Published in final edited form as:
Behav Processes. 2018 December ; 157: 161–170. doi:10.1016/j.beproc.2018.09.012.

Maintaining performance in searching dogs: Evidence from a rat model that training to detect a second (irrelevant) stimulus can maintain search and detection responding

Eric A. Thrailkill[1], **Fay Porritt**[2], **Alex Kacelnik**[3], and **Mark E. Bouton**[1]

[1:]University of Vermont, USA

[2:]Defence Science and Technology Laboratory, Fort Halstead, UK

[3:]University of Oxford and Oxford Risk, UK

Abstract

Scent-detecting dogs perform a sequence, or chain, of behaviors that, at minimum, includes searching followed by a detection behavior that signals the presence of a target stimulus to the handler. However, when working, dogs often engage in prolonged periods of searching without encountering a target. It is therefore important for trainers to use methods that promote persistent search behavior and target detection accuracy. Laboratory models can provide insights to the important variables that influence search persistence and accuracy. The present experiments examined a rat model of detection dog behavior. Two experiments assessed the use of practice with a single target stimulus to maintain search and detection of another previously-trained target. In Experiment 1, after learning a search➔detection chain with two auditory targets, rats received either brief or extended training with only one of the targets before being tested for detection of both targets in extinction. The results suggest that single-target training strengthened the ability of the other target to control the detection behavior. Experiment 2 found that even infrequent target encounters were still effective at maintaining detection behavior to the other trained target. Importantly, the treatment was effective when the target stimuli were from different sensory modalities. Overall, the results support the utility of the rat model of search-dog behavior for evaluating novel training methods. We suggest several useful procedures for enhancing search persistence and accuracy in detection dogs that can be implemented in training protocols.

Keywords

Canine; rat; detection; behavior chain; extinction; generalization

Address correspondence to: Eric A. Thrailkill, Department of Psychological Science ,University of Vermont ,Burlington, VT 05405-0134 ,602 291-7311, eric.thrailkill@uvm.edu.

1. Introduction

Scent-detecting dogs are used for a wide range of detection tasks, from searching for lost people to the detection of contraband goods such as drugs, firearms and explosives. While trained dogs are highly adept at performing detection behaviors in response to a range of targets, performance has been shown to decrease when dogs are required to repeatedly search the same location without encountering any targets (Porritt, Shapiro, Waggoner, Mitchell, Thomson, Nicklin, & Kacelnik, 2015, Gazit, Goldblatt, & Terkel, 2005). This is not a concern for some working dogs as they regularly encounter target odors during work. However, in some important tasks dogs are required to search in very low target-density environments. n such cases it is possible that target detection may deteriorate as a result of repeated searches that fail to produce a target if mitigation measures are not put in place; in learning theory such a decline in pre-established behavior with nonreinforced performance is known as extinction.

A simple approach to reduce the decline in search performance due to extinction is to plant many samples of the target stimulus in the work environment and reward dogs for correctly detecting and indicating it to their handlers. Because this method provides frequent trials with the major target of interest, it can be called a "gold standard" approach. However, for working dogs, training with the main target can require the placement of contraband targets in areas where contraband is not permitted; while proven to be a successful mitigation approach, this is logistically burdensome and an alternative approach would be beneficial for this subset of scenarios (Porritt et al, 2015). As an alternative, Porritt et al. (2015) trained dogs on an additional innocuous odor and placed this odor in the simulated work environment. When dogs received practice detecting this "silver standard" stimulus, it prevented the decline in performance observed when dogs repeatedly searched with no planted stimuli, and maintained detection on all trained odors as effectively as use of the gold standard approach; there was no evidence that extended use of a single "silver standard" stimulus was detrimental to detection of the "gold standard" stimulus. The authors suggested that training with an innocuous odor in addition to the target could be an effective approach to preventing extinction in low target-density working environments. The present study was concerned with confirming the robustness of the effect reported by Porritt et al (2015) and with further exploring the longevity of the effect and its possible limitations.

Search dogs use olfactory cues to identify targets of interest. therefore, the stimuli used by Porritt et al. (2015) were understandably all olfactory. However, olfactory stimuli are particularly liable to cross contamination; if substances are stored or transported together even for short periods they can rapidly acquire volatile compounds from each other as well as from the environment (Gazit et al., 2005). If these contaminating odors are salient to the dogs and the same contaminating odors are present on all target stimuli, very low levels of contamination can lead to false alarms. For example, if the single "silver standard" odor stimulus used by Porritt et al. had been contaminated with the "gold standard" stimulus, it is possible that the maintenance of performance on gold standard stimuli could have been due to a failure to implement proper extinction conditions. Another important possibility is the potential confusion or generalization between the gold and silver stimuli. In this case the conclusion that exposure to a single stimulus maintains performance on all trained stimuli may be limited to stimuli that are highly generalizable. Both concerns may be addressed through use of stimuli from modalities that cannot cross contaminate each other.

While empirical data collection with dog and handler teams is crucial to allow application of research, it is inherently difficult to control external variability in field based trials (e.g. weather) and often logistically unfeasible to collect data under double blind conditions. The use of a well-controlled laboratory method reduces the possibility for unintended experimenter bias and allows more detailed exploration of the effect under scrutiny. Recent work in our laboratory has developed a procedure in which rats learn to perform a sequence of two separate behaviors, a *behavior chain*, in order to obtain a food reward. We have recently suggested that such a chain might be useful for studying processes involved in the searching behavior of detection dogs (Thrailkill, Kacelnik, Porritt, & Bouton, 2016). The present study used this procedure to study the effect of training with a secondary (silver standard) target stimulus on rats' performance in detecting a primary (gold standard) stimulus. In the rat case assignment to primary or secondary category is arbitrary and randomized, but in the dog case the gold standard is the critical detection target. The approach was to replicate as many aspects of the dog procedure as possible in order to study the generality of the effect.

As a minimum, a behavior chain requires one response to create the opportunity for a second response that can cause the delivery of a reinforcer; it is common for each response to be unique and to be occasion-set by distinct discriminative stimuli (SDs). Detection dogs perform a behavior chain that includes searching (e.g., sniffing) in the presence of a search SD (e.g., presence of a car) that eventually leads to a target SD (e.g., the odor of an explosive) which signals that a "detection" target response (e.g., sitting) will be reinforced (e.g., with a play item or with food). In our laboratory analogue (Thrailkill, Kacelnik, et al., 2016), rats learn to make a "search" response (e.g. pulling a chain) in the presence of a search SD (e.g. a light on the wall of the test chamber); this eventually leads to the presentation of a target SD (e.g. a tone) that signals that a target response (e.g. lever press) will be reinforced (i.e. with a food pellet). Initial studies of behavior chains investigated what the animal learns in such chains (see Thrailkill & Bouton, 2016a, 2017a for recent reviews). They discovered an important role for an association between the two behaviors in the chain (e.g., Thrailkill & Bouton, 2015; 2016b) as well as contextual and motivational factors that influence them (Thrailkill & Bouton, 2017b; Thrailkill, Trott, Zerr, & Bouton, 2016). These studies took a theoretical approach to understanding behavior chains. In contrast, Thrailkill, Kacelnik, et al. (2016) took a more applied approach and uncovered two methods that make search behavior persistent when it goes unreinforced in extinction: partial reinforcement of the chain during training and occasional free (noncontingent) presentations of the reinforcer during extinction.

The present study extended the applied approach and further investigated Porritt et al.'s (2015) finding that practice with a "silver standard" stimulus can also maintain search behavior. It used a modified version of the previous rat model, illustrated in Figure 1, whereby search responses in the presence of the search SD led to the presentation of one of two different target SDs (e.g. different auditory tones or lights) that each set the occasion for the detection response and could experimentally serve as gold and standard stimuli. The first experiment investigated The robustness of Porrittetal’s (2015)”silver standard” findings by conducting an analogous study using rats in a laboratory controlled environment and replacing olfactory stimuli with auditory stimuli. It also examined the effect of different durations of exposure to training with a single silver standard stimulus on maintenance of responding to the other (gold standard) stimulus to determine whether there is any detriment to extended use of a single stimulus.

A second experiment addressed two new questions. First, how does the frequency of exposure to a single silver standard affect the ultimate detection of the gold standard? The answer has operational implications for how often a handler should place out the silver standard stimulus during working searches. Second, the experiment studied whether exposure to a stimulus from one modality (e.g. auditory) can maintain detection performance of a stimulus from a different modality (e.g. visual). If the “silver standard effect” occurs across modalities, then the effect on target detection cannot be due to contamination, stimulus generalization, or lack of discrimination between the two target stimuli. This would add to the robustness of the effect and raise the possibility of different approaches to maintain search dog performance. This is crucial in our case, as we wish to test the generality of the effect across species with different predominant sensory modalities.

2. Experiment 1

This experiment attempted to reproduce Porritt et al.’s (2015) canine results. the basic outline of the dog experiment was therefore replicated. Rats were given training on two auditory target stimuli (dogs had been trained on four olfactory stimuli) and were then moved to a “work phase”. Here, half the rats were not given any opportunity to respond to their trained target stimuli during searches (i.e., they received extinction); this is analogous with the “zero target” dog group and reflects dogs working in a low target environment. The other half of the rats received repeated opportunities to respond to only one of their trained target stimuli (a “silver standard”) following the search behavior; this is analogous with the “one target” dog group and reflects dogs that have an innocuous odor placed in their working environment. The experiment also asked whether exposure to a single stimulus continues to provide an advantage even after very extended use; this addresses the concern that animals may attend to the single stimulus to the detriment of other trained stimuli. To investigate this question, after learning the chain, half the rats in the silver standard and extinction groups underwent a work phase that was three times longer than the one received by the other half.

2.1. Materials and methods

2.1.1. Subjects—Thirty-two female Wistar rats (75–90 days old) were obtained from Charles River (St. Constance, QC). Rats were individually housed in a climate-controlled vivarium with a 16:8 light:dark cycle. Rats had unlimited access to water in their home cages and were maintained at 80% of their free-feeding weights with supplementary feedings of home chow (Prolab RMH 3000, Lab Diet; Richmond, IN, USA) approximately 2 hr after each daily session. Experimentation took place at approximately the same time each day during the light period of the light-dark cycle. 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; all model numbers are from 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 × 24.13 × 29.21 cm (Length × Width × Height). The sidewalls consisted of clear acrylicpanels, and the front and rear walls were made of brushed aluminum. recessed food cup was centered on the front wall approximately 2.5 cm above the floor. A retractable lever (model ENV-112CM) was positioned to the left of the food cup. A chain-pull response manipulandum (model ENV-111C) was positioned to the right of the food cup. Two 28-V (2.8 W) panel lights (diameter = 2.5 cm; model ENV-221M) were mounted on the wall near each manipulandum. One light was immediately above the lever and the other was behind the chain. A Sonalert (2900 ± 500 Hz, 75–85 dB; model ENV-223HAM) and a Clicker (75–85 dB; model ENV-135M) were mounted on the chamber wall directly above the food cup. A click-train could be made by repeatedly turning the Clicker on and off (0.4-s ON, 0.4-s OFF; click). The chambers were illuminated by 7.5-W incandescent bulbs mounted to the ceiling of the sound-attenuation chamber. Reinforcement consisted of the delivery of a 45-mg grain-based 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 training. During training, one session of 30–35 minutes was conducted each day, 7 days a week. Animals were handled each day as part of the transport and weight measurement procedure. Supplemental feeding was provided to maintain at their target weight when necessary.

2.1.3.1. Food cup training: Rats first received two training sessions with response manipulanda removed in which 30 food pellets were delivered to the food cup according to a random time (RT) 60 s schedule.

2.1.3.2. Search➔detection chain training: Following food cup training, the target response consisting of a lever press or chain pull (each for half therats)was trained over two sessions; this response is referred to as a “detection” response in analogy with a dog search➔detection behavior chain. Two target discriminative stimuli (target S s) were used to occasion the detection response; these were the tone from the Sonalert and click-train from the Clicker. Each target SD was presented 15 times, intermixed across 30 trials with a 45-s variable inter-trial interval (ITI). Only the target manipulandum (lever or chain) was present during these trials. A detection response (lever press or chain pull) emitted when the target SD was present (1.) turned off the target SD and (2.) immediately produced a food pellet according to a continuous reinforcement schedule, thereby teaching the animal that a detection response in the presence of either target SD would lead to a reinforcer. A trial otherwise terminated if a response was not made within 60 s of the target SD onset.

Next, the other manipulandum (chain or lever counterbalanced) was added to the chamber. Now, each trial was initiated by the search discriminative stimulus (search SD); this was always a panel light near the new (search) manipulandum. A single response on the search manipulandum, from here on referred to as a “search response”, turned off the search SD and immediately turned on one of the target SDs, in the presence of which a single detection response produced a food pellet and initiated the next ITI. This procedure was used for two training sessions in which search responding led to 15 presentations of each target SD. In order to increase the amount of detection responding, we introduced partial reinforcement for the detection response. In the next two sessions, the detection response requirement was increased to fixed-ratio (FR) 2 (i.e. two responses on the target manipulandum required before a food pellet was provided). For sessions five and six, the FR was increased to 4. Finally, the target SD was removed for a randomly-selected 10 of the 30 trials in each session to replicate a search in which no target was encountered. Specifically, search responding led to 10 presentations of the tone target SD, 10 presentations of the click target SD, and 10 empty non-reinforced trials (dummy trials) for the remaining 12 sessions of the training phase. In terms of the dog analogy, of the 30 trials, 10 led to the Silver Standard and then to food (Search➔Silver➔Food➔ITI), 10 led to the Gold Standard and then to food (Search➔Gold➔Food➔ITI), and 10 led to neither Silver not Gold and hence no food (Search➔ITI; see Figure 1).

<u>2.1.3.3. Work phase:</u> Following acquisition, rats were assigned to one of four treatment groups (n = 8) for the next phase, the “work phase”. Groups received either 5 (Short) or 15 (Long) sessions during this phase. Half the rats in the Long group and half in the Short group continued to receive reinforcement of their detection response, but only following one of the two target SDs. In each session, there were 20 trials with Search➔Silver➔Food➔ITI (tone or click counterbalanced), 0 trials with Search➔Gold➔Food➔ITI, and 10 dummy trials with Search➔ ITI; these rats are referred to as “silver standard (Silver)” subjects. The remaining Short and Long group animals received extinction of search responding. Here, search responding turned off the search SD but did not lead to a target SD or a reinforcer (30 Search➔ITI”dummy”trials).

<u>2.1.3.4. Tests of search and detection behaviors:</u> Following the final session of the work phase, groups received a test (Test 1) in which presentations of the search SD led to each target SD under extinction conditions (search➔detection chain test). The test allowed us to compare the effects of each work phase treatment on group performance under identical conditions. All groups received 16 intermixed search➔detection trials in which (A) Search➔Silver➔ITI and (B) Search➔Gold➔ITI occurred in ABBA or BAAB order (counterbalanced). To assess search response rates during the search SD, a variable interval (VI) 10 s contingency was introduced for the search response. Response made an average of 10-s after search-SD onset transitioned to the target SD. This allowed the observation of several search responses during SD in the test. The search SD automatically transitioned to a target SD and target SD to the ITI after 20 s if either schedule requirement had not been met. The food pellet was never presented.

Following the search➔detection chain test, all groups received two sessions of retraining. These two sessions followed the procedure used in the final Work Phase sessions. A final “detection test” (Test 2) consisted of eight non-reinforced presentations of (A) Silver➔ITI and Gold➔ITI in intermixed ABBA or BAAB order (counterbalanced), without a preceding search SD. Target SDs (Silver or Gold) could be terminated according to FR 4, but otherwise ended after 20 s. This test allowed comparison of detection responding occasioned by the target SDs without potential influence of different levels of responding to the search SD between the groups.

2.1.4. Data analysis—To describe search responding occasioned by the SD, we calculated elevation scores by subtracting the response rate on the search manipulandum during the 30 s immediately preceding the search SD (the pre-search SD period, during the ITI) from the response rate during the search SD. The advantage of the elevation score is that it indicates the actual increase in responding that an SD produces above baseline. As befitting strong discrimination performance, detection responding occurred at a very low rate during the pre-search- and search-SD periods. We therefore analyzed detection responding as absolute response rate during the target SD. The search elevation scores and detection response rates were evaluated with analyses of variance (ANOVAs) with between-subject variables (e.g., work phase group) entered as fixed factors and within-subject variables (e.g., target stimuli, sessions, blocks of trials) entered as within-subject factors. Mean responses in the pre-SD periods are reported. These data were analyzed separately and were rarely found to uncover group differences that complicated interpretation of the elevation scores; in the interest of maintaining brevity, the analyses are not reported here unless they uncovered group differences. Search elevation scores and target response rates during the training, work, and test phases of the experiment were each of interest and were therefore analyzed. The rejection criterion was set at $p < .05$ for all ANOVAs.

2.2. Results

In overview, the rats learned the search➔detection chain without incident. Silver-standard training in the work phase was found to be effective at maintaining search responding and detection of both the silver and gold standard targets, especially in the group given the extended training (Group Long).

2.2.1. Search➔target chain training—All rats learned the search➔detection chain. Search response elevation scores are summarized in Figure 2a. A within-subject ANOVA lanned found a significant effect of session reflecting the increase in elevation scores increased over sessions, $F(11, 341) = 14.35$, $MSE = 41.93$, $p < .001$. Mean search response rates (responses per min) in the period preceding the search SD were 5.5 and 9.4 in the first and final sessions of training.

Detection responding can be seen in Figure 2b. The rats came to discriminate the two reinforced Targets from the empty (Dummy) trials, and the groups (not shown) evidently did so equivalently. A Target stimulus (Tone, Click, Dummy) by Duration (Long, Short) by Treatment (Silver, Extinction) ANOVA compared target responding in the final session of the training phase. There was significant effect of target stimulus, $F(2, 56) = 91.96$, $MSE = 110.03$, $p < .001$, and no other effects of interactions, largest $F = 2.74$. tests compared detection responding in tone, click, and dummy periods in the final training session. In comparison to dummy trials, detection responding was significantly greater in tone, $F(1, 31)$

= 123.14, *MSE* = 147.77, *p* = .001, and click, *F*(1, 31) = 75.05, *MSE* = 151.32, *p* = .001. Detection responding was also significantly greater in the tone in comparison to the click, *F*(1, 31) = 14.17, *MSE* = 56.63, *p* = .001.

2.2.2. Work phase—The results of the work phase are presented in Figure 3. The use of a single target stimulus (the silver standard) in the Silver groups clearly maintained greater search responding than did extinction (Figures 3a and 3b). This observation was supported by statistical analysis. Examining the first four sessions (when all groups received treatment), a Group (Silver, Extinction) by Duration (Long, Short) by Session (4) ANOVA revealed that search responding was greater in the Silver groups than the Extinction groups, *F*(1, 28) = 12.70, *MSE* = 194.85, *p* < .001, and that search responding increased over sessions, *F*(3, 84) = 7.76, *MSE* = 53.69, *p* < .001. A visual trend toward a difference between Silver groups in Short versus Long did not reach statistical significance, *F*(1, 28) = 4.04, *p* > .05, and there was no Group by Duration interaction, *F* < 1.

We also analyzed baseline search responding in the pre-search SD periods. There was more responding at that time in the Silver groups than in the Extinction groups. In the first four sessions, a Group (Silver, Extinction) by Duration (Long, Short) by Session (4) ANOVA found effects of Group, *F*(1, 28) = 8.60, *MSE* = 41.12, *p* = .007, Session, *F*(3, 84) = 10.59, *MSE* = 2.79, *p* < .001, and a Group by Session interaction, *F*(3, 84) = 8.97, *p* < .001. Search responding in the pre-SD periods remained consistent for the Silver groups, but decreased from Session 1 to Session 4 in the Extinction groups. In Group Short, mean response rates (responses per min) in the pre-SD period in Silver and xtinction groups were 5.4 and 3.9 in Session 1 and 5.0 and .06 in Session 4. In Group Long, mean response rates in the pre-SD period for Silver and Extinction were 5.4 and 5.3 in Session 1 and 5.0 and 0.7 in Session 4.

As shown in the bottom row of Figure 3, detection responding in the Silver groups (in the presence of the silver standard target) remained high and much higher than it was in the dummy trials for Groups Short (Figure 3c) and Long (Figure 3d). A Duration (Long, Short) by Stimulus (Target, Dummy) by Session (4) ANOVA revealed more detection responding on Silver trials, *F*(1, 28) = 47.12, *MSE* = 516.76, *p* < .001. No other effects reached significance, largest *F* = 2.37.

2.2.3. Tests phase

2.2.3.1 Search➔detection chain test: Search responses during the search➔detection chain test are summarized in Figure 4, which shows both search responding (panel a) and detection responding (panel b) for the different groups. Long training with the silver standard maintained search responding and detection of both the silver- and gold-standard targets. First consider search responding. A Duration (Long, Short) by Group (Silver, Extinction) ANOVA found significant effects of Duration, *F*(1, 28) = 7.51, *MSE* = 70.78, *p* = .01, Group, *F* = 22.95, *p* < .001, and a Duration by Group interaction, *F* = 13.62, *p* = .001. Planned ANOVAs compared search responding in Groups Silver and Extinction at each work-phase duration. After the long work phase, Group Silver made more search responses than Group Extinction, *F*(1, 14) = 45.93, *MSE* = 55.43, *p* < .001. In contrast, after the short work phase, search responding in Group Silver was similar to that in Group Extinction, *F* <

1. Search responding in the 30-s pre-search periods were 4.4, 2.2, 0.8, and 1.5 in groups Long Silver, Short Silver, Long Extinction, and Short Extinction. Duration by Group ANOVA found lower pre-search responding in the extinction groups, F(1, =28) 7.35, MSE = 5.11, p = .01, but no effect of Duration or interaction, largest F = 3.45.

Turning to detection responses (panel b), there was more responding to Gold and Silver SDs in Group Long Silver than in Group Short Silver. A Duration (Long, Short) by SD (Gold, Silver) ANOVA found a significant effect of Duration, $F(1, 14) = 11.48$, MSE = 249.13, p = .004, and no effect of SD or interaction, largest $F(1, 14) = 3.24$, MSE = 71.24. Separate NOV s compared detection response rates during each target SD in Group Silver with the mean detection responding in the two SDs in Group Extinction. In Group Short, detection responses to Gold and Silver target SDs did not differ from responding in Group Extinction, Fs < In Group Long, detection responses in both the Silver and Gold SDs were substantially higher than in group Extinction, smallest $F(1, 14) = 13.62$, MSE = 132.37, p = .002 for Gold. Thus, a long training phase with the silver SD clearly enhanced detection to Gold. The analyses were not complicated by differences in detection responding in the pre-search SD periods. For Groups Short Silver, Short Extinction, Long Silver, and Long Extinction, mean detection response rate was 5.8, 3.1, 2.5, and 2.4.

2.2.3.2. Detection test: Test 2 examined detection responding occasioned by each target SD when they were tested without being preceded by the search SD. The results were compatible with Test 1, although (not surprisingly, given the novelty of the test conditions) they were more variable. A Duration (Long, Short) by SD (Gold, Silver) ANOVA comparing responding in Silver groups found no statistically significant differences, largest $F(1, 14) =$ 1.41, MSE = 88.06. For the hort groups, shown on the left in Figure 5, detection responding to each SD in Group Silver did not differ from mean detection responding in Group Extinction, largest $F(1, 14) = 2.21$, MSE = 44.55. In contrast, as shown on the right, the Group Long Silver made significantly more detection responses in the Silver SD than SD responding in Group Long Extinction, $F(1, 14) = 16.25$, MSE = 67.49, p = .001. The difference between responding in the Gold SD and SD responding in Group Long Extinction fell just short of statistical significance, $F(1, 14) = 3.99$, MSE = 115.56, p = .07. comparison of the extinction groups did not reach significance, but suggested a trend toward a greater responding after a Short duration than after the Long duration, $F(1, 14) = 4.29$, MSE = 15.35, p = .06. In the pre-SD period, mean detection response rate was 4.9, 1.5, 0.9, and 0.4, for Groups Short Silver, Short Extinction, Long Silver, and Long Extinction. There was greater detection responding in the pre-SD period in the Short groups, a Duration by SD ANOVA found a reliable effect of SD, $F(1,14) = 10.07$, MSE = 12.42, p = .007, other Fs < 1. There was also a trend toward greater responding in the Short Extinction group during pre-SD periods, $F(1, 14) = 3.97$, MSE = 1.24, p = .07.

2.3. Discussion

Rats learned the search➔detect chain and came to make the detection response on occasions when the target SDs followed the search SD rather than occasions when no target followed the search SD (dummy trials). The latter result indicates that the rats were attending to the targets and not merely performing detection responses “blindly” after termination of the search SD. During the work phase, reinforcing detection responses during a single (silver standard) target SD maintained the search response during its SD. The crucial finding from this experiment is that the silver-standard method also maintained detection of the separate (gold standard) target SD. After extended training (the Long groups), detection responding remained high when occasioned by either the silver or (most importantly) the gold target SD. he results are consistent with previous experiments studying silver-standard training with dogs (Porritt et al., 2015). We would note that, like the dog experiments, silver and gold were from the same stimulus modality (both were auditory here, and olfactory in Porritt et al.). One possibility is that silver standard training was effective at maintaining detection responding to the gold standard because of stimulus generalization (or lack of discrimination) between targets of the same modality. The next experiment addressed whether presenting target SDs from the same modality is necessary to observe the silver standard effect.

3. Experiment 2

The second experiment was designed to ask whether similar results could be obtained when the target stimuli (silver and gold) were from different sensory modalities (auditory vs. visual). Such a result would be important for dog trainers, and suggest that a simple stimulus generalization explanation (e.g., mistaking the tone for a click or the click for a tone) could not account completely for the effect in Experiment 1. The experiment further asked whether the silver standard effect would still occur with less frequent presentations of the silver standard during the work phase. Accordingly, during the work phase one group received 20 silver standard trials (20 Silver) per training session, as in Experiment 1, whereas another received only 5 such trials (5 Silver). The 5 Silver training regime was expected to result in weaker search responding and detection responding to the gold and silver target SD than the 20 Silver training. The experiment thus provides additional information for application of a silver standard procedure in working dogs; it evaluated two levels of target frequency during the work phase and detections to gold and silver target SDs from different stimulus modalities.

3.1. Method

3.1.1. Subjects and Apparatus—Twenty-four female Wistar rats (75 −90 days old) were obtained from the same supplier and maintained under the same conditions as in Experiment 1. The apparatus and data collection procedures were the same as in Experiment 1.

3.1.2. Search➔target chain training—Training procedures were identical to those in Experiment 1 except that the target SDs were from different modalities and a VI schedule for the search response was introduced during training. Specifically, the target SD was either a tone or a flashing panel light (0.5 s on; 0.5 s off; flash) located on the panel near the detection manipulandum. For search, VI 5 s was introduced along with FR 2 for detection on session three and four. On session five and six, the VI and FR were increased to 10 s and 4, respectively. Finally, the target SD was removed for a randomly selected 10 of the 30 trials in each session. For the final 12 sessions of training, search responding in the search SD led to 10 presentations of the tone target, 10 of the flash target, and 10 empty non-reinforced trials (dummy trials). Search responses required a VI 10-s schedule to elapse before a response produced a target SD or dummy trial. In a target SD, target responses ended the target SD and delivered a food pellet according to FR4.

3.1.3. Work phase—Rats were assigned to one of three groups (n = 8). For each group, search responding in the search SD continued to turn off the search SD according to VI-10 s. Group 20 ilver received 30 search SD trials; 20 of which led to a single target SD (Silver; flash or click, counterbalanced), and 10 were nonreinforced dummy trials. Group 5 Silver also received 30 search SD trials, but only 5 led to presentation of a target SD (Silver; flash or click; counterbalanced); the remaining 25 trials were dummy trials. Group Extinction received 30 presentations of the search SD, but search responding never led to a target SD or the reinforcer. Sessions lasted approximately 35 min. the work phase continued for 15 daily sessions.

3.1.4. Tests of search and detection behaviors—There were two tests. In Test 1 (search➔detection chain test), subjects received 16 nonreinforced trials in which the search SD was followed by either the silver or gold target SD. Similar to Experiment 1, targets were presented after a search SD contingent on a search response after VI 10 s, but otherwise after 20 s of search SD time elapsed. Groups then received two sessions of retraining as per the final acquisition sessions following Test 1. In Test 2 (detection test), subjects received 8 nonreinforced presentations of each target SD. In each test, target SDs were presented according to an ABBA or BAAB order, counterbalanced.

3.2. Results

3.2.1. Search➔target chain training—The results of chain training (Figure 6) were similar to those in Experiment 1. Search elevation scores (Figure 6a) increased across sessions similarly in each group (not shown). A Group (20 Silver, 5 Silver, Extinction) by Session (12) ANOVA found a significant effect of Session, $F(11, 231) = 3.33$, $MSE = 10.99$, $p < .001$,andnoeffectorinteractioninvolvingGroup, Fs < 1. Mean search response rates (responses per min) in the period preceding the search SD (pre-search SD periods) were 13.0 and 18.9 in the first and final sessions of training. Search response rates in the 30-s periods preceding the search SD increased during the training phase. A Group by Session ANOVA found a significant effect of Session, $F(11, 231) = 11.35$, $MSE = 12.02$, $p < .001$, and no effect or interaction involving Group, largest $F = 1.07$.

Detection response rate during the tone- and flash-target SDs, as well as the dummy trials, is summarized in Figure 6b. Each group (not shown) acquired the discrimination between target SDs and dummy trials. A Group (20 Silver, 5 Silver, Extinction) by arget SD (Tone, Flash, Dummy) ANOVA compared responding in the final session of training and found only an effect of SD, $F(2, 42) = 82.68$, $MSE = 235.47$, $p < .001$. Planned ANOVAs compared detection in each target SD, and each target SD against Dummy responding. The analysis found that detection responding on dummy trials was lower than responding on Tone, $F(1, 21) = 88.99$, $MSE = 308.15$, $p < .001$, and on Flash, $F(1, 21) = 91.99$, $MSE =$

335.67, p <.001. There was no difference in detection response rates in Tone versus Flash trials and there were no effects involving Group in any of the analyses, Fs < 1.

3.2.2. Work phase—Results of the work phase are summarized in Figure 7, with Figure 7a depicting search responding and 7b detection responding. As shown in Figure 7a, frequent presentations of the silver standard sustained high levels of search responding across the phase. A Group (20 Silver, 5 Silver, Extinction) by Session (15) ANOVA found effects of Group, $F(2, 21) = 7.32$, $MSE = 416.39$, $p = .004$, Session, $F(12, 294) = 6.73$, $MSE = 7.93$, $p < .001$, and a Group by Session interaction, $F(28, 294) = 4.36$, $p = .001$. Planned ANOVAs compared responding in each pair of groups. For Groups 20 Silver and 5 Silver, there was a significant effect of Session, $F(14, 196) = 1.85$, $MSE = 10.08$, $p = .03$, a Group by Session interaction, $F(14, 196) = 3.11$, $MSE = 10.08$, $p < .001$, and no Group effect, $F(1, 14) = 1.43$, $MSE = 620.21$. The interaction is consistent with the fact that Group 5 Silver's search responding declined over training. For Groups 5-Silver and Extinction, the analysis found significant effects of Group, $F(1, 14) = 10.17$, $MSE = 223.16$, $p = .01$, Session, $F(14, 196) = 11.38$, $MSE = 7.63$, $p < .001$, and an interaction, $F(14, 196) = 3.83$, p .001. Finally, for Groups 20-Silver and Extinction, there were significant effects of Group, $F(1, 14) = 14.77$, $MSE = 405.79$, $p = .002$, Session, $F(14, 196) = 5.89$, $MSE = 6.08$, $p < .001$, and an interaction, $F(14, 196) = 7.11$, $p < .001$. ean search rates in the 30-s pre-search SD periods in Groups 20 Silver, 5 Silver, and Extinction were 19.3, 14.0, and 14.8, and 21.2, 12.7, and 0.7 in the first and final sessions of the work phase. Separate analyses of search responding in pre-search SD periods reflected the different number of reinforced trials among the groups.

As shown in Figure 7b, Groups 20 Silver and 5 Silver both maintained high levels of detection responding in the target SD. (Responding in Group Extinction, which never received a target SD in this phase, is included for visual comparison, but was not analyzed.) Detection responding in Silver and Dummy trials decreased across the work phase in Group 5 Silver, whereas these remained stable in Group 20 Silver. A Group (20 Silver, 5 Silver) by Trial (SD, Dummy) by Session (15) ANOVA found significant effects of Trial, $F(1, 14) = 38.71$, $MSE = 6095.26$, $p < .001$, and Session, $F(14, 196) = 1.84$, $MSE = 66.08$, $p = .04$, as well as a Session by Group interaction, $F(14, 196) = 2.46$, $p = .003$. To assess the interaction, responding in SD and Dummy trials was compared across sessions in each group. For Group 5 Silver, there were significant effects of Trial, $F(1, 7) = 9.92$, $MSE = 9234.07$, $p = .02$, and Session, $F(14, 98) = 3.17$, $MSE = 82.81$, $p < .001$. For Group 20 Silver, there was only a significant effect of Trial, $F(1, 7) = 49.94$, $MSE = 2956.45$, $p < .001$.

3.2.3. Test phase

3.2.3.1. Search➔detection chain test: The results of the test of the search➔detection chain are presented in Figure 8. Search responding (Figure 8a) was greater in Silver groups than in Group Extinction. one-way ANOVA found a marginal effect of Group, $F(1, 21) = 3.16$, $MSE = 23.75$, $p = .06$, but planned comparisons between the groups found greater search responding in Group 20 Silver than Group Extinction, $F(1, 14) = 5.42$, $MSE = 27.03$, $p = .03$, marginally greater responding in Group 5 Silver than Group Extinction, $F(1, 14) = 4.32$, $SE = 13.78$, $p = .06$, and no difference between the two Silver groups, $F < 1$. Mean search response rates during the pre-SD periods were 16.0, 13.0, and 4.2 for Groups 20

Silver, 5 Silver, and Extinction. A one-way ANOVA found an effect of Group, $F(2, 21) = 8.29$, $MSE = 36.29$, $p = .002$. Planned comparisons found less responding in Group Extinction than Group 20 Silver, $F(1, 14) = 17.05$, $MSE = 32.56$, $p = .001$, and Group 5 Silver, $F(1, 14) = 10.15$, $MSE = 30.81$, $p = .007$. There was no difference between the Silver groups, $F < 1$.

Detection responding in the presence of the Gold and Silver targets is summarized in Figure 8b. Detection responding was similar in the gold and silver targets in both Silver groups, which did not differ from each other, as suggested by a Target SD (Gold, Silver) by Group (20 Silver, 5 Silver) ANOVA. There were no significant effects, largest $F(1, 14) = 1.01$, $MSE = 156.85$. To assess possible differences in Target SD responding between Groups 20 Silver, 5 Silver, and Extinction, detection response rates were collapsed across SDs in the Silver groups. A one-way ANOVA group failed to find an overall group effect, $F(2, 21) = 1.42$, $MSE = 83.26$ (but see Detection test, below). Mean detection response rates during the pre-SD periods were 2.3, 1.8, and 1.2 for Groups 20 Silver, 5 Silver, and Extinction.

3.2.3.2. Detection test: After two sessions of retraining, rats received a test of detection responding during each target SD without a preceding search SD. The test results are presented Figure 9. Collapsing across SDs and comparing Silver groups with Group Extinction, a one-way ANOVA found a significant group effect, $F(1, 21) = 7.85$, $MSE = 30.45$, $p = .003$. Planned comparisons indicated there was significantly less responding in Group Extinction than in either Group 20 Silver, $F(1, = 9.98$, $MSE = 25.23$, $p = .007$, or Group 5 Silver, $F(1, 14) = 19.05$, $MSE = 23.06$, $p = .001$. Detection responding in the two Silver groups did not differ, $F < 1$. Importantly, each silver standard treatment enhanced responding to the Gold SD. Planned comparisons supported the prediction that Gold SD responding in Groups 20 Silver and 5 Silver would be significantly greater than target SD responding in Group Extinction, $F(1, 14) = 4.55$, $MSE = 35.15$, $p = .05$, and $F(1, 14) = 5.91$, $MSE = 33.91$, $p = .03$. Gold SD responding in Silver groups did not differ, $F < 1$. There was a visual trend suggesting a tendency for the Silver SD to occasion more detection responding than the Gold SD in the Silver Groups. A Target SD (Gold, Silver) by Group (20 Silver, 5 Silver) ANOVA found only marginal support for this trend between Target SDs, $F(1, 14) = 4.14$, $MSE = 98.34$, $p = .06$, and no group difference or interaction, Fs < 1. Mean detection response rates during the pre-SD periods were 1.2, 1.6, and 0.2 for Groups 20 Silver, 5 Silver, and Extinction.

3.3. Discussion

As in Experiment 1, all rats acquired the search➔detect chain with the two target SDs and accurately discriminated the target trials from non-reinforced dummy trials. Importantly, the silver standard effect from Experiment 1 was also replicated with Gold and Silver target SDs from different stimulus modalities. This result suggests that the silver standard effect does not depend on direct stimulus generalization (or lack of discriminability) between the Gold and Silver SDs. Further, delivery of more frequent Silver trials (20 vs. 5) each session during the work phase maintained a higher rate of searching across the work phase, but did not create better transfer of Silver training to Gold responding. That is, the Gold and ilver target SDs appeared similarly interchangeable in both Silver groups.

4. General Discussion

Overall, the present results add to our previous work suggesting that laboratory studies with rats can provide useful information for trainers who design training protocols for working dogs (Thrailkill et al., 2016). The present experiments developed a laboratory technique to examine variables that influence the maintenance of a search➔target behavior chain in the silver standard method developed with dogs by Porritt and colleagues (2015). The gold standard SD remained effective in the sense that when it was encountered in the test, days after its initial training, it was still effective at occasioning detection responses. There was no evidence to suggest that extended use of a single "silver standard" target results in a diminished ability of "gold standard" targets to occasion the detection response. In fact, the contrary appears to be true, in that extended (Long) training appeared more effective at maintaining responding to the Gold Standard than was less extensive (Short) training (Experiment 1).

The present experiments addressed three pragmatic questions that may interest dog trainers. First, as noted above, the results of Experiment 1 suggest that extending the work phase, in which searches lead to reinforced detection responding in the presence of a single silver standard target SD, is effective for maintaining the detection responses to a gold standard target SD not encountered since acquisition training. Second, the results of Experiment 2 suggest that training with relatively infrequent silver standard encounters may cause a lower searching rate, but is nonetheless effective in maintaining the detection response to the gold standard. Finally, training with a silver standard from a different stimulus modality did not weaken the response to the gold standard. This last result suggests that the effects in each experiment were not due to simple generalization, or lack of discrimination, between the target stimuli. Instead, the result suggests that something about training with a single silver standard allowed rats to maintain the target response to radically different targets quite generally.

The fact that the silver standard effect occurred even when the silver and gold targets were from different modalities (Experiment 2) may seem surprising but is consistent with theories of associative learning. First, both the targets were associated with the same food-pellet outcome, which is known to encourage the animal to generalize between two otherwise discriminable stimuli (e.g., Honey & Hall, 1989). Second, conditioning theories often assume that training with two, or more, stimuli results in learning about both their unique and their shared features (e.g., Pearce, 1994; Rescorla, 1976). Shared features (which might include similar onset properties, durations, etc.) would allow even distinct stimuli to control the same response to some extent. Unique features would allow animals to discriminate the stimuli if they were differentially reinforced. In the present experiments, rats learned the search➔detection chain with two target SD stimuli, each of which was paired with reinforcement. Crucially, training with different target stimuli would allow the shared features to dominate (because they are present and reinforced on every trial) and "block" the conditioning of the unique stimuli, thus encouraging generalization between the stimuli. Either way, animals might eventually learn to generalize even between very different and discriminable stimuli from different modalities. These mechanisms may account for the effectiveness of even cross-modal Silver Standard stimuli in the present training protocol.

The results have several practical implications for handlers' approaches to training working dogs. In each experiment, training with a silver standard maintained the ability of the gold standard target to occasion the target detection behavior. In the present Experiment 2, a lower frequency of target encounters was not as effective as a higher frequency of encounters at maintaining the rate of search behavior. However, it did not weaken responding to the gold standard. Perhaps most importantly, training dogs with gold and silver standards of different modality could be effective for maintaining detection behavior. This suggests that trainers could use the presentation of a silver standard target of a different modality (e.g., whistle, patterned image, collar vibration) to maintain search behavior for odor targets in working dogs.

In summary, the present results are consistent with those of Porritt et al. (2015), who first demonstrated the silver standard effect in working dogs. They also make several further suggestions for effective training procedures. The silver standard method can maintain search behavior over relatively long periods of searching. Frequent silver standard trials are more effective than less-frequent silver standard trials. And even training with targets from different stimulus modalities enabled the silver standard effect, suggesting that trainers may have success in maintaining search behavior with a non-odor silver standard without weakening dogs' later odor detection performance. Finally, the present study and our previous work (Thrailkill, Kacelnik, et al., 2016) suggest that laboratory experiments are a rapid and cost-effective method for providing useful insights for improving working dog performance.

Acknowledgments

This research was supported through joint funding by NIH Grant RO1 DA 033123 to M.E.B and collaborative funding provided by a number of UK government departments including the Home Office, Department for Transport, the Ministry of Defence and the Centre for Protection of National Infrastructure. The funding bodies were not involved in experimental design, data analysis, interpretation or article preparation.

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Highlights:

- We developed a laboratory procedure with rats to explore search dog performance
- Rats made search and detection responses when they encountered different stimuli
- Practice with one target stimulus supported search, and detection of other stimuli
- Extended practice with a single target did not harm detection of a second one
- Detection was accurate when targets differed in modality (auditory and visual)

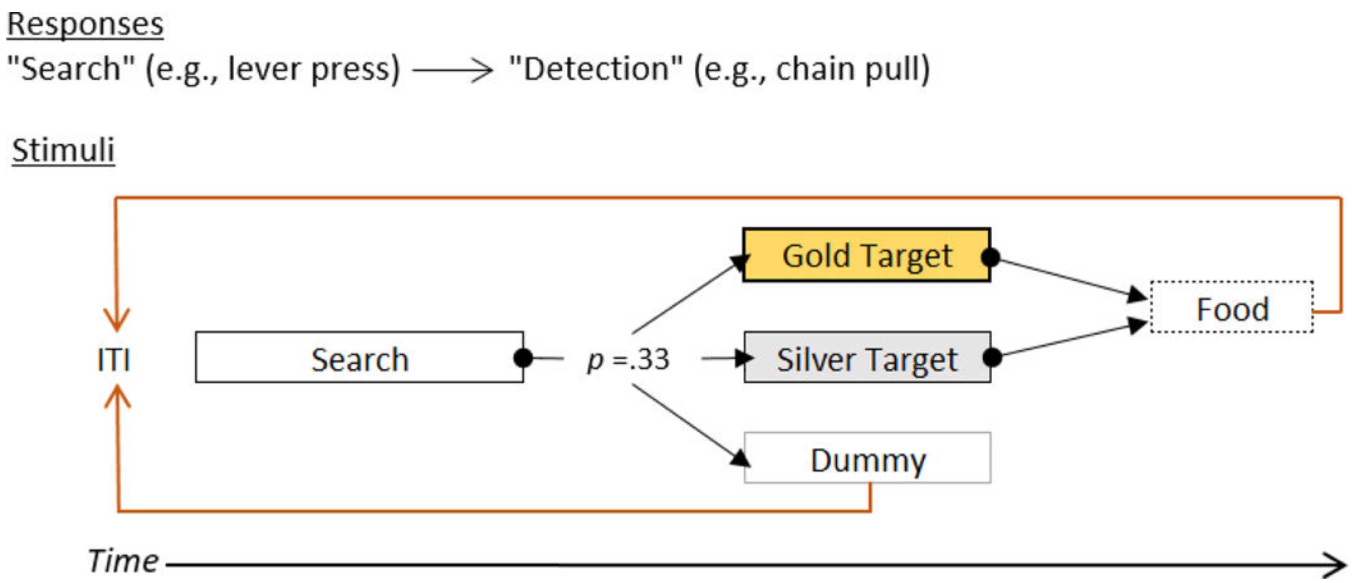

Figure 1.

Timeline of events in our search➔detection chain procedure. The flowchart describes the behavioral chain learned in the acquisition training phases of each experiment. "ITI" = intertrial interval, Manipulanda corresponding to the Search and Target responses were counterbalanced. "$p = .33$" refers the equal chance that search contingently led to the presentation of Gold Target, Silver Target, or started the next ITI ("Dummy") with equal likelihood on each trial. The sequence of events repeated itself across time in the session. See text for details.

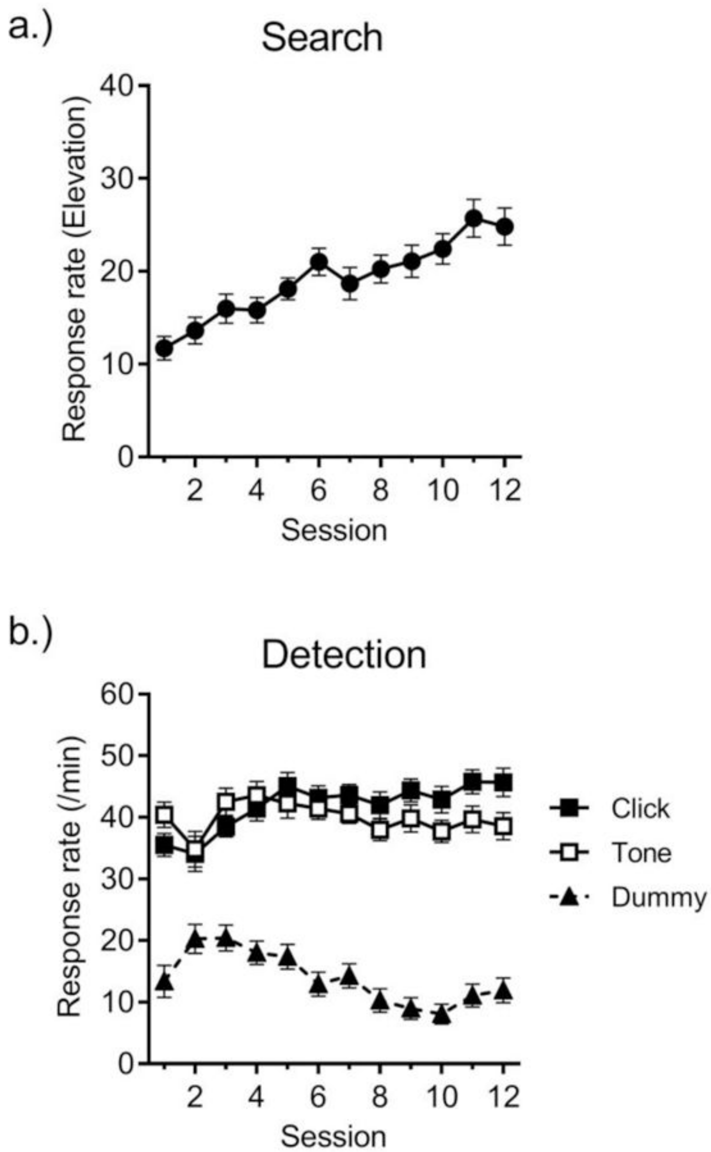

Figure 2.

Acquisition of the search➔detection chain in Experiment 1. a.) Search response rate (responses per minute on the search manipulandum), elevation scores (see text) averaged across individual rats over sessions of the acquisition phase. b.) Target (detection) response rate (responses per minute on the detection manipulandum) for all rats during Click, Tone, and Dummy trials over sessions of the acquisition phase. Error bars are the standard error of the mean.

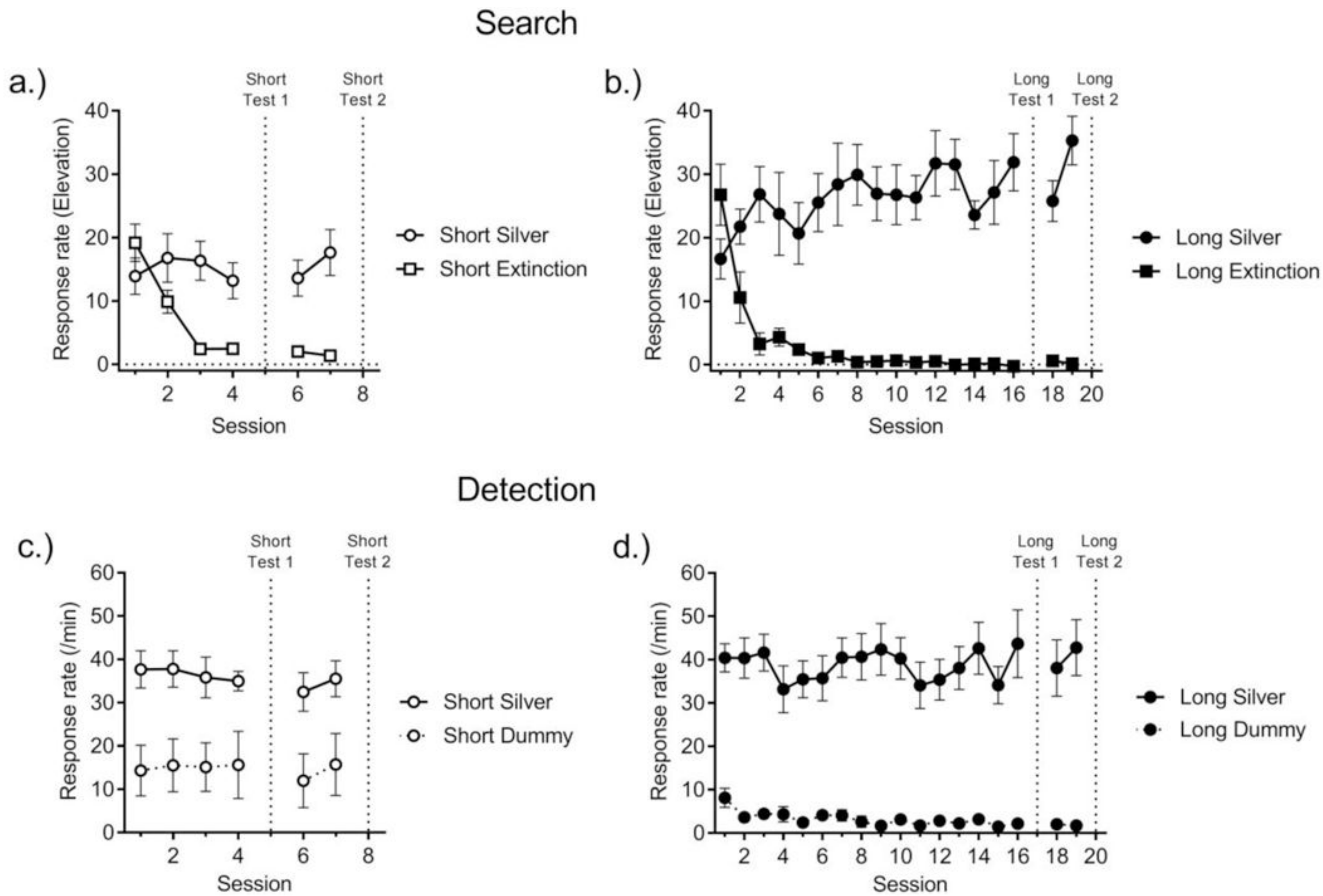

Figure 3.

Work phase results from Experiment 1. Top Row: Response rate elevation scores (responses per min) on the search manipulandum in rats that received Silver (circles) or Extinction (squares) treatment for a brief work phase (Short; a.) and for an extended work phase (Long; b.) over sessions of the work phase. Bottom Row: Response rate elevation scores on the detection manipulandum over sessions of Short (c.) and Long (d.) work phases. The search➔detection chain test (Test 1) and detection test (Test 2), the results of which are shown in Figures 4 and 5, took place on days 5 and 8, and 17 and 20 for rats that received the Short and Long work phase, respectively. Error bars are the standard error of the mean and mostly appropriate for between group comparisons.

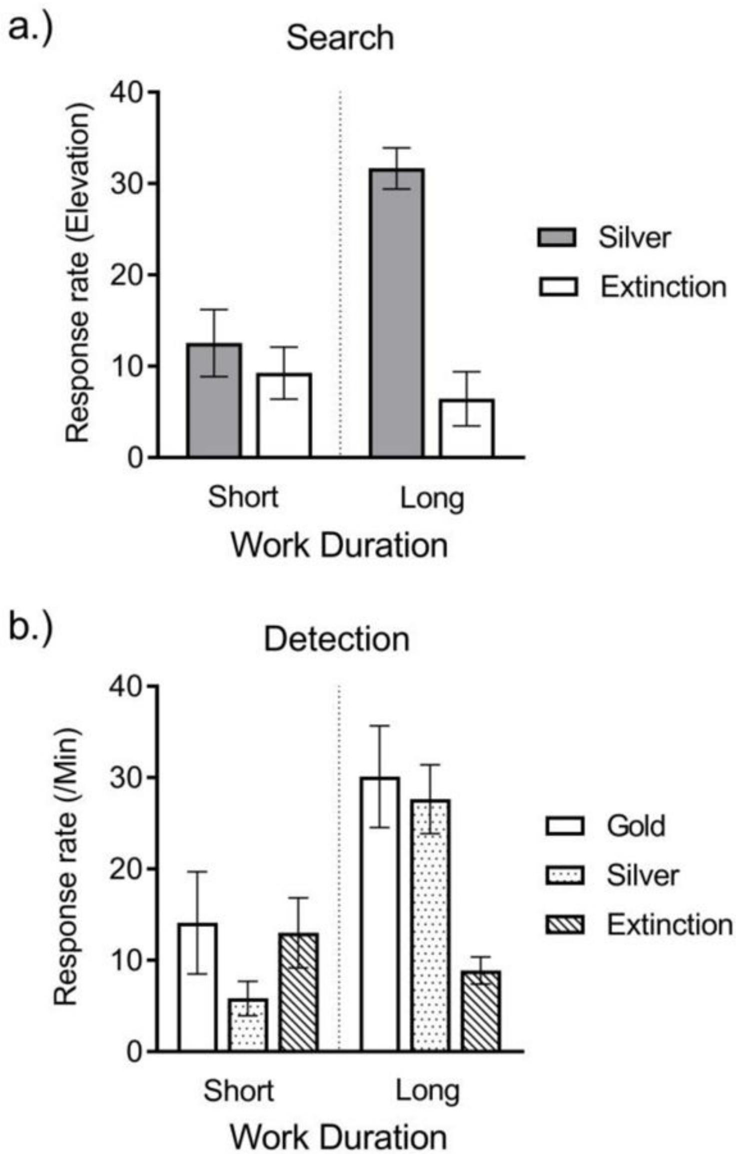

Figure 4.

Results of the search➔detection chain test (Test 1) from Experiment 1. (a.) Search responding elevation scores and (b.) detection responding elevation scores after short (left) and long (right) training with the silver standard. Error bars are the standard error of the mean and only appropriate for between-group comparisons.

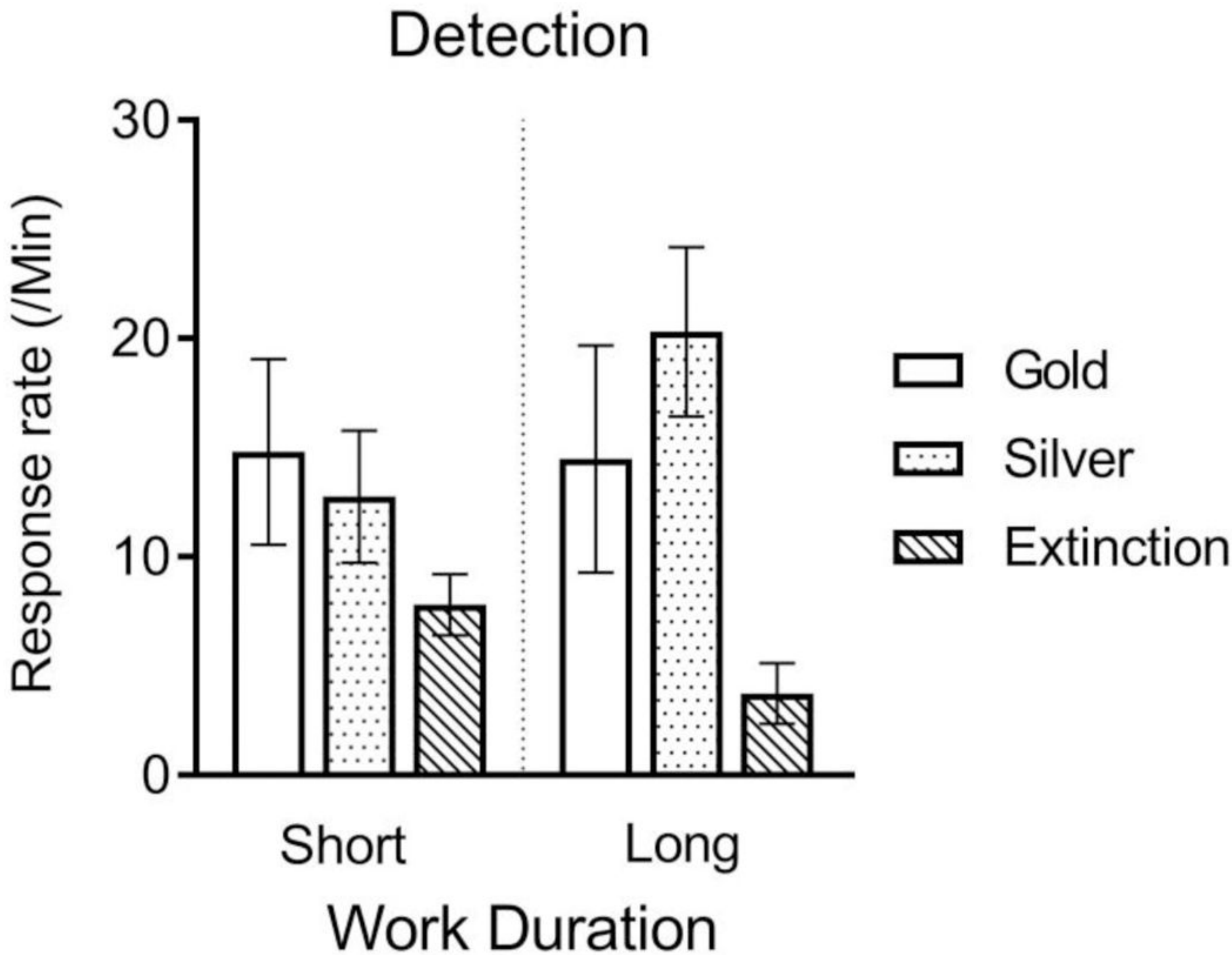

Figure 5.
Results from the test of detection responding with the gold and silver standard stimuli (Test 2) in Experiment 1. Left.) Detection response rates in short work phase groups. Right.) Detection response rates in the long work phase groups. Error bars are the standard error of the mean and only appropriate for between group comparisons.

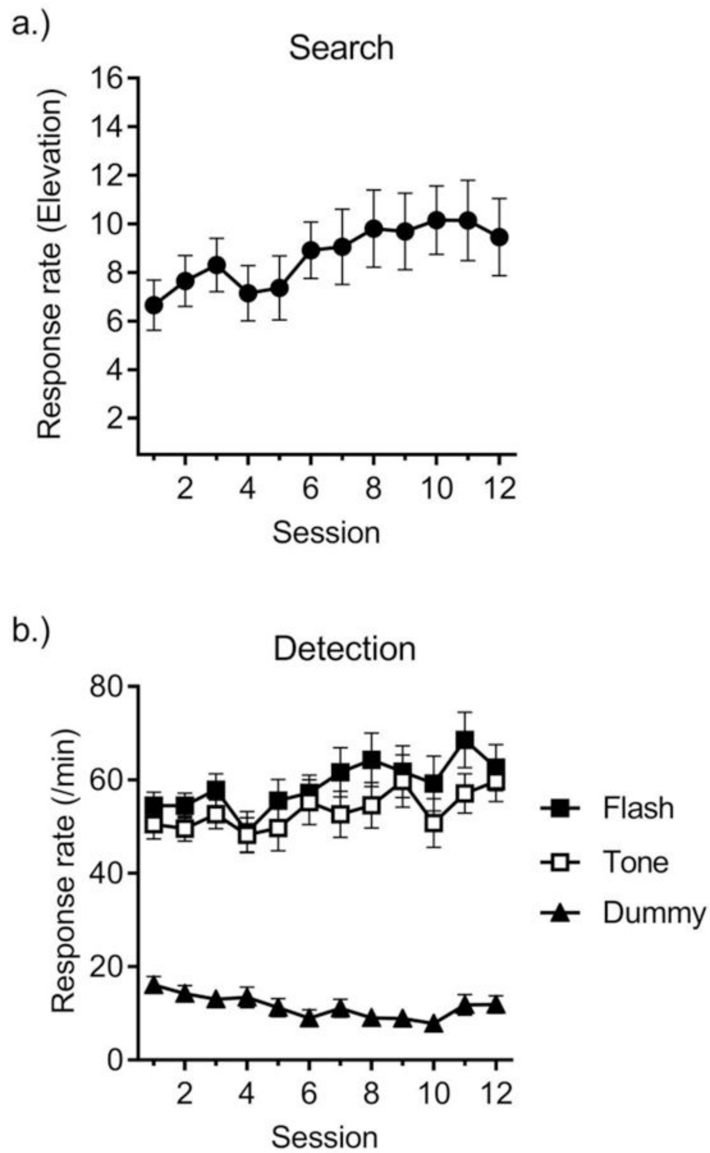

Figure 6.

Acquisition of the search➔detection chain in Experiment 2. a.) Search response rate (responses per minute) elevation scores (see text) for all rats over sessions of the acquisition phase. b.) Target (detection) response rates for all rats during Flash, Tone, and Dummy trials over sessions of the acquisition phase. Error bars are the standard error of the mean.

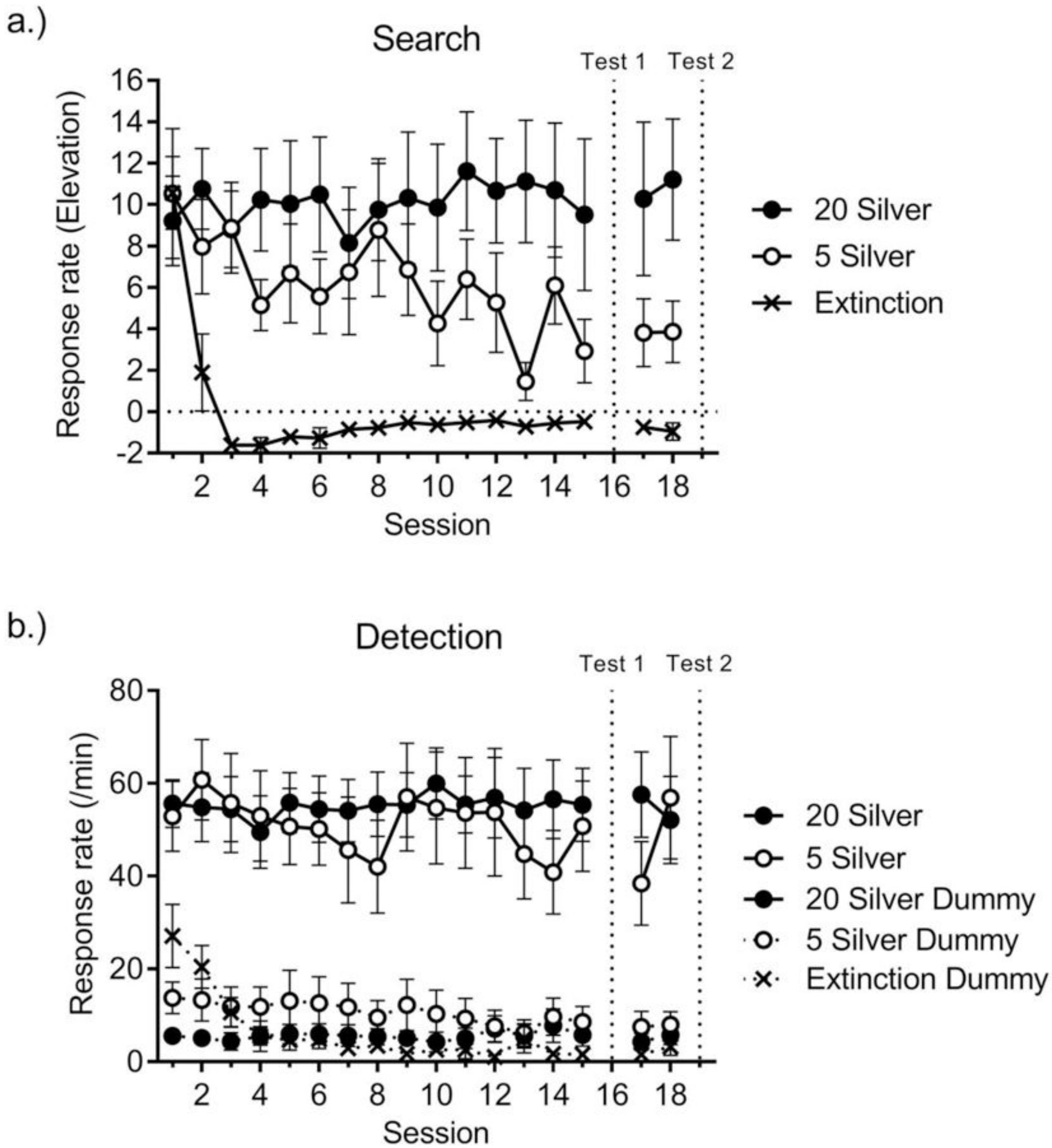

Figure 7.

Work phase responding in Experiment 2. a.) Search response rates (elevation) and b.) Detection response rates over sessions of the work phase. The search➔detection chain test (Test 1) and detection test (Test 2), the results of which are shown in Figures 8 and 9, occurred on days 16 and 19, respectively. Error bars are the standard error of the mean.

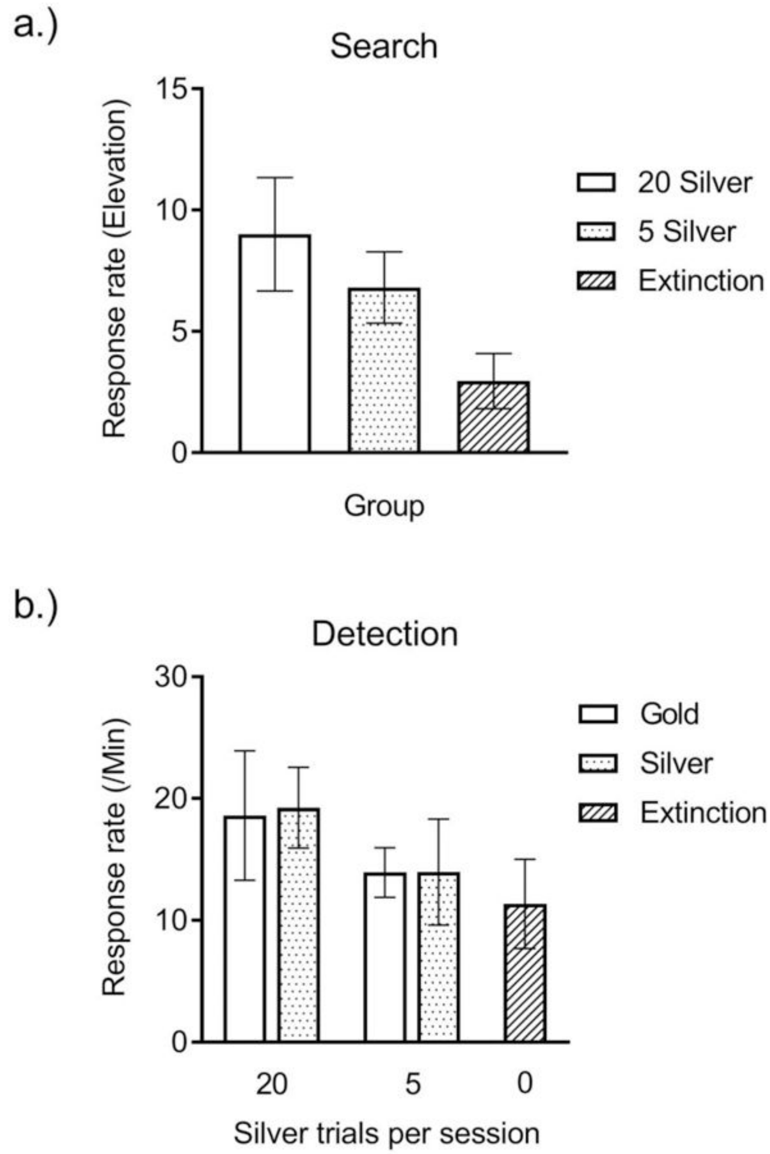

Figure 8.

Search➔detection chain test (Test 1) results from Experiment 2. a.) Search response rate elevation scores and b.) Detection response rates in the search➔detection chain test (Test 1). Error bars are the standard error of the mean.

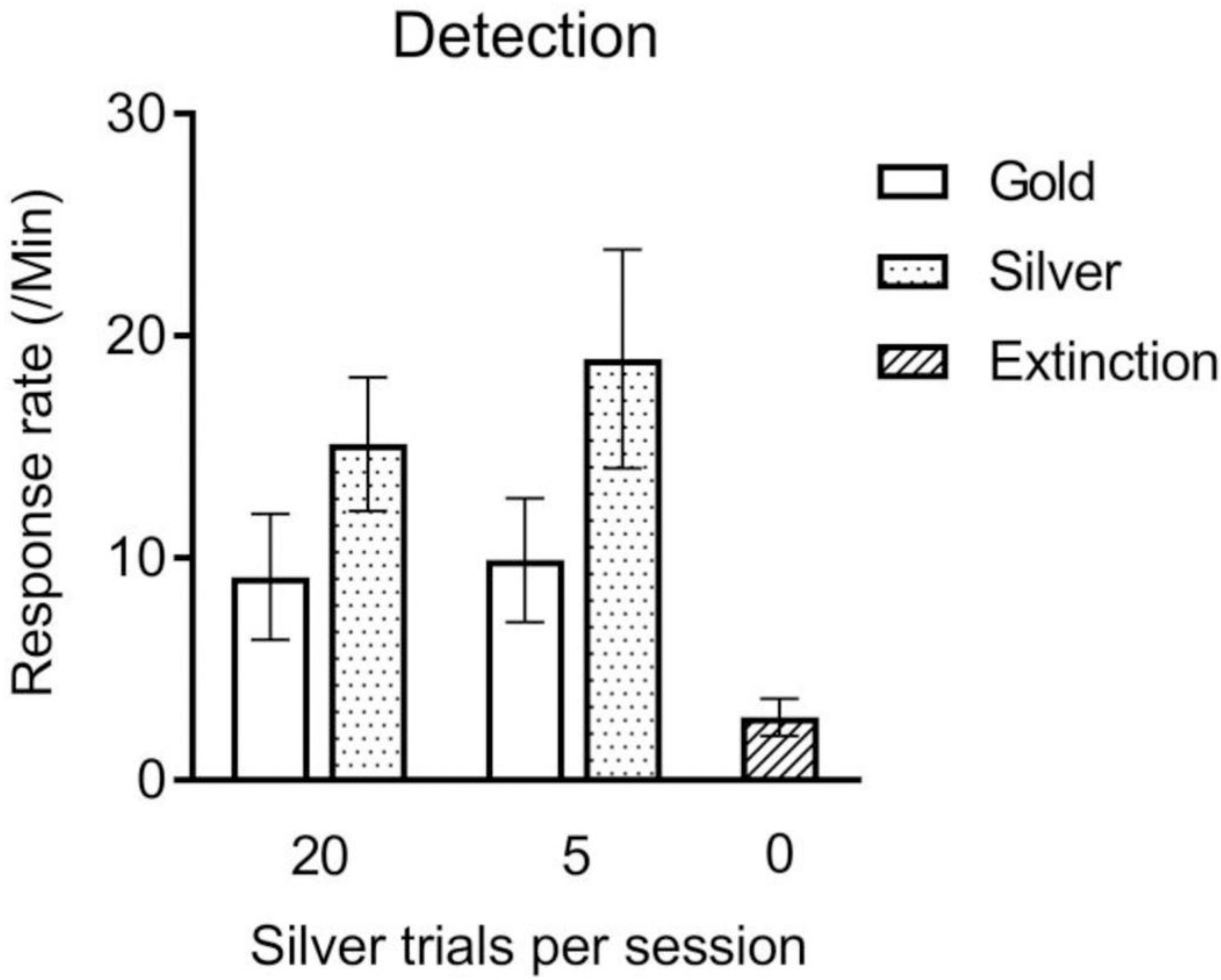

Figure 9.
Results from the detection test (Test 2) in Experiment 2. Error bars are the standard error of the mean and only appropriate for between-group comparisons.