PAVLOVIAN CONDITIONING ENHANCES RESISTANCE TO DISRUPTION OF DOGS PERFORMING AN ODOR DISCRIMINATION

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Domestic dogs are used to aid in the detection of a variety of substances such as narcotics and explosives. Under real-world detection situations there are many variables that may disrupt the dog's performance. Prior research on behavioral momentum theory suggests that higher rates of reinforcement produce greater resistance to disruption, and that this is heavily influenced by the stimulus-reinforcer relationship. The present study tests the Pavlovian interpretation of resistance to change using dogs engaged in an odor discrimination task. Dogs were trained on two odor discriminations that alternated every six trials akin to a multiple schedule in which the reinforcement probability for a correct response was always 1. Dogs then received several sessions of either odor Pavlovian conditioning to the S+ of one odor discrimination (Pavlovian group) or explicitly unpaired exposure to the S+ of one odor discrimination (Unpaired group). The remaining odor discrimination pair for each dog always remained an unexposed control. Resistance to disruption was assessed under presession feeding, a food-odor disruptor condition, and extinction, with baseline sessions intervening between disruption conditions. Equivalent baseline detection rates were observed across experimental groups and odorant pairs. Under disruption conditions, Pavlovian conditioning led to enhanced resistance to disruption of detection performance compared to the unexposed control odor discrimination. Unpaired odor conditioning did not influence resistance to disruption. These results suggest that changes in Pavlovian contingencies are sufficient to influence resistance to change.
   Key words: domestic dogs, odor discrimination, olfaction, Pavlovian conditioning, behavioral momentum

Dogs are used to aid the detection of a variety of stimuli including but not limited to narcotics (Jezierski et al., 2014), explosives (Adamkiewicz et al., 2013; Furton & Myers, 2001), wildlife (Cablk & Heaton, 2006; Cablk, Sagebiel, Heaton, & Valentin, 2008) and cancer (Cornu, Cancel-Tassin, Ondet, Girardet, & Cussenot, 2011; Willis et al., 2004). Dogs, however, work in a variety of real-world environments that contain distractors that might disrupt their performance. For example, a variety of potentially distracting odors may be present in an operational environment. In addition, in real-world environments, an alert, a response from the dog that indicates to a handler that an odor has been detected, is many times not reinforced

(McLean & Sargisson, 2005). This practice varies by organization but is particularly common in explosives detection where it could be hazardous to confirm a correct indication in the field (McLean & Sargisson). The same is true for Giant African Pouched Rats (*Cricetomys gambianus*), which have been tasked with similar detection work as dogs. These rats have been trained to detect landmines (Poling, Weetjens, Cox, Beyene, Bach et al., 2011; Poling, Weetjens, Cox, Beyene, & Sully, 2010) and even tuberculosis (Poling, Weetjens, Cox, Beyene, Bach et al., 2011). When the rats are tasked with detection of landmines, training is conducted under reinforcement conditions but operational work is done under extinction (Mahoney et al., 2012). Mahoney et al. showed that their rats' performance became variable after repeated sessions under extinction (simulated operational work), which could be alleviated with additional reinforcement training (see also Mahoney et al., 2014). Dogs, and even detection rats, are therefore required to maintain high detection accuracies in the presence of potential behavioral disruptors.

Behavioral momentum theory provides a framework to predict and evaluate the resistance

of behavior in the presence of disruptors. This theory posits that the magnitude of behavioral disruption is directly related to the magnitude of the disruptor and inversely related to the "behavioral mass" or, more specifically, the richness of the reinforcement history (Nevin & Grace, 2000; Nevin & Shahan, 2011). Experimental research has demonstrated that, for a variety of species, richer schedules of reinforcement lead to greater resistance to disruption than do leaner schedules (Nevin & Grace). In these experiments, subjects are typically trained under multiple schedules, in which the reinforcement schedule in one component is significantly richer than in the other and each component is signaled by a discrete stimulus. Behavior is then disrupted in both components by disruptors such as presession feeding, delivering noncontingent food during intercomponent intervals, or extinction. Prior research has demonstrated that higher proportions of baseline responding are observed under the richer component compared to the leaner one (Nevin & Grace). This general phenomenon has been demonstrated in several species including pigeons (Nevin, Mandell, & Atak, 1983), rats (Cohen, Riley, & Weigle, 1993) and humans (Mace et al., 1990).

Evidence suggests that resistance to change is heavily influenced by Pavlovian (stimulus-reinforcer) contingencies (Mauro & Mace, 1996; Nevin & Grace, 2000; Nevin, Tota, Torquato, & Shull, 1990; Podlesnik & Shahan, 2008), although response–reinforcer relationships also appear to have an influence (Bell, 1999; Podlesnik & Shahan). If the response–reinforcer relationships across components in a multiple schedule are identical, but one component contains additional response-independent food presentations (i.e., stimulus–reinforcer pairings), resistance to change is higher for the components with additional stimulus–reinforcer pairings (Nevin et al.; Podlesnik & Shahan). This suggests that Pavlovian conditioning enhances "behavioral mass" and resistance to change. This finding, however, is open to several criticisms (Williams & Bell, 2000), one being that although food was response-independent, it could have functioned as unsignaled, delayed reinforcement for the response–reinforcer relationship (Williams & Bell).

Recent work has attempted to more directly test whether Pavlovian (stimulus–reinforcer) contingencies underlie behavioral momentum phenomena. Podlesnik and Fleet (2014) trained pigeons on a two-component multiple schedule in which the response–reinforcer contingencies were identical. During both components there was also an identical response-independent food delivery (Pavlovian contingency); however, in one component Podlesnik and Fleet attempted to degrade the Pavlovian contingency by changing the discriminative stimulus to a separate discrete stimulus during the response-independent food phases. The authors found that attempts to degrade the Pavlovian contingency did not reduce resistance to change, suggesting that there may not be a simple relationship between the Pavlovian contingency and resistance to change.

Given the evidence suggesting that Pavlovian conditioning may enhance resistance to change we decided to explore its implications for detector dog training. Pavlovian conditioning is easy to implement procedurally, requires few resources, and can be done at times when operant field training a dog might be otherwise impractical. We have previously shown that, by pairing an odorant with food, Pavlovian conditioning enhances acquisition of odor discrimination in dogs (Hall, Smith, & Wynne, 2014), the aim of the present study is to assess whether Pavlovian conditioning may also enhance resistance to disruptors.

The scenario of dogs engaging in an odor discrimination task is procedurally quite different from most prior behavioral momentum studies using a free operant response under multiple schedules. In particular, for dogs engaging in a detection task, the measure of interest is percent correct, and not response rate. In typical odor detection tasks, response rate is limited by trial presentation, but accuracy of detection is the critical outcome. Recent work, however, has demonstrated that a higher probability of reinforcement for a correct response for pigeons working on a delayed match-to-sample task led to greater resistance to disruption of matching accuracy (Nevin, Milo, Odum, & Shahan, 2003). Recent applied research with dogs has also suggested that compared to lower rates of reinforcement, higher rates of reinforcement produce higher levels of detection accuracy (Sargisson & McLean, 2010). Sargisson and McLean manipulated the reinforcement rates for identifying a target odor while working on a Remote

Explosive Scent Tracing task. In this task a vacuum pump is used to pull air from an outdoor area that potentially contains explosives across a filter pad to capture odorant molecules. The filters are then presented to the dog, which is required to alert to filters that have come from areas containing explosives. Increasing reinforcement rate for hits from a low rate (20-30% of hits were reinforced) to either a medium (35-50% of hits reinforced) or high rate (60-75% of hits reinforced) led to increased detection accuracy. It should be noted, however, that the order of implementing the different reinforcement conditions was not counterbalanced across subjects (reinforcement rate increased across conditions), so it is possible that dogs' detection accuracy simply increased with time in the experiment.

The aim of the present study was to test whether Pavlovian conditioning enhances dogs' resistance to disruptors when performing an odor discrimination. To do this, dogs were trained on two different odor discriminations with two pairs of odorants in an alternating procedure akin to a multiple schedule. Both odor discriminations, however, had an equal probability of reinforcement for a correct response ($p = 1$). Using our Pavlovian conditioning procedure from Hall et al. (2014), we were able to conduct the Pavlovian conditioning in separate sessions with different equipment from the discrimination testing sessions. By doing this, we were able to eliminate the possibility that adventitious reinforcement was delivered for alerting responses that occurred during response-independent food delivery. In addition, by conducting the Pavlovian conditioning during separate sessions, we were able to control for total stimulus exposure and food presentations with an explicit unpaired odor exposure group. By maintaining identical response–reinforcer rates for both odor discriminations, we were also able to achieve similar baseline accuracies prior to implementing the disruptor conditions.

Method

Subjects

Twelve healthy dogs between the ages of 6 months and 10 years (seven males and five females) were recruited for this study. All dogs were household pets, and were trained and tested in the owner's home. Subjects were of varying and unknown mixed breeds. Two dogs (Bessa and Luke) had prior experience with odor-discrimination training but all dogs were naïve to the experimental odors. All procedures were approved by the University of Florida Institutional Animal Care and Use Committee.

Experimental Design

The dogs were trained on two different odor discriminations on a two-choice task (see Table 1 for the two odor pairs). Dogs were trained until reaching 85% accuracy on both odorant pairs for two sessions. If during initial training, dogs made more correct responses on one odorant pair compared with the other, they received additional trials on the odorant pair with the poorer performance until an equal number of reinforced responses to the S+ of both odorant pairs was achieved.

Dogs were then exposed to one odorant according to their assigned stimulus condition (described in detail below). Figure 1 shows the experimental layout and the exposure dogs received according to their assigned conditions throughout the experiment. Half of the dogs were assigned to the Pavlovian conditioning group and were given five sessions of Pavlovian conditioning to the S$^+$ of one of the odor pairs (exposed odor pairs were counterbalanced across dogs). Dogs in the unpaired group received explicit unpaired trials with an S+ from one of the odor pairs for five sessions. Dogs' resistance to disruption was then tested under three disruption conditions which were separated by 3 days of intervening baseline training and additional odor exposure.

Table 1

Odorants used. Table shows the odors used for each odorant pair and the source of the extract.

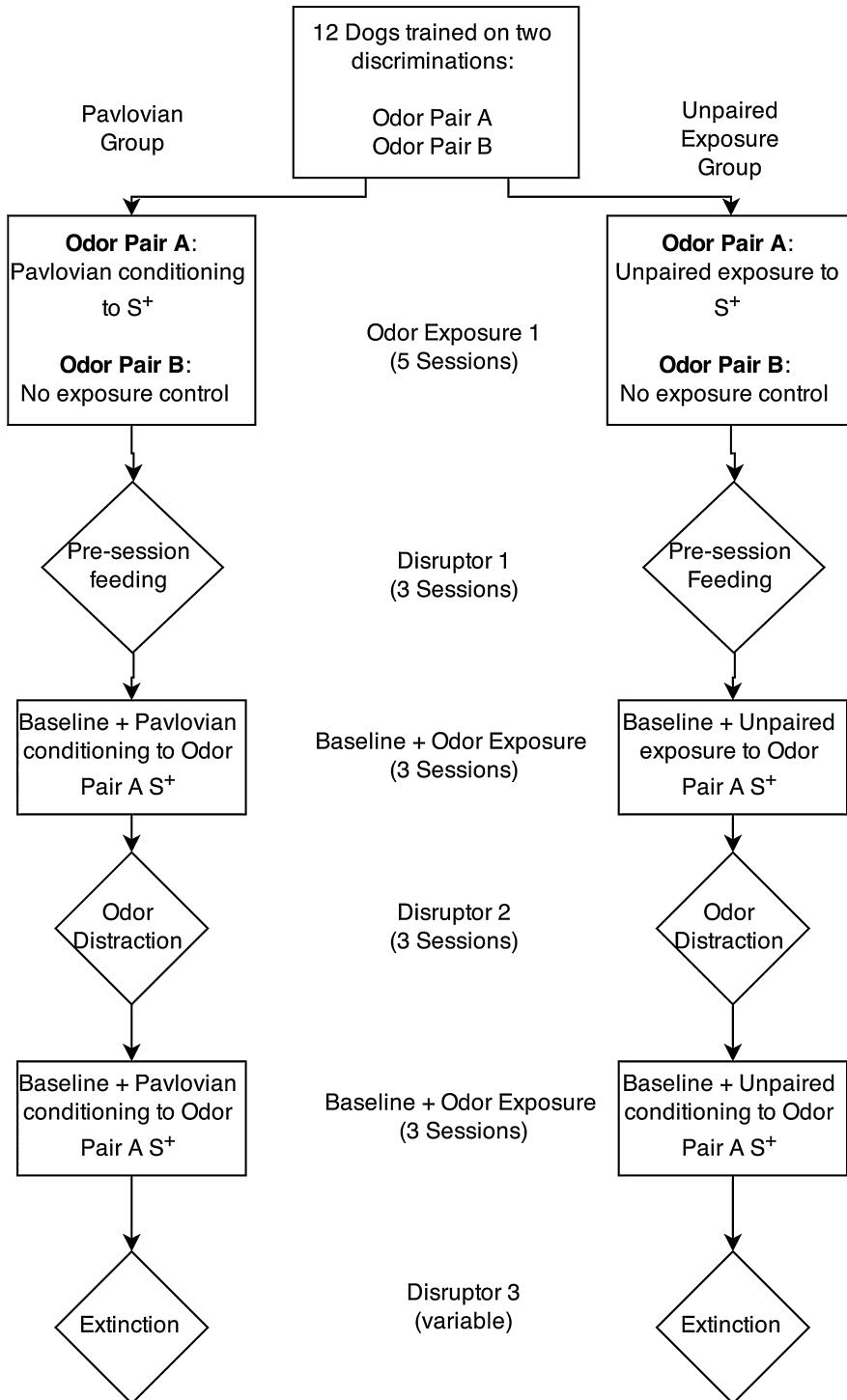|	Odor	Source
Odorant Pair		
S$^+$	Root beer Extract	Watkins^{TM}
S$^-$	Lemon Extract	McCormick^{TM}
Odorant Pair		
S$^+$	Hazelnut Extract	McCormick^{TM}
S$^-$	Mint Extract	McCormick^{TM}

Fig. 1. Experimental overview. Figure shows the exposures for each group and the overall experimental design. Rhombuses indicate a disruptor condition. Baseline indicates sessions in which the discrimination training was conducted in the absence of experimental disruptors. The odor pair that was exposed (odor pair A or B) during exposure phases was counterbalanced across dogs.

Materials

Dogs were trained on the two different odor discriminations shown in Table 1. These S+ and S- odorants were chosen as they are readily available and dogs were likely only slightly familiar with them. Odorants were prepared by placing 1 ml of the extract on a 100% cotton pad, which was subsequently buried 2.5 cm in pine shavings inside a plastic Sterilite^{TM} dishpan bin (30cm x 36cm x 15cm) filled halfway with pine shavings. For food reinforcers, we used commercial dog treats that dogs would readily consume, such as Pupperoni^{TM}, cut into 1cm by 1cm size pieces.

Detection Training

Odor-detection training followed the procedures previously described in Hall et al. (2014) . In this procedure, dogs are presented with two bins of pine shavings and are trained to 'alert' to a target odorant by digging in the bin that contains the cotton pad scented with that odorant.

Alert training. At the start each session, dogs were trained in eight brief trials to 'alert' to a bin containing the S+ odorant by digging in that bin. The purpose of these trials was to shape the initial digging 'alert' response. The first two alert-training trials trained approaching the bucket. To do this, a treat was placed on top of the pine shavings in the bin and presented to the dog. When the dog consumed the food, the experimenter said "good dog" and gave the dog a treat by hand. For the subsequent three trials, the treat was buried 2.5 cm in the pine before presenting the bin to the dog. This prompted the dog to dig the treat out of the shavings. Once the dog began to dig, the experimenter said "good dog" and delivered a treat by hand. For the final three trials, no food was presented in the bin, but instead, the experimenter waited for the dog to start digging in the bin. Once the dog began to dig, the experimenter delivered a treat by hand. To prevent potential food-odor contamination, the bins used for alert training were not used in discrimination training.

Discrimination training. At the start of each trial, the experimenter placed an S+ scented bin and an S- scented bin 0.25 m apart and equidistant from the dog that was held by an assistant 2 m back from the mid-point of an imaginary line connecting the bins. The experimenter then stepped back at least one meter, and stood in a neutral position with his arms behind his back and looked straight down at the ground. An observer that was naïve to which bin contained the target odorant watched the dog investigate the bins. When the observer determined that the dog had appropriately dug in one of the bins, the observer called out "choice". This informed the experimenter of a response and he then looked up to see in which bin the dog was responding. The experimenter then delivered the appropriate consequence (a "good-dog" and food for digging in the target bin, or simply removing the bins for an incorrect response). If a dog did not alert to a bin within 30 s, the bins were picked up and re-presented. If the dog again did not alert to either bin within 30 s, "no choice", was recorded and scored as incorrect. The intertrial interval was approximately 20 s, which reflected the time needed to prepare for the next trial.

For each training session, dogs were trained on both odorant pairs in alternating blocks of five discrimination trials and one control trial (control trials are described below). Sessions were composed of three blocks of trials for each odor pair (six blocks total). Prior to the start of the first block of trials for each odorant pair, eight alert-training trials were conducted to train alerting in the initial sessions, but served as "warm-up" trials for later sessions. The location (left or right) of the target bin was pseudorandomly determined with the requirement that the same location was not correct more than twice in a row. Correction trials were conducted following an incorrect response if a dog had responded to the same position (left or right) for four consecutive trials. These trials attempted to break a potential side bias. For these trials 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 opposite location of the side bias. Correction trials were rarely necessary; only a total of 10 correction trials were necessary throughout the entire study across all dogs.

If during discrimination trials dogs did not respond for two consecutive trials (i.e. two "no choices"), or made three consecutive incorrect responses, we conducted two of the alert-training trials in which the food was placed on top of the pine. These trials ensured the dog

was motivated to participate. If a dog did not respond on these trials (i.e., when food is freely available and on top of the pine), experimental trials were suspended for that day and the subsequent session was started the following day. If a dog's testing had to be suspended for 2 consecutive days due to it failing to take available food, testing for that dog was terminated. No dogs met this criterion.

Control testing. Every sixth trial was a control trial. These trials were conducted to test whether dogs could follow unintentional cues that the experimenter may provide. Control trials were conducted identically to experimental trials except that neither bin held the target odorant. Instead, the experimenter designated one container to be the "correct" container. Responses to the pseudo-correct alternative were reinforced whereas responses to the pseudo-incorrect bin were not. 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. If dogs were not following unintended cues, we expected performance to drop to chance on control trials or that they would not respond. In addition, a subset of double blind, noncontrol trials were conducted, in which the experimenter did not know which bin contained the target odorant. A third person prepared the bins, placed them in the Experimenter's hands ready for the next trial, and left the room. After the observer scored a "choice" the third person entered the room to inform the experimenter whether the choice was correct. If dogs were following the olfactory cues, we expected dogs' performance would not differ from nonblind trials; however, if dogs were following experimenter-given cues, performance would deteriorate on double blind trials. A total of 384 double-blind trials were conducted across 67 sessions. The specific session in which double-blind trials were conducted depended on the availability of a third experimenter, but they were conducted across all dogs and phases of the experiment.

Odor Exposure Conditions

An identical apparatus to Hall et al. (2014) was used for the odor exposure sessions except that when odor was not being presented, clean air was presented. The apparatus allowed a human operator to control the airflow of an air pump to either deliver a stream of clean air (500 ml/min) to the dog or divert the stream through a saturation jar containing the target odor, and then deliver the odor-saturated stream towards the dog as it waited behind a baby gate or in a crate. For Pavlovian conditioning trials, an odorant stimulus was presented for 15 s; at 10 s into the odor exposure, the experimenter pulled on the food hopper door that allowed food to drop to the dog, thereby pairing the odorant with presentation of the food. Once the 15 s of odorant was complete, clean air was pumped through the tubing to clear any residual odorant. The intertrial interval was 5 min; six trials were conducted per 30-min session daily. For the unpaired exposure group, food was delivered to the dog on the same time schedule as the Pavlovian conditioning group; however, the 15 s of odor was presented halfway through the interval between food deliveries. Thus, odor delivery for the unpaired group occurred 2.5 min before and/or after food delivery and was never paired directly with the food. Five odor exposure sessions were conducted immediately prior to the first disruptor, and additional exposure sessions were conducted during the baseline sessions intervening between the disruption conditions.

Post-Training Conditions

Baseline. This condition assessed dogs' performance on both odor discriminations in the absence of any disruptors. Baseline sessions followed the discrimination training procedures described above and preceded each disruptor. The mean accuracy of the two baseline sessions preceding the presession feeding disruptor served as baseline accuracy for presession feeding. Similarly, the mean of the three baseline sessions preceding food–odor distraction served as baseline accuracy for that disruptor and the three baseline sessions preceding extinction served as the extinction baseline.

Presession feeding. This disruptor condition tested resistance to a reduction in the establishing operation by feeding dogs immediately prior to the session. Owners were asked how much their dogs were normally fed over a typical 24-hr period. During the first session of presession feeding, dogs were fed 50% of the reported daily diet and tested using the same

procedure as described above for training. On the second testing session, all procedures were identical, except the dog was fed 100% of its daily diet. On the third presession feeding session, dogs were fed 200% of their daily diet. If, after feeding 50% or 100% of the diet, the dog failed to respond on both odor discriminations and the session was terminated early, the feeding percentage was not increased for the subsequent session. This occurred for three dogs (Clash, Chiquita, and Big).

Food-odor distraction. This disruptor condition tested dogs' resistance to food-odor 'distractors' in which attending to food odors and not the target odor would disrupt performance. This condition was aimed to simulate potential real-world scenarios in which a detection dog may encounter food odors that might disrupt performance. In this condition, 1-cm long pieces of Pupperoni[TM] were buried in both the S+ and S- bins for both odor pairs. The food was cut to uniform sizes and placed inside a stainless steel tea ball and buried 2.5 cm deep in the pine shavings. The tea balls were used to prevent the dogs from accessing the buried Pupperoni and prevent incidental reinforcement for S- responses. During the first food-odor distraction session only one 1-cm piece of Pupperoni was used, during the second session three pieces were used, and nine pieces were used in the third session.

Extinction. This disruptor condition tested resistance to extinction of odor discrimination performance. Extinction was identical to baseline training except that the experimenter did not deliver a food reinforcer for responding for either odorant pair. Procedures for warm-up trials, and contingencies for saying "good dog", re-presenting a trial, and for alert-training motivation tests were identical across all experimental sessions. Thus, if dogs failed to respond for two consecutive trials, two alert-training trials were conducted. Extinction sessions continued until responding dropped to less than 33% correct (including no choices as incorrect responses) or the dog failed to respond to alert-training trials for two sessions.

Analysis

During each session, percent correct was calculated for each odorant pair by dividing the number of correct responses by the total number of correct plus incorrect responses.

An incorrect response was scored if the dog responded to the S-, or failed to respond on a trial. If a dog did not complete a session because it met the session termination contingency (failure to respond to freely available food), percent correct was calculated for all trials up to meeting the termination contingency unless fewer than five trials had been completed, in which case, the session was scored as missing. There was only one case of a session being scored as missing (Chiquita prefeeding session 3).

The proportion of baseline accuracy was calculated by dividing the percent correct during each disruptor session by the mean percent correct during the baseline sessions immediately prior to the disruptor condition. Due to the large variability across dogs in number of sessions to reach the extinction criterion (see Fig. 2), we averaged the proportion of baseline accuracy across all extinction sessions to produce one extinction mean for each subject. A mixed-effects linear regression model was then fitted with the group (Pavlovian conditioning or Unpaired exposure), odor pair (exposed or nonexposed pair), the disruptor type (presession feeding, food-odor distraction, or extinction), and an interaction between the group and odor pair as predictors of the proportion of baseline accuracy. The optimal random effects parameterization was then determined by fitting different random effects models to the data, and comparing models via a likelihood ratio test and changes in the Akaike Information Criterion (AIC). The optimal random effects structure included random intercepts for the subject and an interaction between the session number and subject. Model assumptions were examined via inspection of plots of standardized residuals versus fitted values and density plots of the residuals.

Results

Figure 2 shows the proportion correct across each baseline and disruptor session for each dog. The left column shows the six dogs in the Pavlovian conditioning group and the right column shows the six dogs in the unpaired group. Open circles indicate performance for the exposed odor pair: the Pavlovian conditioned odor for the Pavlovian conditioning group or the unpaired odor for the unpaired group. Filled squares indicate performance on
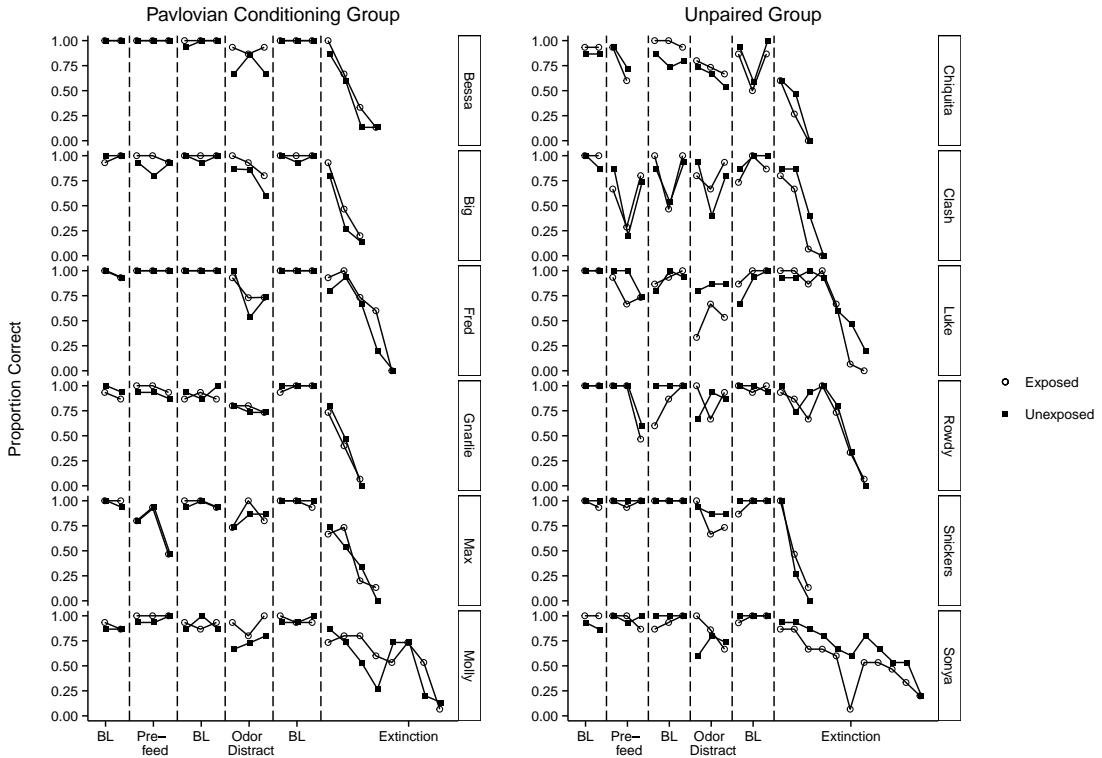
Fig. 2.   Proportion correct across all sessions. The proportion correct for the exposed odorant pair and unexposed odorant pair is shown across all sessions (baseline and disruptor sessions). The left column shows dogs in the Pavlovian conditioning group and the right column shows dogs in the unpaired exposure group. Dashed lines show experimental phase changes. BL indicates a baseline phase, Pre-feed indicates the pre-feeding disruptor, odor distract is the food-odor distraction disruptor. Solid squares are the unexposed control discrimination.

the unexposed control for both groups. All dogs showed relatively high proportion correct on both odor discriminations across baseline sessions. Baseline accuracy for the Pavlovian conditioning group was 96% (SD = 4%) for the exposed odor pair and 94% (SD = 7%) for the unexposed odor pair. Similarly, dogs in the unpaired exposure group showed similar accuracy across baseline for the exposed (97%, SD = 4%) and unexposed odors (94%, SD = 8%). A linear mixed effect model revealed that baseline performance did not vary across the exposure groups, the exposed or unexposed odor pairs, nor an interaction between these variables ($p > .05$), indicating baseline performance was comparable across all experimental variables.

Separation between the exposed and unexposed odors in Figure 2 is largely observed only during disruption conditions. During disruption conditions, several dogs in the Pavlovian

conditioning group tended to perform better on the Pavlovian conditioned odor pair (Exposed data points in Fig. 1), however, the results were less clear for Gnarlie on the food-odor distraction and extinction disruptors and for Max across all three disruptors. Several dogs in the unpaired group showed no differential disruption between the unpaired (Exposed) and the unexposed odorant, whereas some (e.g., Luke or Sonya during extinction) showed worse performance for the unpaired odorant than the unexposed odorant.

Figure 3 shows the mean proportion of the preceding baseline performance for the exposed and unexposed odors for each dog averaged across each disruptor phase. The top row shows the dog in the Pavlovian conditioning group and the bottom row shows the dogs in the unpaired group. Overall, the figure shows a similar pattern to Figure 2. In these disruptor tests, dogs in the Pavlovian conditioning group
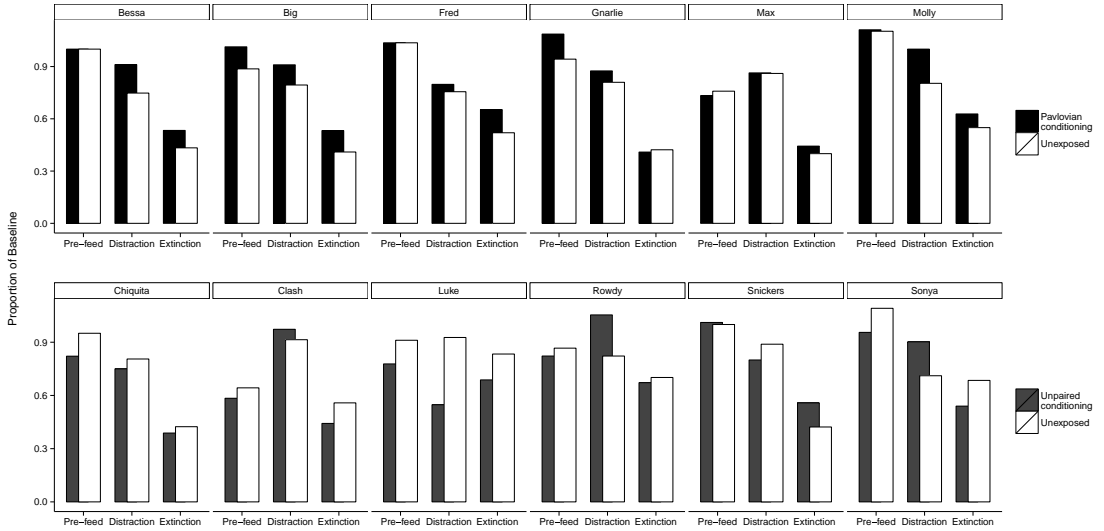
Fig. 3. Proportion of baseline accuracy. Each bar shows the mean proportion of baseline accuracy for each dog under each disruptor condition in the Pavlovian conditioning group (top row) and Unpaired group (bottom row). Pre-feed shows the mean proportion of baseline across the three presession feeding sessions. Distraction shows the mean for the odor-distraction condition, and Extinction shows the mean across extinction.

showed greater proportion of baseline accuracy on the Pavlovian conditioned odorant pair compared to the unexposed pair, except Max who again shows no differentiation. Dogs in the unpaired group again show no consistent trend, but some individual dogs show greater resistance for the unexposed odor compared to the unpaired odor (e.g., Luke and Sonya in extinction).

Figure 4 shows the overall group mean proportion of baseline accuracy and 95% confidence intervals, estimated via bootstrapping, across each session for both groups of dogs. Similar to the individual trends, dogs generally showed higher accuracies for the Pavlovian conditioned odor compared to the unexposed odor, whereas the dogs in the unpaired group did not show this differentiation. Given the high detection accuracies for most dogs during disruptor conditions on the unexposed odors, this yielded only small improvements in proportion of baseline accuracy for the Pavlovian conditioned odor compared to the unexposed odors, with some inconsistent effects. Thus, further statistical analysis was performed. A linear mixed-effects analysis was conducted with the proportion of baseline accuracy as the dependent variable. Predictors included group (Pavlovian conditioning or unpaired exposure), the exposure pair (exposed odor pair vs. unexposed odor pair), the disruptor type, and an interaction between the group and effect of exposure to the target odor. The correlation between the observed data and the model's predicted values was 0.84. The effect of exposing the dogs to a target odor depended on group (Pavlovian conditioning or Unpaired exposure), in which the highest proportions of baseline performance were observed for the Pavlovian conditioned odor ($t_{80.95} = 3.31$, $p < .01$; see Table 2). There was also a significant effect of the disruptor type which indicated that extinction and food-odor distraction were significantly more disruptive than presession feeding (respectively, $t_{69.24} = 7.78$, $p < .001$; $t_{69.35} = 2.27$, $p < .05$).

To further analyze the significant interaction between the effect of the additional exposure of a target odorant and the type of exposure (Pavlovian conditioning or unpaired exposure), separate mixed effects models were run for the Pavlovian conditioned group and the unpaired exposure group. The correlation between the observed data and the model predictions were 0.93 and 0.76, respectively. For the Pavlovian conditioned group, dogs performed significantly better on the Pavlovian conditioned odorant pair compared to the unexposed odorant pair (mean = 0.07 higher
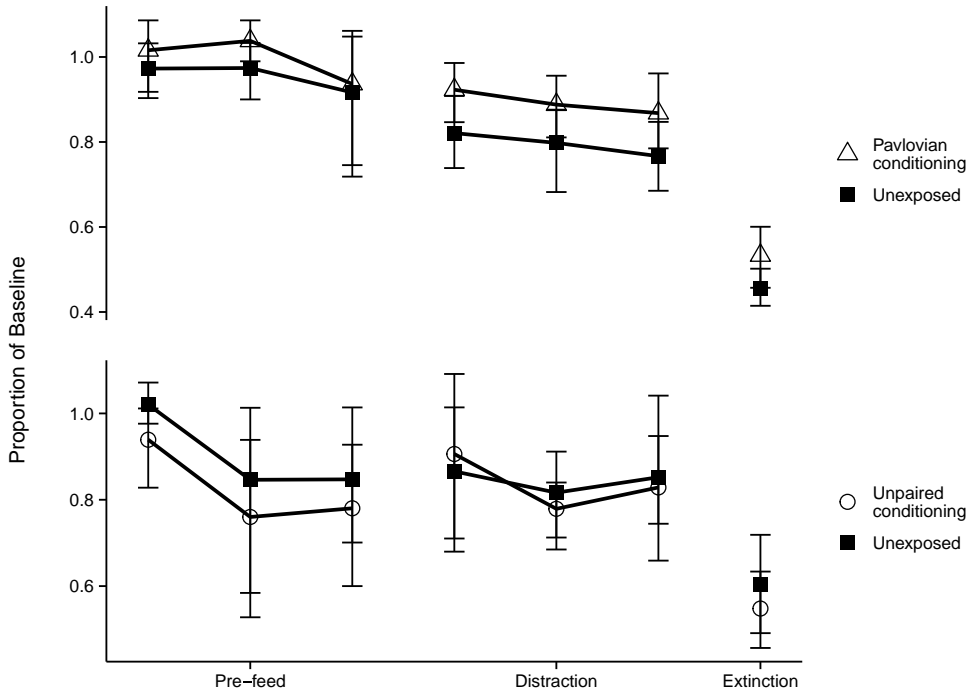
Fig. 4.   Mean proportion of baseline during disruptor sessions on both odorant pairs. Points show the mean proportion of baseline accuracy for the disruptor sessions. Error bars show 95% confidence intervals. The top graph shows the Pavlovian conditioning group and the bottom graph shows the unpaired exposure group.

proportion of baseline, 95% CI: [0.04, 0.10], $t_{40.95} = -4.83$, $p < .001$). In contrast, dogs in the unpaired exposure group showed no difference in performance between the explicitly unpaired odorant pair and the unexposed odorant pair (mean $= -0.04$, 95% CI: [-0.10, 0.02], $t_{39.98} = 1.38$, $p = .17$). Both analyses indicated that extinction was more disruptive than presession feeding (Pavlovian group: $t_{34} = -9.37$, $p < .01$; Unpaired exposure group: $t_{38} = -3.54$, $p < .01$). The food-odor distraction condition was more disruptive than presession feeding for the Pavlovian conditioned group, but not for the Unpaired exposure group (Pavlovian group: Presession feeding vs. food-odor distraction $t_{34} = -3.62$, $p < .01$; Unpaired exposure group: $t_{38} = -.46$ $p = .65$).

An additional group comparison was made to see whether Pavlovian conditioning enhanced absolute resistance to disruption, or simply within-subject resistance relative to the unexposed odorant pair. To do this, we compared the proportion of baseline accuracy for the Pavlovian conditioned odorant pair from the Pavlovian conditioned dogs to the

performance of the dogs in the unpaired group on the unpaired odorant pair. There was a trend for the Pavlovian conditioned group to show a higher proportion of correct responses relative to baseline than the unpaired group (mean $= .09$, SE $= .05$, $t_{10} = 1.84$, $p = .09$). This difference, while not statistically significant, was similar in magnitude to the difference observed when comparing within-subject accuracy on the Pavlovian conditioned odor to the unexposed odor (mean $= .07$, SE $= .015$, 95% CI: [0.04, 0.10]).

The control trials indicated that the dogs were not following unintended cues provided by the experimenter; overall performance on control trials was 37.5% correct, indicating dogs could not identify the target bin above chance in the absence of the target odorant. Many dogs failed to respond during control trials, which lowered overall performance to below chance. After ignoring no-choice responses, performance on control trials across all sessions was at chance (51% correct, one-sample t-test: $t_{194} = .73$, $p = .47$). Dogs also did not show any indication of following unintended cues during

Table 2

Summary of mixed effects model.

	Estimate	Std. Error	df	t-value
Intercept	0.88	0.033	32.41	26.17**
Exposed Odorant vs. Unexposed	0.04	0.024	80.95	1.78
Exposure by Group	0.09	0.038	14.51	2.36*
Disruptor Type: Food-odor distraction	−0.08	0.035	69.35	−2.27*
Disruptor Type: Extinction	−0.38	0.049	69.24	−7.78***
Interaction: Exposure by Exposure Group	−0.12	0.035	80.95	−3.31**

*$p < .05$, **$p < .01$, ***$p < .001$. Degrees of freedom reflect a Satterthwaite approximation.

double blind trials; mean performance on double-blind trials was similar to performance on the non-double-blind trial conducted immediately preceding the double blind trial (double-blind trials: 82% correct; non-double-blind trials: 81% correct). There was no overall difference between the number of correct double-blind and non-double-blind trials across the 67 sessions in which they were conducted (paired *t*-test $t_{66} = .69$, $p = .49$). In addition, to insure reliability of the observer scoring the dog's alerting response, 19 videos (∼680 trials) were scored by an independent observer from video to assess interobserver agreement of the alerting response. Mean interobserver agreement was 99.4% (range: 97.5–100%), indicating high agreement between the observer that was blind to the correct bin and the independent video scorer.

Discussion

Overall, the results show that Pavlovian conditioning enhanced resistance to the disruptor conditions, while unpaired odorant exposure had no effect on resistance to the disruptors. Taken together, these results suggest that increasing the history of reinforcement in the presence of the odorant in the form of Pavlovian conditioning leads to enhanced resistance to disruption. Although any simple and cost-effective procedure that offers protection from performance decrement could be a useful application for detection dog work, it is worth noting the small magnitude of the observed improvement in proportion of baseline accuracy (mean = 0.07, 95% CI: [0.04, 0.10]). Several factors could have led to this small improvement. First, the difference in reinforcement history between the odorant pairs was small. The Pavlovian conditioning

group received only 30 additional reinforcers (i.e., Pavlovian conditioning trials), over a span of five sessions, prior to the first disruptor compared to the unexposed odor. Prior to the second disruptor condition, the Pavlovian group received only 18 additional reinforcers, and, by the extinction sessions, a total of only 66 Pavlovian conditioning trials had been conducted. Thus, the small amount of Pavlovian conditioning may underlie the small effect.

A second possible factor is that by conducting the Pavlovian conditioning in separate sessions, while the dog was in a crate or behind a baby gate to prevent it from making the digging alert response to the odor, we introduced a context change between the Pavlovian conditioning and detection training phases. This context change could have significantly reduced the effectiveness of the Pavlovian conditioning. Pavlovian conditioning is influenced by the context in which training occurs (e.g., Balsam & Tomie, 2014; Bouton & Swartzentruber, 1986; Holland & Bouton, 1999). Had we maintained a more similar context between the Pavlovian and detection phases, we may have observed a greater effect of the Pavlovian contingency during detection training. While it was convenient for experimental manipulation to separate the Pavlovian conditioning from the detection training, potential applied uses of Pavlovian conditioning to enhance resistance to disruption might best aim to reduce potential context effects.

Third, facets of our procedure may have led to a ceiling effect limiting the magnitude of the observed effect. Dogs maintained high levels of accurate responding during much of the disruptor conditions (extinction excluded). The discrete-trials procedure may have facilitated this ceiling effect because it limited us to looking at accuracy instead of response rate, as

the first response terminated a trial. In addition, although a lack of a response decreased accuracy ("no choice" was coded as incorrect), our criterion for a no-choice, being no response after two 30 s presentations of the bins containing the S+ odorant, made our accuracy measure relatively insensitive to decreases in response rate. The response rate had to drop to less than 1 response per min for percent accuracy to be influenced by no-choice responses, which occurred almost exclusively during extinction. If our criterion for no choice had been briefer, allowing a more sensitive measure of response rate, we may have been able to detect additional changes in response rate and observe a greater magnitude of effect of Pavlovian conditioning.

It is interesting to note how presession feeding had little to no impact for some dogs. In particular, despite eating 200% of their daily diet prior to an experimental session, many dogs showed no decrease in accuracy (e.g., Bessa in Fig. 2). In addition, although burying food in both the S+ and S- bins disrupted performance, the disruptive effects were surprisingly small, and dogs quickly learned to ignore the smell of the food.

The present results have both theoretical and applied implications. Theoretically, this study provides further evidence that behavioral momentum phenomena are influenced by Pavlovian contingencies (Mauro & Mace, 1996; Nevin & Grace, 2000; Nevin et al., 1990; Podlesnik & Shahan, 2008). The present study extends the Pavlovian interpretation of behavioral momentum by separating the experimental manipulation of the stimulus–reinforcer contingency (i.e. Pavlovian conditioning) from the response–reinforcer contingency. By separating the experimental stimulus–reinforcer manipulation into separate sessions this allowed us to keep the response–reinforcer contingency for odor detection identical for both odor discriminations across all sessions, giving us comparable baseline performances across experimental groups.

In addition, the present study extends the theoretical work by including an unpaired exposure group that controls for the presentation of reinforcers alone and the overall familiarity of the stimuli. Thus, our results are unlikely due to one stimulus simply being more familiar, or the mere presentation of additional reinforcers, as this alone did not influence resistance to change.

Podlesnik and Fleet (2014), however, recently found no effect of degrading the Pavlovian contingency on resistance to disruption in pigeons responding for food on a two-component multiple schedule. This result raises questions about the straightforward relationship between the strength of the Pavlovian contingency and resistance to disruption. Podlesnik and Fleet attempted to degrade the discriminative stimulus–reinforcer relation by introducing a stimulus change (from the discriminative stimulus to a different discrete stimulus) during response-independent periods of food in one component. They found that when responding was disrupted with presession feeding, free food during the intercomponent interval (ICI), or by an extinction procedure that controlled for generalization decrement, there were no differences in resistance to disruption in the presence of the discriminative stimuli of the two components. This suggests that the introduction of the discrete stimulus to degrade the Pavlovian conditioning to the discriminative stimulus had no effect on resistance to disruption. Interestingly, for presession feeding and free intercomponent food, greater resistance to disruption was observed during the presence of the *discrete* stimulus compared to the discriminative stimuli of either component. Thus, the discrete stimulus itself was more resistant to disruption, but it did not influence the resistance to disruption of the discriminative stimulus. Thus, additional research is needed to evaluate how direct manipulations of the Pavlovian contingency influences resistance to change.

One growing area of research that might contribute to this topic is that of Pavlovian to Instrumental Transfer (PIT). In many PIT experiments, a conditioned stimulus (CS) is paired with a reinforcer (e.g. food) in an initial Pavlovian phase. Subjects are then trained to engage in an operant response for the same reinforcer used in the Pavlovian phase. Then, under an extinction test condition, the Pavlovian CS is presented which increases rates of responding compared to a control group that did not receive CS–US pairings (i.e., greater resistance to extinction; for a review see Holmes, Marchand, & Coutureau, 2010). One could consider a behavioral momentum experiment that manipulates the Pavlovian contingency directly to be related to a within-subject

PIT experiment in which there is an additional discriminative stimulus that also serves as the Pavlovian CS.

This interpretation might help resolve, in part, the differences between the present results and those of Podlesnik and Fleet (2014). In the present study, we strengthened the Pavlovian stimulus–reinforcer relation, which led to greater resistance to disruption of the operant response. In Podlesnik and Fleet, the procedure that degraded the discriminative stimulus–reinforcer relation, also created an additional discrete CS. This CS could have supported PIT, which might explain the greater responding during the discrete stimulus compared to the discriminative stimuli under presession feeding and intercomponent-interval free food. This explanation, however, doesn't resolve the lack of differences in resistance to disruption observed between the discriminative stimuli of the two components.

Future research could explore the potential intersections between findings in PIT research and behavior momentum research. Interestingly, if behavioral momentum and PIT reflect a similar underlying mechanism, research from the PIT literature would suggest that increased responding during extinction would not be greatly impacted by attempts to degrade the Pavlovian contingency with extinction trials or reinforcer devaluation procedures. Exploring whether these manipulations have the same effect in a traditional behavior momentum paradigm would be an interesting extension of the present work. Exploring behavior momentum with a focus directly on manipulating the Pavlovian contingency and its effects on operant behavior could be a future direction of research in the study of behavior momentum.

Our present results also have potential practical implications. As discussed in the introduction, dogs in real world detection scenarios are likely to encounter numerous distractors that may appear in the environment. Enhancing dogs' performance in the face of these distractors would be useful in maintaining high levels of detection accuracy. We show here that Pavlovian conditioning that occurs outside of the training context can enhance resistance to disruption. Thus, Pavlovian conditioning might be a useful method to help maintain dogs' detection performance in the field. One potential limitation requiring further exploration, however, is the fact that resistance

to disruptors tends to be observed in multiple schedules, and not in simple schedules (Cohen et al., 1993; Nevin & Grace, 2000). It is not clear whether Pavlovian conditioning would only exert a relative effect (i.e., enhance performance for the conditioned odor relative to leaner reinforced discriminations) or would increase the absolute level of resistance to disruption at a group level. We did see a trend in the right direction in our group comparison but this difference did not reach statistical significance. Prior applied research has observed behavior momentum effects across conditions outside of typical multiple schedules (e.g. Ahearn, Clark, Gardenier, Chung, & Dube, 2003; Mace et al., 2010); however, additional research would be needed to assess whether the results would extend to enhancing detection performance outside of an alternating discrimination procedure or multiple schedule.

Overall, the results show that Pavlovian conditioning enhances resistance to disruptors for dogs performing an olfactory discrimination. This shows that behavioral momentum theory can be extended to dogs performing an olfactory discrimination. In addition, the results provide some evidence that behavioral momentum phenomena are influenced by Pavlovian contingencies, but more research is needed to explore how Pavlovian contingencies influence resistance to change. In addition, more research is needed to confirm the potential benefits Pavlovian contingencies might provide for enhancing detector dog training, but the present results suggest they hold promise .

References

Adamkiewicz, E., Jezierski, T., Walczak, M., Górecka-Bruzda, A., Sobczyńska, M., Prokopczyk, M., & Ensminger, J. (2013). Traits of drug and explosives detection in dogs of two breeds as evaluated by their handlers and trainers. *Animal Science Papers & Reports*, *31*(3), 205–217.

Ahearn, W. H., Clark, K. M., Gardenier, N. C., Chung, B. I., & Dube, W. V. (2003). Persistence of stereotypic behavior: examining the effects of external reinforcers. *Journal of Applied Behavior Analysis, 36*(4), 439–448. http://doi.org/10.1901/jaba.2003.36-439

Balsam, P., & Tomie, A. (2014). *Context and Learning*. New York: Psychology Press.

Bell, M. C. (1999). Pavlovian contingencies and resistance to change in a multiple schedule. *Journal of the Experimental Analysis of Behavior, 72*(1), 81–96. http://doi.org/10.1901/jeab.1999.72-81

Bouton, M. E., & Swartzentruber, D. (1986). Analysis of the associative and occasion-setting properties of

contexts participating in a Pavlovian discrimination. *Journal of Experimental Psychology: Animal Behavior Processes*, *12*(4), 333–350. http://doi.org/10.1037/0097–7403.12.4.333

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.

Cablk, M. E., Sagebiel, J. C., Heaton, J. S., & Valentin, C. (2008). Olfaction-based detection distance: a quantitative analysis of how far away dogs recognize tortoise odor and follow it to source. *Sensors*, *8*(4), 2208–2222.

Cohen, S. L., Riley, D. S., & Weigle, P. A. (1993). Tests of behavior momentum in simple and multiple schedules with rats and pigeons. *Journal of the Experimental Analysis of Behavior*, *60*(2), 255–291. http://doi.org/10.1901/jeab.1993.60-255

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*(2), 197–201.

Furton, K. G., & Myers, L. J. (2001). The scientific foundation and efficacy of the use of canines as chemical detectors for explosives. *Talanta*, *54*(3), 487–500. http://doi.org/ doi: 10.1016/S0039-9140(00)00546-4

Hall, N. J., Smith, D. W., & Wynne, C. D. L. (2014). Effect of odor preexposure on acquisition of an odor discrimination in dogs. *Learning & Behavior*, *42*, 144–152. http://doi.org/10.3758/s13420-013-0133-7

Holland, P. C., & Bouton, M. E. (1999). Hippocampus and context in classical conditioning. *Current Opinion in Neurobiology*, *9*(2), 195–202. http://doi.org/10.1016/S0959-4388(99)80027-0

Holmes, N. M., Marchand, A. R., & Coutureau, E. (2010). Pavlovian to instrumental transfer: A neurobehavioural perspective. *Neuroscience & Biobehavioral Reviews*, *34*(8), 1277–1295. http://doi.org/10.1016/j.neubiorev.2010.03.007

Jezierski, T., Adamkiewicz, E., Walczak, M., Sobczyńska, M., Górecka-Bruzda, A., Ensminger, J., & Papet, E. (2014). Efficacy of drug detection by fully-trained police dogs varies by breed, training level, type of drug and search environment. *Forensic Science International*, *237*, 112–118. http://doi.org/10.1016/j.forsciint.2014.01.013

Mace, F. C., Lalli, J. S., Shea, M. C., Lalli, E. P., West, B. J., Roberts, M., & Nevin, J. A. (1990). The momentum of human behavior in a natural setting. *Journal of the Experimental Analysis of Behavior*, *54*(3), 163–172. http://doi.org/10.1901/jeab.1990.54-163

Mace, F. C., McComas, J. J., Mauro, B. C., Progar, P. R., Taylor, B., Ervin, R., & Zangrillo, A. N. (2010). Differential reinforcement of alternative behavior increases resistance to extinction: clinical demonstration, animal modeling, and clinical test of one solution. *Journal of the Experimental Analysis of Behavior*, *93*(3), 349–367. http://doi.org/10.1901/jeab.2010.93-349

Mahoney, A., Durgin, A., Poling, A., Weetjens, B., Cox, C., Tewelde, T., & Gilbert, T. (2012). Mine detection rats: effects of repeated extinction on detection accuracy. *Journal of ERW and Mine Action*, *16*(3), 61–64.

Mahoney, A., Lalonde, K., Edwards, T., Cox, C., Weetjens, B., & Poling, A. (2014). Landmine-detection rats: An evaluation of reinforcement procedures under simulated operational conditions. *Journal of the Experimental Analysis of Behavior*, *101*, 450–456. doi: 10.1002/jeab.83

Mauro, B. C., & Mace, F. C. (1996). Differences in the effect of Pavlovian contingencies upon behavioral momentum using auditory versus visual stimuli. *Journal of the Experimental Analysis of Behavior*, *65*(2), 389–399. http://doi.org/10.1901/jeab.1996.65-389

McLean, I., & Sargisson, R. J. (2005). *Mine detection dogs: operations case studies of operational systems*. Geneva: Geneva International Centre for Humanitarian Demining.

Nevin, J. A., & Grace, R. C. (2000). Behavioral momentum and the law of effect. *Behavioral and Brain Sciences*, *23*(1), 73–90.

Nevin, J. A., Mandell, C., & Atak, J. R. (1983). The analysis of behavioral momentum. *Journal of the Experimental Analysis of Behavior*, *39*(1), 49–59. http://doi.org/10.1901/jeab.1983.39-49

Nevin, J. A., Milo, J., Odum, A. L., & Shahan, T. A. (2003). Accuracy of discrimination, rate of responding, and resistance to change. *Journal of the Experimental Analysis of Behavior*, *79*(3), 307–321. http://doi.org/10.1901/jeab.2003.79-307

Nevin, J. A., & Shahan, T. A. (2011). Behavioral Momentum Theory: equations and applications. *Journal of Applied Behavior Analysis*, *44*(4), 877–895. http://doi.org/10.1901/jaba.2011.44-877

Nevin, J. A., Tota, M. E., Torquato, R. D., & Shull, R. L. (1990). Alternative reinforcement increases resistance to change: Pavlovian or operant contingencies? *Journal of the Experimental Analysis of Behavior*, *53*(3), 359–379. http://doi.org/10.1901/jeab.1990.53-359

Podlesnik, C. A., & Fleet, J. D. (2014). Signaling added response-independent reinforcement to assess Pavlovian processes in resistance to change and relapse. *Journal of the Experimental Analysis of Behavior*, *102*(2), 179–197. http://doi.org/10.1002/jeab.96

Podlesnik, C. A., & Shahan, T. A. (2008). Response-reinforcer relations and resistance to change. *Behavioural Processes*, *77*(1), 109–125. http://doi.org/10.1016/j.beproc.2007.07.002

Poling, A., Weetjens, B., Cox, C., Beyene, N., Durgin, A., & Mahoney, A. (2011). Tuberculosis detection by Giant African Pouched Rats. *The Behavior Analyst*, *34*(1), 47.

Poling, A., Weetjens, B., Cox, C., Beyene, N., & Sully, A. (2010). Using Giant African Pouched rats (*Cricetomys Gambianus*) to detect landmines. *The Psychological Record*, *60*, 715–728.

Poling, A., Weetjens, B., Cox, C., Beyene, N. W., Bach, H., & Sully, A. (2011). Using trained pouched rats to detect land mines: another victory for operant conditioning. *Journal of Applied Behavior Analysis*, *44*(2), 351–355. http://doi.org/10.1901/jaba.2011.44-351

Sargisson, R. J., & McLean, I. G. (2010). The effect of reinforcement rate variations on hits and false alarms in remote explosive scent tracing with dogs. *The Journal of ERW and Mine Action*, *14*(3), 64–68.

Williams, B. A., & Bell, M. C. (2000). The uncertain domain of resistance to change. *Behavioral and Brain Sciences*, *23*(1), 116–117.

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