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Training rats to search and alert on contraband odors

James Otto[a,*], Michael F. Brown[b], William Long III[b]

[a]*University of Baltimore, 1420 N. Charles Street, Baltimore, MD 21201, USA*
[b]*Villanova University, Villanova, PA, USA*

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Abstract

This paper describes a series of behavioral experiments that were conducted to test a new concept using rats to detect contraband odors, such as explosives, drugs, or prohibited foodstuffs. Under this concept, the trained alerting behavior of rats is remotely monitored by humans and/or computers to determine when the animals detect a scent of interest (e.g. contraband) during their search behavior. The rats alert on a scent by rearing on their hind legs, which is detected by computer. Our experimental measures include performance (hit rate and false alarm rate) and search effectiveness (number of cups visited and number of unique cups visited) for three to six rats, detecting a variety of odors including explosive, cocaine, and bleach scents. Their performance was measured both with and without distractor scents (almond extract and motor oil) present. Results of the experiments showed good olfactory performance in the laboratory setting. © 2002 Published by Elsevier Science B.V.

Keywords: Rat; Odor detection; Odor discrimination; Contraband; Explosives

1. Introduction

Working dogs serve humans in a variety of ways including guards, guides, herders, trackers, and search and rescue (Weiss and Greenberg, 1997). One important service that they provide is the olfactory detection of contraband, such as explosives (Lovett, 1992), illicit drugs (Adams and Johnson, 1994), and prohibited foodstuffs (Eastwood, 1990). In this paper, we present the results of laboratory experiments that explore the possibility of using rats to provide the same service.

Rats—because of their size, temperament, and cost—may be useful in situations where dog use may be inappropriate. Rats have a highly sensitive and discriminating olfactory

* Corresponding author. Tel.: +1-410-917-8240; fax: +1-413-702-8467.
E-mail address: jotto01@yahoo.com (J. Otto).

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system. They are inexpensive, and are relatively easy to procure and maintain. Using computer-controlled instrumentation, it may be possible to train large numbers of rats in parallel and in an automated fashion. Because rats are small, they can squeeze into small areas and may be able to infiltrate areas that dogs cannot (e.g. rubble fields). Unlike dogs, rats are relatively unaffected by the presence of humans or by social bonds with specific humans. This may reduce the dependency of the working animal on a specific human handler. Rats may also be better than other working animals at maintaining performance during long periods of repetitive work. A female rat can have pups every few months (up to 10 pups per litter with up to four litters per year). Thus, it may be relatively easy to selectively breed for behavioral performance. Finally, we may be able to use rats in ways that we cannot use other animals due to social and political constraints. For example, in some cultures it might be more socially acceptable to place a rat in harms way than a dog.

The idea of using rats to detect substances has been studied previously by a few researchers. In all the cases, the researchers brought odors to the rats (or other rodents) for classification. Nolan et al. (1978) and Weinstein et al. (1992) studied devices that rewarded rats for proper explosive odor detection using electrical brain stimulation (EBS). Odors were delivered to rats in conditioning chambers and odor classification was accomplished via typical lever pressing and via direct monitoring of the rat's cortical frequency spectra. Beiderman (1978) investigated the use of gerbils to detect a variety of explosives using a conditioning chamber and lever pressing. Marshall et al. (1981) investigated the ability of rats in conditioning chambers to detect explosive taggants.

Similar research has been conducted with dogs. That is, the dogs are housed in an instrumented chamber and the scent is brought to the dog for classification. In most of these efforts, the purpose was to ascertain the lowest threshold at which the dogs could detect the scent. Johnston (1998a,b,c) and Johnston and Waggoner (1998) published a number of research studies involving odor (illicit drugs and explosives) detection and classification by dogs using a controlled test chamber similar to the ones used for the rat experiments.

Our research goes beyond this previous rat olfactory research by taking the rats out of the cage and measuring how well the rats can search for, and alert on odors of interest. This approach more closely resembles how dogs are typically used and a number of possible applications come to mind. For example, dogs are currently used to detect explosives or mines. The dogs must be in the near vicinity, or accompanied by human handlers on these missions (Nolan and Gravitte, 1977; Mitchell, 1976). Allowing unaccompanied rats to roam a suspected minefield searching for mines reduces the risk to man and dog at the possible expense of lost rat(s). Additionally, we instrument the rats, so that their location and alerting behaviors can be monitored from afar by computer and/or humans. This automatic monitoring of animal movement and behavior may also have possible applications for working dogs.

A number of possible types of measurements were considered to detect scent alerting. They included physiological measurements such as electroencephalograms or cardiac rate, and behavioral measurements such as jaw movement, head jerking, digging, sitting still, or the behavior that we chose—rearing up on their hind legs. Our general approach to testing the ability of rats to find scents of interest involved instrumenting the rats with trackers that measured their three-dimensional position as they moved through an arena searching for an odor. If they found the odor and correctly reared (which the computer tracker could detect),

then the rats were rewarded. These experiments and their results are discussed in detail in the Section 2.

2. Experiments

We conducted laboratory experiments to test the feasibility of the concept as described in this section. In the first series of experiments, we did not instrument the rats. In the second series of experiments, we instrumented the rats so that we could remotely monitor their location and alerting behavior via computer. Our primary experimental measures were related to detection accuracy, which was assessed by hit rate (correct rearing to the presence of the target odor) and false alarm rate (incorrect rearing). We were also interested in the rat's search dynamics and effectiveness, so we also measured the order and number of cups visited by the rats prior to rearing (the experimental apparatus involved a series of cups with or without odor). The number of cups visited measure corresponds to the primary dependent measures that are used in studies of spatial choice, e.g. in the radial arm maze (Olton and Samuelson, 1976; Foreman and Ermakova, 1998).

2.1. Uninstrumented rat experiments

The first series of experiments involved uninstrumented training and testing. That is, the rats were not remotely monitored by computer or other automated monitoring equipment. The methods and results of these experiments are discussed in this section.

2.1.1. Method

2.1.1.1. Subjects. The subjects were six male albino Sprague-Dawley rats obtained from Harlan Sprague-Dawley Inc. (Indianapolis, IN). All rats were experimentally naive. They were housed in two groups of three in plastic cages, located in a colony room with a reverse 12:12 h light:dark cycle. All experimental procedures occurred during the dark phase of the cycle. The rats were maintained on a mild food deprivation diet consisting of ad libitum access to water and 13 g of rat chow (Purina) per day. This diet maintained the animals between 85–90% of their free-feeding weight, as determined by growth curves provided by the vendor (Harlan Sprague-Dawley Inc.). For 2 days prior to experimental procedures, the subjects were given 15–20 45-mg sucrose pellets (BioServe Inc.) each day to familiarize them with the reinforcers.

2.1.1.2. Apparatus. The apparatus (shown in Fig. 1) was a 125 cm × 125 cm × 7 cm (tall) arena, constructed of plywood. The floor of the arena contained a 5 × 5 matrix of 5 cm holes spaced 20 cm apart. White plastic drinking cups (Solo Corp., Urbana, Ill., product no. P3A, 6.5 cm diameter at top, 4.7 cm diameter at bottom) were filled with bedding material (Beta Chips from Northeastern Products Corp., Warrensburg, NY; the same bedding material used in the subjects' home cages), up to 2 cm below the lip of the cup. The cups were placed in the holes so that the lips of the cups held them at the surface of the arena. Two start boxes were attached at opposite sides of the arena, separated from the arena by

Fig. 1. Experimental setup showing matrix of cups.

metal doors in sliding tracks. A thin, transparent piece of Plexiglas covered each start box, secured with Velcro. The doors controlled access to the arena via a string-and-pulley system. A manual reinforcer delivery system included a plywood canopy, 88.9 cm above the floor of the arena, secured using four wooden supports at the corners of the maze. There was a 5×5 matrix of 2 cm diameter holes in the canopy, which corresponded to the cups below on the floor of the arena. This system allowed for the administration of sucrose pellets from above, with the reinforcement falling into the cups on the floor of the maze. The underside of the canopy contained PVC tubes, 7 cm in length, to ensure accurate guidance of the reinforcement into the cup. A manual push delivery system was constructed on top of the canopy. A plastic grid material was used such that unidirectional pressure on the grid pushed 95 mg sucrose pellets over the holes, such that they fell through the PVC tubes and into the cup below. Thus, pellets could be delivered to one or more cups by the experimenter.

The apparatus was painted flat black. A sparse layer of bedding material covered the floor of the arena. The apparatus was located in a small room that contained a variety of objects and was illuminated by fluorescent tubes.

2.1.1.3. Search and odor detection (SOD) training. At the beginning of each trial, one cup and one starting box were chosen randomly. Six 45 mg sucrose pellets (BioServe Inc.) were placed on top of the bedding in the target cup. The subject was released from the starting box by remotely lifting the metal door using the string-and-pulley system, and the duration and sequence of cups chosen were recorded. A cup visit was defined for all experimental

protocols as touching the wood chips in a cup or the lip of the cup with the nose. The trial ended when the rat had eaten the pellets from the target cup or 8 min had elapsed. This phase 1 of SOD training lasted until the subject found the baited cup within the allotted 8 min for a total of five trials.

During phase 2 of SOD training, one pellet was placed on the surface of the target cup, and five pellets were buried approximately 2 cm below the surface. This phase lasted until the subject found the buried pellets within the allotted 8 min for a total of five trials. Phase 3 of SOD training consisted of all six pellets being buried in the target cup. This phase lasted until the subject found the buried pellets for a total of five trials.

In phase 4 of SOD training, we introduced an odor to the target cup. A cotton ball was soaked with almond extract (McCormick Inc.) and placed in a 3 cm long PVC tube closed at the ends with nylon mesh. This odor container was placed in the bottom of the target cup, the cup was filled with bedding material, and six pellets were placed on top. The cup was then filled with bedding up to 2 cm of the lip. One pellet was placed on top of the target cup. When the subject found the buried pellets for a total of three trials, the pellet on top was not present in subsequent trials. Phase 4 continued until the rat found the baited cup for a total of three trials. All phases of training and testing were recorded on videotape.

2.1.1.4. Rearing response (RR) training. After training the rats to dig up the pellets in the target cup, we trained them to rear in the presence of the almond odor. Three 45 mg sucrose pellets were placed in the target cup with the odor apparatus. One large sucrose pellet (95 mg, BioServe Inc.) was suspended through the hole in the feeding platform from the ceiling of the room using thin string. Following the discovery of the three buried pellets, the large sucrose pellet was lowered until it hit the head of the rat. The rat behavior was shaped to a rearing position by raising the pellet. Phase 1 of RR testing lasted until the rat reared in anticipation of the suspended reinforcement for a total of five trials.

During phase 2 of RR training, the rat was required to rear in response to the correct cup for 2 s before the suspended pellet was lowered.

2.1.1.5. Testing. Testing occurred in two phases. During test phase 1, almond odor was used as in training. As during training, the target cup and start box was chosen randomly (with replacement) for each trial. To control for any human odors introduced when the odor was placed inside the target cup, each of the 25 cups was touched by the experiment just prior to placing the rat in the start box prior to each trial. Also, to control for any odor left in the Beta Chip substrate of the cup or the cup itself, cups used as the target cup were replaced following the trial.

The rat was allowed to visit cups until it reared in response to the correct cup. Hits and false alarms are defined in reference to cup visits. Each time a rat visits a cup, it either does or does not rear, resulting in either hit, miss, false alarm, or correct response on each cup visit. A cup visit was defined as in training. A RR required that the rat have both forelimbs suspended for at least 2 s. The sequence of cup visits and RRs was recorded by the experimenter. A RR to the target cup resulted in delivery of a pellet from the overhead mechanism into or near the target cup. The rat was removed from the apparatus after eating the reinforcement pellet. Twenty-seven daily trials of testing were conducted.

During phase 2 of testing, a second target odor was used: A simulated cocaine scent in powder form, which is used in the training of dogs for drug detection (Sigma Chemical, product no. P2423). Approximately 0.5 gm of the cocaine simulant was mixed with enough bedding material to fill the target cup with half as much bedding material as there was in the remaining cups. Bedding material was then added on top of the mixture to the same level as the non-target cups. Trials with conducted in the same manner as in phase 1 of testing. Thirty-two daily trials were conducted, with each of the two target odors (almond and cocaine simulant) used during half of the trials (structured in randomized blocks of eight trials each).

2.1.2. Results

2.1.2.1. Training. All six rats readily completed the SOD training. Phases 1, 2, 3, and 4 of the SOD training were completed in means of 10.7, 6.2, 5.0, and 6.3 trials, respectively. All six rats also readily learned the RR during the training. Phase 1 of RR training was completed in a mean of 22.2 trials, and phase 2 was completed in a mean of 5.3 trials.

2.1.2.2. Searching behavior. Our primary measure of searching performance was the number of unique cups visited before (and including) the visit to the target cup. During SOD training, a substantial proportion of trials ended without the subject visiting the target cup (i.e. 8 min elapsed without a visit of the target cup). However, starting with RR training, trials without a visit to the target cup within the 8 min limit were very rare (less than 5% of trials). Thus, we report searching performance only for RR training and testing. The performance measure does not include revisits to cups that were visited earlier.

Fig. 2 shows the mean number of unique cups visited by each rat during RR training and phase 1 of testing (left panel) and during phase 2 of testing. Also shown is an estimate of chance performance provided by 1000 iterations of a Monte Carlo simulation of random selection from 25 alternatives without replacement. There is no evidence that searching efficiency improved during these experimental phases. However, in all phases, the rats visited fewer cups than would be expected if cups were visited randomly.

For phase 2 of testing, mean values for each rat are shown for the trials using almond extract and those using the cocaine simulant. All, but one, of these values is less than the value expected by chance. There was no evidence that the values for almond extract and cocaine stimulant differed, $t(5) = 1.3$.

2.1.2.3. Detection and alerting behavior. To measure the extent to which rearing behavior was directed preferentially to cups containing the target odor, we determined the hit rate (proportion of visits to target cups that elicited a RR) and the false alarm rate (proportion of visits to non-target cups that elicited a RR). Fig. 3 shows the mean hit rate and false alarm rate for the almond and cocaine scents during phase 2 of testing. The rats' performance was very good. A rate $\times$ odor analysis of variance (ANOVA) confirmed the difference between the hit rate and false alarm rate, $F(1, 5) = 877.3$, $P < 0.001$. However, there was no evidence that the difference between the hit rate and false alarm rate differed as a function of the target odor, in that there was no evidence of a rate $\times$ odor interaction, $F(1, 5) = 0.0$.

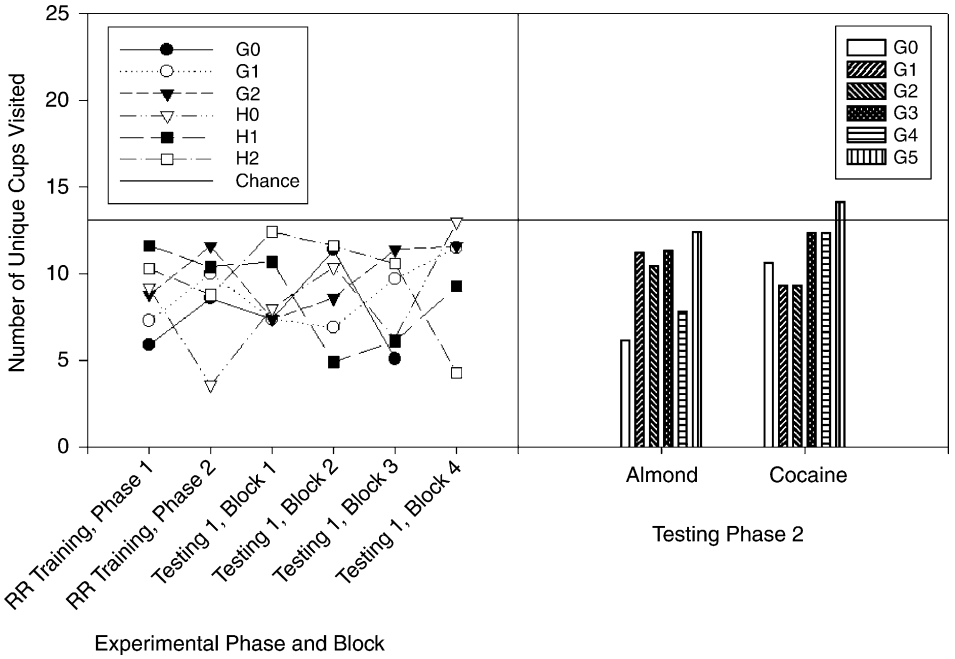

Fig. 2. Mean number of unique cups visited by each rat during the training and testing phases of experiment 1.

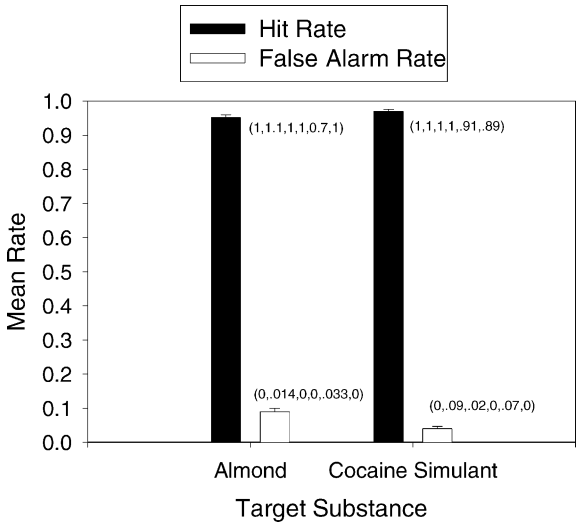

Fig. 3. Mean hit rate and false alarm rates for detection and alerting on almond and cocaine simulant scents during testing phase 2 of experiment 1.

2.2. Instrumented rat experiments

During a second set of experiments, the test rats were instrumented to remotely monitor their location and alerting behavior by computer. These experiments are described in this section.

2.2.1. Methods

2.2.1.1. Subjects. The subjects were six male albino Sprague-Dawley rats obtained from Harlan Sprague-Dawley Inc. All rats were experimentally naive. They were housed in groups of three in plastic cages, located in a colony room with a reverse 12:12 h light:dark cycle. All experimental procedures occurred during the dark phase of the cycle. The rats were maintained on a mild food deprivation diet consisting of ad libitum access to water and 13 g of rat chow (Purina) per day. For 2 days immediately prior to experimental procedures the subjects were given 15–20 sucrose pellets in their home cages each day to familiarize them to the reinforcers.

2.2.1.2. Apparatus. The arena used in experiment 1 was also used in the present experiment. A motion tracking system (MiniBird system, Ascension Technology Corporation) was used to automate the recording of cup visits and the rearing behavior of the subjects. The system consists of a sensor (8 mm × 8.1 mm × 8.1 mm), which is attached by a cable to the animal. The sensor was held on the subjects back, approximately neck level, using a fabric harness (Alice King Chatham Medical Arts Co., Hawthorne, CA). The cable entered the arena through a hole in the center of the overhead canopy, and allowed sufficient slack that the subject could move freely throughout the arena. Fig. 4 shows a subject with the sensor and harness in the arena. The system determined the position of the sensor in a three-dimensional space defined by a magnetic field. Fig. 5 shows an output screen for an *X*, *Y* track of the rat through the apparatus. The positional information provided by this system was used in computer programs produced using MicroSoft BASIC to record the sequence of cup visits and RRs made by the rat. These measures were recorded in real-time, and used to determine when the trial was completed. A cup visit was defined when the sensor came within 1.0 cm of the outside edge of a cup (in two-dimensional space). Rearing behavior was defined when the sensor was more than 12.7 cm above the surface of the arena. Fig. 6 shows the *Z* output for the rat moving through the apparatus. As can be seen, a rear is declared when the sensor on the rat exceeds a threshold height of 12.7 cm (5 in.).

A conditioning chamber was also used (Coulbourn Instruments, Allentown, PA, Model H10-11R-TC). The chamber was 30.5 cm × 25.4 cm × 30.5 cm (tall). The conditioning chamber was contained in a light and sound attenuating chamber. There was a nose poke apparatus (Coulbourn Model H21-09R) on one side of the chamber, into which odor could be delivered with a forced-air odor delivery system (Coulbourn Model H15-03OL control, Coulbourn Model H15-20 olfactant evaporation chambers and Tetra Model I aquarium air pump). A pellet dispenser (Coulbourn Model H14-01R/H14-22R-45) was mounted on the opposite side of the chamber. A linear arrangement of photo emitters and detectors (Coulbourn Model H20-95) was mounted in the chamber, such that a photobeam was

Fig. 4. Image showing rat with sensor and harness attached.

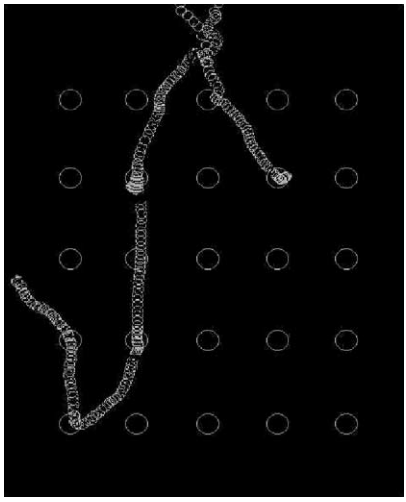

Fig. 5. Plot showing the *X*, *Y* tracking of a rat through the apparatus.

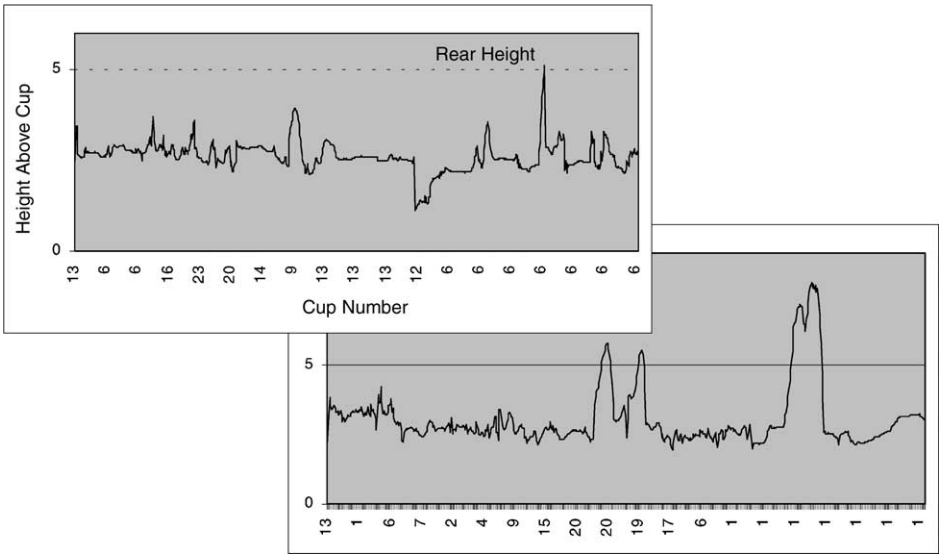

Fig. 6. Plot showing *Z* axis movement of the sensor on the rat.

broken when the subject reared to a height of 19.0 cm within 14.0 cm of the wall on which the nose poke apparatus was mounted. Two exhaust fans inside the chamber and an additional fan outside of the chamber ensured that air was exhausted from the box and from the room in which the chamber was located. All of the stimulus devices and response sensors were controlled using Coulbourn Graphic State Notation software.

2.2.1.3. Rearing response training. Subjects were first trained to rear in response to chlorine odor in the conditioning chamber. They were trained to eat pellets from the food magazine by placing them, for 45 min, in the chamber with the magazine illuminated and containing 10–15 45-mg sucrose pellets. This occurred on two consecutive days.

Magazine training was followed by a series of procedures intended to train the subjects to rear in response to chlorine odor (presented in the nose poke apparatus), but not rear when no odor was presented. In all of these procedures, odor was provided by placing an open vial of chlorine solution (Clorox Brand) in one of the evaporation chambers, and ionized water in the other chamber. The same airstream led from the pump to the two evaporation chambers, but the valve system determined which evaporation chamber was included in the airstream leading to the nose poke apparatus. In all procedures, daily experimental sessions consisted of 50 trials, with an inter-trial interval (ITI) of 30 s.

The first six sessions involved an autoshaping procedure. In each trial following the ITI, the air stream was presented in the nose poke apparatus and the nose poke apparatus was illuminated. The air stream contained the target odor on a randomly selected half of the trials, and did not contain odor on the remaining trials. On odor trials following 5 s or a RR, the air stream and nose poke illumination were terminated, a single 45-mg sucrose pellet was delivered into the food magazine and the magazine was illuminated for 3 s. On no-odor trials following 5 s, the trial was terminated.

Sessions 7 and 8 were equivalent, except that a nose poke response was required in order for the trial to proceed to the next step. If the nose poke response sensor was not activated within 5 s following nose poke apparatus illumination, then the trial was terminated (and the ITI began). Sessions 9–30 added a requirement that the subject rear during the 5 s odor presentation. If a RR did not occur, then reinforcement was not provided. In addition, punishment was introduced for a RR on trials when the air stream did not contain odor. Specifically, the ITI was increased to 90 s when there was a RR to the air stream not containing odor.

2.2.1.4. Search and alert training. Training in the cup maze was very similar to that described in experiment 1. Differences were intended to eliminate unnecessary phases and, thereby, reduce training time. In phase 1, one randomly chosen cup was baited with a 190 mg sucrose pellet prior to each trial. Rats were placed in the sensor harness and released from one of two randomly chosen starting points in the maze (two opposite corners of the arena). This phase lasted until the rat visited the baited cup within 5 min for a total of three trials. In phase 2, odor was added to the baited cup. Using a dropper, 45–60 ml of bleach was added to a piece of filter paper (Fisher Scientific) and placed at the bottom of the cup. The cup was then filled with bedding up to 2 cm from the lip. The remaining 24 cups contained a piece of filter paper, but no odorant. Prior to each trial, all of the cups were touched by the experimenter (with an ungloved finger) to control for effects of possible contamination of the target cup during the baiting process. Following each trial, the target cup was removed and replaced by a new cup containing fresh bedding material. Phase 2 lasted until the rat visited the target cup within 5 min during three trials.

In phase 3 of training, the reinforcement was suspended from the arena canopy. The rats were shaped into a rearing position at the target cup until anticipatory rearing occurred when the rat visited the correct cup. Phase 3 lasted until the rat reared in response to the target cup for a total of five trials.

2.2.1.5. Testing. After training, we used the MiniBird tracking system to quantify searching behavior and alerting performance. Prior to each trial, the rat was placed in the sensor harness and released from one of two randomly chosen starting points. Fig. 4 shows a subject wearing the harness and sensor. Following a 2 s RR within 2 cm of the correct cup, the pellet was dropped from above the target cup. Each rat was tested in 12 daily trails under these conditions.

Three rats were then tested in trials with distracter odors present (the remaining three rats were tested in experiments not reported in this paper). During six daily trials, 12 of the cups (randomly chosen) contained the odor of motor oil. Using a dropper, 45–60 μl of motor oil (Mobil) was placed on a piece of filter paper, which was placed at the bottom of the cup. Thus, one cup contained the target odor, 12 contained a distracter odor, and 12 contained only the bedding material substrate. The 13 cups containing odor were replaced following each trial.

During the next six daily trials, two different distracter odors were used. Six cups contained motor oil, and an additional six contained almond odor. Using a dropper, 45–60 μl of McCormick almond extract was placed on a piece of filter paper, which was placed

at the bottom of the cup. As before, there was a single cup containing the target odor, as well as 12 cups containing no explicit odorant.

2.3. Results

2.3.1. Rearing response training

Two rats did not acquire the RR during the training. Specifically, they reared during fewer than 5% of trials, during the last five sessions of training. Among the remaining four rats, rearing occurred on a mean of 78% of the odor trials and 76.5% of the no-odor (control) trials during the last five sessions of training. Thus, although some of the rats acquired the RR in the conditioning chamber, there was no evidence that the RR was more likely following an odor stimulus than following a control stimulus. The explanation for this null result is unclear.

2.3.2. Search and alert training

Rats completed phases 1, 2, and 3 of the search and alert training in means of 10.3, 15.6, and 12.5 sessions, respectively.

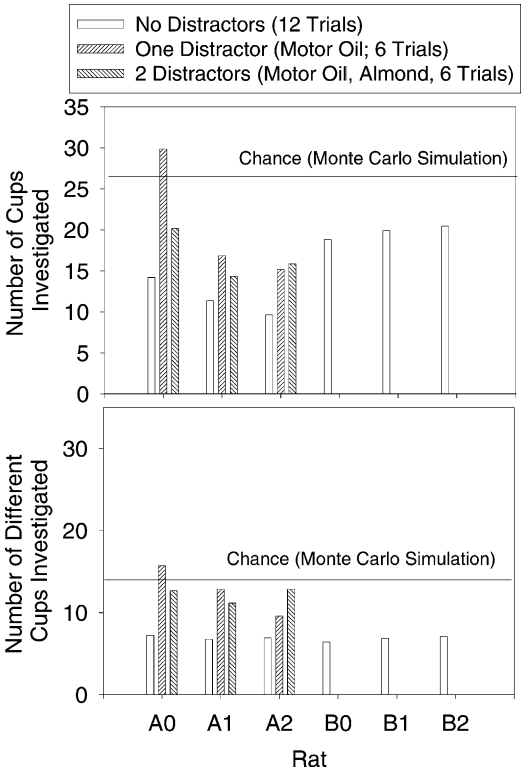

Fig. 7. Number of cups visited during the testing phase of experiment 2.

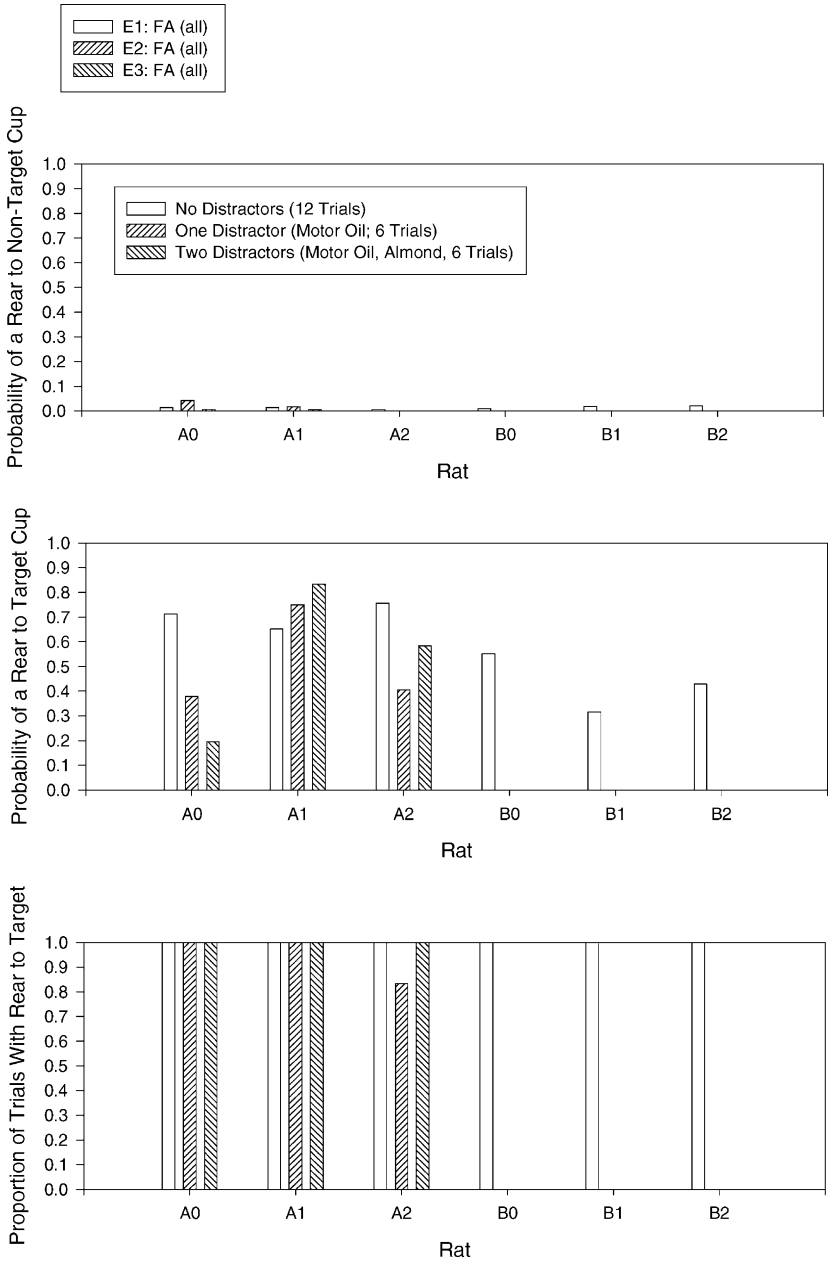

Fig. 8. Hit rate and false alarm rates for detection and alerting in the presence of distractors during the testing phase of experiment 2.

2.3.3. Testing

Fig. 7 shows the mean number of cups visited (top panel) and the mean number of unique cups visited (bottom panel) during the test trails. During the first phase of testing (no distracter odors), all six rats visited fewer cups that would be expected on the basis of chance before locating the target cup As shown in the bottom panel, the number of unique visits to cups visited is not much better than expected by chance.

Comparisons of the number of cups visited during the three test phases (0, 1, or 2 distracter odors; comparisons based on within-subject ANOVAs using data from the three subjects that received test phases 2 and 3) revealed that the distracter odors resulted in more unique cups being visited, $F(2, 4) = 9.0$, $P < 0.05$). The effect of distracter odors on the total number of cup visits (including revisits to the same cup) did not reach statistical significance, $F(2, 4) = 5.4$, $0.10 > P > 0.05$.

Fig. 8 shows the hit rates and the false alarm rates for these same trials. False alarm rates were very low regardless of whether distractor odors were present (top panel). The probability of responding when a target cup was chosen varied, but was on the order of 0.5 (middle panel). However, rats virtually always reared to the target during the trial (bottom panel). Thus, on many trials, rats investigated the target cup more than once before responding to it.

3. Discussion

Our overall interpretation of the results from the cup arena experiments is that the concept of using rats to remotely search for, and alert on, scents of interest is promising. The rat's choice accuracy, in terms of both hit rates and false alarms rates, is very high—both with and without distractor odors present. As can be seen in Fig. 3, the hit rate for both cocaine and almond scents are over 90% with a false alarm rate of less than 10%. The bottom plot of Fig. 8 shows that the hit rate for the bleach scent experiments with zero, one, and two distractors was 100% in every case, but one, where the hit rate was 80%.

Our experiments demonstrated the feasibility of using a lever box to pre-train the rats to rear in the presence for the odor of interest, and this approach appears to increase the efficiency of the training protocol.

The rats choose fewer cups than would be expected by chance before choosing the target cup (assuming sampling with replacement). This could be explained in either of three ways. First, it could be that the rats follow a scent gradient in locating that target odor. However, the rats do not appear to be following a scent gradient when searching for the odors of interest because the number of unique cups that they visit is similar to chance. This suggests that the rats are not going directly to the cup with the odor of interest and, thus, may not be following a scent gradient. Second, The rats may be remembering which cups they have visited, and are thereby able to avoid returning to the cups without the odor. This would be consistent with a large body of evidence for the use of spatial memory to avoid revisits to locations in laboratory tasks (see Thinus-Blanc (1996) for a review). Third, it may be that the rats searched for the target cup using a systematic search pattern that reduced the number of cups revisited.

These results clearly demonstrate that rats can learn to exhibit unique alerting behaviors when they find a variety of odors. We also developed semi-automated means of training and

testing rat alerting behavior in a laboratory environment. Additionally, we developed a method for remotely detecting the rats' alerting behavior in the laboratory.

Related to this last observation, an important potential outgrowth of our research might be the development of automated training techniques for working animals. Such techniques might reduce the time and labor needed for training. Instead of humans administering the training, a computer can monitor the animal's behavior and administer reinforcement mechanisms as appropriate. For example, a computer could remotely monitor and appropriately reward free roaming sniffer dogs in a warehouse (e.g. a remotely controlled backpack could administer a food reward). Additionally, providing more consistent training may result in a better characterized detector.

In conclusion, our research suggests that the concept of using rats to search out and alert on odors of interest is feasible in the laboratory. The next step is to investigate the concept in field settings.

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