A Comparison of the Efficiency and Stability of Discriminated Responding in Multiple Schedules using Restricted or Free-operant Paradigms

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Abstract

Two common conditioning arrangements– free- and restricted-operant (i.e., discrete trial) –are used to measure acquisition, stability, maintenance, and generalization of a response. In a free-operant paradigm, the organism can freely make a response with no restrictions imposed upon them, whereas, in a restricted-operant paradigm, the organism must wait for trial initiation prior to responding. Although researchers have used both to establish novel stimulus-behavior relations, the benefits and limitations of either paradigm for the acquisition and stability of a new response represent an understudied area in the field. Yet, benefits and limitations of each arrangement could offer insight for optimal conditioning arrangements for types of learning and contextual considerations. We investigated the efficiency of either training procedure on the discrimination and stability of a lever press using four Long Evans rats. Results suggest rats learned novel discriminations more quickly in a free-operant paradigm with more stable performances in the presence of distracting auditory stimuli.

Keywords: restricted operant, free operant, discrete trial, simple discrimination.

Resumen

Dos disposiciones comunes de condicionamiento —operante libre y operante restringido (es decir, ensayo discreto)— se utilizan para medir la adquisición, la estabilidad, el mantenimiento y la generalización de una respuesta. En un paradigma de operante libre, el organismo puede emitir una respuesta libremente sin restricciones impuestas, mientras que en un paradigma de operante restringido el organismo debe esperar la iniciación del ensayo antes de responder. Aunque los investigadores han utilizado ambos para establecer nuevas relaciones entre estímulo y conducta, los beneficios y limitaciones de cada paradigma para la adquisición y estabilidad de una nueva respuesta representan un área poco estudiada en el campo. Sin embargo, los beneficios y limitaciones de cada disposición podrían ofrecer información para optimizar los arreglos de condicionamiento según los tipos de aprendizaje y las consideraciones contextuales. Investigamos la eficiencia de cada procedimiento de entrenamiento en la discriminación y estabilidad de una respuesta de presión de palanca utilizando cuatro ratas Long Evans. Los resultados sugieren que las ratas aprendieron discriminaciones novedosas más rápidamente en un paradigma de operante libre, con desempeños más estables en presencia de estímulos auditivos distractores.

Palabras clave: operante restringida, operante libre, ensayo discreto, discriminación simple.

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A Comparison of the Efficiency and Stability of Discriminated Responding in Multiple Schedules using Restricted or Free-operant Paradigms

Discrimination occurs when an organism engages in accurate and efficient responding under appropriate stimulus conditions, such as when a stimulus is correlated with the availability of reinforcement (e.g., discriminative stimulus [SD]) for a specific response (Pierce & Cheney, 2017). Measuring discrimination is useful for determining an organism's acquisition and inhibition of specific response-reinforcer relations in the presence of relevant contextual stimuli. For example, in a multiple schedule (MULT) an SD (e.g., flashing light) may be used to signal reinforcement for presses to a right lever and extinction for presses to a left lever. Following the elapse of 60 s, an alternate SD (e.g., steady light), signals reinforcement for presses to the left lever and extinction for presses to a right lever. When a subject learns to press the right lever only in the presence of the flashing light and press the left lever only in the presence of the steady light, discrimination has occurred.

A discrimination index (DI) is a mathematical calculation that produces a quantitative score which represents the proportion of correct responses of all responses in the presence of an SD (Pierce & Cheney, 2017). Researchers use this index to ascertain how accurate a subject responds to an SD. The index score ranges from 0–1 and is calculated by dividing the total number of correct responses by the sum of all (i.e., correct plus incorrect) responses. DI scores close to 1, .5, and 0 are indicative of accurate, chance, or inaccurate responding, respectively. Indexes are typically calculated after each session and provide iterative data on how a subject is learning novel discriminations. Historically, a DI of .9 is considered to be demonstrative of mastery. One way to use a DI is to ascertain efficiency (i.e., the number of sessions it takes for a subject to reach .9). When subjects reach .9 more quickly in one condition compared to another, responding is considered more efficient in the condition that reached .9 first.

Another way to use a DI is to assess for how the score remains the same across time even in the presence of novel, distractor stimuli. This method allows for determination of the stability of discrimination. That is, if a subject reaches a .9 DI and continues to maintain a .9 DI in sessions in which there are distractor stimuli, a subject has demonstrated stability. Researchers have used numerous arrangements (e.g., signal detection tasks) to evaluate whether these environmental arrangements can produce discriminated operant behavior in various organisms (e.g., rats, pigeons, humans). As such this line of research has shown that non-human animals can acquire discriminated responding and these arrangements prove useful for investigating several variables, such as rate of reinforcement and fluency, as it relates to operant conditioning (e.g., Bulla et al., 2024; Herrick et al., 1959). Yet, very few studies have directly compared to these arrangements leaving a research gap about optimal selection of conditioning arrangements in terms of acquisition, efficiency, and stability of responding.

Free-operant (FO) and restricted-operant (RO) conditions (sometimes also referred to as a discrete trial [DT]) represent two types of learning arrangements used to demonstrate acquisition and maintenance of a target response (e.g., Bulla et al., 2024; Bulla, 2023; Evans et al., 2022). In an FO condition, the organism can freely make a response at any time (e.g., Hachiya & Masato, 1991). For example, a rat may have continuous access to a lever and could press the lever at any time with no other limitations on whether the operandum is available or the response could occur. In an RO condition, the organism is prohibited from making a target response because the enabling stimulus required to complete the response is absent. For example, a lever may retract at specific intervals thereby only being present for specific periods of time. This arrangement includes an inter-trial interval (ITI), which is the period between trials in which the necessary operandum (e.g., lever) required to make a target response is not present. ITIs have been documented to produce a ceiling effect on responding such that the rat can only engage in a response when the external stimulus is present (Cooper et al., 2020; Johnston & Pennypacker, 2009). This ceiling effect directly affects the overall rate of responding, which in turn, impacts the number of response-reinforcer opportunities available in each session. As such, because the response-reinforcer relation affects overall acquisition of responding including discrimination, the duration of the ITI is directly correlated with acquisition and discrimination (e.g., Hachiya & Masato, 1991).

Previous research shows that, in part, the acquisition of a response is directly related to the number of response-reinforcer relations suggesting that the higher number of opportunities of response-reinforcer relations that might occur, the more quickly, and at greater frequencies, the rat will acquire a target response (Herrnstein, 1961). Many studies in the experimental analysis of behavior analysis using animals employ FO arrangements to precisely control for a variety of variables including reinforcement delivery (e.g., Hachyia & Ito, 1991; Herrnstein, 1961; Herrnstein, Loveland, & Cable, 1976). This is likely because the probability for response-reinforcer relations is unlimited and solely dependent on the number of correct responses emitted by the rat.

Although these procedural variables are known to directly impact the acquisition of discriminated responding, the extent of the impact between these two types of training paradigms is under investigated. Interestingly, very few published studies have directly or adequately compared these two conditioning paradigms. For example, McCarthy et al. (1982) compared differences in discrimination between an RO (i.e., signal-detection task) and FO paradigm using a MULT VI 60 s with six pigeons. In the FO arrangement, two keys were continuously available, and a peck to one key produced reinforcement while a peck to the other key resulted in extinction. In a modification of the RO arrangement, a peck to a one key produced reinforcement while a peck to the other key resulted in a blackout period in which a response to either key did not result in reinforcement. Although the levers remained available, neither key produced reinforcement. Results indicated that discriminated key pecking was significantly lower in the RO arrangement. However, the authors concluded that these differences only became apparent if the target discrimination stimulus did not remain present during the choice task.

In another study, Hachiya and Masato (1991) trained rats on a successive discrete-trial discrimination (i.e., RO) between two tonal stimuli to examine the effect of availability of levers during ITIs. Under RO conditions, the researchers removed the lever during the ITI. Under the FO condition, a lever remained present during both trials and ITI. They trained discriminative performances using a free-operant condition with a 50-s ITI, and then improved on poor discrimination performance using discrete-trials with a 5-s ITI. Both experiments controlled for time, and they also controlled for rate of reinforcement in the RO condition. Results suggested that presentation of a lever to start a trial may overshadow or mask the control of a discriminative stimulus and as a result, obstruct the acquisition and maintenance of discriminative performances. Additionally, the increased length of the ITI may strengthen the masking effect.

Taken together, these few studies suggest that RO arrangements may detrimentally impact or inhibit acquisition of responding ultimately leading to poorer levels of discrimination. If this is the case, this may offer direct implications to other types of settings (e.g., applied) in which efficient and accurate responding is desirable. Interestingly, the most common training arrangement in clinical settings is an RO arrangement (i.e., DTT; Ghezzi, 2007). Therefore, it is imperative to investigate these two arrangements to more precisely identify the conditions under which RO or FO arrangements should be selected.

Currently, across basic studies, conclusions about optimal conditioning arrangements for efficacy and stability of discriminated responding is not known. Although we have presented a handful of studies that have employed RO and FO arrangements, there are a number of critical procedural differences across studies (e.g., differences in stimuli, number of available enabling stimuli). Given the lack of basic empirical investigations, and consistency across procedures in comparing these learning paradigms, yet an abundance of use of DTT in applied settings, additional research is necessary. Thus, the current study sought to identify the experimental methods necessary to evaluate FO and RO training arrangements on discriminated lever pressing in Long Evans rats.

Method

Subjects

Four male Long Evans rats approximately 7 months old served as subjects. All subjects had prior conditioning during a graduate-level operant conditioning lab. Specifically, all subjects had been previously shaped to lever press and had undergone discrimination and chained-response training. No subject had prior exposure to the SDs used in the present study. All subjects were maintained at 80% of their free-feeding weight (Hurwitz & Davis, 1983).

All experimental and husbandry procedures were approved by the Institutional Animal Care and Use Committee (IACUC 23009) guided by the Guide for the Care and Use of Laboratory Animals. All subjects were housed individually in approximately 17.78 cm X 21.59 cm X 40 cm clear-wall cages that were equipped with a wired roof. All cages were lined with Bed O Cobbs ¼ in. pellet laboratory animal bedding and contained a chewing block, colored-plastic tunnel, and up to two approximately 15.24 cm X 25.4 cm iso-Pads for shredding with a continuous water feeder. All cages were stored in a university-approved and secured rat colony which had a 12 hr light–dark light cycling. We conducted daily wellness checks that included feeding, weighing, and handling. Subjects also received weekly enrichment in the form of exercise on a wheel three days per week throughout the course of the experiment.

Apparatus

All sessions were conducted in a Coulbourn operant chamber. The chamber had two manually retractable levers spaced equally apart on the same wall the feeder between the two levers. Depending on subject, condition, and component, each lever was with a correlated with a blue and yellow light or a flashing and steady white light as the relevant SD. We used 20 mg Rodent, Dustless, Grain-Based Precision Pellets® from Bio-Serv, a manufacturing company for non-human animal research.

Design

For all subjects, we used an alternating treatment design as an intra-subject experimental design for comparison between FO and RO conditions on differences in discriminated lever pressing. We randomized the order of condition that each subject was exposed to first on each day to control for sequence effects.

Response Measurement and Data Analysis

We measured frequency of lever presses in each condition. We calculated DIs by summing the number of correct responses in the presence of the relevant SD and divided it by the number of total responses in each session. We defined acquisition as when the subject met a .9 DI in either condition. We tested for stability in which we evaluated maintenance of performance in the presence of distracting stimuli (e.g., tonal stimuli).

Procedures

This study used a MULT fixed ratio 1 (FR1) FR1 schedule in an FO and RO condition, to examine the differences in acquisition and stability when exposure to each condition was held constant. We counterbalanced SDs, lever sides, and order of conditions to control for bias, preference of levers, and sequence effects. All sessions were 30 min and alternated between SDs (e.g., 60 s flashing light/60 s steady light) for the RO and FO condition. There were no inter-component intervals between the two 60-s components. We exposed subjects to two sessions daily, such that subjects experienced both FO and RO conditions and until they reached a .9 DI in both conditions.

Free Operant Condition

In the FO condition, both levers were continuously available such that subjects could make a response (correct or incorrect) at any time.

Restricted Operant

In the RO condition, researchers imposed a 5-s ITI throughout the session such that both levers were manually retracted for a period of 5 s following each response (either correct or incorrect). Following the elapse of 5 s, the levers were reinserted. The 5-s ITI was included in the total 60-s component making each component across both conditions equitable.

Stability Probe

We conducted probes to assess for differences in the stability of the .9 DI following either condition. The purpose of this probe was to determine if one conditioning procedure produces more stable performances when subjects are exposed to novel distractor stimuli following acquisition. Researchers conducted stability probes in the sessions that immediately followed the session in which subjects reached acquisition (i.e., .9 DI) in both conditions. We randomized the order of exposure of condition for each subject. Sessions were identical as previously described in both conditions, including reinforcement contingencies and procedures for enabling stimuli, with the exception that researchers opened the sound attenuating box which housed the operant chamber. We exposed subjects to auditory stimuli (i.e., pop music) across both conditions at a volume of 65 db by placing a laptop on top of the box where the operant chamber was housed. The music played continuously from a playlist throughout the session such that no stimulus was repeated in either condition or across conditions.

Results

Generally, across subjects, the FO condition generated greater rate and accuracy of responding than RO conditions. In the FO condition, subjects acquired a .9 DI in fewer 30-min sessions (M = 22; range, 20–23) compared to the RO condition sessions (M = 24.5; range, 18–29), for a mean of 660 min required to achieve criteria under FO conditions and 735 min under RO conditions. Additionally, the FO condition produced discriminated responding more efficiently than the RO condition for subjects three of the four subjects. Table 1 displays the mean incorrect and correct response rate and mean reinforcer deliveries across both components in each condition for all subjects. For all subjects, mean response rates were higher in the FO components compared to RO.

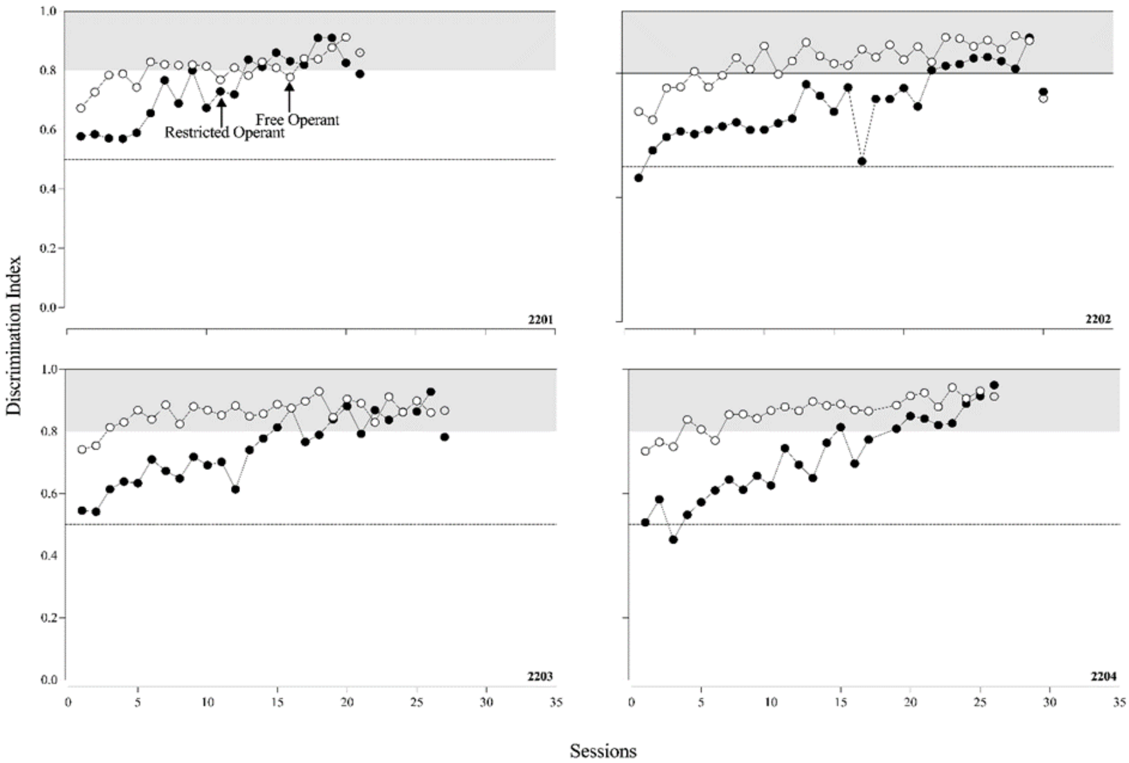
Table 1 Subject Response Rates, Reinforcer Deliveries and Sessions to Criterion Across Conditions

	Free Operant				Restricted Operant			
	Correct M (range)	Incorrect M (range)	Reinforcer Delivery	Sessions to Mastery	Correct M (range)	Incorrect M (range)	Reinforcer Delivery	Sessions to Mastery
2201	*5.2* (2.3–8.3)	1.26 (.17–3.0)	157	20	3.0 (.86–7.2)	.9 (.2–1.73)	90	18
2202	5.6 (3.6–8.0)	1.1 (.27–4.57)	169	23	2.7 (.47–4.6)	1.1 (.27–1.8)	82	29
2203	5.8 (2.8–8.8)	1.0 (.2–3.5)	177	20	2.8 (.8–5.9)	1.0 (.3–2.7)	85	25
2204	5.5 (.87–8.2)	.9 (.17–3)	166	25	2.7 (.13–5.4)	.87 (.1–2.6)	83	26

Note. Mean correct and incorrect responding with ranges across both components in FO and RO conditions. Mean obtained reinforcers and number of sessions completed before achieving .9DI in FO and RO. FO = Free-Operant. RO = Restricted-Operant.

Figures 1 display DIs for both conditions for all subjects. For all subjects, these figures show a difference in the overall DIs between FO and RO conditions such that FO conditions produced greater DIs for nearly all sessions. In addition to DIs across all sessions, we made comparisons between the first and last session for each subject in each condition. These data are displayed in Figures 2–5. Specifically, these figures are cumulative records of correct and incorrect responding in the first and last session of the RO and FO condition for each subject. Generally, these graphs display a similar pattern of behavior across all subjects which demonstrate a higher frequency of correct responses in the FO condition compared to a higher frequency of incorrect responses in the RO condition in the final session. The exception to this is displayed in Figure 1 in which 2204 displayed higher amounts of correct responding in the RO condition compared to the FO condition in the final session. Additionally, no major differences existed between measures obtained during stability probes with two subjects achieving higher DIs under RO arrangements, and two subjects achieving higher DIs under FO arrangements. Taken together, three of the four subjects met .9 DI in fewer sessions in the FO condition compared to the RO condition.

Figure 1. Discrimination Indices Under Free Operant and Restricted Operant Conditions.



Note. The gray bar indicates a .9 discrimination index. The dotted line indicates chance responding.

Figure 2. First and Last Session Responding for 2201.

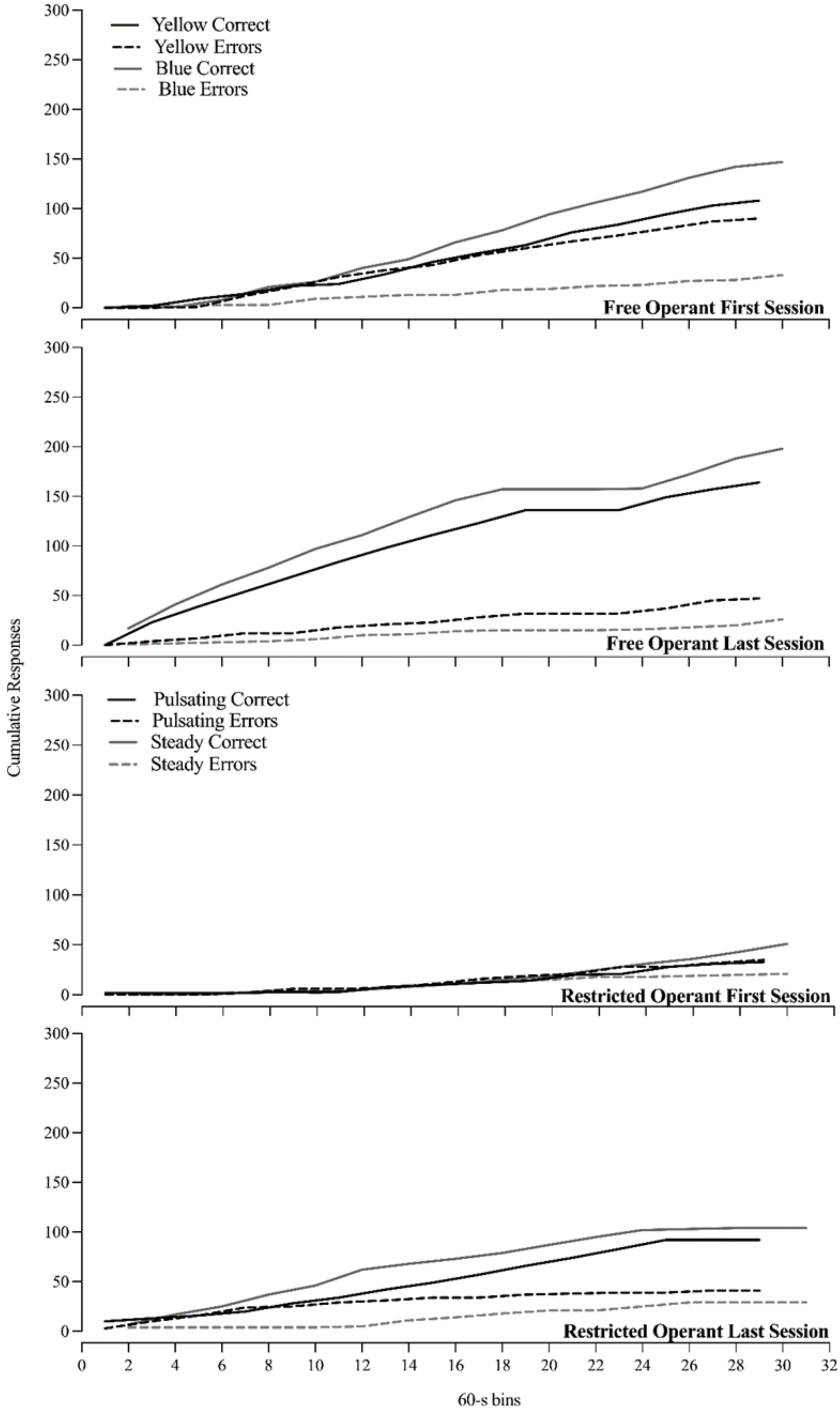


Figure 3. First and Last Session Responding for 2202.

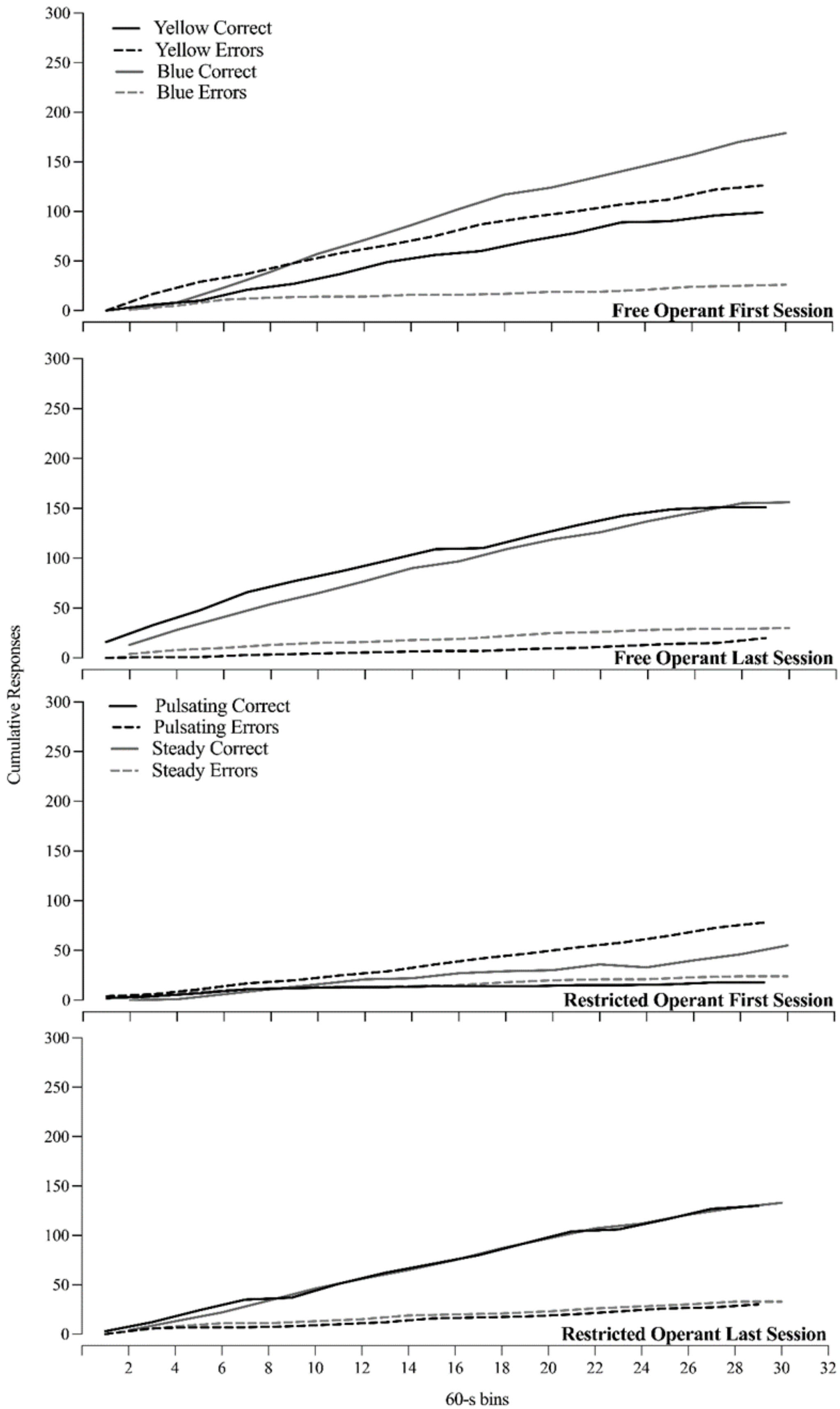


Figure 4. First and Last Session Responding for 2203.

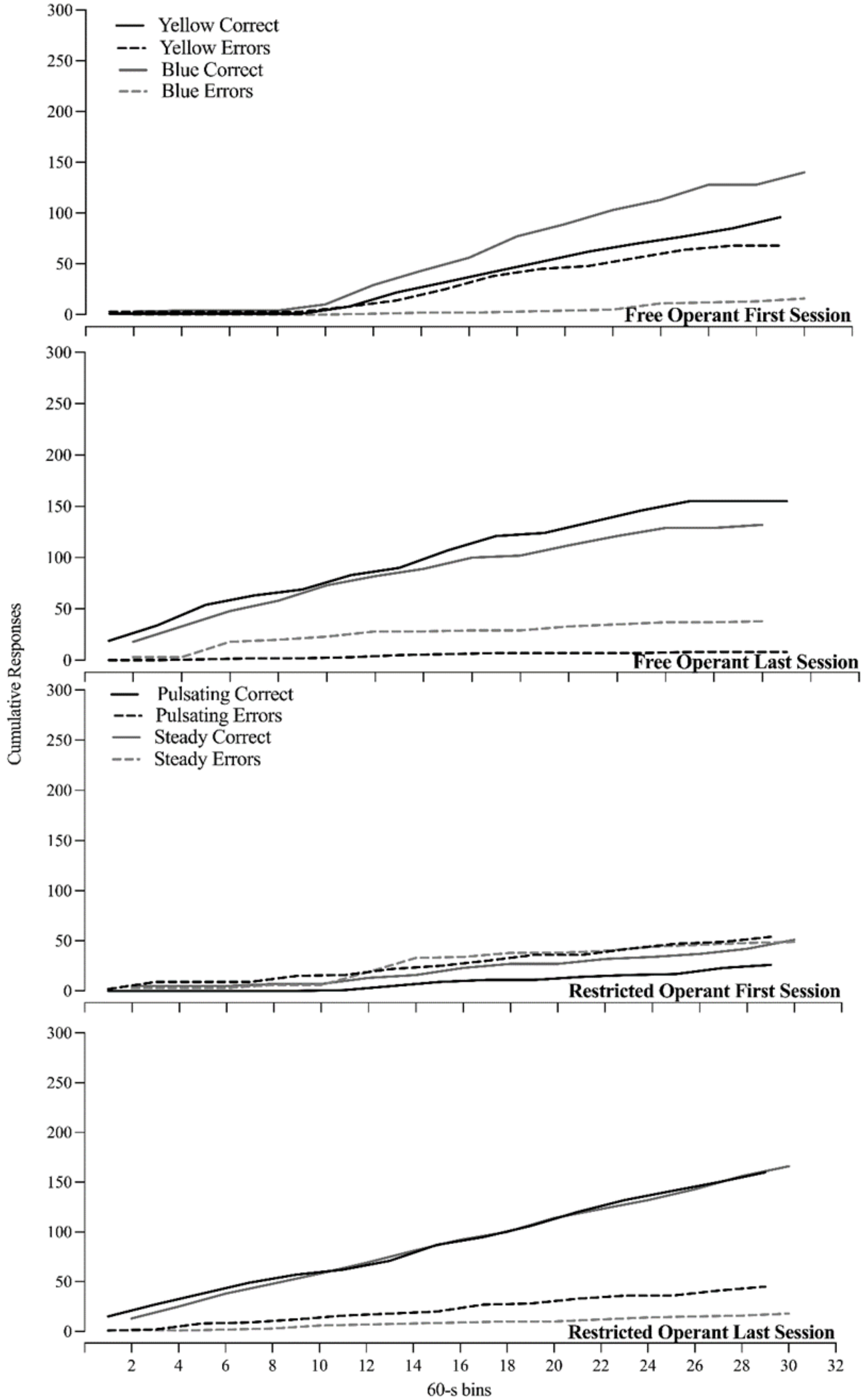
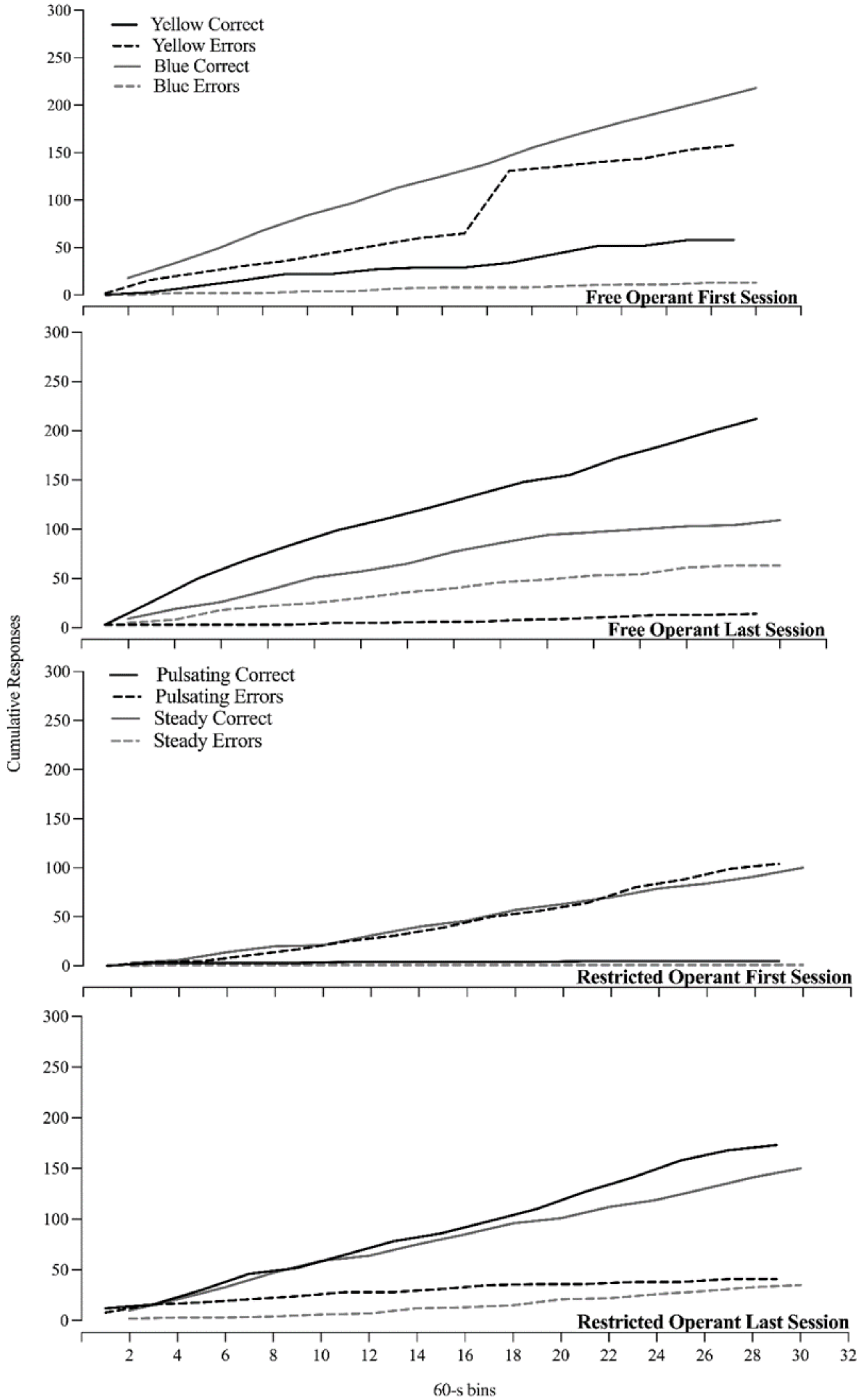


Figure 5. First and Last Session Responding for 2204.



Discussion

We compared differences in discriminated responding when subjects were exposed to two common conditioning arrangements (i.e., RO and FO). This study fills a gap and adds to a small number of basic studies directly investigating a comparison of FO and RO arrangements. Our results showed that the FO condition led to better and more efficient DIs when compared to an RO condition.

Our results replicate findings from previous studies that suggest that FO conditions may lead to more efficient and higher DIs when there is not a ceiling imposed on responding by removing the enabling stimulus during ITIs, a necessary component for the RO arrangement (e.g., Hachiya & Masato, 1991). The removal of the enabling stimulus during the ITI thereby limited the total number of possible responses in the RO condition. Despite the commonality of RO (i.e., DTT) arrangements in basic and applied settings, some considerations for the current results and future studies may be fruitful for consideration. It may be likely that the controlling mechanism for quicker discriminations in the FO condition is because subjects had an unlimited opportunity to make response-reinforcer relation discriminations. In comparison to the RO condition, in which there were a limited number of opportunities, there are fewer opportunities for important response-reinforcer discriminations. Specifically, under RO, if the rat responded at optimal levels throughout the session (i.e., an immediate response after each 5-s ITI), the maximum amount of time the lever remained in the chamber would be 360 s. This is contrasted against FO arrangements, where the lever remained in the chamber for 1800 s. This five-fold difference may have contributed to the overall efficiency in DIs in the FO condition. It is important to note that early sessions indicated that FO conditions immediately resulted in higher and more accurate responding. It is logical to presume that both conditions would initially result in DIs closer to .5. We speculate that immediate disparate rates of DIs between FO and RO is because we did not use experimentally naive subjects who had a learning history of lever-pressing in FO arrangements. It is also possible that the retraction of the levers had a disruptive effect to the subjects resulting in freezing, thereby decreasing response rates in the RO. Although it is not possible to determine which variable ultimately contributed to higher and accurate response rates in FO initially, it is important to note that these variables may have over inflated the efficiency and accuracy to which subjects met the .9 DI in the FO.

Further, availability and opportunity for a given response directly impacts response rates, as well as response persistence. Response persistence can be measured under periods of extinction or in the presence of a disruptive stimulus. Response persistence has been observed to be directly related to the availability of materials necessary for engaging in a response. For example, in a translational study, Randall et al. (2021) compared the availability (i.e., akin to an FO condition) and non-availability (i.e., akin to an RO condition) of an alternative response during extinction on the resurgence of target responding. Researchers found that when participants did not have access to the alternative response, the resurgence of target behavior occurred at greater magnitudes and persistence compared to conditions in which participants had access to the alternative response. Although we did not assess for response persistence, it is worth considering, in light of previous research, that one reason for more favorable responding in the FO condition is that it may have produced more persistent responding compared to the RO condition.

Interestingly, we observed slightly more stable responding in the presence of the distracting stimulus under FO conditions. This may have occurred because higher response rates were already previously observed in the FO condition that the RO condition at the time the stability test was introduced. Thus, this high rate of responding may have also led to another form response persistence in the presence of a disruptive stimulus. This pattern of responding is predicted by quantitative theories (e.g., Behavioral Momentum Theory, BMT) about the persistence of behavior. Specifically, BMT predicts that higher response rates will lead to more persistent behavior in the face of disruption (Nevin, 1983). Although, traditionally, disruption has been the suspension of reinforcement or delivery of noncontingent reinforcement, other stimulus arrangements could qualify as disruptors. In this case, the results of more persistent responding in the FO condition because of higher response rates in in alignment with the predictions of BMT. Notwithstanding, it is difficult to ascertain the extent to which the programmed distracting tonal served as a disruptive stimulus. Thus, future research may consider other types of disruptive stimuli (e.g., other tonal stimuli, visual stimuli, or different decibels) to measure the rate of disruption and the compare it under RO and FO conditions.

When drawing conclusions about efficiency in DIs and differences in the total opportunity for responses, it is important that some variables are held constant so that direct conclusions about findings can be made. Although number of opportunities for responding varied in our comparisons between FO and RO conditions, we held the overall amount of training time equitable and consistent across both conditions. These results suggest that with the control of time, organisms acquire discrimination tasks faster underneath free operant conditions across stimulus types. It might also be necessary to control for other potential confounding variables (e.g., number of responses, rate of reinforcement). For example, we employed a dense schedule of reinforcement which may have impacted the efficiency to which subjects acquired discrimination in the FO. The subject could engage in more responding (i.e., incorrect or correct responses) in the FO, whereas responding was limited in the FO. Therefore, for true comparisons, number of responses should be held constant across the two arrangements. In addition, an intermittent schedule of reinforcement, as opposed to an FR1 would have allowed for some variability in reinforcer delivery helping equate opportunities to responding on the enabling stimulus. Further, we used a dense schedule of reinforcement which may have impacted results such that in the FO, if the subject pressed the correct lever initially, it is likely subjects persisted on that lever. Some recent research considers these limitations and has used experimental arrangements in which these limitations have been controlled (see Bulla et al. (2024).

Interestingly, there were no differences in DIs for any SD except for the yellow SD condition such that there was a noticeable reduction in performance across subjects. It is unclear why this SD led to a decreased performance across subjects. Perhaps one reason is that the yellow light may have been less discriminable or more like the white steady light to the subjects. Thus, future research may address the limitation in the current study by selecting a more distinct SD than a yellow light. We used an experimental design that exposed subjects to both procedures eliminating that differences could be attributed to individual variability and increasing confidences that differences were because of the conditions, but we had a small number of subjects which limits the overall conclusion that can be made across subjects.

We extended the literature by directly comparing two common conditioning arrangements for acquisition of discriminated lever pressing. We found that overall, the FO arrangement led to quicker and more accurate responding than the RO arrangement. These data contribute to our understanding about the necessary environmental arrangements for training and what arrangements are critical to evoke and reinforce new response. Although these data are limited in terms of scope, as well as the number of subjects, these data can offer implications for the use of the RO procedures in basic and applied settings. For example, although DTT is a common RO procedure in clinical settings, perhaps more naturalistic FO arrangements may be better suited to bring about more efficient responding. This might be especially considered when the overall amount of time dedicated to teaching a specific skill may be limited (e.g., limited time for insurance authorization in a clinical setting). Further, an FO arrangement may be more desirable for persistent and maintenance of responding across time. Although conclusions about the selection of an RO or FO arrangement are tentative and should be carefully considered considering the other exigent variables (e.g., client needs, staff arrangement, types of learning). Notwithstanding, the present experiment offers an example of basic research contributing to our understanding of both basic and applied arrangements for training new skills.

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