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Training and maintaining the performance of dogs (*Canis familiaris*) on an increasing number of odor discriminations in a controlled setting

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Abstract

The number of substances detector dogs are trained to detect varies depending on the mission of the agency they serve. No studies have been conducted concerning how training multiple odor discriminations affects detection performance and refresher training requirements. This study used a controlled field setting to examine the effects of training dogs to detect multiple substances on their subsequent detection performance and refresher training requirements. Dogs were first trained to detect a single odor. Their detection performance was tested 10 days later and refresher training was then given to bring their performance back up to a predetermined standard. Following refresher training, detection of a new substance was trained, and approximately 10 days later the detection of both trained substances was tested. This sequence of testing, refresher training, and new odor training continued every 10 days until the dogs had been trained and tested on 10 odors. The detection of previously learned odors did not decrease as the number of substances trained increased. In fact, the amount of training required to refresh detection performance and to train new odor discriminations tended to decrease as more odor discriminations were trained.

Keywords: Detection dog; Odor discrimination; Refresher training; Olfaction

1. Introduction

The detector dog and its handler constitute a technology that plays a major law enforcement role in the detection of a wide variety of substances, including explosives,

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illicit drugs, other contraband, and land mines, as well as identification and location of criminals, disaster victims, and missing persons (Technology Against Terrorism, 1991). Detector dog-handler teams are currently employed by a multitude of national and local law enforcement agencies, private organizations, and militaries throughout the world. Although dogs seem to be remarkably effective at detecting a variety of targets, little is known about how they accomplish detection tasks or the effectiveness with which they do so. Similarly, little is known about how to optimize their performance.

In order to fully evaluate the effectiveness of this technology, integrate it with other technologies, understand its limitations, and further its development, detector dogs must be subjected to the same level of scientific scrutiny as other detection technologies, which are typically thoroughly understood and documented. Considering the widespread reliance on detector dogs, a thorough understanding of their capabilities, limitations, and behavioral mechanisms underlying detection performance is required. The limited literature concerning detection dog performance consists of studies describing basic olfactory capabilities and field demonstrations.

There have been only a few laboratory studies directed at determining the sensitivity of the dog's olfactory system. For instance, Ashton et al. (1957) and Moulton et al. (1960) reported olfactory detection thresholds for eight fatty acids. Krestel et al. (1984) reported absolute olfactory thresholds for unverified dilutions of amyl acetate using a conditioned suppression procedure. Additionally, Moulton and Marshall (1976) reported psychometric functions for dogs detecting alpha-ionone. For many years, the only reported work examining the sensitivity of dogs to explosives was a study conducted by Becker et al. (1962). More recently, Johnston et al. (1995) and Waggoner (1997) generated psychometric functions describing the detection of smokeless powder by mixed breed dogs. Finally, Williams et al. (1997, 1998) determined the odor detection signature for a number of explosives.

Some researchers have examined aspects of dog olfaction other than sensitivity. For instance, Allen (1936) used an avoidance procedure in an attempt to classify some stimuli as pure olfactory stimuli and others as both olfactory and trigeminal stimuli. Brisben and Austad (1991) conducted a discrimination experiment in which dogs learned to discriminate the scent of different humans when the scent was acquired from the humans' hands. However, when the scent source was the crook of the arm dogs failed to discriminate between humans. Finally, there have been some studies examining the role of canine olfaction in pet-owner relationships (Filiatre et al., 1991; Filiatre et al., 1990).

Field studies of detection dogs have largely been limited to demonstrating the utility of dogs as detectors of various substances. For instance, Skovronek et al. (1987) demonstrated the feasibility of using dogs to assess the effectiveness of heavy equipment decontamination after use at a hazardous waste site or spill and for detecting leaking storage tanks. Arner et al. (1985) also reported limited success in using a dog to delineate a toxic area. After conducting field and laboratory work, Ashton and Eayrs (1970) concluded that dogs were of limited use in detecting buried objects. In an extensive study, however, Nolan and Gravitte (1977) reported on the efficacy of using dogs to detect mines under a variety of climatic conditions. Finally, Furton et al. (1996) demonstrated that cocaine detection dogs would alert to methyl-benzoate, a compound produced by the hydrolysis of cocaine.

These laboratory studies and field demonstrations leave a broad array of yet-to-be addressed issues. Although much remains to be learned about the olfactory capabilities of dogs, operational agencies tend to be especially interested in learning about training protocols, maintenance requirements and procedures, and deployment protocols. In spite of the commonality across agencies of the basic detection task, these features tend to vary from one program to another, and are largely determined by agency missions and traditions.

The present study addressed the effects of the number of target odors dogs are trained to detect. Although dogs are clearly able to detect the odors required by different agencies, the effects on detection performance of training multiple odors for detection have yet to be examined. This study was designed to examine how dogs' detection of previously trained target odors might change as they learn to detect an increasing number of odors. The effects of training multiple targets for detection on (1) learning new targets, (2) retaining detection skills, and (3) refresher training requirements were of particular interest.

2. Method

2.1. Subjects

Two female and two male random source (pound source, unknown age), mixed breed, intact, adult dogs (Department of Lab Animal Health, Auburn University, AL) served as subjects. All dogs were maintained at 85–95% of their free-feeding body weight (to maintain the efficacy of food reinforcers) by adjusting the quantity of their daily food intake.

2.2. Experimental setting

The search task was controlled by requiring dogs to sample odors at 20 marked positions forming a 12.8 m diameter circle. Each position consisted of one 0.6 m × 0.13 m board with a handle mounted on one end centered with respect to the width of the board and oriented parallel with the length of the board and a unused paint can containing a cotton patch used as a substrate for the odor source material mounted on the opposite end (Fig. 1). The bottom of each board was coded according to the odor contained in the can. The search site was a partially grassed area fenced and visually screened to minimize distractions.

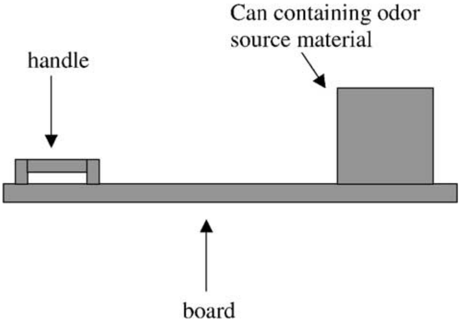

Fig. 1. Diagram of apparatus used to present odors to dogs.

Table 1
Source materials used to generate target and non-target odors

Non-target	Target
Cinnamaldehyde	Allyl sulfide
Vanillin	Isopropylbenzene
Eugenol	Dimethylthiazole
Octanol	Alpha-pinene
Hexanal	Benzaldehyde
Amyl butyrate	Menthol
Limonene	Cyclohexanone
Undecane	Eucalyptol
Alpha-ionone	Pentanethiol
Amyl acetate	Toluene
Geraniol	
Carvone	
Methyl-benzoate	

2.3. Odor source material

Table 1 lists the target and non-target odor source materials used in this study. These substances were selected since they are known to produce distinctive odors, are relatively safe (therefore easy) for humans to work with, minimize health risks to dogs, and are easily acquired in a highly pure form. Approximately 2 ml of each substance was placed on a cotton substrate. This substrate was then covered with an additional cotton patch to produce visually consistent odor sources. Cans containing these materials were closed when not in use. During preparation, each cotton patch was handled using a new pair of latex gloves. In order to avoid cross contamination of odors, each can was used only for a particular odor source material. All odor sources were prepared once a week except toluene, alpha-pinene, and methyl-benzoate, which were prepared twice a week (preparation frequency was based on suggestions made by the supporting chemistry laboratory and was largely based on vapor pressures). The quantities and preparation intervals used were designed to make the odors easily discriminable at all times during a sample's period of use.

2.4. Procedure

The sampling (nose positioned above the can) and alert (sitting) chain was trained using a single position. This response chain was initially established using visual and verbal prompts. Following the fading of all prompts, shaping was used to establish the final form of the response chain. At this point, the remaining positions were used and the discrimination was established. The training of additional targets did not require prompting or shaping, the contingencies established by the correction procedure described below were sufficient to train these discriminations.

Beef flavored jerky style dog treats were used as reinforcers throughout the experiment. All alert responses following sampling from a can with a target odor were reinforced.

Correct responses following sampling from cans containing non-target odors (continuing to the next position) were not reinforced.

A trial consisted of a dog sampling from all of 10 or 20 odor positions following the random placement of odors. Sessions consisted of a block of contiguously run trials. The number of trials within a session varied depending on the type of session being conducted. Prior to the beginning of a trial the dog and handler left the immediate area and the scorer matched the odors to positions using a list of random numbers selected prior to the session. During all trials the probability of any position containing a target odor was 0.5.

During all sessions, when the dog engaged in an alert response, the handler would query the scorer by saying, ‘‘hit?’’ If the can contained a target odor, the scorer would reply ‘‘hit’’ and the response was reinforced by the handler prior to continuing. If the response was a false alarm, the scorer would reply ‘‘no’’ and a correction procedure was followed. The correction procedure required interruption of the testing sequence and repeated sampling from the position where the error occurred until the dog walked past the position without making an alert response. Likewise, when the dog continued to walk past a target odor, the scorer informed the handler of the miss and the correction procedure was implemented requiring the dog to sample from the position until it alerted. Data collected during the correction procedure were not used for analysis.

Training sessions used only 10 of the 20 available positions. Five cans contained a new target odor (the same odor was in each can), and each of the remaining five cans contained a non-target odor. Each non-target can contained a different odor, there was no odor redundancy across non-target cans. Dogs were trained to walk from one position to the next sampling vapor from the cans, sitting after sampling a can containing the target odor and continuing to the next can after sampling a non-target odor. The scorer recorded all responses throughout each session. Following sampling from non-target cans, dogs were trained to walk to the next position without stopping. No reinforcers were given for correct reactions to non-target odors. Training sessions consisted of 5–15 trials per session and were conducted daily until each dog made no errors for five consecutive trials.

Conditions during test sessions were similar to those for training sessions. However, all 20 positions were used and the target odors consisted of all of the target odors learned to date by the dog. A session consisted of 10 such trials and only one test session was run following the completion of training to detect a new target odor.

Refresher sessions were identical to training sessions except that the target odor was one with which the dog had experience. The target odors used during these sessions were those the dog had missed during the previous test session. Refresher sessions were run with each such target odor until the dog responded with no errors for five consecutive sessions.

An average of 8 days after a training session, the dogs were tested on that odor to evaluate their detection performance. If a dog missed the target odor at least once during the 10 test trials, refresher sessions were conducted until the dog performed without any misses or false alarms for five consecutive trials. Following refresher sessions, dogs were trained to alert to a second target odor. An average of 8 days later, a test session was conducted using the first and second target odors, and this session was also followed by refresher sessions using any targets the dog missed during testing. If the dog did not miss any targets, no refresher sessions were conducted. This timed sequence of testing, refreshing, and training the detection of a new odor was continued until the final test session included 10 target odors. The participation of subject 6548 was terminated after testing a maximum of nine odors due to health problems not associated with this study.

Because test sessions consisted of only 10 trials, a test session could be completed in 1 day. However, because the termination of refresher and training sessions was performance based, training each new odor took an average of 2 days and refresher training took an average of 2 days following each test. It is important to note that although the total number of positions containing target odors remained constant at 10 across all test sessions, the number of opportunities to contact a particular target odor decreased as the number of target odors trained increased to 10.

Throughout the experiment, one of the non-target odors used in a session was not used in the previous session for the subject.

The list below summarizes the sequence of session types. This sequence is repeated until the dog has been trained to detect a total of 10 target odors. As can be seen from this sequence, the earlier an odor is trained in the procedure, the more test sessions containing this odor the dog was exposed to. Therefore, the first odor was subjected to a total of 10 test sessions throughout the duration of the study while the last odor trained was tested only once.

(1) Train an odor to criteria.
(2) Test all trained odors (single 10 trial session).
(3) Refresh all odors that produced errors (individual sessions for each odor).

Data were evaluated for individual dogs and then averaged across all dogs to produce the figures presented. Additionally, regression analyses were used to evaluate the relationships between the number of odor discriminations trained and (1) test performance (defined by percent hits and percent false alarms), (2) the number of trials required to train each odor discrimination, and (3) the number of refresher trials per odors needing refreshing. Additionally, descriptive measures examining the cumulative number of trials required to both train an increasing number of odors and to re-establish performance to criteria were compiled.

3. Results

Fig. 2 shows overall detection performance across odors, and no systematic changes in hits or false alarms (averaging across odors trained) are evident as a function of the number of target odors trained (target odor discriminations were trained in the sequence as listed in Table 1). A regression analysis indicated no significant relationship between the percent of hits and number of odors tested ($R^2 = 0$ and $P = 0.88$). Likewise, a regression analysis indicated no significant relationship between the percent of false alarms and number of odors tested ($R^2 = 0.02$ and $P = 0.73$).

Fig. 3 shows the mean number of trials required to teach each new target odor. In general, the more target odors the dogs had learned to discriminate from non-target odors, the fewer training trials were required. This is particularly evident when comparing the number of trials required to train the first four or five odors with the number of trials required to train the last four or five odors. The number of trials required to train the allyl sulfide

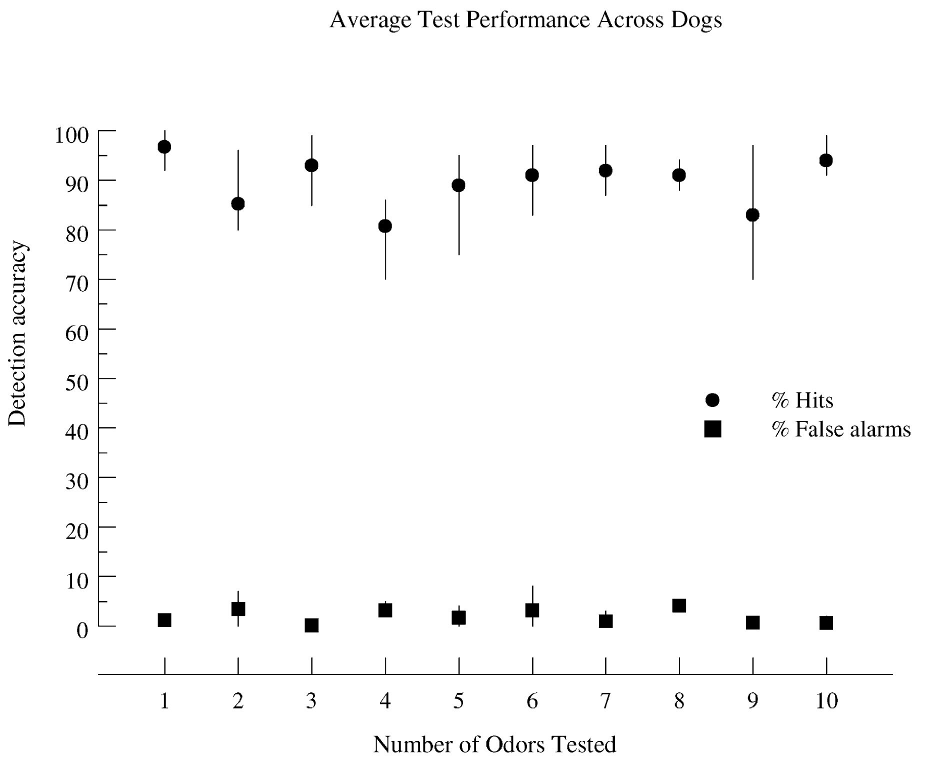

Fig. 2. Mean percentage of hits and false alarms during test sessions by dogs trained to detect in an increasing number of odors. Bars indicate range of performance from all dogs.

discrimination to criteria was omitted because this odor was used in pretraining naïve dogs and includes training the search task as well as the odor discrimination. The odor discriminations shown in Fig. 3 required a total of 215, 166, 129, and 173 trials for subjects 6548, 7910, 8013, and 6561, respectively. However, as a gross measure of rate of completion, the first four sessions accounted for 75, 62, 64, and 68% of the total training trials required for subjects 6548, 7910, 8013, and 6561, respectively. In other words, more than half of the total training trials required across all odors were accounted for before any individual dog was trained to detect half of the odors. A regression analysis indicated that the relationship between the number of trials required to reach the criteria and the number of odor discriminations trained was significant ($R^2 = -0.53$ and $P = 0.03$).

Fig. 4 shows the amount of refresher training required by depicting the mean number of refresher trials needed to meet criteria per odor needing refreshing across tests. As shown in Fig. 4, there was no increase in this value as the number of odor discriminations trained increased. Subjects 6548, 7910, 8013, and 6561 required a total of 65, 55, 46, and 78 refresher trials per odor needing refreshing, respectively. Two subjects, 6548 and 8013, completed slightly more than half of the cumulative value (57 and 64%) of refresher trials per odors needing refreshing after the fourth series of refresher trials. Subjects 7910 and

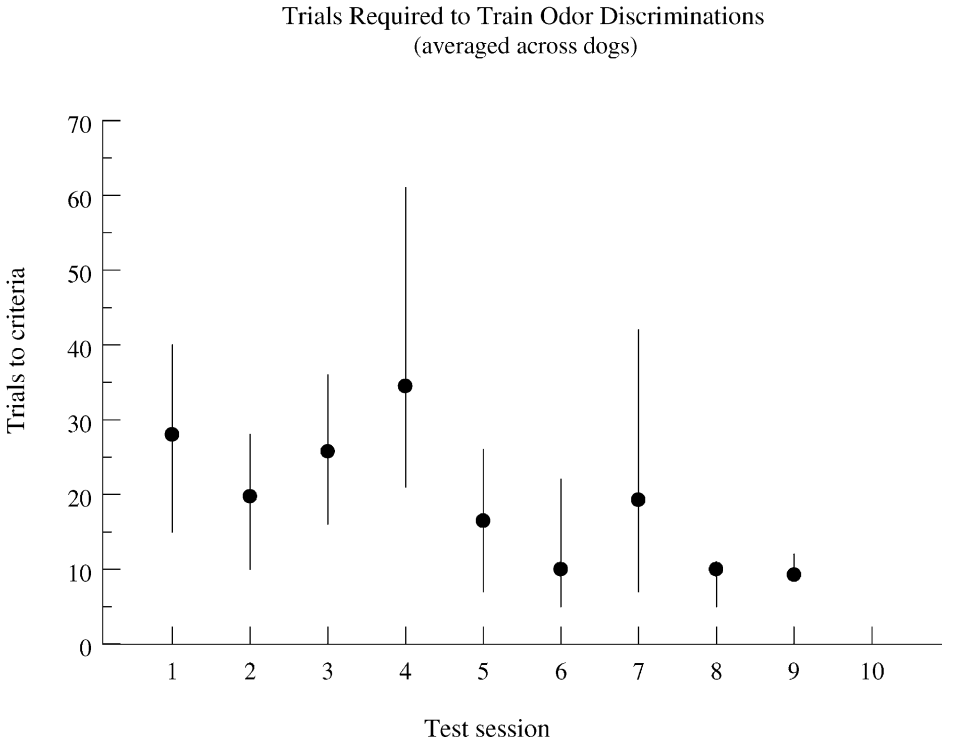

Fig. 3. Mean number of trials required to train each new odor discrimination. Bars indicate range of performance across dogs.

6561 completed 41 and 54%, respectively, of the refresher trials per odor needing refreshing after the fifth series of refresher trials. Therefore, only one subject (7910) showed a slight increase in the number of refresher trials required per odors needing refreshing during the final half of the experiment. In other words, as the dogs learned an increasing number of targets, the overall amount of refresher training required did not increase but did exhibit a decreasing trend in two cases. With data averaged across dogs, the regression analysis showed a significant relationship (negative correlation, $R^2 = -0.52$, $P = 0.03$, and data from the first test excluded since no refresher training should be expected).

The proportion of positions containing a target odor was held constant at 0.5 to decrease the biasing effects of target stimulus presentation. This left the opportunity for detection performance throughout the course of a trial to increase as a function of the handler or dog's local experience of target and non-target density. To determine the possible effects of maintaining a constant number of targets from trial to trial on detection performance, the percent of correct responses at each position was calculated across all tests for individual dogs. A regression analysis of the percent of correct responses as a function of the number of positions sampled using data from individual dogs and collapsed across dogs did not test significant (alpha = 0.1).

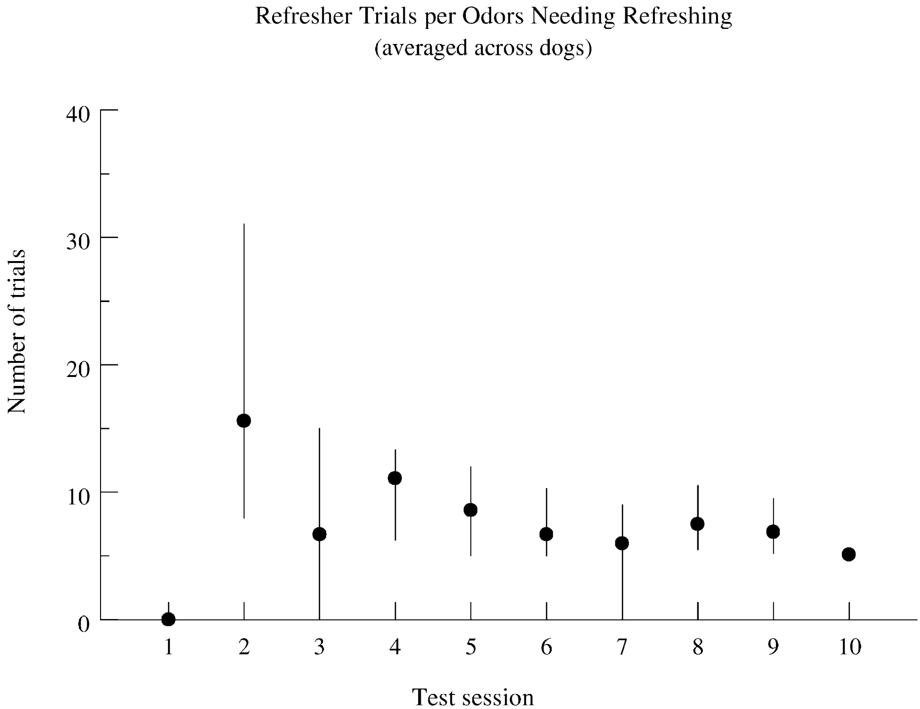

Fig. 4. Mean number of refresher trials per odors needing refreshing as additional odor discriminations were established. Bars indicate range of performance from all dogs.

4. Discussion

The present findings show that training dogs to detect as many as 10 odors in a fixed search scenario did not approach the point at which detection performance began to deteriorate. Indeed, whether a new odor discrimination was the second, fifth, or ninth mastered had no consistent impact on detection performance. Dogs also tended to learn additional odors with increasing ease, as shown by the decreasing number of trials required to train new odors. Finally, it is notable that the amount of refresher training required to maintain performance not only did not increase as the number of odor discriminations mastered increased but decreased for three of the dogs.

Given that the findings show that the odor detection capabilities of these dogs were not challenged by the conditions of this study, it should be noted that the conditions of this study required a more difficult set of olfactory discriminations than detector dogs normally face in deployment scenarios. Although dogs from some agencies are required to detect 10 or more odors, they are not required to discriminate those odors from a changing set of 10 specific other odors under otherwise static conditions.

Finally, unrelated to the focus of the study, the reasons for alternating across sessions the non-target odors used is worthy of elaboration. As described previously, the set of odors comprising the non-targets used during a session was changed between sessions for a single subject such that one of the non-targets being used one non-target odor was changed in each session. During early training sessions, as novel non-target odors were introduced, one subject's (6548) initial response to non-targets indicated that the discrimination responses established could be based on the target odors, the non-target odors, or both. She was the only subject that, when a novel odor (intended by the experimenter's as a non-target odor) was introduced, engaged in an alert response after the first sampling response. In essence, she demonstrated that without a sufficiently large or varying stimulus class of non-target odors, the discrimination being learned was walking past non-target odors following sampling and sitting following sampling from any other odor. However, the remaining subjects' first response following sampling novel odors was to sit, indicating that the alert response was based on individual stimuli comprising the target odor stimulus class. Since this is the kind of discriminative responding that mimics working detection dogs, additional non-target odors were introduced until a sufficiently large or varying stimulus class was established and the subject's first response to these odors was to walk past it. In order to maintain sufficient experience with the stimuli comprising this stimulus class (all non-targets could not be used within a single session), a non-target odor was changed between consecutive sessions for a single dog.

These findings have practical implications for training and maintaining the odor detection skills of dogs. They confirm under controlled conditions what trainers and handlers may have long known—that dogs can master at least 10 odor discriminations with ease. The results also suggest that this requirement does not have detrimental effects on refresher training requirements. These data also provide general support for the usefulness of the dog as the basis for an effective detection technology.

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