

Increasing the persistence of a heterogeneous behavior chain:  
Studies of extinction in a rat model of search behavior of working dogs

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### Abstract

Dogs trained to search for contraband perform a chain of behavior in which they first search for a target and then make a separate response that indicates to the trainer that they have found one. The dogs often conduct multiple searches without encountering a target and receiving the reinforcer (i.e., no contraband is present). Understanding extinction (i.e., the decline in work rate when reinforcers are no longer encountered) may assist in training dogs to work in conditions where targets are rare. We therefore trained rats on a search-target behavior chain modeled on the search behavior of working dogs. A discriminative stimulus signaled that a search response (e.g., chain pull) led to a second stimulus that set the occasion for a target response (e.g., lever press) that was reinforced by a food pellet. In Experiment 1 training with longer search durations and intermittent (partial) reinforcement of searching (i.e. some trials had no target present) both led to more persistent search responding in extinction. The loss of search behavior in extinction was primarily dependent on the number of non-reinforced searches rather than time searching without reinforcement. In Experiments 2 and 3, delivery of non-contingent reinforcers during extinction increased search persistence provided they had also been presented during training. Thus, results with rats suggest that the persistence of working dog performance (or chained behavior generally) may be improved by training with partial reinforcement of searching and non-contingent reinforcement during both training and work (extinction).

*Keywords:* Persistence, Extinction, Heterogeneous chains, Detection, Canine, Rat

## 1. Introduction

Learned behavior often takes place in the form of separate but linked sequences or *chains* of behavior (e.g., Skinner, 1934; 1938). A behavior chain minimally consists of one response that provides the opportunity to perform another response that leads to a reinforcer. Each response is occasioned by a unique discriminative stimulus (SD). In a simple heterogeneous behavior chain, an SD sets the occasion for the first response that leads to the presentation of a second SD, which sets the occasion for a second response to be reinforced and serves as a conditioned reinforcer for the first response. Since many behaviors occur in a chain, a comprehensive understanding of learned behavior must include an understanding of behavior chains.

Understanding behavior chains in the laboratory may be useful for addressing behavior in applied settings. We have recently proposed that heterogeneous behavior chains studied in the laboratory describe behaviors analogous to those involved in drug or junk-food procurement and consumption (Thrailkill & Bouton, 2015a, b). In that case, our goal was to reduce undesirable behaviors that take place in a chain. However, the analysis of behavior chains may also be useful for characterizing variables that promote *desirable* behaviors that take place in a chain. For instance, working search dogs are trained to perform a behavioral chain with the goal of detecting explosives or other contraband (see Helton, 2009). A period of search responding (e.g., sniffing) in the presence of an SD (e.g., a car) eventually leads to a target SD (e.g., the odor of an explosive) which signals that a target response (e.g., pointing) will be reinforced. Fortunately perhaps, most working dogs will encounter prolonged periods in which searching does not result in discovery of the target odor. Therefore, a great deal of search behavior will never yield a reinforcer and responding could undergo extinction (Porritt et al., 2015).

In order to address this paucity of targets in some working environments, dog trainers commonly extend the period of time between target detections in the initial training phases (e.g. Garner et al., 2001; Goldblatt, Gazit, & Terkel, 2009). However, training time is limited, particularly once dogs are operational and there is a trade-off between extending the length of searches and ensuring that dogs get sufficient reinforcement on all targets during training days. Thus, a better understanding of search extinction and variables that influence search persistence would benefit users and enable them to optimize their use of limited training time.

Extinction generally refers to a procedure in which the reinforcer delivered during response acquisition is removed (Pavlov, 1927). Extinction learning is evidenced by a gradual decline in the response with repeated nonreinforced performance. Pavlovian and instrumental extinction have been a topic of intense interest in experimental and applied settings (e.g., Conklin & Tiffany, 2002; see Vurbic & Bouton, 2014 for a review). Although resistance to extinction has been studied in simple free operant and discrete-trial operant procedures (Amsel, 1967; Capaldi, 1966; Vurbic & Bouton, 2014), there has been no systematic investigation of the extinction of behavior chains. Laboratory studies of both Pavlovian and discrete operant behaviors have identified the crucial role of generalization between the conditions of reinforced training and extinction in creating resistance to extinction (Capaldi, 1966, 1994). Methods that increase the similarity between the conditions of training and extinction decrease the speed of the decline in responding during extinction by enhancing generalization between the two contexts; two such major methods are known to be effective.

First, extinction is slower when training involves reinforcement of only some responses (intermittent or partial reinforcement; PRF) as opposed to every response (continuous reinforcement; CRF). This partial-reinforcement extinction effect (PREE) is a well-known and

widely-replicated property of extinction learning; it has been observed in a wide range of species, including dogs (e.g., Mackintosh, 1974; Feuerbacher & Wynne, 2011). The PREE has been demonstrated with responses learned in Pavlovian, free operant, discriminated operant, and discrete-trial operant paradigms. The PREE is thought to occur, at least in part, because introducing occasions when the response is not reinforced during training makes the conditions of extinction more similar to those of training (Capaldi, 1994). Responding persists in extinction, a condition in which all responses are nonreinforced, because the organism learned to respond after recent occasions in which the response was not reinforced.

A second method for slowing extinction is to present the reinforcer used in training independently of the response during extinction (i.e. noncontingent reinforcement). Suspending the response-reinforcer contingency, but continuing to deliver the reinforcer, results in a slower decline compared to removing the reinforcer entirely (e.g., Baker, 1990; Rescorla & Skucy, 1969; Winterbauer & Bouton, 2011). One hypothesis is that reinforcers acquire a discriminative function for the response in addition to strengthening the response. That is, during training, the animal is reinforced for making responses soon after receiving a reinforcer. Noncontingent presentations of the reinforcer slow down extinction because the reinforcer presentations continue to set the occasion for the response. Both partial reinforcement and noncontingent reinforcers can slow extinction because they functionally increase the similarity, or generalizability, between training and extinction conditions.

Although the effects of partial reinforcement and noncontingent reinforcers on extinction have been widely studied in simple operant and Pavlovian procedures, to our knowledge there have been no studies of how these variables affect extinction of behavior trained in a heterogeneous behavior chain. We therefore investigated them here. Recent work by two of us

has developed a procedure in which rats learn to make a discriminated heterogeneous behavior chain (Thrailkill & Bouton, 2015a, b). In the method, rats learn to make a search response (e.g., pulling a chain) in the presence of a search SD that leads to the presentation of a target SD that sets the occasion for a target response (e.g., pressing a lever) that is then reinforced with a food pellet. A search stimulus first sets the occasion for a search response, and a target stimulus then sets the occasion for the target response (while potentially also serving as a conditioned reinforcer for search). (Our previous descriptions of the method labeled the first response “procurement” and the second response “consumption,” but the “search” and “target” labels used here are better suited for the working-dog application).

The present experiments used the procedure to investigate the contributions of partial reinforcement and noncontingent reinforcement to extinction of search responding. Figure 1 shows a diagram of the events in the procedure. In our first experiment, we used a factorial design to compare extinction of search responding after training with continuous versus partial reinforcement (sometimes search responding ended the search SD without an opportunity to make the target response), and long versus short search stimulus durations (longer search durations yielded more search responses that were not reinforced). In a second experiment, we then asked how noncontingent pellet deliveries during extinction would influence the persistence of searching in extinction. The results suggest that each of the variables investigated can in fact increase the persistence of search responding in extinction.

## **2. Experiment 1**

In Experiment 1, we studied the contributions of partial reinforcement of search and of search duration as factors influencing extinction in a 2 X 2 factorial design. Rats learned a discriminated heterogeneous behavior chain consisting of presentations of a search SD (panel

light located adjacent to the response manipulandum) that set the occasion for a search response (e.g., chain pull) which, according to a variable-interval (VI) schedule, could lead to a target SD that set the occasion for a target response (e.g., lever press) being reinforced. The rats received 30 such trials every training day. One factor in the design was the VI schedule used to reinforce the search response. Different groups could earn access to the target SD (and an opportunity to receive reinforcement of the target response) according to either VI-10 s (“Short” groups) or VI-30 s (“Long” groups) schedule. Notice that the “Long” interval potentially provided the opportunity for more search responses that did not produce the target SD. The two groups were further divided into two additional groups that differed in the proportion of search trials that actually led to the target SD. For the “CRF groups” (continuous reinforcement), 30 out of 30 trials led to the target SD; for the “PRF groups” (partial reinforcement), 10 randomly chosen trials out of 30 did so. The design thus included four groups of rats that received different treatments during training (Short CRF, Long CRF, Short PRF, and Long PRF). After training was complete, all groups underwent extinction of search responding. Search extinction was compared in two tests. First, groups received presentations of the search SD in which search responses had no scheduled consequences. We attempted to match the subjective search SD duration among the groups by fixing the length of search SD presentations at the geometric mean of the average experienced duration in the Short and Long groups (Church & Deluty, 1977). Second, following brief retraining, extinction of search responding was assessed again with several long duration (6-min) presentations of the search SD. This second extinction test assessed how the training conditions influenced extinction of searching across prolonged periods, in which the search SD was present but making the search response no longer led to the target SD. This is analogous to a long nonreinforced period of searching (relative to training searches)

encountered by a working dog. We hypothesized that both longer search VIs (the Long groups) and partial reinforcement (PRF) in training would promote better generalization to extinction conditions in contrast to both short search interval and continuous reinforcement (CRF). This leads to the prediction that Long intervals and PRF in training will increase persistence of search behavior during the extinction tests.

## 2.1. Method

### 2.1.1. *Subjects*

Thirty-two female rats (75-90 days old) were housed individually in suspended wire-mesh cages and maintained at 80% of their free-feeding weights. Rats had unlimited access to water in their homecages and were given supplementary feeding approximately 2 hr after each session. All animal care and handling procedures were approved and monitored by the University of Vermont Institutional Animal Care and Use Committee.

### 2.1.2. *Apparatus*

The apparatus consisted of two unique sets of four conditioning chambers (model ENV-007-VP; Med Associates, St. Albans, VT) located in separate rooms of the laboratory. Each chamber was housed in its own sound-attenuating chamber. All boxes measured  $31.75 \times 24.13 \times 29.21$  cm (Length  $\times$  Width  $\times$  Height). The sidewalls consisted of clear acrylic panels, and the front and rear walls were made of brushed aluminum. A recessed food cup was centered on the front wall approximately 2.5 cm above the floor. A retractable lever (model ENV-112CM, Med Associates) was positioned to the left of the food cup. The lever was 4.8 cm wide and 6.3 cm above the grid floor. It protruded 2.0 cm from the front wall when extended. A chain-pull response manipulandum (model ENV-111C, Med Associates) was positioned to the right of the food cup. The chain was 23.5 cm long and 5.7 cm above the grid floor. It was spaced 2.0 cm



from the front wall. Two 28-V (2.8 W) panel lights (diameter = 2.5 cm) were mounted on the wall near each manipulandum, 10.8 cm above the floor and 6.4 cm from the center of food cup. One light was immediately above the lever and the other was behind the chain. These lights served as SDs for lever pressing and chain pulling, respectively. The chambers could be illuminated by 7.5-W incandescent bulbs mounted to the ceiling of the sound-attenuation chamber. Ventilation fans provided background noise of 65 dBA.

The two sets of chambers had unique features that allowed them to serve as different contexts in other experiments, although they were not used for that purpose here. In one set of boxes, the floor consisted of 0.5 cm diameter stainless steel floor grids spaced 1.6 cm apart (center-to-center) and mounted parallel to the front wall. The ceiling and side wall had black horizontal stripes, 3.8 cm wide and 3.8 cm apart. In the other set of chambers, the floor consisted of alternating stainless steel grids with different diameters (0.5 and 1.3 cm, spaced 1.6 cm apart). The ceiling and side wall were covered with dark dots (2 cm in diameter). Reinforcement consisted of the delivery of a 45 mg food pellet into the food cup (MLab Rodent Tablets; TestDiet, Richmond, IN). The apparatus was controlled by computer equipment in an adjacent room

### *2.1.3. Procedure*

Food restriction began one week prior to the beginning of the experiment. During the experiment, one session was conducted each day, 7 days a week. Animals were handled each day and maintained at their target weight with supplemental feeding when necessary.

*2.1.3.1. Training.* Rats first received two 30-min sessions of “magazine training” with response manipulanda (levers and chains) removed. In each session, there were 30 pellet deliveries scheduled according to a random time (RT) 60 s schedule. Pellet delivery was not

contingent on the rat making a particular response. Over the next two sessions, the target response was trained. At this time, only the target response manipulandum (lever or chain) was present and the target stimulus was presented on 30 trials with a variable 45-s intertrial interval (ITI). Manipulanda were counterbalanced across subjects; the target SD was always the panel light nearest the target manipulandum. A target response turned the target SD off and immediately produced a food pellet according to a CRF schedule. A trial was terminated if a response was not made within 60 s of stimulus onset. In the next session, the search response manipulandum was added to the chamber. At the start of each of 30 trials, the new search SD (panel light nearest the search manipulandum) was illuminated. A single search response in the presence of the search SD turned off the stimulus, and immediately illuminated the target SD, in the presence of which a single target response then produced a food pellet. Training of both responses on CRF proceeded this way in chain sessions 1 and 2. The response requirement for search was increased to variable-interval 5-s to 10-s for all groups over sessions 3 and 4. The VI schedule in the Long groups were further increased from 20-s to 30-s in sessions 5 and 6. Partial reinforcement was introduced in PRF groups such that search led to the presentation of the target SD on 20 and then 15 of the 30 trials over sessions 7-10. Finally, the probability of a target presentation was further reduced to 10 of 30 trials, thus reaching the final conditions designed for all groups. Conditions remained the same for 12 more sessions after reaching the final conditions. Sessions lasted approximately 35 min.

*2.1.3.2. Test 1.* Once the training phase was completed, rats received a test session consisting of 30 search SD presentations. Search responding during the search SD no longer led to the presentation of the target SD or turned off the search SD. The duration of each search SD

presentation was the geometric mean of the search SD durations experienced by all the animals in the final session of acquisition.

*2.1.3.3. Test 2.* Following Test 1, all rats received two sessions of retraining under the same conditions as in the training phase. Next, a second test (Test 2) of search responding was conducted in which all rats received six presentations of the search SD. Each presentation lasted 6 min, during which search responses were recorded but had no consequence.

*2.1.4. Data analysis.* To describe search and target responding occasioned by the corresponding search and target SDs, we calculated elevation scores by subtracting the response rate on search and target manipulanda during the 30 s immediately before the search stimulus was presented (the pre-search SD period) from the response rate during the search and target stimuli, respectively. The elevation scores and pre-search response rates were evaluated with analyses of variance (ANOVAs) using a rejection criterion of  $p < .05$ .

## 2.2. Results

*2.2.1. Training.* Acquisition of the search-target chain proceeded smoothly. Once groups met their final respective training schedules (Short CRF, Long CRF, Short PRF, and Long PRF), the rate of searching continued to increase. Search elevation scores on each of the last sessions of the training phase are shown in Figure 2. The lowest rate of search responding was observed in the group that received training with partial reinforcement and a long delay to the target SD (Group Long PRF). A VI (Long, Short) by Reinforcement (PRF, CRF) by Session (12) ANOVA comparing search elevation scores during training supported these observations. Responding was significantly higher in VI-10 s (Short) than the VI-30 s (Long) groups,  $F(1, 28) = 6.39$ ,  $MSE = 417.62$ ,  $p = .02$ , and increased over sessions for all groups,  $F(11, 308) = 5.86$ ,  $MSE = 10.57$ ,  $p < .001$ . Neither VI nor Reinforcement factors interacted with Session,  $F_s < 1$ , but there was a three

way interaction,  $F(11, 308) = 2.11, p = .02$ . The overall effect of partial reinforcement tended toward significance,  $F(1, 28) = 2.96, p = .10$ , and there was no interaction between Reinforcement and VI,  $F = 1.45$ . To further analyze the three-way interaction, separate Reinforcement x Session ANOVAs were conducted at each level of VI. For Groups trained with VI-10 s (Short), responding increased over sessions,  $F(11, 154) = 3.92, MSE = 13.89, p < .001$ , but there was no effect of partial reinforcement (CRF vs. PRF),  $F < 1$ , and this variable did not interact with Session,  $F = 1.43$ . For Groups trained with VI-30 s (Long), responding increased over sessions,  $F(11, 154) = 2.13, MSE = 7.25, p = .02$ , and was reliably greater in the CRF group,  $F(1, 14) = 5.29, MSE = 337.54, p = .03$ , with no interaction,  $F = 1.41$ . Finally, a VI by Reinforcement ANOVA comparing responding in the final session before Test 1 revealed only a significant effect of VI,  $F(1, 28) = 5.44, MSE = 54.41, p = .03$ , and no effect of Reinforcement or interaction ( $F$ s = 2.37, and .06, respectively). This pattern was also maintained in the final session before Test 2, only the VI effect was reliable,  $F(1, 28) = 5.81, MSE = 60.35, p = .02$ , and the Reinforcement effect and interaction were not ( $F$ s = 2.73, and .04, respectively).

Our analysis of search responding as an elevation score was not complicated by differences in pre-search SD responding. Average search response rates (responses per min) in the 30-s period preceding search SD onset were 2.3, 3.8, 2.8, 3.5 in the first session of the final training condition, and 2.1, 6.7, 3.3, and 2.2 in the final session prior to Test 1 in groups Long CRF, Short CRF, Long PRF, and Short PRF, respectively. A VI (Long, Short) x Reinforcement (PRF, CRF) x Session (12) ANOVA on search response rates in the pre-search SD periods found a significant effect of Session,  $F(11, 308) = 2.18, MSE = 1.93, p = .01$ , but no other main effects, Largest  $F(1, 28) = 2.69, MSE = 95.02$ . Although Session did not interact with VI or Reinforcement factors individually,  $F$ s < 1, there was a reliable three-way interaction,  $F(11, 308)$

$= 2.68, p < .01$ . To analyze the three-way interaction, separate ANOVAs compared responding at each level of VI. In the Long groups, responding in the pre-search period increased over Session,  $F(11, 154) = 3.12, MSE = 0.94, p = .001$ , but there was no Reinforcement effect or interaction, largest  $F = 1.17$ . In contrast, pre-search responding in the Short groups decreased primarily in the PRF group: There was a significant Reinforcement by Session interaction,  $F(11, 124) = 1.96, MSE = 2.93, p = .03$ , and no main effect of Session or Group, largest  $F(1, 14) = 1.97, MSE = 136.27$ . Search responding in the pre-search SD period in the final session was compared in a VI (Long, Short) by Reinforcement (CRF, PRF) ANOVA. There was a significant VI by Reinforcement interaction,  $F(1, 28) = 5.26, MSE = 12.62, p = .03$ , and no other significant effects. Subsequent comparisons of Reinforcement at each level of VI found marginal evidence of greater pre-search responding in Group Short CRF,  $F(1, 15) = 3.87, MSE = 21.02, p = .07$ .

*2.2.2. Test 1.* In the first extinction test session, search elevation scores were initially greater in the Short groups, but by the end of the session, responding was highest in the Long PRF group. Results are presented in Figure 3a. A VI (Long, Short) by Reinforcement (CRF, PRF) by Block (6) ANOVA revealed significant effects of VI,  $F(1, 28) = 6.39, MSE = 62.34, p = .02$ , Reinforcement,  $F(1, 28) = 7.27, p = .01$ , Block,  $F(5, 140) = 23.41, MSE = 21.62, p < .001$ , and a Block by VI interaction,  $F(28, 140) = 6.89, p < .001$ . There were no other interactions, largest  $F(1, 28) = 1.19$ . Long and Short groups were further assessed in separate Reinforcement by Block ANOVAs. In Short groups, PRF maintained greater responding, but each group decreased similarly over test blocks, there were significant effects of Reinforcement,  $F(1, 14) = 7.28, MSE = 61.72, p = .02$ , and Block,  $F(5, 70) = 23.79, MSE = 24.91, p < .001$ , and no interaction,  $F = 1.01$ . In Long groups, CRF and PRF maintained similar responding over blocks. Responding decreased over blocks,  $F(5, 70) = 3.39, MSE = 18.33, p = .008$ , but there was no

effect of Reinforcement,  $F(1, 14) = 1.27$ ,  $MSE = 63.76$ ,  $p = .28$ , and no interaction,  $F = 1.01$ .

Search elevation scores were evaluated in the final block of the test session in order to determine which group demonstrated the most persistent search behavior. A VI (Long, Short) by Reinforcement (CRF, PRF) ANOVA found greater responding in Long groups,  $F(1, 28) = 6.47$ ,  $MSE = 9.15$ ,  $p = .02$ , and no effect of Reinforcement, or interaction, largest  $F(1, 28) = 2.56$ .

Mean search elevation scores were also analyzed over the final 5 blocks of the test session as a proportion of the average responding in the first 5-trial block (Figure 3b). This method of describing the data corrected for baseline group differences at the start of the test session, which are more a result of the independent variables' effects on acquisition rather than extinction. Here there was a clear tendency for responding to be more persistent in the PRF and Long groups. Consistent with this, a VI (Long, Short) by Reinforcement (CRF, PRF) by Block (5) ANOVA revealed significant effects of VI,  $F(1, 28) = 8.09$ ,  $MSE = 0.32$ ,  $p < .01$ , Reinforcement,  $F(1, 28) = 5.56$ ,  $p = .03$ , and Block,  $F(4, 112) = 13.95$ ,  $MSE = 0.11$ ,  $p < .001$ , with no interaction, largest  $F(4, 112) = 1.63$ .

Our use of elevation scores in analyzing test data was not complicated by differences in pre-search SD response rates. Mean search response rates (responses per min) in the 30 s pre-search SD period were 6.3 and 3.9 for Groups Long CRF and PRF, and 5.7 and 1.1 for groups Short CRF and PRF, respectively. A VI (Long, Short) by Reinforcement (CRF, PRF) ANOVA on the first 5-trial block revealed significantly greater responding in CRF groups,  $F(1, 28) = 5.15$ ,  $MSE = 19.56$ ,  $p = .03$ , with no effect of VI or interaction, largest  $F = 1.25$ . Mean response rates in the final block were .2, and 1.4 for Groups Long CRF and PRF, and .1, and .2 for Groups Short CRF and PRF, respectively. A VI (Long, Short) by Reinforcement (CRF, PRF) ANOVA found no differences in responding in the final block, largest  $F(1, 28) = 3.41$ ,  $MSE = 0.99$ .

Search responding in the pre-search SD periods was analyzed for the entire test session in a VI (Long, Short) by Reinforcement (CRF, PRF) by Block (6) ANOVA. There was a significant effect of VI,  $F(1, 28) = 13.02$ ,  $MSE = 9.83$ ,  $p = .001$ , and a VI by Reinforcement interaction,  $F(1, 28) = 5.47$ ,  $p = .03$ , with no main effect of Reinforcement,  $F < 1$ . Pre-search responding decreased over the session for all groups,  $F(5, 140) = 11.00$ ,  $MSE = 5.62$ ,  $p < .001$ , but a Block by Reinforcement interaction suggested responding decreased more slowly in the PRF groups,  $F(5, 140) = 4.33$ ,  $p = .001$ , there were no other interactions, largest  $F = 1.78$ .

*2.2.3. Test 2.* Recall that the second test examined search responding during several 6-min presentations of the search SD. Search response rates were analyzed in 2-min bins within each 6-min search SD (Figure 3c). Responding decreased both between and within search SD presentations. The PRF groups showed this pattern but tended to respond at a higher rate than the other groups. A VI (Long, Short) by Reinforcement (CRF, PRF) by Bin (3) by SD presentation (4) ANOVA found significant effects of SD presentation,  $F(3, 84) = 43.84$ ,  $MSE = 40.11$ ,  $p < .001$ , and Bin,  $F(2, 56) = 46.43$ ,  $MSE = 12.73$ ,  $p < .001$ , as well as a SD presentation by Bin interaction,  $F(6, 168) = 20.13$ ,  $MSE = 12.37$ ,  $p < .001$ , and a SD presentation by Bin by Reinforcement interaction,  $F(6, 168) = 5.76$ ,  $p < .001$ . There were no other significant effects or interactions, largest  $F(2, 56) = 2.59$ . A VI by Reinforcement by Bin ANOVA also compared responding in the first SD presentation. There was a significant decrease over bins,  $F(2, 56) = 45.00$ ,  $MSE = 26.09$ ,  $p < .001$ , a reliable Bin by Reinforcement interaction,  $F(2, 56) = 6.36$ ,  $p = .003$ , and a Bin by Reinforcement by VI interaction,  $F(2, 56) = 3.23$ ,  $p = .04$ . Further Reinforcement by Bin ANOVAs compared responding at each level of VI. For Long groups, there was a reliable effect of Bin,  $F(2, 28) = 16.69$ ,  $MSE = 30.86$ ,  $p < .001$ , and a Bin by Reinforcement interaction,  $F(2, 28) = 7.72$ ,  $p = .002$ , and no other effect,  $F < 1$ . For Short groups,

there was a significant decrease across bins,  $F(2, 28) = 31.12$ ,  $MSE = 21.34$ ,  $p < .001$ , but no other effects or interactions,  $F_s < 1$ . Finally, a VI by Reinforcement by Bin ANOVA compared responding in the final SD presentation. There was significantly greater responding in the Long groups,  $F(1, 28) = 6.11$ ,  $MSE = 19.16$ ,  $p = .02$ , but no other significant effects or interactions, largest  $F = 2.74$ .

### 2.3. Discussion

Rats learned the search-target chain with each combination of search VI length and probability of whether search responding led to the target SD. In general, increasing search time (from VI-10 s to VI-30 s) and decreasing the probability of reinforcement (from CRF to PRF) each led to both slower search responding in training and a slower loss of responding in extinction. When search responding in each group was compared across nonreinforced presentations of the search stimulus, both longer search VI and partial reinforcement during training led to increased search persistence. Notice that the Short PRF and the Long CRF groups reached the target SD after the same amount of time searching in the search SD (30 s each, on average). When rate of reinforcement was equated this way, decreasing the probability of the target SD on each trial (Group Short PRF) led to slower search extinction. Therefore, search extinction depended on the number of nonreinforced search trials. This pattern is consistent with predictions of a trial-based account of the PREE (Bouton, Woods, & Todd, 2014; Capaldi, 1966, 1967), but not accounts that emphasize the accumulation of nonreinforced time in the search SD (cf. Gallistel & Gibbon, 2000).

When searching was compared over long nonreinforced presentations of the search SD, partial reinforcement, but not longer time in the search stimulus, produced more persistence in extinction (Long PRF and Short PRF). The most persistent group was the group that received



partial reinforcement along with the longer search VI (Long PRF). Overall, the results suggest that increasing the amount of nonreinforced time while searching and decreasing the probability that each search yielded a target in training both promoted search persistence in extinction.

### **3. Experiment 2**

The second experiment investigated the effects of presenting noncontingent reinforcers during extinction as a second method for promoting search persistence. Rats learned the same search-target chain as Group Short CRF in Experiment 1. In Experiment 2, groups trained this way received a search extinction test, but differed in whether (and when) noncontingent reinforcers were presented during the test. Group Extinction received no pellets, Group Search received 2 free pellets during the search SD, Group Late ITI received the pellets in the final 20 s of the ITI prior to the onset of the search SD, and Group Early ITI received the pellets in the first 20 s ITI. In the search test, evidence for an increase in search persistence would consist of greater search responding in the search SD in any group compared to responding in Group Extinction. If the similarity of acquisition and extinction conditions contributes to extinction of search, then groups with noncontingent reinforcers were expected to decrease searching more slowly than simple extinction without reinforcers. This leads to the prediction that noncontingent pellet delivered during search extinction will increase the persistence of searching.

#### **3.1. Method**

##### *3.1.1. Subjects and Apparatus*

Experiment 2 used 32 female rats (75-90 days old) housed and maintained under the same conditions as in Experiments 1. The apparatus and control of procedures was the same as in Experiment 1.

##### *3.1.2. Procedure*

Food restriction, training schedules, handling, and feeding procedures were the same as in Experiment 1.

*3.1.2.1. Training.* Rats first received magazine training following the procedure used in Experiment 1. Over the next two sessions, the target response was trained. At this time, only the target response manipulandum (lever or chain) was present and the target stimulus was presented on 30 trials with a 60 s variable ITI that ranged from 50 s to 70 s. Half the rats received training with the lever and half received training with the chain; the target SD was always the panel light near the target manipulandum. A target response turned the SD off and immediately always produced a food pellet. A trial was terminated if a response was not made within 60 s of stimulus onset. In the following session, the search response manipulandum was added to the chamber. The new search SD (panel light near the search manipulandum) was presented at the start of each trial. A single search response in the presence of the search SD turned off the stimulus, and immediately turned on the target SD, in the presence of which a single target response produced a food pellet. Training of both responses proceeded this way in sessions 1 and 2. Next, the response requirement for search was increased to VI 5-s in sessions 3 and 4. Finally, the VI was increased to 10 s, for the remaining 12 sessions of the acquisition phase. Sessions lasted approximately 40 min.

*3.1.2.2. Extinction of Search Responding with Noncontingent Pellets.* Following acquisition, rats were assigned to four groups after matching them on the rate of search responding. One group (Group Extinction) received thirty 20-s presentations of the search SD separated by a variable 60-s ITI. Search responding during the search SD had no scheduled consequences (i.e., the SD remained on for 20-s on each trial). Extinction conditions during search SD presentations were similarly in effect for the remaining three groups. However, each

received two noncontingent pellets separated by 10 s on average. Noncontingent pellets were delivered such that one occurred in each half of the 20-s period, were separated by at least 4-s, and did not occur within the first and last 2-s of the period. Group Early ITI received pellets in the first 20 s of the ITI, Group Late ITI received pellets in the final 20 s of the ITI, and Group Search received pellets in the search SD.

*3.1.2.3. Extinction of Target with Noncontingent Pellets.* Next, rats received two sessions of retraining, and were then regrouped such that each of the previous groups was equally represented in new groups formed prior to a test of target responding. In a single session, one group (Group Extinction) received 30 presentations of a 20-s *target* SD during which target responding was recorded but had no scheduled consequences. Extinction conditions were similar for the remaining three groups with the exception that each received two pellets separated by 10-s on average. Group Early ITI received pellet presentations in the first 20-s of the ITI, Group Late ITI received pellets in the final 20-s of the ITI, and Group Target received pellets in the target SD.

### 3.2. Results

*3.2.1. Training.* Each group acquired search responding over the course of the acquisition phase (Figure 4a). A Group by Session ANOVA confirmed an increase in search elevation scores over sessions,  $F(11, 308) = 7.57$ ,  $MSE = 19.91$ ,  $p < .001$ , and did not find differences between Groups or an interaction with session, largest  $F = 1.05$ . A one-way ANOVA comparing groups on the final session before the Search test and the reconstituted groups before the Target test did not find a significant difference in search responding in either case,  $F(3, 28) = .33$  and 1.64 respectively. Our analysis of search elevation scores was not complicated by differences in search responding during the 30-s pre search period. Search response rates (responses per min) in

the pre-search SD period were 3.2, 3.0, 5.2, and 4.4 in the first session, and 2.3, 2.4, 7.5, and 5.2 in the final session prior to the Search test in groups Search, Late ITI, Early ITI, and Extinction, respectively. A Group by Session ANOVA found a significant increase in pre-search responding over sessions,  $F(11, 308) = 2.42$ ,  $MSE = 1.87$ ,  $p < .01$ , but no group difference,  $F < 1$ , or interaction,  $F(33, 308) = 1.39$ ,  $p = .08$ . A one-way ANOVA comparing pre-search responding on the final session before Test 1 and the reconstituted groups before Test 2 did not find a significant difference in search responding prior to either test ( $F(3, 28) = 1.22$ ,  $MSE = 40.74$ , and  $F(3, 28) = .94$ ,  $MSE = 20.14$ , respectively).

*3.2.2. Extinction of Search Responding with Noncontingent Pellets.* Search responding during the first extinction test is summarized in Figure 4b. Presenting noncontingent pellets hastened the loss of responding in Groups Search and Late ITI, which showed lower search elevation scores than Groups Extinction and Early ITI. The data were analyzed in a Group (4) by Block (6) ANOVA. There were significant effects of Group,  $F(3, 28) = 10.18$ ,  $MSE = 127.96$ ,  $p < .001$ , Block,  $F(5, 140) = 12.99$ ,  $MSE = 24.78$ ,  $p < .001$ , and a Group by Block interaction,  $F(5, 140) = 3.96$ ,  $p < .001$ . Planned LSD comparisons revealed that Groups Search and Late ITI each responded significantly less than Groups Early ITI and Extinction,  $ps < .005$ . Groups Search and Late ITI, and Early ITI and Extinction did not differ from each other  $ps = .21$  and  $.91$ , respectively. There was evidence for an effect of noncontingent pellets on search extinction in Group Early ITI. A one-way ANOVA found a significant group effect in the final search-SD block,  $F(3, 28) = 3.38$ ,  $MSE = 12.61$ ,  $p = .03$ , and follow up comparisons found that Group Early-ITI had a higher search elevation score than Groups Search, Late-ITI, and Extinction,  $ps = .03$ ,  $.01$ , and  $.02$ , respectively, and these groups did not differ from one another, lowest  $p = .45$ . Differences in pre-search SD responding on the search manipulandum may have contributed to

the elevation score results. In the first and last blocks, pre-search SD response rates were 5.8, 3.7, 1.4, and 9.2, and 0.4, 2.7, 0.9, and 8.4 in Groups Extinction, Early ITI, Late ITI, and Search, respectively. The same ANOVA was used to compare pre-search SD responding. There was a significant effect of Group,  $F(1, 28) = 5.28$ ,  $MSE = 147.32$ ,  $p = .005$ , and no effect of Block or interaction, largest  $F(5, 140) = 1.71$ ,  $MSE = 9.78$ . Planned comparisons revealed that Group Search responded on the search manipulandum at a significantly higher rate during the pre-search SD period than groups Late ITI, Early ITI, and Extinction,  $ps = .001$ ,  $.008$  and  $.004$ , respectively, and the other groups did not differ from one another, lowest  $p = .48$ .

*3.2.3. Extinction of Target Responding with Noncontingent Pellets.* The results of the test of target extinction is shown in Figure 4c. Noncontingent pellets did not disrupt target responding as much as they had disrupted search responding. The data were analyzed in a Group (4) by Block (6) ANOVA. There was a significant decrease in responding over blocks,  $F(5, 140) = 8.70$ ,  $MSE = 10.67$ ,  $p < .001$ , but no effect of Group, or interaction, largest  $F(3, 28) = 1.18$ . Evidently, the presentation of noncontingent pellets did not disrupt target responding as much as it had disrupted search responding. Differences in pre-target SD responding on the target manipulandum may have contributed to the elevation score results. Target response rates in the 30-s pre-target SD period were 1.1, 0.4, 2.1, and 6.5 in the first, and 0.1, 0.1, 3.0, and 5.3 in the last block in Groups Extinction, Early ITI, Late ITI, and Target, respectively. The same analysis found a significant effect of Group,  $F(3, 28) = 3.96$ ,  $MSE = 121.23$ ,  $p = .02$ , but neither the Block or Group by Block interaction reached significance, largest  $F(5, 140) = 2.14$ ,  $MSE = 4.36$ . Planned comparisons revealed that Group Target responded at a significantly higher rate during the pre-target SD period than groups Late ITI, Early ITI, and Extinction,  $ps = .005$ ,  $.05$ , and  $.008$ , respectively, that the other groups did not differ from one another, lowest  $p = .30$ .

### 3.3 Discussion

Rats again acquired the search-target chain. Delivering noncontingent reinforcers during extinction had different effects on search and target responding. In the case of search responding, adding noncontingent reinforcers in extinction hastened (rather than slowed) the loss of responding that occurred in extinction. It is worth noting that the test was the first time the rats had received pellets in the search SD or anywhere near search responding in time. This could have caused generalization decrement, a failure to generalize completely from training to the test phase. Indeed, noncontingent pellets during the search SD and pre-search SD periods immediately weakened search responding. Group Search, in particular, showed a large increase in pre-search SD responding. This anticipatory pre-search SD responding, along with competition from food cup responding in the search SD, contributed to the decrease in search SD responding. Search responding was also weakened in Group Late-ITI, but this did not correspond with an increase in pre-search SD responding. This was presumably due to competition from behavior directed toward collecting and consuming the food pellet in the pre-search SD and search SD periods. By the end of the search test, however, resistance to extinction was greatest in Group Early-ITI. This suggests that noncontingent pellets can increase search resistance to extinction when they are delivered in a manner that does not interfere with search responding, or, perhaps, shortly after an unsuccessful search attempt. In the case of target responding, noncontingent reinforcers delivered in extinction produced a similar pattern of results. Here, pellet presentations during the target SD and late in the ITI may have caused generalization decrement because the pellet had been associated with the offset of the target SD during training. Indeed, there was a trend toward enhanced target responding caused by pellets delivered shortly

after the target SD, which is also consistent with the idea that target responding, but not search responding, is mediated by an expectancy of the pellet reinforcer (e.g., Corbit & Balleine, 2003).

#### 4. Experiment 3.

Experiment 3 examined the effectiveness of adding noncontingent reinforcers to extinction when such reinforcers had also been included during training. During training, the rats received two noncontingent pellets in the final 20 s of each ITI preceding the onset of the search SD. All rats then received a search extinction test. One group (P) continued to receive noncontingent pellets, and the other group (NP) received search extinction without noncontingent pellets. We expected the noncontingent pellets to increase generalization from acquisition to extinction. This leads to the prediction that noncontingent pellets delivered across search acquisition and extinction will increase the persistence of searching.

#### 4.1. Method

##### *4.1.1. Subjects and Apparatus*

Experiment 3 used 16 female rats (75-90 days old) housed and maintained under the same conditions as in Experiments 1. The apparatus and control of procedures was the same as in Experiment 1.

##### *4.1.2. Procedure*

Food restriction, training schedules, handling, and feeding procedures were the same as in Experiment 1.

*4.1.2.1. Training.* The target response was trained in the same manner as in Experiment 3. As before, manipulanda (lever or chain) were counterbalanced across subjects. The target response was trained in the presence of the target SD for two sessions and then the search stimulus was added with the search SD. The entire chain was trained with both responses on

CRF in sessions 1 and 2. Next, the response requirement for search was increased to VI 5-s for all groups in sessions 3 and 4. The search VI was increased to 10 s for session 5 prior to the introduction of two noncontingent pellets in the final 20 s of the ITI prior to search SD onset on session 6. All rats received further acquisition training with noncontingent pellets for 12 sessions. Sessions lasted approximately 40 min.

*4.1.2.2. Extinction of Search Test.* Following acquisition, rats were matched on acquisition performance and assigned to two groups. One group (Group P), received 30 presentations of the 20-s search SD. For this group, search responding during the search SD ended the search SD presentation according to VI 10-s but did not lead to the target SD or reinforcement. As usual, noncontingent pellets preceded the trials. The remaining rats (Group NP), received the same search extinction conditions with noncontingent pellets removed from the ITI.

## *4.2. Results*

*4.2.1. Training.* Following initial acquisition of the chain, the introduction of noncontingent reinforcers disrupted search responding. Three rats did not develop an elevation in search responding above the pre-search SD rate, and were dropped from the experiment. The remaining rats continued to perform the search-target chain reliably (Figure 5a). A Group (2) by Condition (last pre-noncontingent, first noncontingent) ANOVA confirmed that noncontingent reinforcement disrupted search elevations in each group similarly. There was a significant decrease in search responding from the final pre-training session (far left of Figure 6a) to the first session containing noncontingent pellets,  $F(1, 12) = 9.77$ ,  $MSE = 13.85$ ,  $p = .01$ , and no effect of Group,  $F(1, 11) = 1.42$ ,  $MSE = 68.02$ ,  $p = .26$ , or interaction,  $F < 1$ . Groups maintained elevated search responding with noncontingent reinforcers over the final 12 sessions of acquisition. A



Group by Session ANOVA found no difference between groups,  $F(1, 11) = 1.21$ ,  $MSE = 145.10$ ,  $p = .29$ , and no further change in search elevation scores across sessions or interaction,  $F_s < 1$ .

The analysis of elevation scores was not complicated by differences in pre-search SD responding. Search response rates in the pre-search SD periods were 5.1 and 5.6 in the session prior to, 4.2 and 6.7 in the first session of training with noncontingent reinforcers, and 0.8 and 4.0 in the final session prior to the test in Groups NP and P, respectively. A Group by Session ANOVA found that the introduction of noncontingent reinforcement had no effect on search responding during the pre-search SD period, and there was no effect of Condition, Group, or interaction,  $F_s < 1$ . Search responding in the pre-search SD period decreased over the 12 sessions,  $F(11, 121) = 2.60$ ,  $MSE = 5.53$ ,  $p = .005$ , but did not differ between groups,  $F(1, 11) = 1.91$ ,  $MSE = 65.99$ , or interact,  $F = 1$ .

*4.2.2. Test.* We were interested here in assessing how the removal of noncontingent reinforcers affected search responding compared to the baseline of responding with noncontingent reinforcers. Search responding during the extinction test was therefore expressed as the proportion of the average search elevation score in the final session of acquisition in blocks of 2 search SD extinction trials. Figure 5b shows that Group P maintained a greater proportion of baseline search responding than Group NP. A Group (P, NP) by Block ANOVA confirmed these observations. There were significant effects of Group,  $F(1, 11) = 5.44$ ,  $MSE = 0.78$ ,  $p = .04$ , and Block,  $F(7, 77) = 4.44$ ,  $MSE = 0.29$ ,  $p < .001$ , and no interaction,  $F < 1$ . The difference in search responding was not complicated by differences in pre-search SD responding. In blocks 1 and 8, search response rates in Groups NP and P were 0.8 and 1.1, and 0.3 and 0.1, respectively. A Group (2) by Block (8) ANOVA did not reveal any reliable difference between

groups,  $F(1, 11) < 1$ , and there was no reliable difference over blocks,  $F(7, 77) = 1.42$ ,  $MSE = 0.41$ ,  $p = .21$ , or interaction,  $F = 1.43$ .

#### 4.3. Discussion

Rats again acquired the search-target chain. Training with noncontingent reinforcers appeared to render them effective at slowing the extinction of search responding. This is consistent with the idea that noncontingent reinforcers are effective when they can promote generalization from training to extinction. Further consistent with the generalization decrement hypothesis explanation for Experiment 2, the noncontingent reinforcers disrupted search responding when they were first introduced during the training phase. But more important, continuing to deliver noncontingent reinforcers in extinction (Group P) maintained search responding in comparison to a group for which they were simply removed (Group NP). Delivering noncontingent reinforcers during training also seemed to decrease the overall rate of search responding relative to that observed in Experiment 2, although such a cross-experiment comparison must be treated cautiously (the effect of the variable was not evaluated experimentally). Nonetheless, the rats did continue to perform the search-target chain, and noncontingent reinforcers prolonged extinction. In this case, the omission of pellets (Group NP), rather than the inclusion of pellets (Group P), would have caused the greater generalization decrement and a faster decline in search responding.

### 5. General Discussion

The present experiments begin to characterize the variables that contribute to the extinction of search responding in a discriminated heterogeneous behavior chain. Experiment 1 documented that acquisition of the chain with both longer search durations prior to occurrence of the target SD and a partial reinforcement contingency leads to more persistence of searching

during extinction. Experiments 2 and 3 identified a role for sensitivity to generalization decrement in search responding. As with Pavlovian and simple instrumental responses, manipulating generalization decrement from acquisition to extinction influenced persistence of the search response. Introducing noncontingent pellets during training allowed them to prolong search responding when they were also presented in extinction (Experiment 3). In contrast, if noncontingent pellets were introduced for the first time during extinction (Experiment 2), they hastened the loss of search responding (though they slowed the loss of target responding). Overall, the results suggest that extinction of the search response is influenced by the types of variables that are also known to influence the extinction of simple (nonchained) operant and Pavlovian responding. The results are consistent with the overarching idea that increasing the similarity between training and extinction conditions leads to greater behavioral persistence.

Overall, the results are consistent with the literature suggesting that generalization decrement contributes to extinction and that increasing generalization from acquisition to extinction will slow extinction. The fact that noncontingent pellets during acquisition contributed to search persistence in comparison to extinction without noncontingent pellets is consistent with related work showing that continued presentations of stimuli associated with learning in one phase of an experiment can promote generalization to the new conditions of a different phase (Brooks & Bouton, 1993, 1994; Lindblom & Jenkins, 1981; Rescorla & Skucy, 1969). The role of generalization across conditions is also consistent with theoretical accounts of the PREE (Capaldi, 1966; 1994).

Although our laboratory procedure does not model every aspect of searching in dogs, it is clear that search dogs engage in a chain of two or more behaviors (Porritt et al., 2015). Therefore, partial reinforcement and noncontingent reinforcers could influence persistence of the

responses in the chain. It is also likely, though not addressed here experimentally, that efforts to increase the persistence of one response will influence the persistence of the other behaviors in the chain because the behaviors become associated during training (Thrailkill & Bouton, 2015a, b).

Nonetheless, understanding the extinction of a heterogeneous behavior chain has applied potential for addressing situations in which chained behaviors undergo extinction. The present results may be useful for developing training methods for search dogs that promote search vigilance and target detection accuracy under conditions in which reinforced target encounters occur infrequently (Gazit et al., 2005; Porritt et al., 2015).

The results of Experiment 1 clearly suggest that including both nonreinforced searches and longer periods of nonreinforced searching during training can lead to greater search persistence during the extinction conditions experienced during many work searches. Furthermore, the finding that search extinction appears to depend on the number of nonreinforced search trials rather than the accumulation of nonreinforced time searching implies that the optimum use of limited training time would be to conduct a large number of short searches on a training day, a proportion of which do not contain any targets, rather than a small number of long searches that each contain targets. This approach would serve to reduce the differences between training and operational days thereby promoting generalisation.

Experiment 2 showed that presenting noncontingent reinforcers during search extinction actually reduce search behavior by creating generalization decrement when this practice is not followed in training. However, we also found that delivering noncontingent reinforcers during extinction can increase search persistence if their presentation is also included as part of the training protocol (Experiment 3). While the initial introduction of “free” reinforcers during

training reduced search responding, it did not break down search responding and resulted in increased persistence under extinction. The implication is that if the dog handler provides reinforcers during training that are not contingent on searching or pointing, then continuing to present them during extinction will serve to maintain performance and increase the persistence of searching.

The present results might suggest four important recommendations for dog trainers: First, introducing partial reinforcement of the target response as a component of the training protocol improves search persistence; and the optimum way to do this with limited training time would be to conduct a greater number of short searches per training day to allow for some searches to contain no target. Second, increasing the duration of search time without encountering a target will encourage searching when target encounters are infrequent (Garner et al., 2001). Although, this might comparatively reduce search rate under normal working conditions, our results suggest it would lead to more persistent search under prolonged periods of search without a target encounter. Third, delivering noncontingent reinforcers during periods of nonreinforced searching can help maintain search behavior when they have been used and integrated into the training and working conditions. Finally, the results overall suggest that using measures that increase generalization across (i.e., similarity between) training and working phases will promote search persistence in general.

In sum, the present study extends the analysis of extinction to behaviors that occur in a discriminated heterogeneous chain. Overall, the results suggest that the same variables that influence extinction of simple operant behavior also influence extinction of behavior in a chain. Partial reinforcement and noncontingent reinforcers are two methods of increasing generalization

across acquisition and extinction conditions. The methods may be useful in applications for increasing persistence of behavior that takes place in a chain.

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This research was supported through joint funding by UK government departments through the CONTEST programme (FP and AK) and by NIH Grant RO1 DA 033123 to MEB. Send correspondence to Eric A. Thrailkill (eathrail@uvm.edu) or Mark E. Bouton (mbouton@uvm.edu).

Figure 1

*Figure 1.* Diagram of the discriminated heterogeneous behavior chain procedure. Search and target responses can occur freely. After an inter-trial interval (ITI), the Search SD (S) turns on. Search responses during the Search SD can produce the simultaneous offset of the Search SD and onset of the Target SD (T). Target responses during the Target SD can produce the simultaneous offset of the Target SD, presentation of the reinforcer (\*), and initiate the next ITI. (*t* stands for time.)

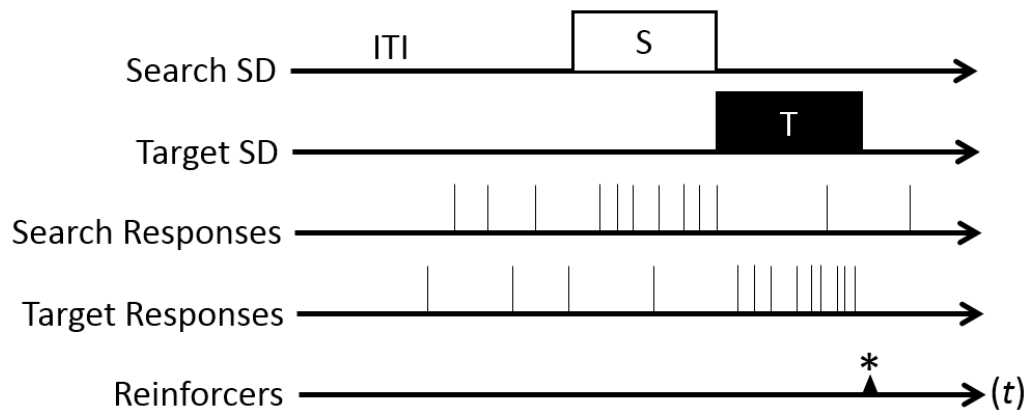


Figure 2

*Figure 2.* Acquisition of search responding in Experiment 1. Search response rate elevation scores in each group over sessions of the acquisition phase. Tests 1 and 2 took place on session 13 and 16 respectively. Error bars are the standard error of the mean.

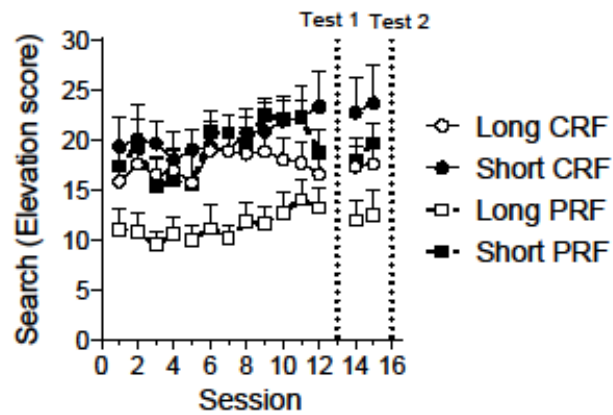


Figure 3

*Figure 3.* Test results from Experiment 1. a.) Search response rate elevation scores in each group over blocks of 5 search-SD presentations during Test 1. b.) Search response rate elevation scores in each group expressed as a proportion of the first 5 search-SD block in Test 1. c.) Search response rate elevation scores in each 2-min block of each six 6-min search SD presentations in Test 2. Error bars are the standard error of the mean.

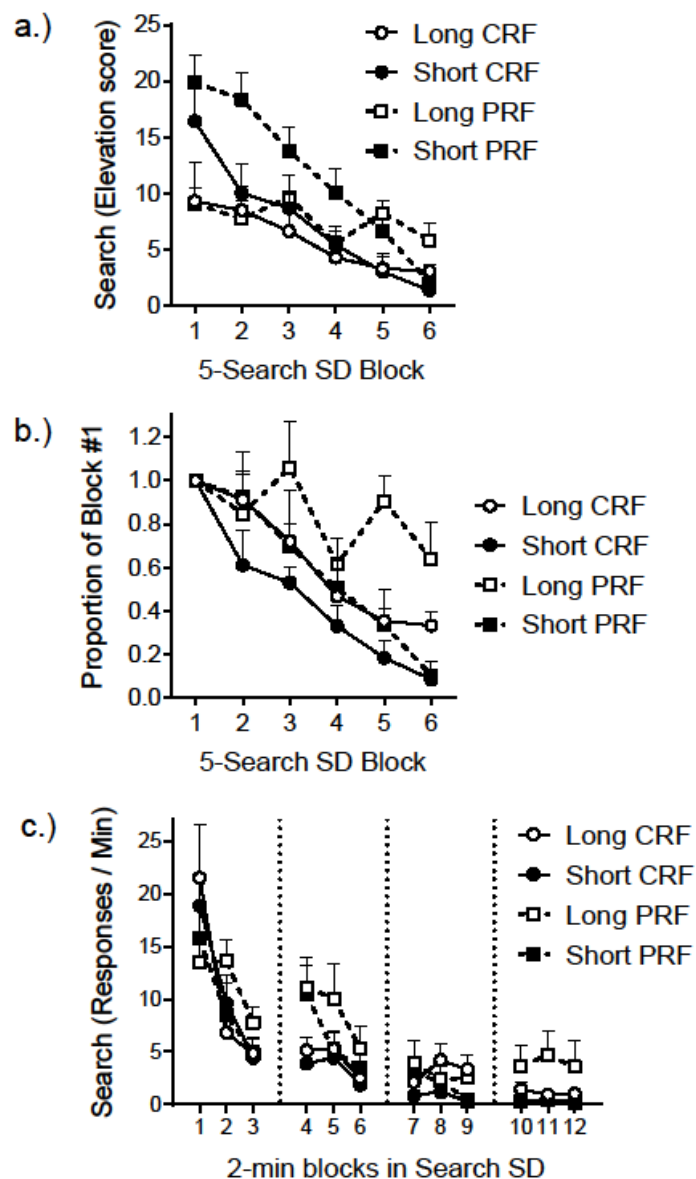


Figure 4

Figure 4. Results of Experiment 2a. a.) Search response rate elevation scores in each group over session of the acquisition phase. b.) Search elevation scores in each 5 search-SD block in Test 1. c.) Target response rate elevation scores in each 5 target-SD block in Test 2. Error bars are the standard error of the mean.

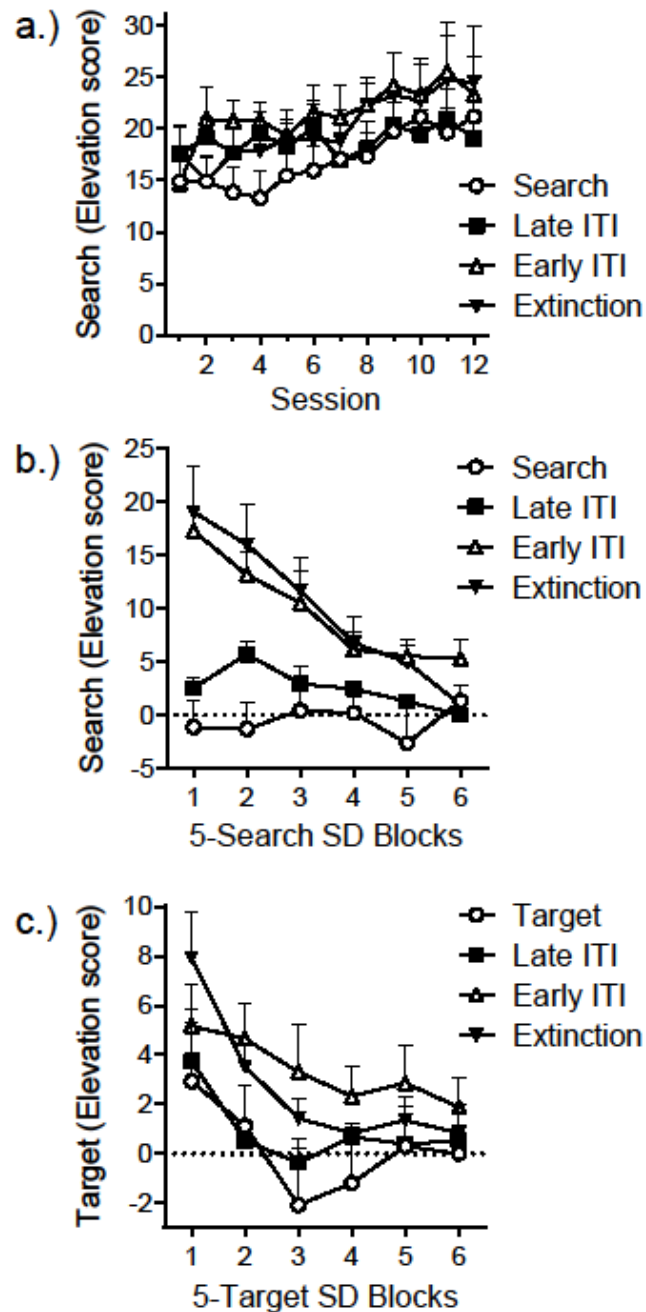


Figure 5

*Figure 5.* Results of Experiment 2b. a.) Search response rate elevation scores in each group in the session preceding introduction of noncontingent pellets, and over subsequent sessions of the acquisition phase with noncontingent pellets. b.) Search response rate elevation scores over the test session as a proportion of the average search elevation score in the final session of the acquisition phase (Session 12). Error bars are the standard error of the mean.

