pigeons continued to peck for a food reinforcer when pecks also occasionally produced shock when they were food deprived. In Study 2, we ensured that there was a motivating operation to ask for teacher help by giving the participants difficult puzzles. Further, the reinforcer presentation in a full-session DRL is potentially delayed from the time of a response. Full-session DRL arrangements that provide an immediate reinforcer for responses within an interval as well as a reinforcer for remaining below a set criterion may be more likely to maintain responding. For example, in Study 2, we reinforced bids for attention with brief attention and presented a sticker at the end of each interval for requesting attention two times or fewer. Thus, if a child is motivated to get attention (e.g., child needs help) and bids for attention are immediately reinforced, bids for attention may maintain. However, if motivation is low or there is no immediate reinforcer, bids may decline. Further research investigating the immediacy of reinforcement and motivating operations may help address these questions.

Finally, in Study 3, the nonparametric effect size, percentage of zero data (PZD) was higher for the full-session DRL than it was for the spaced-responding DRL, indicating the full-session DRL more often leads to response elimination. In fact, in no dataset did PZD show response elimination for the spaced-responding DRL, whereas approximately 21% of full-session DRL datasets had at least some data points at zero. This somewhat contrasts both with the other studies and the results of the meta-analysis, which showed no significant differences between DRL types. It is important to note that there was no evidence of response elimination for the majority of full-session DRL datasets. Nevertheless, about 11% of full-session datasets did show elimination for the majority of data points. These effects may have been masked in the meta-analysis because of the large degree of variability across datasets. The variability is evident in both large level 2 variation in the meta-analysis and the large standard deviation of PZD. Moreover, the meta-analysis may not exactly capture the subtle distinction between response reduction and response elimination. We did attempt to account for a reduction versus elimination by including the percentage reduction from baseline covariate. This allowed us to see whether the DRL conditions reduced behavior above and beyond what would be expected based on baseline rates of responding and the optimal response rate. Although the full-session DRL, and not the spaced-responding DRL, reduced behavior relative to baseline after including this covariate, there did not appear to be a significant difference between the DRL types. Unfortunately, the statistical properties of PZD are unknown and it is not possible to statistically compare the DRL conditions based on PZD with confidence. To address this, one possibility may be to further study PZD to determine its distribution, sampling error, and other relevant properties. Another possibility is to identify another statistical technique that can better capture the degree of reduction. This may be more feasible when the optimal percentage reduction is consistent across datasets. In the current study, the percentage reduction ranged from 99% to

Although there were some differences across studies, the general picture regarding DRL schedules was consistent. There did not appear to be major differences in the effects of the DRL types. In both experimental studies, response rate was similar in the two DRL types. In the meta-analysis, no significant differences were observed between the DRL types. As such, these results indicate that the full-session DRL may not eliminate responding in most circumstances. Thus, it supports the use of the full-session DRL in application, which is likely an easier procedure for practitioners to implement.

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Appendices

Appendix A

Screenshots of Each Condition in Experiment 1

Figure A1. The variable ratio condition of the reinforcer assessment. The target items to place in the trash bin are the apple core, the banana, and the cookie.

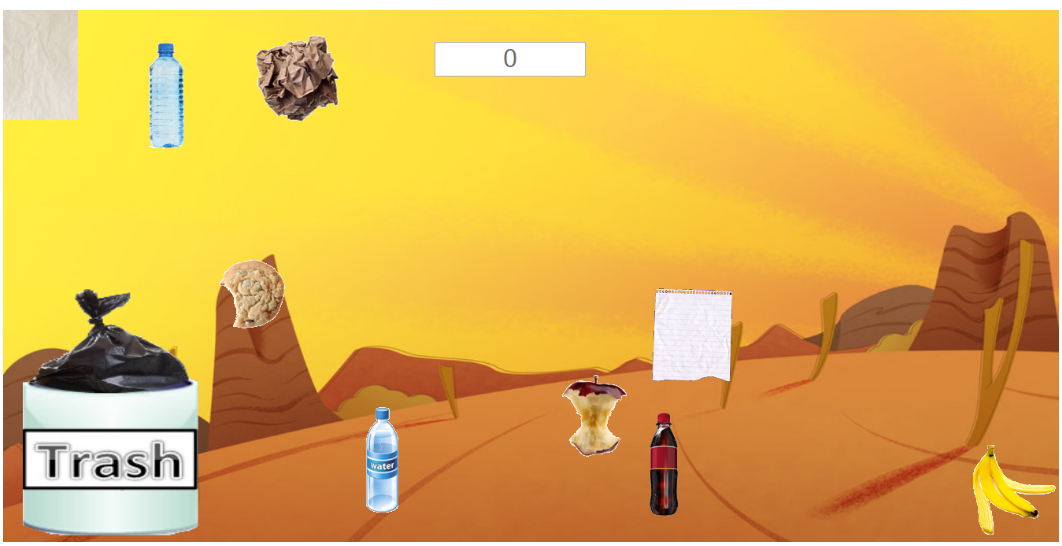


Figure A2. The extinction condition of the reinforcer assessment. The target items to place in the trash bin are the apple core, the banana, and the cookie.

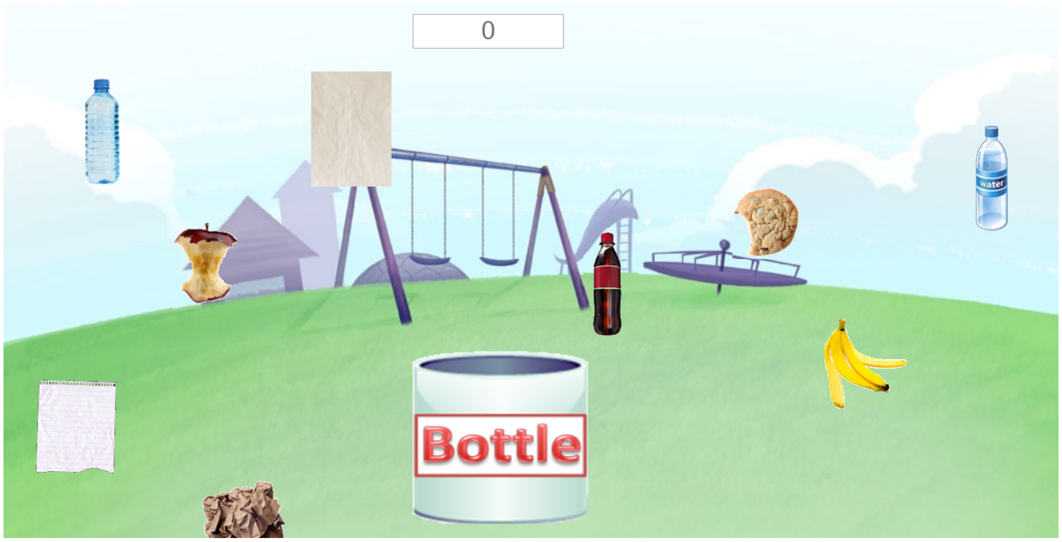


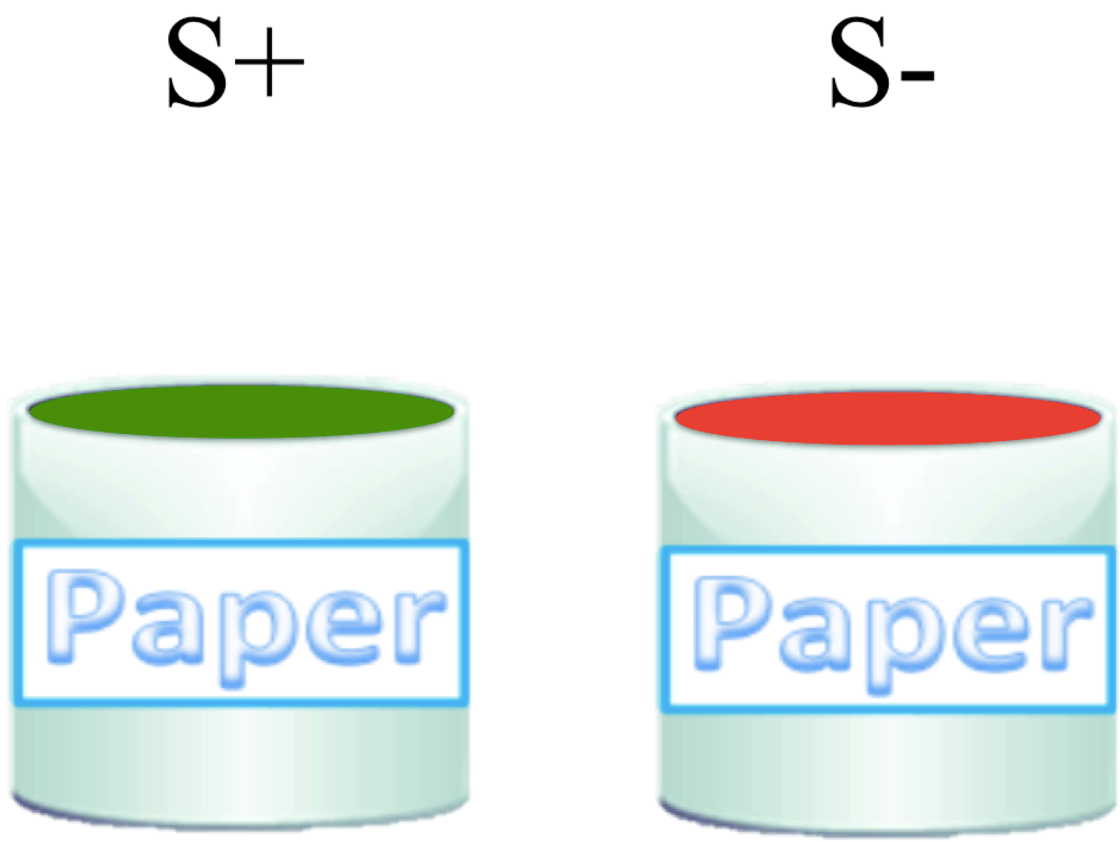
Figure A3. The spaced-responding differential-reinforcement-of-low-rate (DRL) condition. The target items to place in the bottle bin are the water bottle, unmarked water bottle, and soda bottle.

Figure A4. The full-session DRL condition. The target items to place in the paper bin are the lined white paper, plain white paper, and crumpled brown paper. The point counter, located top center, turns green when a point is earned.

Appendix B

Experiment 3 Example Stimuli

During Experiment 3, the signals were modified from the open (S+) and closed (S-) bag depicted in Figure 1 to green (S+) and red (S-) colors on the receptacles. Below are example stimuli from the full-session differential-reinforcement-of-low-rate condition.



Appendix C

Teacher Social Validity Survey

Caleb is a 4-year-old student in your class who constantly asks for your help and attention when he is supposed to be working independently. Usually, Caleb asks for your attention two times a minute. You want to decrease Caleb's bids for attention to a lower rate. Read the following plans to reduce Caleb's bids for attention to a more acceptable level and answer the questions that follow.

Plan 1

When you give Caleb independent work, you place a green index card on his desk. When Caleb requests your attention (e.g., asks for help, shows you his progress), you give him brief attention and a sticker. Then, you remove the green card, place a red card on his desk, and set a timer for two minutes. The timer is not visible to Caleb; it is only to help you keep track of time. You tell him your attention is not available, and he will have to wait. If Caleb waits two minutes without asking for attention, you put out the green card again, and repeat. If he asks for attention before the two minutes is up, you restart the timer for two min, and keep the red card out. This continues until the independent work is completed. Thus, Caleb only gets attention and a sticker if it has been at least two minutes since the last time he asked for attention. If Caleb only asks for attention when the green card is out, this will result in a 75% reduction from his initial level (about once every other minute).

Rate how much you agree or disagree with the following statements.

1. **I would be likely to implement Plan 1.**

Strongly Agree | Agree | Disagree | Strongly Disagree

2. **Plan 1 would take too much time to implement.**

Strongly Agree | Agree | Disagree | Strongly Disagree

3. **Plan 1 will be effective at reducing Caleb's bids for attention to a more acceptable level.**

Strongly Agree | Agree | Disagree | Strongly Disagree

4. **Plan 1 seems like it would be difficult to implement.**

Strongly Agree | Agree | Disagree | Strongly Disagree

5. **I would recommend Plan 1 to other teachers who are struggling with a child that requests too much attention.**

Strongly Agree Agree Disagree Strongly Disagree

Please provide comments about why you would or would not be willing to implement Plan 1.

Plan 2

When you give Caleb independent work, you place a green index card on his desk. Then, you set a timer for four minutes. The timer is not visible to Caleb; it is only to help you keep track of time. The first two times Caleb asks for your attention (e.g., asks for help, shows you his progress), you give him brief attention. After the second request, you remove the green card and place a red card on his desk. You tell him your attention is not available, and he will have to wait. At the end of the four minutes, if Caleb has not asked for any more attention, you give him a sticker, and put the green card back out. This repeats until the independent work is completed. Thus, Caleb gets a sticker if he asks for attention two times or less in each four-minute block. If Caleb only asks for attention when the green card is out, this will result in a 75% reduction from his initial level (about once every other minute).

Rate how much you agree or disagree with the following statements.

1. **I would be likely to implement Plan 2.**

Strongly Agree Agree Disagree Strongly Disagree

2. **Plan 2 would take too much time to implement.**

Strongly Agree Agree Disagree Strongly Disagree

3. **Plan 2 will be effective at reducing Caleb's bids for attention to a more acceptable level.**

Strongly Agree Agree Disagree Strongly Disagree

4. **Plan 2 seems like it would be difficult to implement.**

Strongly Agree Agree Disagree Strongly Disagree

5. **I would recommend Plan 2 to other teachers who are struggling with a child that requests too much attention.**

Strongly Agree Agree Disagree Strongly Disagree

Please provide comments about why you would or would not be willing to implement Plan 2.

If you had to choose between Plan 1 and Plan 2, what would you choose and why?

Appendix D

Coding Instructions and Data Sheet

DRL Coding Instructions

<u>**Basic Info**</u>

Journal: the journal that the article was published in

- **JABA** = Journal of Applied Behavior Analysis
- **JEAB** = Journal of Experimental Analysis of Behavior
- **JOBE** = Journal of Behavioral Education
- **ETC** = Education and Treatment of Children
- **BI** = Behavioral Interventions
- **BAP** = Behavior Analysis in Practice
- **Other** = any other journal, write in

Year: year article was published; if the article is an online publication from the current year (2016), include the year and put "O" for online.

First author: the first listed author of the article

Page: the page number that the article starts on

N: total number of datasets that meets inclusion criterion; count each single-subject design graph as 1 (if no graph, do not count)

Measurement: the metric used to capture the target dependent variable

- **Fr** = frequency; the count of total responses
- **D** = duration; the number of seconds a response occurred
- **R** = rate; the number of responses that occurs per unit time (e.g., responses per minute)
- **PI** = percentage of intervals; the response is scored as occurring or not occurring in intervals within a session and graphed as the percentage of intervals the behavior is occurring
- **PD** = percent duration; the number of seconds a response occurred is divided by the total session duration

Target response: the topography of the response targeted for behavior change by the DRL schedule (e.g., hand-raising); if it varied across participants put "see Participants"

Study purpose: the authors' stated purpose for using the DRL schedule

- **E** = eliminate; to eliminate the target response to zero
- **R** = reduce; to reduce the target response relative to baseline, but to not eliminate it
- **M** = maintain; to maintain the target response relative to baseline

N = not enough information to determine

Design: the type of single-case design used in which the conditions are baseline (A) and DRL (B). Ignore other conditions (e.g., if there is a baseline phase followed by a multi-element comparison of DRL and DRO and then a return to baseline, the design would be coded as a reversal rather than a multi-element). If more than one design was used to compare baseline to DRL, circle all that apply.

AB = AB design, one baseline (A) and one DRL (B) phase
R = reversal; ABA, ABAB, BAB, etc.
MB = multiple baseline; a series of AB designs across participants, settings, or responses in which the introduction of B is staggered across tiers
ME = multi-element; rapid alternation of A and B conditions
Other = specify what the design was

Session duration: the duration, in minutes, of each session. If the session duration changes across session, indicate the range (lowest to highest duration).

<u>DRL Info</u>

DRL type: the type of DRL contingency used in the study; circle all that apply

Spaced: a reinforcer was provided for a response if at least a certain amount of time had elapsed since the last response
Full: a reinforcer was provided at the end of the session if X or fewer responses occurred during the session
Interval: a reinforcer was provided at the end of an interval that is not the entire session if X or fewer responses occurred during each interval

Signals: whether or not there were unique signals to indicate when responses would and would not be reinforced (e.g., a green signal when responses are reinforced, a verbal instruction that responses would now be reinforced). If yes, Y; if no, N.

Type: specify what the signals were (e.g., colors, rules, sounds)

<u>DRL Parameters</u>

Interval size: the initial (for the first three data points of the DRL) interval size in seconds used in the DRL schedule; if it varied across participants put "see Participants"

Interval change: did the DRL interval size or tolerance change throughout the study? If yes, Y; if no, N.

Tolerance: the number of responses permitted in each interval (interval DRL) or session (full-session DRL). Does not apply to spaced-responding DRL.

Resetting: did the DRL interval start over if a response occurred too soon?

<u>**Consequence Provided**</u>
Functional: whether the consequence (reinforcer) is the same reinforcer as the reinforcer used in the baseline condition. If yes, Y; if no, N; if unknown, U.

Token: whether the reinforcer is a token (i.e., a conditioned reinforcer that can later be exchanged for a back-up reinforcer) or not. If yes, Y; if no, N.

<u>**Contingency Type**</u>
Individual: the DRL intervention is applied to only one person at a time
Group: the DRL intervention is applied to more than one person as a time

> **Indep** = independent; provision of the reinforcer depends on individual performance for each individual, but the same intervention is in place for all
> **Dep** = dependent; provision of the reinforcer depends on the performance of a subset of individuals in the group (e.g., one student's responses)
> **Inter** = interdependent; provision of the reinforcer depends on group-level performance (e.g., total responses made by the class)

GBG: whether the DRL intervention is part of the Good Behavior Game

<u>**Treatment integrity**</u>
Assess: did the article evaluate the integrity with which the experimenter implemented the DRL intervention? If yes, Y; if no, N.

Type: the type of integrity that was scored; score all that apply

> Omission: scored whenever experimenter made a mistake by failing to implement the procedure (e.g., not delivering the reinforcer when it is supposed to be delivered)
> Comission: scored whenever the experimenter made a mistake by ADDING something that was not supposed to happen (e.g., delivering a reinforcer even though it was not earned)
> ND: not able to determine based on the information provided

If yes, for: if integrity was assessed, indicate what aspect of the DRL schedule was monitored. Select all that apply.

> Time: the timing of the intervals
> Response: the number of responses permitted in each interval (for full session and interval only)
> Reinforcer: reinforcer delivery

% Sessions: the percentage of sessions for which integrity data was assessed

% Integrity: the mean integrity score (percentage of opportunities that procedure was correctly implemented)

<u>Data Collection</u>
Data Collector: your name

Date: the date you entered data from the article onto the data sheet

Primary / Secondary: whether you are the primary data collector or the secondary data collector.

<u>Participant Info</u>
For individual participants within the study. Only record participants who have at least three data points per phase.

Participant: name, number, or code

Sex: male or female

Age: the age in years

Other characteristics: diagnoses, medications, or other reported demographic information

Interval: the DRL interval, if it varied across participants. If the same across participants, put a "/"

Tolerance: the DRL tolerance (full-session or interval DRL), if it varied across participants. If the same across participants, put a "/"

Other: include anything else unique to participants that are coded on page 1. For example, if the response topography varies, put that here.

Basic Info

Journal: JABA JEAB JOBE ETC BI BAP **Year**: ______ **First Author**: ______________ **Page**: ____________ **N:** __________

Other: ____

Measurement: Fr D R PI PD

Target response: ______________________

Study purpose: E R M N

Design: AB R MB ME Other: ________________

Session duration: ___________

DRL Info

DRL type: spaced full interval

Signals? Y N **If yes, type**: ___________________

DRL parameters

Interval size: _________ **Interval change?** Y N

Tolerance (for fDRL): ___________

Consequence provided

Functional? Y N U **Token** Y N

Contingency type

Ind Group **If G, type:** Indep dep inter **GBG?** Y N

Treatment integrity

Assess? Y N **If yes, for:** Time Responses

If yes, for: Time Response Reinforcer

% sessions: __________ **% integrity:** ________

Data collection

Data collector: ________________________________

Date: ___________________

Primary / Reli

Participant Info

Participant	Sex	Age	Other characteristics	Interval	Tolerance	Other

Appendix E

Supplementary Analyses for Multi-Element and Percentage of Interval Data

Multi-Element Designs

The same equations and approach as was used with the multi-level model with rate data was used to analyze the multi-element data. However, because there is no phase change from baseline to treatment, time was not centered for this analysis.

Results

There were five studies consisting of 98 datasets that used a multi-element design. Table E1 displays study-level information about the articles using a multi-element design. Four of five studies used the spaced-responding DRL. In addition, all targeted an arbitrary response (e.g., mouse clicks), did not use signals, used a functional reinforcer, applied an individual contingency, and measured the outcome as a rate.

There was no significant immediate effect of phase (λ_{00} = -2.62, z= -0.47, p = .64) nor did the immediate effect vary across DRL types (λ_{00} = -4.13, z= -0.88, p = .38). That is, combined, both DRL procedures did not appear to reduce responding from baseline. There was significant variability across datasets for the effect of phase (τ_2^2 = 61.75, $z(189)$ = 6.83, p < .001). The low number of studies and high degree of variability across datasets may explain why there was no immediate effect of phase. Nonetheless, results are partially consistent with the AB pairs in that there appeared to be no difference in effect sizes across the DRL types

Percentage of Interval Data

Percentage data best fit on a binomial distribution (Shadish et al., 2012). Thus, we had to transform the data to run the mult-level model. For the percentage of intervals data, an arcsine square root transformation was applied to each raw data point per dataset to account for the binomial distribution. Then, the models for the multi-level model as described for the rate data were conducted in an identical manner.

Results

There were 10 studies consisting of 25 datasets that measured the outcome percentage of intervals (described in Table E2). Nine studies used a full-session DRL in an interdependent group contingency. One study used a spaced-responding DRL with an individual contingency. All targeted an applied response (e.g., disruptive behavior) and used a nonfunctional reinforcer. There was no significant immediate effect ($\lambda_{00} = 2.97$, $z = 0.73$, $p = .46$) nor did the immediate effect vary by DRL type ($z = -1.90$, $p = .06$). The effects varied significantly across datasets ($\tau_2^2 = 10.52$, $z(29) = 2.56$, $p = .01$). Thus, like the multi-element analysis, these results are partially consistent with the other results of the study. Although there did not appear to be a reduction of target responding in either DRL relative to baseline, there was also no difference between the DRL types. Again, failure to find an effect of phase may be due to a small number of studies (or datasets) and significant variability across datasets.

Table E1

Study-level information About Multi-Element Studies

Article	Data sets	Data disp	Target response	DRL type	Sig	Func	Cont type
Hayes, Brownstein, Zettle, Rosenfarb, & Korn (1986)	33	IND	Button presses	S	No	Yes	IND
Hirai, Okouchi, Matsumoto, & Lattal (2011)	20	IND	Button press	S	No	Yes	IND
Okouchi, Lattal, Sonoda, & Nakamae (2014)	5	IND	Button presses	F	No	Yes	IND
Poppen (1972)	6	IND	Lever presses	S	No	Yes	IND
Wulfert, Greenway, Farkas, Hayes, & Dougher (1994)	34	IND	Button pushes	S	No	Yes	IND

Note. Datasets = number of datasets meeting inclusion criteria, Data display = whether data are displayed as an individual person (IND) or group of people (GROUP), target response = the response targeted in the intervention (responses that are italicized were considered applied responses; non-italicized are arbitrary responses), DRL type = full-session DRL (F) or spaced-responding DRL (S), Signals = signals with rules (Rules), signals without rules (Other), or no signals (No), Func = the reinforcer was the same as baseline (Yes) or not the same (No), Cont. type = individual (IND) or interdependent group (INT) contingency.

Table E2

Study-level information About Multi-Element Studies

Article	Data sets	Data disp	Target response	DRL type	Sig	Func	Cont type
Darveaux (1984)	2	IND	*Disruptive behavior*	F	Rules	No	INT
Grandy, Madsen, & Mersseman (1973)	1	GRO	*Disruptive behavior*	F	Rules	No	INT
Lannie & McCurdy (2007)	1	GRO	*Disruptive behavior*	F	No	No	INT
Mitchell (2014)[a]	3	GRO	*Disruptive behavior*	F	Rules	No	INT
Nolan (2014)[a]	3	GRO	*Disruptive behavior*	F	Rules	No	INT
Saigh & Umar (1983)	1	GRO	*Disruptive behavior*	F	Rules	No	INT
Singh, Dawson, & Manning (1983)	3	IND	*Stereotypy*	S	No	No	IND
Theodore, Bray, & Kehle (2001)	5	IND	*Disruptive behavior*	F	Rules	No	INT

Article	Data sets	Data disp	Target response	DRL type	Sig	Func	Cont type
Wahl, Hawkins, Haydon, Marsicano, & Morrison (2016)	4	GRO	*Disruptive behavior*	F	Rules	No	INT
Wright & McCurdy (2011)	2	GRO	*Disruptive behavior*	F	Rules	No	INT

Note. Datasets = number of datasets meeting inclusion criteria, Data disp = whether data are displayed as an individual person (IND) or group of people (GROUP), target response = the response targeted in the intervention (responses that are italicized were considered applied responses; non-italicized are arbitrary responses), DRL type = full-session DRL (F) or spaced-responding DRL (S), Sig = signals with rules (Rules), signals without rules (Other), or no signals (No), Func = the reinforcer was the same as baseline (Yes) or not the same (No), Cont type = individual (IND) or interdependent group (INT) contingency.
[a] Dissertation