Behavioural Processes 216 (2024) 105014

Contents lists available at ScienceDirect

Behavioural Processes

journal homepage: www.elsevier.com/locate/behavproc

Evaluation of the capability of oil specific discrimination in detection dogs

Mallory T. DeChant[a,*], Paul C. Bunker[b], Nathanial J. Hall[a]

[a] Texas Tech University, Lubbock, TX, United States
[b] Chiron K9, LLC, San Antonio, TX, United States

ARTICLE INFO

Keywords:
Oil detection dog
Unweathered target discriminate from weathered
Oil spill
Remediation
Olfaction

ABSTRACT

Dogs are used for oil detection to support spill remediation and conservation, but little is known about the effects of weathering and aging of oil odorants on dogs' ability to generalize and discriminate unweathered oil from aged/weathered tar ball oil. Three dogs were trained to detect unweathered oil odorant using a three-alternative choice procedure and automated olfactometers. We evaluated dogs' ability to discriminate unweathered target oil from four different weathered/tar ball samples. All three dogs successfully discriminated the unweathered target oil from the four nontarget weathered oils with an accuracy of 96%, 97%, and 100%. After the oil discrimination test, dogs' ability to discriminate unweathered target oil from novel natural odorants on a beach (plastic bottle lid, bird feathers, and rocks) was tested in a novel discrimination test yielding an accuracy of 95%, 100%, and 100%. These data suggest dogs are successful in discriminating unweathered oil from weathered oil with explicit training.

1. Introduction

Detection dogs have been successfully used for a wide range of conservation purposes (e.g., Bennett et al., 2022; Cristescu et al., 2015; Fukuhara et al., 2022; Jean-Marie et al., 2019; Reed et al., 2011). One relatively new application for conservation dogs is to rapidly identify oil leaks from buried pipelines or oil from spills that have spread across vast landscapes (Brandvik and Buvik, 2017). Although little work on this topic has made it to the peer-reviewed literature, there has been substantial industry support to investigate oil detection dogs as a tool that can improve efficiency and detection sensitivity of environmentally spilled oils which is otherwise labor intensive and slow for such a time critical detection task (American Petroleum Institute, 2016; Brandvik and Buvik, 2009, Brandvik and Buvik, 2017, Owens and Bunker, 2022).

Industry research has demonstrated dogs' remarkable ability to detect spilled crude oils. For example, four dog-handler teams conducted field searches almost 2 years after the shorelines had been oiled and successfully detected surface and subsurface oil deposits on bedrock, vegetation, coarse sediment, and wooden structures (Brandvik and Buvik, 2009). Similar success was achieved in a series of field tests and deployment demonstrations where dogs detected subsurface oil in beach sediments, snow, ice, and experimentally manipulated fields (Owens and Bunker, 2022). Together, the preliminary work indicates that dogs are more sensitive than any tested handheld oil vapor detection tool and locate oil odor to source potentially saving substantial time (Owens and Bunker, 2022).

Given these successful oil detection canine demonstrations, there remain several important questions that may otherwise limit their use. One such question is whether dogs can be trained to specifically identify recently spilled oil samples in a complex shoreline environment that may contain many natural sources of similar hydrocarbon compounds.

Areas such as the Texas shoreline have weathered oil clumps ("tarballs") that wash-up along the shoreline and are the result of natural oil seepage followed by environmental weathering (exposure to solar radiation, water, microbial activity, etc.). These can be very prevalent along a shoreline whereby the result of a recent Texas shoreline survey indicates tarballs are often as frequent as 1 per meter of shoreline (Bunker and Owens, 2023). Furthermore, some areas may contain residual hydrocarbon contamination from prior spills that would not be indicative of current oil leakage or spillage. Thus, if an oil detection dog was trained to alert to any hydrocarbon in the environment, this could lead to hundreds or thousands of finds per survey unrelated to a current spill or leak. This would substantially reduce the efficiency of a survey of a recent oil spill, potentially making a detection canine an inefficient tool.

Generally, crude oils are complex mixtures made up from hydrocarbons, non-hydrocarbons, and petroleum products (Overton et al., 2016). The concentration of hydrocarbon and non-hydrocarbons within

---

* Corresponding author.
E-mail address: mallory.dechant@ttu.edu (M.T. DeChant).

https://doi.org/10.1016/j.beproc.2024.105014
Received 20 October 2023; Received in revised form 6 March 2024; Accepted 7 March 2024

the crude oil will vary based on the type of crude oil and the region the crude oil is located. Furthermore, weathering can have important impacts. The weathering of crude oil is caused by evaporation, dissolution, dispersion, water-oil emulsification, sedimentation, microbial degradation, and photochemical oxidation of the oil's components (Wang and Fingas, 1995). Within hours to days of an oil spill, evaporation is the dominant weathering process that leads to considerable changes in the chemical and physical composition of oil (Payne and McNabb, 1984). For example, for light and medium crude oils, evaporation loss is estimated between 40-75% whereas heavy or residual oils lose 5–10% volume (Fingas, 1995). As oil further weathers due to environmental factors, the volatility and water-soluble components degrade, and the oil becomes more viscous over time and leaves behind small quantities of refractory residue called tarballs (Overton et al., 2016). In a recent study, three different sediment samples from the Macondo source oil from the Deepwater Horizon incident were collected and analyzed for the chemical composition (Overton et al., 2016). The weathering altered the chemical composition of the original spilled oil as well as the residue's physical and toxicological properties (Overton et al., 2016). Together, these results indicate that oil subject to weathering may be readily distinguishable from an unweathered source (e.g. fresh leak/spill).

Thus, the aim of this project was to conduct a proof of concept to evaluate whether the weathering process produces a sufficiently different odor profile that an oil detection dog can be trained to discriminate an unweathered oil that would simulate a recent oil spill, from the vast number of potential varied weathered natural seepage oils that a dog may encounter in the search environment. To do this, three dogs were trained under laboratory conditions to evaluate whether successful discrimination between an unweathered oil and various weathered oils could be achieved.

2. Methods

2.1. Subjects

Three canines, Bin and Pena (German Shorthair Pointers, approximately 3 years old, neutered male (Bin) and spayed female (Pena)) and Buster (mixed breed, approximately 3 years old, neutered male) were housed at Texas Tech University Canine Olfaction Laboratory. Bin and Pena were purpose-bred detection dogs that were previously excluded from a working dog program. Buster participated in the training for adoption program at Texas Tech University and was from a municipal animal shelter. Dogs had previous olfactory training at Texas Tech University Canine Olfaction Laboratory for another project but were naïve to the odorants utilized in this study. Dogs received at least twice daily walks and play sessions, training for future adoption, and social enrichment with conspecifics and human caretakers. Dogs were housed in pairs when compatible. All procedures were approved by the Institutional Animal Care and Use Committee (IACUC # 21070–09).

3. Materials

3.1. Apparatus

Dogs were trained on a three-choice odor discrimination task using automated olfactometers identical to those used by Aviles-Rosa et al., (2021). Briefly, three independent olfactometers (each with a capacity to present one of six different odorants) were controlled by one central computer. The olfactometer operates as an air delivery system, where air originates from an oilless pump. The air passes through a charcoal filter to remove room contaminants and is then regulated by two rotameters. One rotameter controls a continuous dilution flow (always on) and an odor line (only on during odor activation). To generate an odor, one of the six valves is activated, allowing air to pass through a 40 ml borosilicate glass jar containing the odor source (described below). The headspace from that jar is then displaced to a Polytetrafluroethylene (PTFE, Teflon) manifold where it mixes with the dilution flow. The mixed odor/dilution flow is then delivered to an odor port for the dog to sample. For the duration of the study, 1 L/min was used for the odor line and 2 L/min for the dilution line, producing a 33% air dilution.

Each olfactometer was connected to a Polytetrafluroethylene (PTFE, Teflon) odor port that had a 12 cm diameter entrance that allowed the dog to insert their nose to sample the odor. The three odor ports were mounted to a metal frame in a row, approximately 51 cm from the ground, 25 cm apart. Each odor port had an infrared beam pair that measured nose insertions and duration of nose insertion to each odor port. Above the top of odor port, an exhaust fan removed excess odor from the port out of the testing room.

All odor whetted parts were made of stainless steel, Polytetrafluoroethylene (PTFE, Teflon) and glass materials.

3.2. Odorants

All oils and tar bars were collected from the field during different years (see Table 1 for more details) to represent various weathered oil sources. The target odor was unweathered "Bunker-C" fuel oil that was collected straight from the source and packaged in a solid-walled airtight container. The Bunker-C oil was protected from UV light, the environment, and temperature by being stored in a chemical locker within a climate-controlled room to avoid the weathering process. The unweathered Bunker-C oil (0.5 g) was mixed with 4.5 g of play sand (Quikrete Companies, LLC, Atlanta, GA) to simulate oil on a shoreline for a concentration of 0.11 g/g. Play sand was utilized to ensure there was not environmental debris that is typical in outdoor sand. The oils/sand mixture was then placed in the glass vial and connected to the olfactometer.

The four non-target weathered oils were solid "Husky" tar ball (0.5 g), solid "Padre" tar ball (0.5 g), very weathered semi-solid "Juniper" crude oil (0.5 g) and weathered "CTC" crude oil (0.5 g; see Table 1). All non-target oils were collected from the environment (i.e., the sea or riverbank/river) and were classified as weathered due to undergoing natural weathering by substantial exposure to the environmental elements and their collection from the environment. All non-target weathered oils were mixed with 4.5 g of play sand identical to the target odor, for a concentration of 0.11 g/g. Additional non-target odors included 5 g of play sand (diluent/sand control). For a novel odorant test to ensure dogs would not respond to naturally occurring items on a

Table 1
Description of odorants utilized in this study.

Odorant Name	Source	Dilution Factor	Approximate Age	Use in Study
Bunker-C oil	Superior Refining Company, LLC	0.11 g/g	Sample prepared 09/2017	Target oil
Husky tar ball	Husky oil spill, Saskatchewan, Canada	0.11 g/g	Spill occurred 07/2016. Sample collected 2018	Nontarget oil
Padre tar ball	Padre Island, TX	0.11 g/g	Sample collected 11/2018	Nontarget oil
Juniper oil	Deepwater Horizon oil spill (Vessel USCGC Juniper)	0.11 g/g	Sample collected 07/2010	Nontarget oil
CTC oil	Deepwater Horizon oil spill (Barge No. CTC02404)	0.11 g/g	Sample collected 07/2010	Nontarget oil
Sand	Quikrete Companies LLC	1	2022	Distractor
Rocks	Lubbock	1	Unknown	Distractor
Bird feathers	Lubbock	1	Unknown	Distractor
Plastic bottle cap	Lubbock	1	Unknown	Distractor
Sticks	Lubbock	1	Unknown	Distractor

beach, rocks, bird feathers, plastic bottle cap, and sticks were collected as novel non-target odors.

3.3. General procedures

The dogs were trained in sessions comprising 20 trials by the same handler throughout the experiment. Dogs were worked off leash in an experimental room with the handler sitting in a chair away from the dog. At the start of a trial, the olfactometer would emit a "start" tone. If the dog did not immediately begin search, the handler gestured and told the dog to "search". The dog was allowed to search the three odor ports in any order. An alert to an odor port was defined as a nose hold breaking the infrared beams for 4 continuous seconds (see Fig. 1) for Bin and Buster and 2 s for Pena. The difference in continuous hold time was made due to Pena's increased movement in the port that would interrupt continuous nose hold movement. Nose holds were automatically detected by the olfactometer program running the experiment. The computer scored all responses and informed the handler of correct or incorrect responses via associated "correct" and "incorrect" tones. The handler was blind to the position of the target odor and whether the trial contained the target odor or not across all training and testing.

Correct alerts to unweathered Bunker-C were reinforced on a continuous schedule. A toy was used for Bin. Buster and Pena were given food reinforcers. The target odor was present in one of the three odor ports on 60% of trials (e.g., 12 out of 20 trials) for each 20-trial session. The remaining 40% of trials (e.g., 8 out of 20 trials) were "blank" trials where all three olfactometers presented non-target odors. On these trials, dogs were required to sample each odor port (measured by an infrared beam break >0 s), then not make a nose hold response for 4 s after the last port was sampled. These were considered "all clear" responses and dogs typically returned to the handler during the 4 s wait duration, but this was not required as measured by the olfactometer. Any nose hold exceeding the 2 s or 4 s criterion to a non-target odor was scored as a false alert and terminated the trial. Blank trials were set to a rate of 40% of trials to ensure dogs could readily pass non-target odors when the unweathered target was not present. Correct rejections (i.e., making an "all clear" on a trial without the target) and hits (correct alerts to the target) were reinforced. False alerts and misses were not.

Fig. 1. Picture of Pena holding her nose in an odor port indicating an alert.

3.4. Pre-Training

Because dogs had prior olfactometer training, pre-training was minimal. Dogs were initially transitioned to the experimental room for this study and shaped to make the “alert” response (the nose hold). Once dogs met the nose hold criterion, dogs were trained to respond to the target (unweather Bunker C) and discriminate this from an empty jar and a jar containing diluent sand. Training continued until meeting the criterion of 85% or greater accuracy over 4 consecutive sessions. Dogs then progressed to the Training period.

3.5. Training and oil discrimination test

Following pre-training, non-target oils were added one at a time across sessions to the olfactometer. Training continued with that non-target oil until accuracy reached the training criterion of 85% or greater accuracy for two sessions. Once achieving that, the next non-target oil was added, while leaving the previously introduced non-target as a non-target. Once reaching the training level with the four non-target oils, the diluent sand and empty vials were removed due to space constraints. Non-target odors were presented with equal probability and pseudo-randomly selected each trial by the computer across all sessions. Each olfactometer selected non-target odors independently, thus, it was possible for multiple olfactometers to present the same non-target odor, but never more than one olfactometer presented the target odor in a trial.

One procedural deviation was made during training for Buster. After the second non-target odor was added, Buster failed to meet criterion after double the number of sessions required by Bin and Pena. In addition, nearly all incorrect responses were misses of the target odor which almost never occurred in prior training. We hypothesized that the continuous reinforcement schedule for correct rejections may have been related to Buster’s performance decline. Therefore, Buster’s reinforcement rate for correct rejections (i.e., all clear response) was decreased from 100% to 50% (i.e., half of the correct rejections were reinforced) and ultimately 0% (i.e., no reinforcement for correct rejections). Once reinforcement to all clears was changed to 0%, his performance increased to the training criterion. For the remaining duration of the study, the reinforcement rate for correct rejections remained at 0% for Buster only.

Once dogs met the 85% accuracy criterion for two consecutive sessions with all four non-target oils, dogs continued for a five session (20 trials per session) oil discrimination test. These five sessions were identical to the last stage of training and used to evaluate each dog’s oil discrimination performance across 100 trials.

3.6. Novel odorant discrimination test

The second discrimination test was one session of 20 trials that consisted of dogs discriminating the Bunker-C oil from 4 novel objects (rocks, bird feathers, plastic bottle cap, and sticks; see Table 1). These 4 novel objects were chosen to simulate items dogs may encounter on an operational beach search. The procedures were identical to the oil discrimination test except the discrimination was between the unweathered oil and four novel objects that may be found on a shoreline.

3.7. Statistical analysis

For the oil discrimination and novel discrimination test, three measurements were reported: accuracy, sensitivity, and specificity. Accuracy, which was the overall number of correct trials (hits and correct rejections) divided by the total number of trials; sensitivity, which was the probability of a hit to the target odor on an odor present trial; specificity, which was the probability of a correct rejection on a trial in which the target was absent. To statistically compare the responses to each odor, we used a linear mixed effect model to compare the duration of the nose insertion time as a function of the fixed effect of odor identity and random effect of dog identity. We only included nose insertions greater than zero, to ensure the dog sampled the odor. Tukey-adjusted post hoc tests were then used to compare nose insertion time between the odors.

4. Results

The training period took Bin 20 days, Buster 26 days, and Pena 16 days to complete. Figs. 2 and 3 show the dogs’ performance across the training phase. Fig. 2 highlights the decline in performance after Padre tar ball was added for Buster with the additional vertical lines that demonstrate when reinforcement to all clears was adjusted from 100% to 50%, to 0% as described in the methods. Fig. 3 shows that Pena showed almost no impact to performance with the addition of any non-target oil. Bin showed minimal impact, only requiring a couple extra sessions than the minimum required to meet the accuracy criterion.

Following training, Fig. 4 shows all three dogs’ performance during the five oil discrimination test sessions that immediately followed meeting criterion in training. Pena had an accuracy of 100%, whereas Bin reached 97% and Buster reached 96% accuracy (see Table 2). All three dogs had an accuracy well above chance (33.33%) during the oil discrimination test (binomial test; see Table 2). Pena and Buster both had a 100% sensitivity and Bin reached 95% sensitivity. Finally, Bin and Pena both had a 100% specificity and Buster reached 95.74% specificity during the oil discrimination test (Table 2).

We next compared the total duration of nose insertion time to each port as a function of odor identity. A linear mixed effect model indicated a significant effect of odor identity ($\chi^2=3486$, df=4, $p<0.001$) on nose insertion time. Tukey-adjusted post hoc tests indicate that nose insertion time was greatest for the unweathered oil [2.4, 3.4 s] whereas all other oils had an estimated nose insertion time of approximately 0.4 s. Nose insertion time was greater for the unweathered oil compared to the Husky tar ball (mean difference estimate= 3 s, t=44, df=703, $p<0.001$), Padre tar ball (mean difference estimate= 3 s, t=44, df=703, $p<0.001$), Juniper oil (mean difference estimate= 3 s, t=44, df=703, $p<0.001$), and CTC oil (mean difference estimate= 3 s, t=44, df=703, $p<0.001$). There were no statistical differences in nose insertion between the weathered oil samples.

During the novel odorant discrimination test, Bin and Buster had an accuracy of 100% for the single session, whereas, Pena missed one trial and had an accuracy of 95% (see Table 2). Pena incorrectly alerted to rocks on the first trial of this session. All three dogs had an accuracy well above chance (33.33%) during the oil discrimination test. Bin and Buster had a 100% sensitivity during the novel discrimination test whereas, Pena had 91% sensitivity. Bin and Buster had a 100% specificity and Pena had a 95.23% specificity during the novel discrimination test (Table 2).

5. Discussion

The objective of this study was to determine if dogs could be trained to discriminate an unweathered fuel oil from various weathered fuel oil sources. The results indicate that dogs can readily learn this discrimination achieving accuracy >90%. It took Pena 16 sessions, Bin 20 sessions, and Buster 26 sessions to complete the training period.

Following this project, Bin had an opportunity to search South Padre Island for unweathered oil amongst the naturally occurring tar balls. In addition, another dog not involved in this project and had been trained to alert to unweathered and weathered oil searched the same area. Bin alerted to the two samples of unweathered oil experimentally placed and made no alerts to tarballs in the search area. In contrast, the second dog responded to the two unweathered samples and 9 naturally occurring weathered samples in the same area (Bunker, 2023).

This proof-of-concept study demonstrates that with explicit training, dogs can be trained to ignore tar balls and weathered oils. Nonetheless,

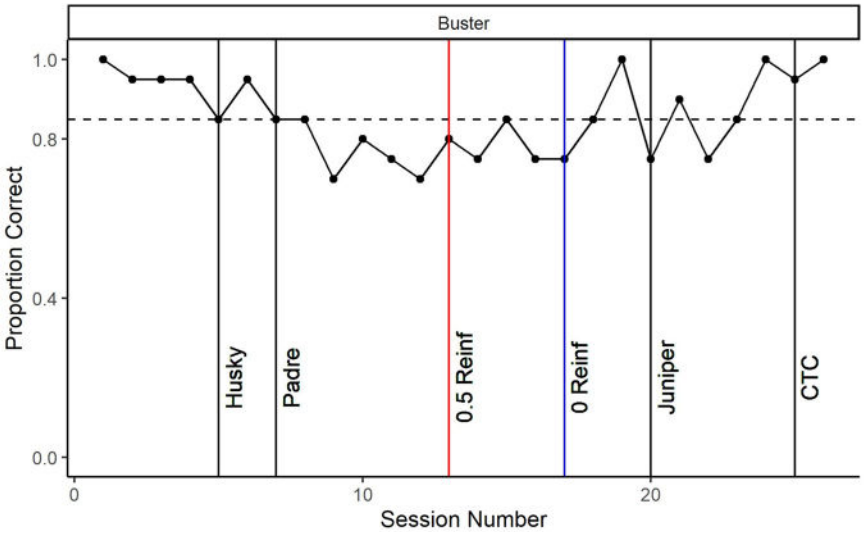

Fig. 2. Performance for Buster during Pre-Training Period and Training Period for the addition of the non-target oils. The dashed horizontal line indicates the 0.85 training criterion for accuracy. Each session represents the average performance for 20 trials. The change in reinforcement schedule for correct rejections (i.e., all clear responses) was adjusted after the addition of Padre tar ball when performance declined (session 9). The red vertical line indicated when the reinforcement schedule for correct rejections was adjusted from 1 to 0.5. The blue vertical line indicated when the reinforcement schedule for correct rejections was adjusted from 0.5 to 0. After this point, the reinforcement schedule for correct rejections was 0 for Buster only.

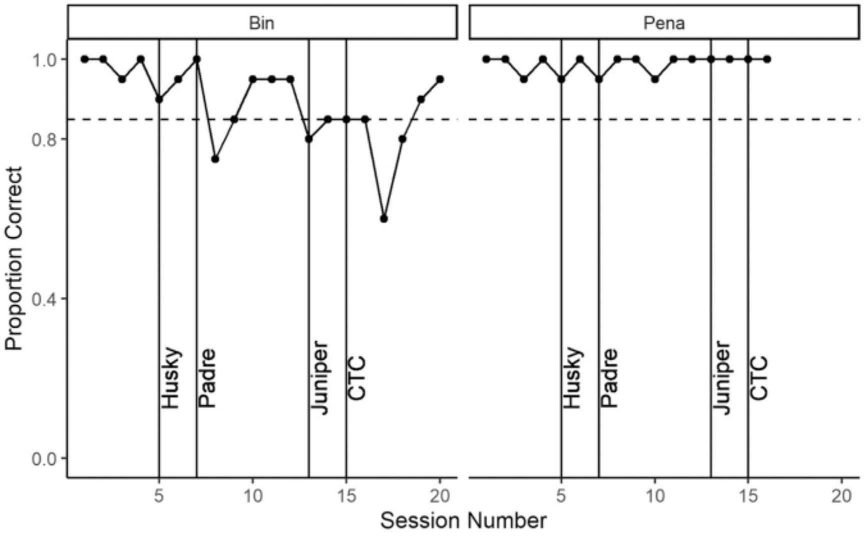

Fig. 3. Performance for Pena and Bin during Pre-Training and Training Period for the addition of the non-target oils. The dashed horizontal line indicates the 0.85 training criterion for accuracy. Each session represents the average performance for 20 trials.

there are some important limitations to the present findings. The first is the lack of analytical chemistry to determine the chemical composition of the oils and tar balls. Secondly, the samples were less controlled than desired. A preferred approach would have included experimentally weathering oil from the same source and compare discrimination performance of the same original sample in its weathered and unweathered state. Finally, there was no generalization test for another unweathered oil conducted and should be included in future studies.

Although our results are specific to a small set of fuel oil products, it is worth considering weathering impacts on odor profiles in various detection dog disciplines. For example, human remains detection dogs often have to search for odor sources that may experience varying degrees of preservation/weathering (Buis et al., 2015, 2019; Lasseter et al., 2003; Rust et al., 2018). Our results suggest that dogs could potentially discriminate between samples of varying weathering which could have varying consequences depending on the detection task. A future extension of this work into different detection dog disciplines could have important impacts.

Overall, this proof-of-concept study demonstrated that dogs can be readily trained to alert to an unweathered oil sample and ignore tar balls and weathered oils. The degree to which the unweathered and weathered oil/tar balls show similarity and differences from a chemical perspective would be an important next step to understand the relationship between chemical similarity and perceptual similarity for the oil detection dog.

CRediT authorship contribution statement

Paul C. Bunker: Writing – review & editing, Writing – original draft, Investigation, Funding acquisition, Conceptualization. **Mallory T DeChant:** Writing – review & editing, Writing – original draft, Visualization, Supervision, Project administration, Methodology, Formal

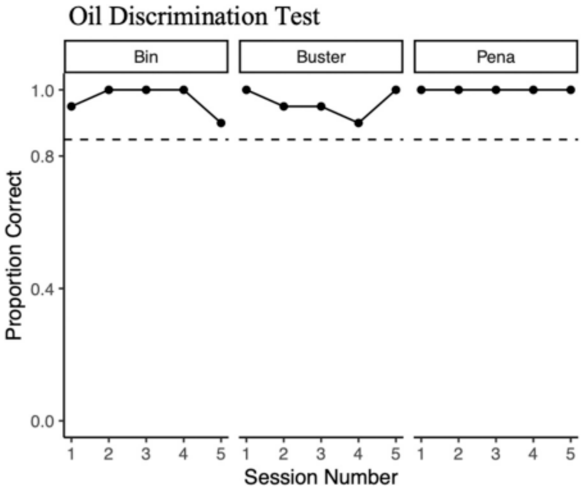

Fig. 4. Performance for all three dogs during the Oil Discrimination Test. The dashed horizontal line indicates the 0.85 training criterion for accuracy. Each session represents the average performance for 20 trials.

Table 2
Accuracy, Sensitivity, and Specificity for each individual dog during both discrimination tests. Shows the number of correct responses/number of trials.

	Accuracy	Sensitivity (Target Present)	Specificity (Target Absent)
Bin	97/100	57/60	40/40
Pena	100/100	60/60	40/40
Buster	96/100	60/60	39/40

analysis, Data curation. **Nathanial J. Hall:** Writing – review & editing, Writing – original draft, Supervision, Project administration, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Data Availability

Data will be made available on request.

Acknowledgements

This material is based wholly or in part upon work supported by the Research and Development program of the Texas General Land Office Oil Spill Prevention and Response Division, under GLO Contract Number 22-005-008-D097. The views contained herein are those of the authors and should not be interpreted as representing the views of the GLO or the State of Texas.

References

Aviles-Rosa, E.O., Gallegos, S.F., Prada-Tiedemann, P.A., Hall, N.J., 2021. An automated canine line-up for detection dog research. Front. Vet. Sci. *8*, 775381 https://doi.org/10.3389/fvets.2021.775381.

Bennett, E., Jamieson, L.T., Florent, S.N., Gill, N., Hauser, C., Cristescu, R., 2022. Detection dogs provide a powerful method for conservation surveys. Austral Ecol., aec.13162 https://doi.org/10.1111/aec.13162.

Brandvik, P.J., & Buvik, T. (2009). Using dogs to detect oil hidden in snow and ice. Results from field training on Svalbard April 2008 (p. 19) [JIP-Report No: 14. SINTEF Report No. F12273].

Brandvik, P.J., Buvik, T., 2017. Using dogs to detect oil spills hidden in snow and ice—a new tool to detect oil in Arctic environments. Int. Oil Spill Conf. Proc. *2017* (1), 2219–2236. https://doi.org/10.7901/2169-3358-2017.1.2219.

Buis, R.C., Rust, L., Nizio, K.D., Rai, T., Stuart, B.H., Forbes, S.L., 2015. Investigating the sensitivity of cadaver-detection dogs to decomposition fluid. J. Forensic Identif. *65* (6).

Buis, R.C., Rust, L., Nizio, K.D., Rai, T., Stuart, B.H., Forbe, S.L., 2019. Investigating the sensitivity of cadaver- detection dogs to aged. Diluted Decompos. Fluid. J. Forensic Identif. *69* (3).

Bunker, P. (2023). *Specific Oil Detection Canines- Shoreline Survey's Latest Friend.* Proceedings of the 44th AMOP Technical Seminar]. Environment and Climate Change Canada, Ottawa, ON, Canada.

Bunker, P., Owens, E., 2023. Specific Oil Detection by Oil Detection Canines. Owens Coastal Consultants,, pp. 1–17.

Cristescu, R.H., Foley, E., Markula, A., Jackson, G., Jones, D., Frère, C., 2015. Accuracy and efficiency of detection dogs: A powerful new tool for koala conservation and management. Sci. Rep. *5* (1), 8349. https://doi.org/10.1038/srep08349.

Fingas, M., 1995. Evaporation of crude oil spills. J. Hazard. Mater.

Fukuhara, R., Agarie, J., Furugen, M., Seki, H., 2022. Nesting habitats of free-ranging Indian peafowl, Pavo cristatus, revealed by sniffer dogs in Okinawa, Japan. Appl. Anim. Behav. Sci. *249*, 105605 https://doi.org/10.1016/j.applanim.2022.105605.

Jean-Marie, B., Raphael, G., Fabien, R., Aurélien, B., Sébastien, C., Nicolas, B., Xavier, B., 2019. Excellent performances of dogs to detect cryptic tortoises in Mediterranean scrublands. Biodivers. Conserv. https://doi.org/10.1007/s10531-019-01863-z.

Lasseter, A.E., Jacobi, K.P., Farley, R., Hensel, L., 2003. Cadaver Dog and Handler Team Capabilities in the Recovery of Buried Human Remains in the Southeastern United States. J. Forensic Sci. *48* (3), 2002296. https://doi.org/10.1520/JFS2002296.

Overton, E., Wade, T., Radovic, J., Meyer, B., Miles, M.S., Larter, S., 2016. Chemical Composition of Macondo and Other Crude Oils and Compositional Alterations During Oil Spills. Oceanography *29* (3), 50–63. https://doi.org/10.5670/oceanog.2016.62.

Owens, E.H., Bunker, P.C., 2022. Canine Detection Teams to Support Oil Spill Response Surveys. Canine: The Originial Biosensors, 1st ed. Jenny Stanford,, pp. 705–756.

Payne, J.R., McNabb, G.D., 1984. Weathering of petroleum in the marine environment. Mar. Technol. Soc. J. *18* (3), 24–42.

Reed, S.E., Bidlack, A.L., Hurt, A., Getz, W.M., 2011. Detection distance and environmental factors in conservation detection dog surveys. J. Wildl. Manag. *75* (1), 243–251. https://doi.org/10.1002/jwmg.8.

Rust, L., Nizio, K., Wand, M.P., Forbes, S.L., 2018. Investigating te detection limits of scent-detection dogs to residual blood odour on clothing. Forensic Chem. *9*, 62–75.

Wang, Z., Fingas, M., 1995. Study of the effects of weathering on the chemical composition of a light crude oil using GC/MS GC/FID. J. Micro Sep. *7* (6), 617–639. https://doi.org/10.1002/mcs.1220070609.