Effect of odor pre-exposure on acquisition of an odor discrimination in dogs

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Acknowledgments: We thank Marc Branch and Jesse Dallery for numerous discussions on this research topic. We also thank the many research assistants who helped on the project: Courtney Huffman, Joey Galluzo, Adriana Collada, Yoko Tanka, and Laura Arango. This project was supported in part by a Masters Research Grant from the Society for the Advancement of Behavior Analysis (SABA) to NH.

Abstract

In two experiments we investigated the impact of odor pre-exposure treatments on the acquisition of an olfactory discrimination in dogs. In the first experiment four groups of dogs were each given five days odor-exposure treatment prior to discrimination training. Dogs in the exposure group were exposed to anise extract (S+) for 30 minutes daily. Dogs in the Pavlovian-relevant pairing group received six daily delayed conditioning trials to the same S+. The Pavlovian-irrelevant pairing group received conditioning trials to almond extract (S'). Dogs in the control group received no pre-treatment. All dogs were then trained to detect S+ from a background pine odor (an AX vs X discrimination). The Pavlovian-relevant pairing group acquired the odor discrimination significantly faster than all the other exposure and control groups, and the remaining groups acquired the discrimination at the same rate as the no exposure control group. In a second experiment, we extended these results to a within-subject design using an AX vs. BX discrimination. Six dogs were simultaneously trained on two different odor discriminations, one discrimination in which the S+ was previously Pavlovian conditioned, and one discrimination in which the S+ was novel. All dogs learned the odor discrimination with the previously conditioned S+ faster than the novel odor discrimination, replicating the results of Experiment 1 and demonstrating that familiarity in the form of Pavlovian conditioning enhances odor-discrimination training. The potential mechanisms of the facilitated transfer of a Pavlovian CS to discrimination training are discussed.

Keywords: dogs, canine, Pavlovian conditioning, classical conditioning, odor-discrimination, odor-detection

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Dogs have long been deployed to detect odors of explosives and narcotics (Dean, 1972; Goldblatt, Gazit & Terkel, 2009), and have recently been used to detect a variety of chemical stimuli such as those associated with cancer and wildlife (cancer: Cornu, Cancel-Tassin, Ondet, Giardet & Cussenot, 2011; Willis et al., 2004. Wildlife: Cablk, Sagebiel, Heaton & Valentin, 2008). These capabilities make suitably trained dogs a valuable chemical detection tool. Despite the importance and usefulness of the canine sense of smell, relatively few scientific studies have investigated the variables that may influence canine odor perception.

In a recent review of research on canines detecting explosives, Goldblatt et al. (2009) highlighted studies suggesting that repeated exposure to an odor may be a simple way to significantly facilitate detection of that odor. Identifying simple ways to improve canine detection performance could have a significant impact on the costs and effectiveness of these training programs. One important and laborious component of the training process is acquisition of the initial odor discrimination. If pre-exposure to the target odor facilitated acquisition of the discrimination, then pre-exposure could be used as a simple technique to reduce training effort for odor-detection dogs.

Basic research in rodents on the effects of pre-exposure of odors suggests that long term exposure (24hrs a day for months) to an odorant may not enhance acquisition of a discrimination with the exposed odor (Cunzeman & Sltonick, 1984; Laing & Panhuber, 1980), and may even retard acquisition for some odorants (Cunzeman & Sltonick, 1984). In contrast, more recent research suggests that shorter-term exposures to the S+ and S-, or just the S+, for an hour or two per day for several days, can produce spontaneous discrimination between the S+ and S- odors as measured in a habituation/dishabituation task (Escanilla, Mandairon, & Linster, 2008; Mandairon et al. 2006a, Mandairon et al., 2006b). These results suggest that short-term odor exposure may enhance spontaneous odor discriminability and may therefore facilitate acquisition of the discrimination.

Similar research has evaluated the effects of stimulus pre-exposure on taste discrimination. In the basic procedure, the experimenter flavors drinking water with either flavor A or B. One group of subjects is then pre-exposed to flavor B (or flavors A & B), while control subjects remain naïve to flavor B. The rodents then receive taste-aversion conditioning trials to flavor A. In a subsequent test session, rodents with pre-exposure to flavor B show less conditioned suppressed drinking of flavor B than subjects naïve to flavor B, indicating greater discrimination between flavors A and B (e.g. Honey & Hall, 1989). Several subsequent permutations of this experimental procedure have confirmed that flavor pre-exposure enhances subsequent discrimination of the pre-exposed flavor from the flavor that was taste-aversion conditioned (e.g. Mackintosh, Kaye & Bennet, 1991, for a review see Mitchell & Hall, in press).

An alternative to 'mere-exposure' of an odor for the facilitation of acquisition of a discrimination is Pavlovian conditioning. Pavlovian conditioning may be a simple way to prepare dogs for discrimination training. Prior research has demonstrated that Pavlovian conditioning can facilitate subsequent discrimination performance. In one experimental paradigm rats received water (unconditioned stimulus: US) when exposed to one stimulus (a click or tone; CS) and never received water when exposed to a second stimulus (a tone or click; Bower & Grusec, 1964). The rats were later trained on a discrimination task in which half of the subjects were trained to lever press for water in the presence of the previously paired stimulus and not press in the presence of the previously unpaired stimulus (consistent group). The other rats were trained in an inconsistent manner (lever pressing was reinforced in the presence of the *non-paired* stimulus). Rats in the consistent group learned significantly faster, outperforming the inconsistently trained rats. In a subsequent study Mellgren & Ost (1969) showed that rats trained consistently outperformed a group of rats without any prior exposure to the stimuli.

Together, the previous studies demonstrate that stimulus pre-exposure and Pavlovian conditioning may facilitate discrimination learning. The present study aims to extend this research by evaluating the effects of odor pre-exposure on acquisition rates of an odor-discrimination in dogs in two experiments. In Experiment 1 we assess whether Pavlovian conditioning (Pavlovian-relevant group) or mere exposure (exposure group) of an odor facilitates the acquisition of an AX vs. X odor discrimination (where A is the pre-exposed odorant) compared to two control groups. Experiment 2 extends and replicates the effects of Pavlovian conditioning found in Experiment 1 to an AX vs. BX discrimination using a within-subject design.

Experiment 1

In this experiment, we assess acquisition performance of dogs that receive prior Pavlovian conditioning (Pavlovian-relevant group) or mere exposure (exposure group) of an odor (odor A) on an AX vs. X discrimination in which dogs are trained to dig in a container of pine shavings containing the target odor A. Dogs were given either five days of mere exposure to the odor (odor A; exposure condition), five days of Pavlovian conditioning trials to the odor (odor A; Pavlovian-relevant condition), five days of exposure to no odor (control condition), or five days of Pavlovian conditioning to an irrelevant odor (odor B; Pavlovian-irrelevant condition). All dogs were then trained across three sessions to dig in a container of pine shaving holding a scented cotton round over a similar container of pine shavings holding an unscented cotton round.

Methods

Subjects

Thirty-two healthy dogs between the ages of 6 months and 10 years were recruited for this study. Seven dogs were tested at a rescue organization: the remaining dogs were household pets. Subjects were of varying and mixed breeds, but similar breeds were recruited in approximate multiples of four so that breed was approximately balanced across groups (see Table 1). All testing occurred at least 4 hrs after the last feeding.

Materials

We used two odorants that were readily available but likely only slightly familiar to dogs: McCormick anise extract (S+) and almond extract (S'). For food reinforcers, we used commercial dog treats that dogs would readily consume, such as Pupperoni™, cut into 1cm by 1cm size pieces. For the pre-exposure phase of the experiment, a tall cylinder was modified to hold all the experimental materials. The top of the cylinder held a plastic container that served as a food hopper (see Figure 1A). A funnel and tube were placed below the food hopper to deliver the food to the dog. The inside of the cylinder held a 16-oz glass jar that could hold 10 ml of the target odorant, an aquarium air pump, polyethylene airline tubing, and an airline valve calibrated to control air flow to 500 mL/min (see Figure 1B). The airline was fed from the pump to the outside of the cylinder, through the back, to allow the experimenter to control airflow with a main clamp. The airline was then fed into the jar sparging the odorant, and subsequently fed near the food tubing to allow odor delivery to the dog that was either inside a crate appropriate for the dog's size or restricted to a similar sized space with a baby gate. This design allowed the experimenter to operate the airflow and food delivery from behind the equipment and out of direct sight of the dog.

Exposure Conditions

Dogs were randomly assigned to one of four conditions. Each condition ran 30 minutes a day for five days. At the start of each condition, dogs were restricted to a crate or a similar sized space behind a baby gate and remained there for the duration of the 30 min pre-exposure condition. In the *Pavlovian-relevant* condition, dogs were given six delay-conditioning trials per day. For each trial, an anise extract odor stimulus (odor A) was presented for 10-sec immediately prior to the delivery of food (a commercial dog treat) from the food hopper and remained on until the dog had consumed the food. All dogs readily consumed the food. The inter-trial interval was five minutes. For the *Exposure* condition, anise extract was presented for an entire 30-minute session. Food was not delivered. This odor presentation method was designed to be similar to the odor enrichment procedures that have previously been shown to facilitate spontaneous odor discrimination (Escanilla, Mandairon, & Linster, 2008; Mandairon et al. 2006a, Mandairon et al., 2006b). For the *Control* group, no odorant was in the glass jar and air was delivered to the dog for 30 minutes. For the *Pavlovian-irrelevant* group, dogs were given six delay-conditioning trials identical to the Pavlovian-relevant group except that the odor stimulus was almond extract (odor B) instead of anise extract. Following the exposure phase, all dogs underwent standardized odor-detection training to detect anise extract. See Table 2 for an outline of the experimental design.

Detection Training

In odor-detection training, dogs were presented with two bins of pine shavings and were trained to 'alert' to a target odor by digging in the bin containing it using the procedure described in Hall, Smith and Wynne (2013). In this procedure, one bin contains pine and a 100% cotton pad with 1ml of anise extract buried 2.5 cm deep, whereas the other bin contains pine and an unscented cotton pad buried 2.5 cm deep. Therefore dogs were trained to detect the target odor from a background pine odor creating an AX vs. X discrimination, where A represents the anise odor and X represents the background pine-shavings odor.

Alert training. At the beginning of each session, dogs were given eight alert training trials in which they were shaped to dig in a bucket of pine shavings. For the first two trials, dogs were trained to approach, and put their head in the buckets. This was done by visibly placing a piece of food in the target-scented bucket on top of the pine shavings. The dog was shown the treat in the bin and was allowed to take the food. After consuming the food, the experimenter said 'good dog' and delivered an additional treat by hand. For the next three trials, the dogs were taught to dig in the bucket, by burying the food 2.5 cm deep in the pine. Once the dog began to dig in the bucket, the experimenter said 'good dog' and gave the dog an additional treat by hand. For the last three trials of alert-training, no food was placed in the bin. The scented bin was simply presented. Contingent on digging in the bucket, the experimenter delivered a treat by hand. The bin used for alert-training was never used for discrimination training to prevent potential food-odor contamination.

Discrimination training. For each trial, the experimenter placed a scented bin and non-scented bin 0.25 m apart and equidistant from the dog that was held by an assistant 2 m back. After placing both bins down, the experimenter stepped at least one meter back, placed his arms behind his back and looked straight down at the ground. An observer, naïve to which bucket contained the target odor, watched the dog and called out “choice” when the dog began to dig in one of the buckets. This informed the experimenter of a response. He then looked up to see which bucket the dog was responding to, and delivered the appropriate consequence (a “good-dog” and food for digging in the target bin, or removing the bins without spoken comment or food for an incorrect response). If a dog failed to respond in 30 sec, the bins were picked up and re-presented. If the dog again failed to respond in the subsequent 30 sec, “no choice” was recorded. The inter-trial interval was approximately 20 s and corresponded to the time required for the Experimenter to prepare for the next trial.

Each session consisted of the initial eight alert-training trials, 30 odor-detection training trials, and six control trials per day for three days. Alert-training was run at the beginning of the first session to train the dogs to dig, but was continued for each session thereafter as “warm-up” trials. Throughout training, the location of the target bin was determined pseudo-randomly with the stipulation that the same location was not correct more than twice in a row. If the dog responded to the same location on four consecutive trials, a correction trial was conducted. For a correction trial, the experimenter put down both discrimination bins, but prior to the dog approaching either, the experimenter picked up the incorrect bin, forcing the dog to walk to the other location to respond. If dogs failed to respond (i.e. made "no choices") for two consecutive trials or responded incorrectly for three trials in a row, two alert-training trials in which the food was placed on top of the pine were conducted. The purpose of these trials was to insure the dog was motivated to participate. If a dog failed to take food while it was freely available on top of the pine, trials were suspended for that day. If this occurred, the next session started the following day. If the dog failed to take food when freely available in pre-training trials on two consecutive days, testing for that dog was terminated. No dogs met this exclusion criterion during the experiment.

Control Testing. Due to each group of dogs having a unique pre-exposure procedure, experimenters were unable to be kept blinded to group assignment. However, multiple measures were taken to limit observer and experimenter bias, and these potential sources of biases were directly assessed throughout the study. First, all experimenters were informed that it was uncertain whether any group would perform differently, and that it was important to train every dog the same way. The potential for experimenter influence was limited by having all experimenters stand at least 1-2 m away from the bins, keep their arms behind their backs, and look down at the ground with their eyes closed during each trial. In addition, experimenter influence was directly assessed with the use of control trials in which neither bin held the target odorant but one container was designated prior to the experiment to be the "correct" container. Control trials were run every six trials throughout the experiment. The consequences for responding in control trials were identical to experimental trials. The purpose of these trials was to assess whether dogs could identify the target container in the absence of the target odorant, using any other cue than the target odor. To control for observer bias, the observer was blind to the location of the target bin. In addition, a sub-set of sessions (10 sessions) was scored from video by a second naïve observer to calculate agreement. A second observer agreed with the first observer on 95.6% of the trials.

Statistical Analyses

Data were analyzed in Microsoft Excel™, SPSS™, and R™. Before conducting analyses, the dependent variable (percent correct) was assessed for departures from normality using visual inspection of residual plots and histograms. The data appeared to deviate from normality as some dogs performed at chance while others performed above chance. We therefore transformed all percent accuracy data using a rank transform, allowing us to use a traditional ANOVA procedure that is both powerful and robust for our repeated measure design (Iman, Hora, & Conova, 1980). Graphs are presented of the untransformed percent correct data for ease of interpretation, although statistical tests were conducted using ranks. To test for differences between groups, a repeated-measures ANOVA of the ranks was conducted followed by pairwise comparisons of the ranks with the Newman-Keuls post hoc test.

Results and Discussion

Five of the eight dogs in the Pavlovian-relevant group alerted to the target odorant correctly on more trials across the three days of training than *any* of the twenty-four dogs in the remaining three groups. The Pavlovian-relevant group had a median of 70% correct on the first training session, whereas no other group exceeded 52%. By the end of three training sessions, the Pavlovian-relevant group median was 93% correct, whereas the remaining groups medians ranged from 53% to 68% correct (see Figure 2). No other group showed systematic differences from the control group.

A repeated measures ANOVA on the rank transformed data indicated a significant effect of group ($F_{3,22} = 3.40$ $p < .03$), and session ($F_{2,56} = 39.4$, $p < .001$), but no interaction ($F_{6,\ 56} = 1.5$, $p > .05$). Newman-Keuls post hoc tests indicated that the mean rank of percent accuracy for the Pavlovian-relevant group was higher than the Pavlovian-irrelevant group (mean rank difference of 28), control group (mean rank difference of 26) and the exposure group (mean rank difference of 23). These results confirm the visual inspection of the percent accuracy data in Figure 2.

Median performance across all groups on control trials did not indicate that the dogs were following any other cues (median performance across groups: 50% correct). To further confirm that control trials were at chance, we removed trials in which a response was not made (e.g. a “no choice”) and only scored trials in which a choice was made during control trials. Percent accuracy still did not differ from chance on a Wilcox one-sample signed rank test (median percent correct: Pavlovian-relevant: 50%, $p > .9$; Exposure: 60%, $p > .9$; Control: 50%, $p > .33$; Pavlovian-irrelevant: 50%, $p > .58$).

These results indicate that prior odor exposure does have a significant effect on discrimination training performance, however, the type of exposure is important. Exposure alone resulted in no change in performance over the control group. Pavlovian conditioning, in contrast, resulted in a significant increase in performance over the no-exposure control group and the Pavlovian irrelevant control group, indicating that paired exposure to the relevant odor significantly increased discrimination training accuracy. We therefore found no evidence that massed exposure alone (30 min a day for five days) had an impact on discrimination performance; it neither facilitated nor retarded discrimination performance.

Our exposure group was an adaptation for dogs of the enrichment procedures that have been effective of enhancing discrimination in rodents. Two factors may have contributed to our failure to replicate in dogs the effect of exposure alone found by others in rodents. One is that our parameters were too short to be effective. Our exposure phase was shortened compared to the rodent studies for the convenience of the dogs' owners. Prior research with rodents has used 1-2 hr blocked exposures for 10 or 20 days (Escanilla, Mandairon, & Linster, 2008; Mandairon et al. 2006a, Mandairon et al., 2006b), compared to our 30 mins for 5 days. It is also theoretically possible that shorter, distributed exposure trials similar to the Pavlovian conditioning trials rather than longer massed exposure parameters might have been more effective in sensitizing the subjects to the target odor.

Overall, these results extend the research of Bower and Grusec (1964) and Mellgren and Ost (1969), who showed that Pavlovian conditioning can facilitate subsequent acquisition of discrimination training, to the use of Pavlovian conditioning to a single odor stimulus to facilitate acquisition of an odor-discrimination in dogs. To further confirm that Pavlovian conditioning may be a simple way to facilitate subsequent acquisition of an odor discrimination, we extended the finding of Experiment 1 to an AX vs BX discrimination using a within-subjects design.

Experiment 2

In Experiment 2 we utilized a more powerful within-subjects design to replicate the effect of Pavlovian conditioning on subsequent discrimination training as identified in

Experiment 1. In this experiment, six dogs were given five Pavlovian conditioning sessions to odor A (anise extract or almond extract). All dogs were then trained in six discrimination sessions on both an AX vs. BX discrimination and a CX vs. DX discrimination in alternating blocks of trials, where dogs were required to dig in a container of pine shavings scented with the target odor. We hypothesized that Pavlovian conditioning would facilitate acquisition of the discrimination in which dogs had prior Pavlovian conditioning to the target odorant. In addition, although we took several measures to control for possible experimenter cuing in Experiment 1, in Experiment 2 we instituted an additional blinding step for all experimenters and conducted a set of additional double-blinded control trials.

Subjects

Seven pet dogs of varying breeds were recruited for the experiment, but one dog failed to take food when freely available during initial training and was subsequently dropped from the study (more information below). All dogs were tested in the owners' homes at times convenient for the owners. All dogs had not eaten within 4 hrs of all testing sessions to maintain motivation.

Exposure Conditions

The same equipment and the same procedure for conducting the Pavlovian conditioning in Experiment 1 was used for Experiment 2. Three dogs were randomly assigned to receive six conditioning trials a day for five days to anise extract (paired-AN) and three dogs received six conditioning trials a day for five days to almond extract (paired-AL). Odorants were prepared identically to Experiment 1.

Discrimination Training

Odors. All dogs were trained on two odor discriminations: anise extract from cinnamon extract and almond extract from coconut extract. All odorants were prepared by placing 1 ml of the extract on a cotton round and burying the cotton round in the pine shavings.

Procedure. Dogs were trained on both discriminations in rapid alternation. Each session comprised six blocks of six trials each. Each block of trials contained five discrimination trials for one of the odor discriminations and one control trial. The two odor discriminations were alternated across blocks throughout the session. The odor discrimination that was trained first was counterbalanced across sessions within and across dogs. To reduce the possibility of experimenter error in presenting the correct bins, the color of the bins for the two discriminations were different (the anise vs. cinnamon discrimination used tan bins whereas the almond vs. coconut discrimination used white bins). All dogs were trained for six sessions.

Dogs received eight alert-training trials for both discriminations immediately prior to the first block of trials for each respective discrimination in a session. The procedure for alert-training and correction trials, and the criteria according to which subjects would be dropped from the study were identical to Experiment 1. One dog completed four discrimination trials of the first discrimination but failed to respond thereafter, even when food was free available on the top of the pine shavings (i.e. alert-training) for two consecutive days and was therefore not included in the present analysis. One dog failed to take free food after eighteen trials in session 3, though it responded readily during session 4. Data from session 3 are reported for this dog only for the completed trials (see “Mavi” Figure 4).

Control Testing. As in Experiment 1, every sixth trial was a control trial. Unlike Experiment 1, all experimenters were blind to the odor to which the dog had been pre-exposed (anise or almond). In addition to control trials, for each dog, 12 of the scheduled regular trials were double blind trials (six trials per session for two randomly selected sessions), in which the observer and the experimenter did not know which bin contained the target odor. A third person organized the bins for the experimenter to put on the ground; however, the experimenter did not know which bin was correct. The third person then walked away from the testing area. When the dog made a choice, the observer informed the third person of the choice, who in turn told the experimenter and observer whether the choice was correct. The appropriate consequence was then delivered to the dog. We compared accuracy on the trial immediately preceding the double blind control to the accuracy during the double blind control trial. Thus, if the experimenter was not unintentionally cuing the dog, we would expect performance on double blind control trials to be no different from regular trials and for the other control trials to remain at chance. In addition, a naïve second observer scored a sub-set of trials (315 trials) from video to calculate agreement for rooting. The second observer agreed with the first observer on 95.8% of the trials.

Statistical Analyses.

Data were rank transformed as in Experiment 1. A repeated measures ANOVA was calculated to test for differences in performance between the odor discrimination in which the target odor was Pavlovian conditioned compared to the discrimination in which the target odor was novel.

Results and Discussion

Figure 3 shows the performance of each dog on the odor discrimination in which it received Pavlovian conditioning to the target odor and the discrimination in which both odorants were likely novel. The first column shows dogs that received pairing to anise, and the second column shows dogs that received pairing to almond. Figure 3 indicates that out of the 36 sessions recorded, there were only two sessions in which dogs did not perform better on the paired discrimination.

Figure 4 shows the median percent accuracy for the conditioned odor and the novel odor discriminations. Across all six sessions, performance was higher for the conditioned odor than the novel odor. Overall, dogs' median percent accuracy was 32 points higher for the discrimination in which the target odor was conditioned over the novel odor discrimination.

A repeated measures ANOVA confirmed the results from visual inspection of Figures 3 and 4. There was a significant effect of pairing procedure ($F_{1,58} = 9.40$, $p < .003$) showing that dogs learned the odor discrimination in which the conditioned stimulus was the target odor faster than the novel odor discrimination. Dogs also showed significant improvement across sessions ($F_{5,58} = 10.40$, $p < .001$), and there was no evidence of an interaction ($F_{5,58} = 0.50$, $p < .79$).

Performance on control trials remained at chance, as expected. Across all dogs and sessions, median percent correct on control trials was 50%, and was still at chance when "no choice" trials were removed (median: 50%, One sample Wilcox-signed rank test, $p < .09$). Median performance on double-blind trials was very similar to performance on regular trials immediately preceding double blind trials, with no indication of any performance decrement on double blind trials (Double blind trials: 67% correct, immediately preceding trials: 50% correct). A paired Wilcox signed rank test indicated no difference between double blind trials and the immediately preceding trials across the 12 sessions in which they were conducted ($p > .36$). Thus, it is unlikely experimenters were cuing the dogs unintentionally, given that when the experimenters were unaware which bin was correct, performance remained unchanged.

General Discussion

The effects of repeated exposure to an odor have been proposed as a possible means of enhancing canine odor detection (Goldblatt, et al., 2009). Basic research on this topic, however, provides conflicting reports on the effects of odor exposure on acquisition of an odor discrimination. In Experiment 1, we separated exposure into two categories, mere exposure and Pavlovian conditioning. We found that mere exposure had no effect on the acquisition of an odor discrimination in dogs, however Pavlovian conditioning significantly improved acquisition. Experiment 2 was designed with additional controls to replicate and confirm the finding in Experiment 1 and we found a similar result across experiments confirming that exposure to an odor in the form of Pavlovian conditioning has a significant impact on the acquisition of an odor discrimination.

These results indicate that future studies into the effects of “familiarity” or prior exposure to an odor on subsequent discrimination performance should evaluate different types of exposure instead of just comparing exposure and no exposure. The form and parameters of the exposure may have a major impact on discrimination acquisition. In our case, only Pavlovian conditioning enhanced later discrimination acquisition. Future studies could further manipulate the parameters of exposure alone to explore why some studies have found enhancement of discriminability (e.g., Mandairon et al., 2006b) whereas others have found no effect (e.g., Laing & Panhuber, 1980).

The mechanism by which Pavlovian conditioning improves discrimination training deserves consideration. The present results suggest that when the odor is conditioned as an appetitive CS, it may more readily become an operant discriminative stimulus. This mechanism is similar to the Pavlovian to operant transfer of stimulus control proposed by Bower & Grusec (1964) and Mellgren and Ost (1969). Our discrimination training was an explicit operant contingency in which the reinforcer was delivered contingent on digging in the correct bin. The Pavlovian conditioning could have facilitated the operant training by increasing the likelihood the subject would approach the target bin (sign-tracking) compared to the non-target bin, which increased the speed with which the subject would contact the digging contingency. Thus, a Pavlovian approach response could have facilitated correct "choosing" by increasing approach to the correct container, in which subsequent digging under operant control would lead to reinforcement.

Alternatively, the results could be explained by the initial Pavlovian conditioning facilitating a Pavlovian discrimination, in which digging was the conditioned response. Although the experimental contingency during discrimination training was an operant one, the functional contingency may have been Pavlovian in which an odor (CS) was followed by experimenter deliver food (US), with digging being the conditioned response.

We suggest that the likely mechanism for our results was transfer from Pavlovian to operant conditioning. The experimental contingency placed on digging was operant: only contingent on digging was food delivered. In addition, we did not observe any digging-like conditioned responses to the odor during the explicit Pavlovian conditioning phase, but observed digging rapidly during discrimination training when food was presented contingent on digging.

These two different mechanisms could have important consequences. If the present results were the product of creating a Pavlovian digging response to the target odor, this could suggest that the facilitation of discrimination training may be limited to specific behavior topographies (conditioned responses), in the present case, digging. This interpretation predicts that had a different arbitrary response been chosen (e.g., sitting), the facilitation would not have been observed since sitting is an unlikely CR to odor (CS) or food (US). In addition, it further suggests that if digging were an undesirable topography (as, for example, in the detection of land mines), then additional Pavlovian training that creates a digging CR would be undesirable. In contrast, if the results were the product of Pavlovian to operant transfer, possibly via sign-tracking leading to approach of the correct container followed by operant digging, this would suggest that the topography of the alert could be changed from digging to a different arbitrary response with minimal effect on the outcome.

Overall, the present research suggests that Pavlovian conditioning to an odor may reduce training time for an odor discrimination in dogs, though additional parameters need to be evaluated before it can be concluded that Pavlovian conditioning is in general more efficient than operant training alone. For example, we only evaluated the effects of 30 Pavlovian conditioning trials across five days of training. Perhaps fewer conditioning trials would provide a similar impact on discrimination training success. In addition, in an applied context, the financial costs associated with Pavlovian procedures would need to be compared to those of additional days of operant training. Pavlovian procedures may have an advantage in that they are time-based and do not require the dog to emit a specific response that a trainer needs to observe. Thus, they may well be less expensive to deploy than further operant training, which may require more work from experienced trainers. Although more work must be done before Pavlovian conditioning could be deployed to facilitate operant training of detection dogs, the present results certainly suggest the technique holds promise.

References

Bower, G., & Grusec, T. (1964). Effect of prior Pavlovian discrimination training upon learning an operant discrimination. *Journal of the Experimental Analysis of Behavior*, *7*(6), 401–404.

Cablk, M. E., & Heaton, J. S. (2006). Accuracy and reliability of dogs in surveying for desert tortoise (Gopherus agassizii). *Ecological Applications*, *16*(5), 1926–1935.

Cornu, J. N., Cancel-Tassin, G., Ondet, V., Girardet, C., & Cussenot, O. (2011). Olfactory detection of prostate cancer by dogs sniffing urine: A step forward in early diagnosis. *European Urology*, *59*, 197–201.

Cunzeman, P. J., & Slotnick, B. M. (1984). Prolonged exposure to odors in the rat: Effects on odor detection and on mitral cells. *Chemical Senses*, *9*(3), 229–239. doi:10.1093/chemse/9.3.229

Dean, E. E. (1972). *Training dogs for narcotic detection*. Retrieved from http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=A0749302

Escanilla, O., Mandairon, N., & Linster, C. (2008). Odor-reward learning and enrichment have similar effects on odor perception. *Physiology & Behavior*, *94*(4), 621–626. doi:10.1016/j.physbeh.2008.03.008

Goldblatt, A., Gazit, I., & Terkel, J. (2009). Olfaction and explosives detector dogs. *Canine Ergonomics: The Science of Working Dogs*, 135.

Honey, R.C., & Hall, G. (1989). Enhanced discriminability and reduced associability following flavor preexposure. *Learning and Motivation, 20,* 262-277.

Iman, R. L., Hora, S. C., & Conover, W. J. (1984). Comparison of asymptotically distribution-free procedures for the analysis of complete blocks. *Journal of the American Statistical Association*, *79*(387), 674–685. doi:10.1080/01621459.1984.10478096

Laing, D. G., & Panhuber, H. (1980). Olfactory sensitivity of rats reared in an odorous or deodorized environment. *Physiology & Behavior*, *25*(4), 555–558.

Mackintosh, N.J., Kaye, H., & Bennett, C.H. (1991). Perceptual learning in flavor aversion conditioning. *The Quarterly Journal of Experimental Psychology B: Comparative and Physiological Psychology, 43,* 297-322.

Mandairon, N., Stack, C., Kiselycznyk, C., & Linster, C. (2006a). Broad activation of the olfactory bulb produces long-lasting changes in odor perception. *Proceedings of the National Academy of Sciences*, *103*(36), 13543–13548.

Mandairon, N., Stack, C., Kiselycznyk, C., & Linster, C. (2006b). Enrichment to odors improves olfactory discrimination in adult rats. *Behavioral neuroscience*, *120*(1), 173–179.

Mellgren, R. L., & Ost, J. W. (1969). Transfer of Pavlovian differential conditioning to an operant discrimination. *Journal of comparative and physiological psychology*, *67*(3), 390.

Mitchell, C., & Hall, G. (in press). Can theories of animal discrimination explain perceptual learning in humans? *Psychological Bulletin.* doi: 10.1037/a0032765

Sinn, D. L., Gosling, S. D., & Hilliard, S. (2010). Personality and performance in military working dogs: Reliability and predictive validity of behavioral tests. *Applied Animal Behaviour Science*, *127*(1), 51–65.

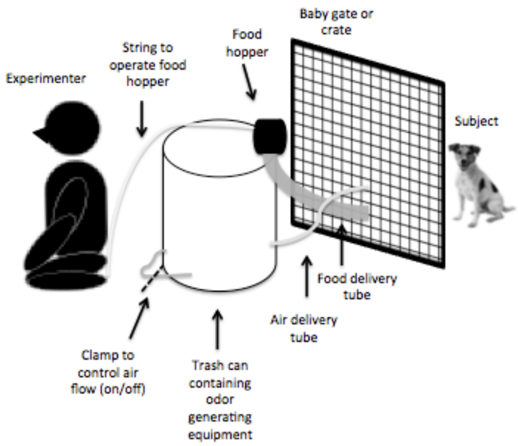
Willis, C. M., Church, S. M., Guest, C. M., Cook, W. A., McCarthy, N., Bransbury, A. J., … Church, J. C. (2004). Olfactory detection of human bladder cancer by dogs: Proof of principle study. *BMJ*, *329*(7468), 712.

	Pavlovian-relevant	Exposure	Control	Pavlovian-irrelevant
Breed				
Pit or Cattle Dog Mix	1	1	1	3
Terrier Mix	2	2	3	2
German Shep Mix	1	2	1	1
Lab Mix	2	2	2	1
Toy Breed	2	1	1	1
Total	8	8	8	8

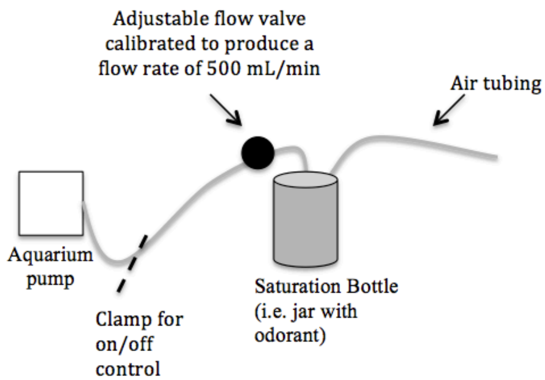
Table 1. Numbers of dogs of each breed in each experimental group in Experiments 1.

	Pavlovian-relevant Group	Exposure Group	Control Group	Pavlovian-irrelevant Group
Type of conditioning	Delay-conditioning for anise extract (odor A)	30 min exposure to anise extract (odor A)	No exposure	Delay-conditioning to almond extract (odor B)
Odor-detection (AX vs. X)	Anise detection (3 days)	Anise detection (3 days)	Anise detection (3 days)	Anise detection (3 days)

Table 2. Experimental design for Experiment 1. Table shows each component of the experiment for all groups.



A



B

Figure 1. Odor exposure equipment. A: Layout for exposure sessions. The experimenter was able to control the odor delivery and food delivery from behind the trashcan. B: Schematic of odor generating equipment.

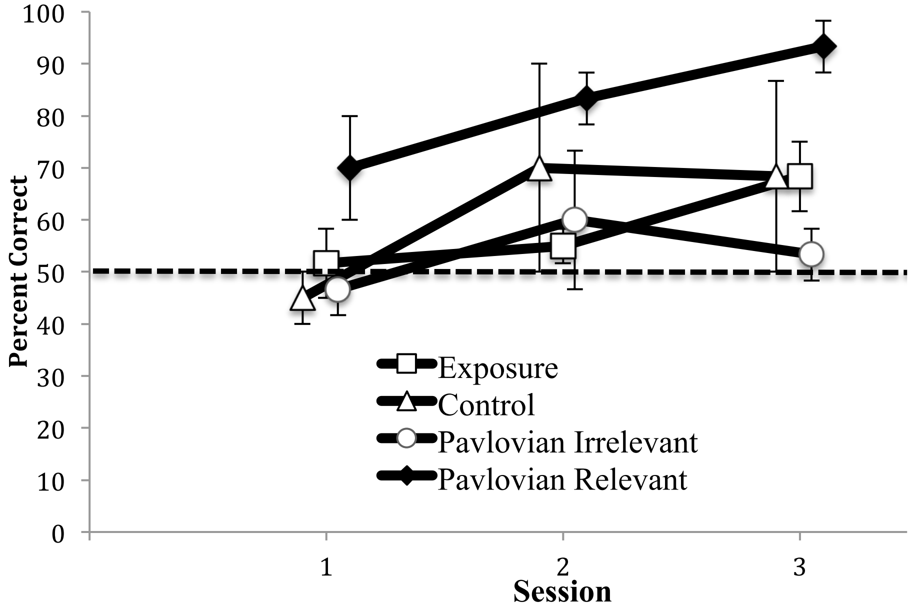


Figure 2. Percent correct in Experiment 1. The median percent correct for each group in Experiment 1 are shown. Error bars indicate the median absolute deviation (MAD). Dashed line indicates chance performance.

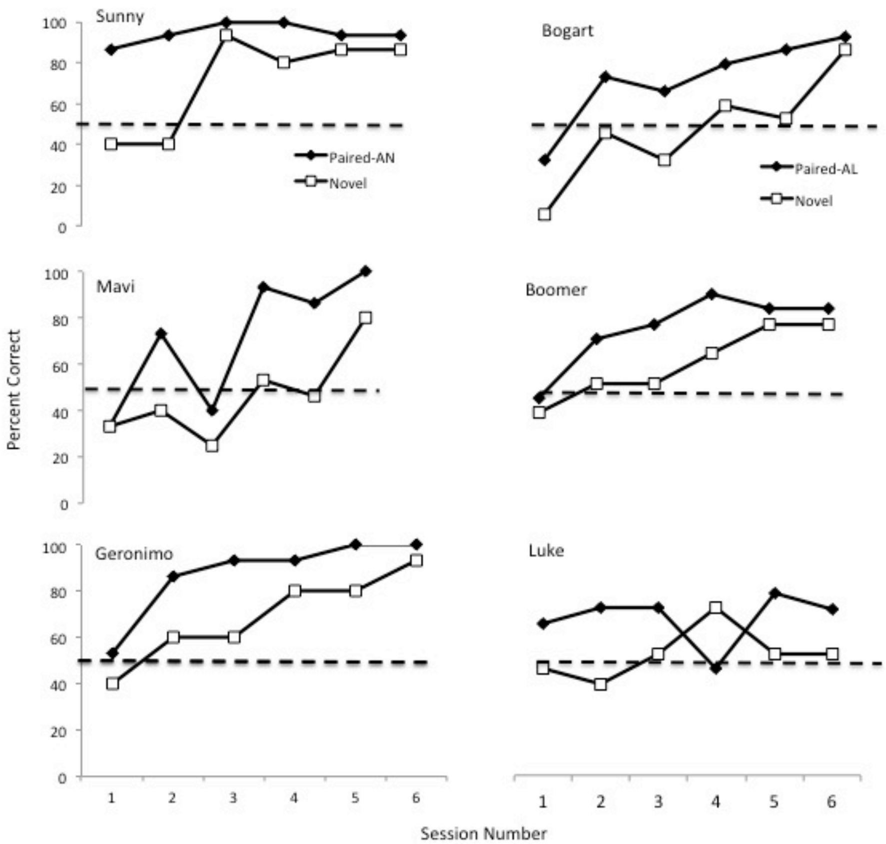


Figure 3. Percent correct for each dog in each session in Experiment 2. The percent correct for each dog in each session are shown for the paired discrimination (filled diamonds) and the novel discrimination (open squares). The first column shows the dogs that received Pavlovian conditioning to anise (Paired-AN) and the second column shows dogs that received conditioning to almond (Paired-AL). Dashed line indicates chance performance.

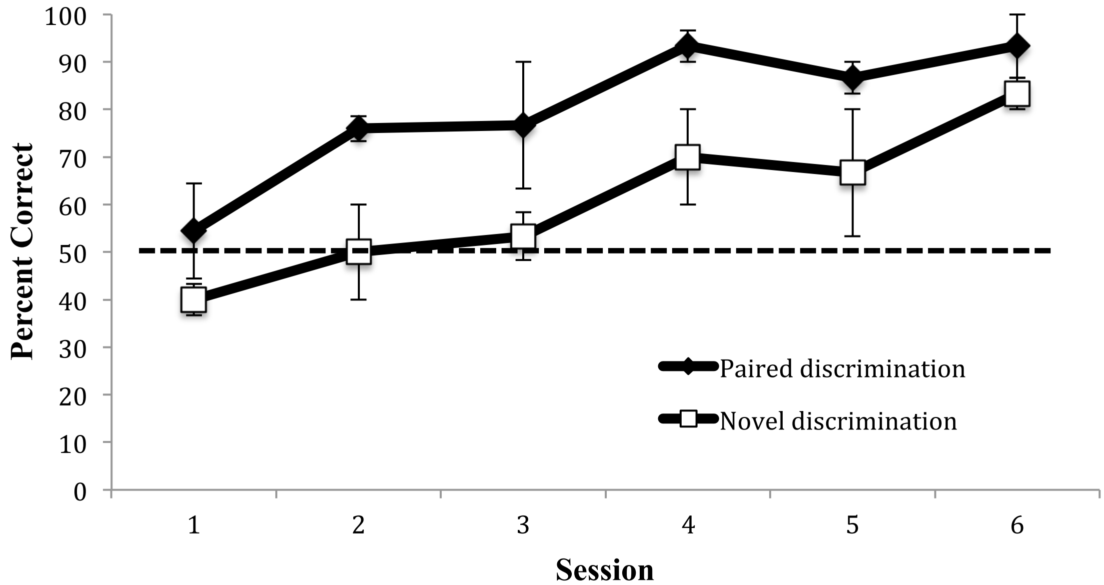


Figure 4. Median percent correct in Experiment 2. Lines indicate median performance and error bars show the median absolute deviation for the paired discrimination and novel discrimination in Experiment 2. Dashed line indicates chance.