Chapter 5
Odour detection: the theory and the practice

Part 1

How do dogs detect landmines?

A summary of research results

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Summary

- The odour discrimination skills of dogs considerably exceed the abilities of laboratory machines used in attempts to investigate those skills, limiting the ability of researchers to study the skills and limitations of dogs for detection of mines.
- Dogs clearly learn to detect mines using the odour of explosives and other chemicals leaking from mines.
- The availability of odour to dogs varies in complex ways with the environment in which the mine occurs. Influences include soil types, soil moisture, activity of micro-organisms, and climatic variables.
- Dogs are able to discriminate extremely faint signals (target odours) against a very noisy background (masking odours).
- Dogs are able to learn to discriminate up to ten odours without difficulty — the limits to the number of odours that can be learned have not been explored.
- Learned discrimination skills are retained for up to 120 days by dogs that are not operational. The longevity of detection skills of operational dogs may be influenced by operational experiences, and this result should not be used to justify a reduction in maintenance training for discrimination skills.
- Leakage rates vary amongst different mines. It is likely that the availability of odours from at least some mines drops below the detection threshold of dogs at least some of the time. This problem requires further research.
- Generalisation from learned discrimination odours to related but somewhat different odours (e.g. TNT from another production source) was not reliable.
- Dogs are able to use many of the contamination, degradation, and other products which occur naturally in TNT, and the actual odours used by any particular dog to detect a mine cannot be known or predicted from the training programme.

- Training programmes for dogs should include experience with bouquets from mines in a deployment theatre, even if the main training programme uses TNT exclusively. Such experience should be updated regularly using a maintenance training programme.

Introduction

The use of dogs for demining purposes began in the 1939-45 war, but dogs have only become established as a significant contributor to the global humanitarian demining effort in the last few years. Today, more than 750 dogs are used in humanitarian demining programmes in some 23 countries.

The main advantages of dogs are that they can verify suspected land faster than manual (i.e. human) demining teams, they offer a relatively low-tech and flexible option in difficult post-war situations, they can find mines with little or no metal content, and they can work in situations where large amounts of metal debris prevent the use of standard metal detectors.

Despite the increased deployment of mine detection dogs in the field, little is known about the processes by which they detect mines. A dog's powerful sense of smell, known as the olfactory ability, is many times better than that of a human. The olfactory centre in the brain of a human is about 40 times smaller than for an average dog. When an odour, consisting of molecules, lands on membrane tissue within the nose, information about it is gathered, processed, and sent to the brain. The type and number of molecules actually required by dogs to identify landmines are not known, and this lack of knowledge negatively effects the training and deployment of mine detection dogs (MDDs).

Today, there is still considerable reliance on tradition and folklore in the vocation of canine detection, and most agencies have different approaches to the training of MDDs. It has to be kept in mind that search dogs trained for roles other than hunting are not seeking odours of natural (or intrinsic) relevance. Rather, the handler / trainer has linked the natural tendency of the dog to search for intrinsic rewards to unnatural target odours, using operant conditioning procedures. Operant conditioning produces an animal that will search for any cues that produce reinforcement (Lieberman, 2000). The challenge for trainers and handlers is to know which cues the operant conditioning should best be based on. With respect to landmines, it is self evident that these cues should be odours from the mine that are most easily detected by the dog and are consistently present in the air or on the soil surface. To identify those cues, researchers address issues arising from the following broad questions:

1. Which substances found in landmines can dogs detect, in what concentrations do they detect them, and how do environmental factors affect their ability to detect these substances?
2. Which of the many chemical substances contained in a mine are actually available in the air above a mine or on the soil surface?

Aim

The aim of this report is to provide a non-technical summary of existing results that address the above two questions and to comment on application of these results to the training and deployment of mine detection dogs. Some preliminary recommendations are made in the conclusions, but it is too early for firm recommendations to be made. The information used comes mostly from published and unpublished research results at Auburn University (*www.vetmed.auburn.edu/ibds*), the U.S. Army Corps of Engineers (*www.usace.army.mil*) and Sandia National Laboratories (*www.sandia.gov*). A detailed technical review is in Chapter 5, Part 2.

Canine olfactory capabilities and characteristics

This chapter summarises results of research that concentrated on identification of substances from landmines that are detectable to dogs. A major centre for such research is at the Institute for Biological Detection Systems (IBDS) at Auburn University in Alabama / U.S.

TNT (Trinitrotoluene) is one of the most common explosives found in landmines — it occurs in approximately 80 per cent of all mines. However, explosives that are based on TNT contain by-products other than pure TNT, primarily impurities and degradation products such as DNB (Dinitrobenzene) and DNT (Dinitrotoluene). When a trained dog detects the explosive TNT, handlers do not know which of these (or other) compound(s) the dog is responding to. In other words, the handler knows that the dog detects what it is trained to detect, but it is unknown which specific vapour (or combination of vapours) the dog uses to recognise TNT. Dogs are thus deployed in very important detection roles without a clear understanding of which stimuli control their alert responses.

To explore the sensitivity of dogs to different chemical components of TNT, the IBDS made specific observations on dogs trained to identify odour from military grade TNT in experimental chambers (Fig. 1).[1] One compound, 2,4-DNT, gave the most consistent response across all dogs studied, followed by 1,3-DNB (Cicoria, 1999). Following this experiment, the sensitivity of dogs to decreasing concentrations of 2,4-DNT was tested, using the same experimental set-up and five dogs. The result was that the sensitivity of the dogs for odour with 2,4-DNT declined rapidly in a region between about 200 parts per-trillion (ppt) and 1000 ppt[2] (Johnston, 1998). These sensitivity estimates approach the limits of current technology for independent measurement of such minute chemical samples (about 1 ppt, J. Phelan, pers. comm.). Dogs are now known to be able to do much better (J. Phelan, unpubl.).

To relate their results to a more natural situation, researchers at the IBDS conducted an additional test, again in the same test chamber. Those dogs that had been trained on TNT were now also tested on various other constituents of landmines, including plastic case uncontaminated with TNT.[3] Again, DNT generated the most consistent response from the dogs. The plastic case was not used as a detection cue by the dogs in this experimental preparation, as its vapour evoked little response (P. Waggoner, pers. comm.).

In a natural situation, the dog must distinguish the odour of TNT or DNT from many other odours extraneous to the target odour. In so-called “masking experiments” at the IBDS, again in the same experimental chambers, target odours were presented to the dogs in combination with numerous other substances. The results indicated that dogs detect very low relative concentrations of target odour in the presence of strong masking odours (Waggoner *et al.*, 1998). At a target odour concentration of about 1 ppb, the concentration of the masking odour needed to be at about 20 ppm before detection performance began to be affected (a ratio difference of more than 3 orders of magnitude, or one in 1,000). Even then, the effect was a decline in performance, not a complete loss of detection skills. As with experiments on detection thresholds by Phelan and Barnet (unpubl., pers. comm.), considerable variation was found among individual dogs.

The researchers investigated time delay (or “forgetting”) in their ability to retain a conditioned discrimination skill without refresher training. There was very little loss of learned discrimination skills after delay periods ranging from 14 to 120 days (Johnston *et al.*, 2000).[4] This result is promising, but the dogs were not operational, so were not receiving regular (i.e. daily) reminder training (whether intended or otherwise) of learned discriminations. It is therefore not appropriate to assume that

1. Methodology: Five random source dogs from animal shelters, medium to large in size, were trained to detect TNT. They worked in an experimental chamber (Skinner box) in which they sampled from an air stream. They then indicated whether they smelled the odour from TNT or clear air by pressing different levers. This performance was trained and maintained by delivery of food for correct responses and a brief blackout of chamber illumination for incorrect responses. To assess which constituents of the vapour from TNT contributed to detection by dogs, individual constituents found in the vapour of TNT were presented to the dogs.
2. 100 ppt approximately equals 1 nanogram per litre, another commonly used unit.
3. The dogs were tested on: DNB, mixtures of DNT and DNB, vapour generated from the landmine plastic case, a landmine case with three different amounts of TNT, a block of TNT from a PMA-1A mine without the plastic case, and toluene (as control substance).
4. In these controlled field experiments, dogs were asked to walk about a circle and sample from fixed sampling positions. The data therefore describe the relationship between training intervals and remembering odour discriminations. The data do not, however, address the frequency of training required to maintain proficiency in operational searching.

operational dogs will similarly retain discrimination skills for long periods in the absence of reminder training.

Figure 1
A dog in the experimental chamber first hears a specific sound (left), sticks her nose into a glass cylinder, in which various odours are presented (middle), and then presses one of the two levers with her snout to indicate whether she had smelled clean air or the target odour (right).

Photo: Institute for Biological Detection Systems (IBDS), Auburn University.

Also of interest was that dogs could easily be trained to detect up to 10 different odours with no indication of a decline in odour discrimination performance when this number was learned. Ten odours was the maximum attempted in the experiment and it seems likely that some or even many more odours could be trained (Williams *et al.*, 1997).

In another experiment at the IBDS, again in the same experimental chamber, dogs were trained on American TNT after which their ability to detect TNT from other countries was tested.[5] All five dogs detected Chinese TNT, four dogs detected re-crystallized American TNT, but only two detected a PMA-1A landmine (which contained mainly TNT; Cicoria, 1999). Currently, the same research institute is repeating this experiment in their controlled field set-up, where dogs sniff TNT from different countries or manufacturers in a circle with fixed sampling positions. The first results indicate that dogs do not readily detect variants of TNT other than that on which they have received explicit training (Paul Waggoner, pers. comm.). Of course, this result may be an artefact of the dogs being trained to detect a specific variant of TNT in a rather sterile context compared to that in which operational dogs are typically trained.

IBDS researchers also assessed how long detection dogs can work under varied conditions. Within the context of the study, they worked effectively for at least 90-120 minutes of continuous searching, which was the maximum they were trained to work for. However, environmental temperature affected dog performance — high temperatures can decrease a dog's detection capability, even if the animal is not tired and was trained to search for extended periods in areas with low target availability (Garner *et al.*, 2000).[6] It should be kept in mind that this study was carried out in the

5. Methodology: five dogs were trained on US. Mil. Spec. TNT and then tested on the following other three types of TNT (apart form a control): (1) re-crystallized Mi. Spec. TNT from the U.S.; (2) TNT produced in China and (3) on a PMA-1A landmine from the former Yugoslavia, which contains mainly TNT.
6. In this study, five trained detection dogs were deployed in a variety of real-world scenarios, indoor and outdoor, and across a 12-month period. Their performance and physiological factors, such as heart rate and body temperature, were then compared with environmental factors, such as outdoor temperature and humidity. High outdoor temperature related to decreased detection performance in two of the dogs. The total search duration weakly related to the number of false alarms, but was not related to the probability of detection.

high humidity of Auburn/Alabama, where the climate is not representative of the dryer heat typical of many countries in which mine detection dogs are deployed. It appeared that humidity had little effect on dog performance, but there were too few days with a combination of high humidity and high heat to adequately assess the effects of these two environmental factors separately (P. Waggoner, pers. comm.).

What substances from landmines are available to the dogs?

The previous section summarised results on the substances from landmines that dogs seem to use as identification cues, and under which conditions they work best. But such knowledge has little value unless it is known what substances from a mine (henceforth simply called “mine substances”) are available to the dogs in a real minefield. Investigating the availability of chemicals offers a good hint on what mine substances dogs may use as detection cues.

The next two sections address the following issue: Do the chemical characteristics of various mine substances (vapour pressure, diffusion, etc.) predict how likely these are to be present in the air or on the soil surface? Or in other words: Can we predict the likelihood of mine substances finding their way to the dog’s nose from their chemical “behaviour”? Linked to this problem is the effect of environmental factors, such as rainfall, on the “behaviour” of mine substances. Finally, which substances are available to dogs in the air or on the soil surface above landmines?

Chemical characteristics of substances found in mines

Table 1 gives a list of substances found in some of the most commonly used military explosives: TNT, DNT and RDX are present in almost all explosives.

The table tells only part of the story, and it is not appropriate to suggest that the substances most consistently present for dogs will be those that are most abundant in the vapour phase on these measurements, i.e. those with the highest vapour pressures. Availability for the dog depends on the combination of source release rates, and degradation and phase partitioning (including vapour pressure, water solubility and soil sorption) in soils. For example, 1,3-DNB has a high vapour pressure, but leakage is low and it does not sorb well to soils (Leggett *et al.*, 2001). Nor is it routinely found in measurements of the air above mines. The energetic materials in an explosive (TNT, RDX) have a much lower vapour pressure than, for example, the impurities DNT or DNB (Williams *et al.*, 1998).[7] Whether they are also less likely to be present in the vapour above a mine than the other substances depends on local circumstances, including how long the mine has been buried.

Fig. 2 shows that the transport of TNT or DNT from a buried landmine to the surface depends on various physical processes, such as diffusion, partitioning and evaporation (Webb and Phelan, 2000; Phelan and Barnett, 2001; Phelan *et al.*, 2001a). These processes are strongly affected by three factors: soil composition, temperature and soil moisture.

7. The following list gives vapour pressures for various substances found in landmines, as obtained from Williams *et al.* (1998). All values are given as Ng/L: RDX: 0.04, PETN: 0.09, HMX: 0.38, 2,4,6-TNT: 70, 2,4-DNT: 1440, 1,3-DNB: 1840. These values can change with temperature (Furton and Myers, 2001).

TNT and DNT are likely to be transported more slowly to the soil surface in dense clay compared to loose sandy soil due to sorption (Phelan and Barnett, 2001; Phelan *et al.*, 2001b). The colder the soil temperature, the less vapour is produced at the soil surface (Phelan and Barnett, 2001; Leggett *et al.*, 2001). Soil moisture affects the vapour levels of TNT and DNT in three ways. With dry soils, sorption is high and vapour levels are depressed. Upon wetting, the water displaces the TNT or DNT from the soil surfaces, causing much greater vapour levels (up to 10,000 times). However, with continued wetting (rain), the water will wash sorbed TNT or DNT from the soil surface, again decreasing the vapour levels (J. Phelan, pers. comm.).

Table 1
Typical compositions of some common military organic high explosives

Military explosive	Main composition
C-2	RDX + TNT +DNT +NC + MNT
C-3	RDX + TNT + DNT + Tetryl + NC
C-4	RDX + Polyisobutylene + Fuel oil
Cyclotol	RDX + TNT
DBX	TNT + RDX + AN + Al
HTA-3	HMX + TNT + Al
Pentolite	PETN + TNT
PTX-1	RDX + TNT + Tetryl
PTX-2	RDX + TNT + PETN
Teryol	TNT + Tetryl

Table from Furton and Myers (2001).

Figure 2
Chemical processes that affect TNT distributions around buried landmines or UXO

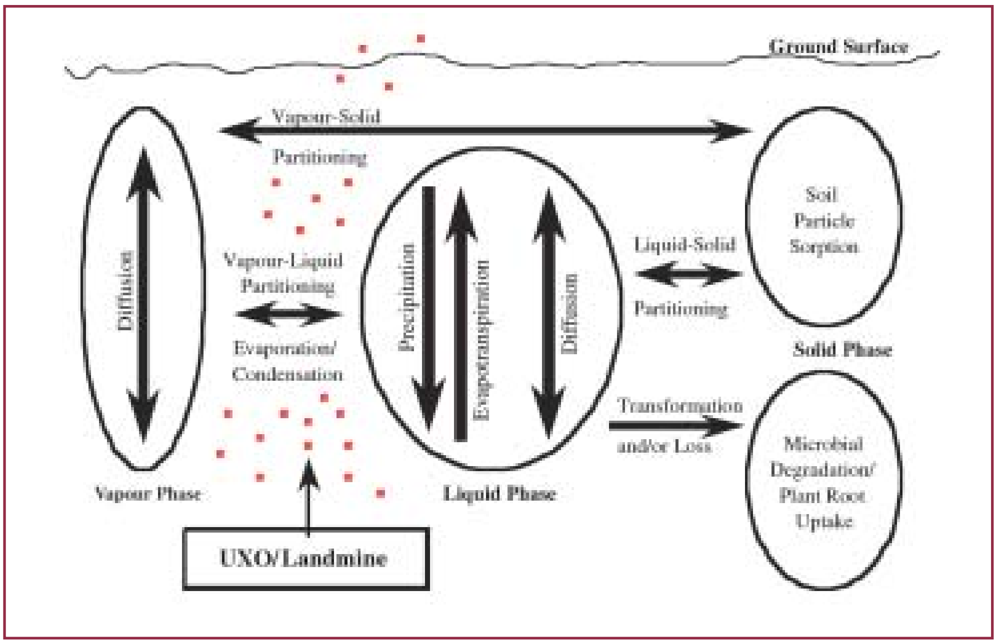

Figure reproduced from Phelan and Barnett (2001).

An additional conclusion from these results is that the strongest smell of a landmine does not necessarily have to be present directly above the mine. If, for example, heavy clay soil or a stone is situated above the mine in the ground, but there are other soil types to the side, the TNT and DNT molecules might be transported laterally, especially if there is a downslope component. They may then reach the surface at some distance from the point directly above the buried mine (M. Krausa, pers. comm.).

Environmental factors also affect another important process: the so-called biotransformation. TNT is not a stable substance, and TNT that leaks from a mine into the ground may be transformed into other, closely related substances. The half-life of mine substances (that is the time after which half the amount has been transformed into other substances) was determined as follows: 1.3 days for 2,4,6-TNT, 9.9 days for 1,3-DNB, 18 days for 2,6-DNT, and 26 days for 2,4-DNT (Miyares and Jenkins, 2000).[8] These values can vary, as the biotransformation of TNT is affected by temperature, moisture and the presence of certain microorganisms, which mediate the transformation (Karg and Koss, 1993; Phelan and Webb, 1998). Dry soil conditions, for example, limit biotransformation and allow accumulation of explosive residues on soils adjacent to the mine (James Phelan, pers. comm.).

Presence of mine substances in soil and vapour

Presence in the soil

Researchers from the U.S. Army Corps of Engineers measured TNT, DNT and DNB concentrations in the soil at various distances from a buried landmine. It became obvious that the highest concentrations of all three chemicals were found under the mine (Table 2). The closer to the surface that samples were taken, the less chemical was available, and nothing was detected in many samples (George *et al.*, 2000). TNT was rarely detected (using laboratory detection systems) on the soil surface or up to 5 cm depth.

Table 2
Concentrations of substances found at different distances from a TMA-5 landmine buried in 20 cm depth

Substance	Concentrations at various distances from a buried TMA-5 landmine (ug/kg)				
	Soil surface	0-5 cm	5-10 cm	10-15 cm	Under mine
2,4,6-TNT	<d	<d	10	8	873
2,4-DNT	52	6	17	150	5480
2-ADNT	49	14	28	207	3428
4-ADNT	41	14	29	163	2802
1,3-DNB	<d	<d	<d	<d	524

<d = not detectable (concentrations too low).
ADNT = Amino-DNT (an environmental transformation product of 2,4,6-TNT)
Table reproduced from George *et al.*(2000).

8. A series of 5.0-g replicate portions of soil from a research minefield at Fort Leonard Wood, Missouri, was fortified with 2,4,6-TNT, 2,4- and 2,6-DNT, and 1,3-DNB at about 0.5 mg / kg. Replicates were held at one of three temperatures (22 ± 2, 4 ± 2, or –4 ± 2°C) in the dark for periods ranging from 4 hours to 30 days and were then extracted with acetonitrile. The extracts were analysed by reversed-phase HPLC to estimate the concentrations of the parent compounds and any detectable transformation products remaining. The values presented here were obtained at 22°C; at lower temperatures the half-lives were considerably longer.

In the same study, the U.S. Army Corps of engineers collected more than 1,000 soil samples at the surface and at depth near buried TMA-5, TMM-1, PMA-1A, PMA-2, and Type 72 landmines.[9] Again, the chemicals detected most often on the surface were 2,4-DNT and two types of ADNT(2- ADNT and 4-ADNT). 2,4,6-TNT was mostly found around the buried mine, but not on the surface (Jenkins *et al*., 2000). An additional result of this study was that the concentrations of the chemicals were much higher around TMA-5 and PMA-1A landmines (which have holes or gaps in the casing) than around TMM-1 and PMA-2 mines (which are well sealed).

Research by the US Army Corps of Engineers also showed that the type of soil that mines are buried in has to be considered: the surface of sandy soil contained much more DNT and DNB than the surface of clay soil (which has higher sorption), and TNT was only detectable in sandy soil in very low concentrations. Additionally, vapour concentrations of these chemicals were much lower in dry conditions than after rain — light rainfall therefore facilitates movement of vapour to the surface (Jenkins *et al*., 1999), although heavier rains can have a flushing effect which removes mine substances.[10]

Presence in vapour

Two research organisations have sampled the vapour above buried landmines: samples were taken in Bosnia and Herzegovina and Cambodia by the Swedish research organisation FOI (A. Kjellström, pers. comm.; Kjellström and Sarholm, 2000), the other samples were taken in the U.S. (P. Waggoner, pers. comm., and at *www.vetmed.auburn.edu/ibds/frame.htm*). Neither detected TNT in the samples. In Bosnia, FOI found 2,4-DNT and 2,6-DNT, and in Cambodia they found these substances and also amino-DNT. In the U.S., the vapour above the landmine also seemed to contain only various forms of DNT and DNB, but not TNT. Both authors concluded that the sensitivity of the analytical methods was not high enough to detect any traces of TNT[11], a point agreed by Jenkins *et al.* (2000), who estimated TNT vapour soil concentrations from soil residues, at about 0.94 pg/L (=0.094 ppt, below detection thresholds).

The U.S. Army Corps of Engineers sealed buried landmines in bags or submerged them in water, to show that temperature affects the vapour emerging from mines (see above). These tests also showed that 2,4-DNT was the principal component of the so-called “vapour-signature” above several types of landmines (Leggett *et al*., 2001).

9. The study took place at a research minefield at Fort Leonard Wood, Missouri, in 1998 and 1999. Soil samples were extracted with acetonitrile and analysed by GC-ECD for nitroaromatic, nitramine, and aminonitroaromatic compounds.

10. The vapour was sampled above buried military grade TNT for one minute, in three types of soil (sand, silt and clay) and at three different levels of air moisture (dry, 2.1% and 3.1% moisture). Analysis after six days (storage was at 23°C) showed: in the samples from sandy soil, DNB and DNT were present in high concentrations, whereas TNT concentrations were 10-204 times lower in the three levels of moisture. In the samples from silt, concentrations of all three substances (DNT, DNB and TNT) were much lower, with again TNT having the lowest concentrations of all. In the samples from clay, only DNB was detectable (TNT and DNB not at all), and this also only in samples taken at 15% and 30% moisture (not those taken in dry air).

11. With respect to these results, there are measurement limitations to the quantities of chemicals that can be detected. Dogs clearly smell much lower quantities of mine substances than can be detected with present instruments. Mine substances are most likely present in much lower concentrations in the air or the soil than can be detected. More and more research is conducted to develop appropriate measurement apparatuses, and nowadays, a variety of analytical techniques are available for the detection of small amount of explosives. But so far, scientists cannot imitate the dog’s nose completely.

Presence on mine surfaces

The U.S. Army Corps of Engineers took chemical samples directly from the surface of four different types of landmines (Leggett *et al.*, 2000). The researchers found that in almost all samples, DNB and DNT were present in higher concentrations on the surface of all four types of mines than TNT (Table 3). The analyses also showed that the quantity of DNB, DNT and TNT varied considerably between different types of mines.

Table 3
Surface concentrations of DNB, DNT, TNT and RDX found on landmines (samples taken with a sponge from the surface of each of 4 types of mine)

Substance	Mean concentrations (ng/cm^2) found on surface of			
	PMA1A	PMA2	TMA5	TMM1
1,3-DNB	9.0	1.3	3.1	7.3
2,4-DNT	4.8	0.9	6.1	11.0
2,4,6-TNT	0.4	1.3	83.9	13.2
RDX	<d	1.2	<d	<d

<d = not detectable.
Table reproduced from Leggett *et al.* (2000).

Discussion and conclusions

One of the clearest conclusions from this summary of research results is that dogs probably routinely use substances other than TNT to locate landmines no matter with what substances they were trained. This conclusion is supported by the following results:

- TNT almost always contains various by-products of the manufacturer and decomposition products, such as DNT and DNB.
- In moist soils, all of these substances are transformed, with the rate of this so-called biotransformation depending on humidity, temperature and the presence of micro-organisms.
- Behavioural testing indicated that the constituent of TNT most likely to evoke a response in the dogs is 2,4-DNT, and not TNT itself. DNT thus seems to be important in the so-called “detection signature” for a landmine.
- TNT has a much lower vapour pressure than many of its associated contamination and decomposition products, although the effects on relative availability of TNT at the soil surface or in the air above a landmine are complex.
- Two research organisations could not detect any TNT in the air above a landmine, but detected DNT and DNB (although the relatively high detection thresholds of the machines mean that TNT was probably still available in these studies, and the Auburn result, indicating the remarkable ability of dogs to pick out weak targets from a noisy background, is relevant here).
- One study found very little TNT on the surface of two types of mines.
- In one study at the IBDS, some dogs that were trained on TNT had difficulties detecting whole PMA1A landmines.

Although some mine detection dogs are trained specifically using TNT, current results suggest that they should not be trained on TNT alone, or at least some variation in the source and quality of the TNT used is desirable. A qualification of this comment is that without laboratory support it is difficult to obtain “pure” TNT, as TNT will always contain breakdown and contamination substances. In reality, dogs trained using “pure” TNT will probably be trained on a bouquet of substances, potentially with an emphasis on DNT. Recent results from Sandia support that implication, as dogs in South Africa trained on “pure” TNT had no difficulty detecting DNT (J. Phelan, pers. comm.).

Detectability of TNT for dogs varied with its origins. Therefore, mines from different sources (or even of different batches from the same source?) are likely to smell different. As well, local climate and micro-organisms in the soil will influence odour availability. For this reason, it is advisable to train dogs in the region where they will be deployed, and to undertake regular maintenance training of detection skills.

A dog may not necessarily use the explosives in a mine (TNT, RDX, Pitric acid) and / or their impurities (DNT, DNB) as the only detection cues. A mine also consists of a metal or plastic housing, which may contain painted stainless steel, polyvinylchlorides and polystyrene. The paint itself may seal in surface contaminants which are released when the mine is first buried. Additives such as waxes, plasticizers (=softeners), solvents and oils may also be present. It is likely that all of these substances impart their own quality on the resulting vapour composition of the landmine, further supporting the principle of training dogs for bouquets of local mines, even if the main training programme uses TNT.

It also seems likely that the vapour composition of a mine will change with time, as the more volatile components such as organic solvents become exhausted. Of course, such changes may be short-term and the vapour could have stabilised by the time the mine is deployed. Research at the IBDS indicated that the plastic case of a landmine was not detected by dogs. However, some operational organisations train using mine cases from discarded mines, and the dogs find them consistently (K. Muftic, pers. comm.). Such cases presumably provide residues from TNT and related chemicals. Many organisations train specifically with TNT because it is the most universal component of landmines, the aim being to produce a dog that should find any mine in any deployment situation. “Tuning” of the dog in the deployment theatre ensures that the dog can detect the mines most likely to be found there. Such tuning can take up to several weeks, and is essentially a generalisation training that links previously trained skills to local vapour signatures. Clearly, much remains to be learned about these issues.

Unfortunately, although there is now considerable knowledge about the effects of environmental factors on odour availability, too little is known about how local climatic factors affect the detectability of landmines for dogs. The GICHD is concurrently conducting a research project in Afghanistan, and Bosnia and Herzegovina where this issue is addressed, in cooperation with the Sandia National Laboratories (U.S.), FOI (Sweden), and local operational organisations. The aim of this research is to develop guidelines about climatic conditions under which mine dog operations should be suspended, because detection thresholds are too low.

An issue that has not been resolved is the role of particles (dust) in the detection process. In dry, sandy environments such as Afghanistan, the low soil moisture decreases the availability of explosive molecules in vapour (because of increased vapour-solid sorption at the soil surface). Nevertheless mine dogs still find mines. It may be that explosive molecules are strongly adhered (or sorbed) to soil particles, which are suspended in the air by low speed winds or which are activated into motion by the sniffing action of the dog. Upon reaching the mucus in the dog's nose, where it is much more humid than outside, the combined soil particle and explosive molecule may separate, allowing the molecule to move through the mucus to the receptor cells (Chapter 2, Part 2; J. Phelan, pers. comm.).

The dynamics of this hypothesised process have not been investigated. Many explosives, and especially TNT and DNT, have a very high tendency to stick to any surface, and it is not clear how moisture adjusts the stability of that bond (M. Krausa, pers. comm.). The "sticking" principle is being exploited in the concept now called REST (Remote Explosive Scent Tracing), in which minefields are vacuumed through a filter, and the filter is offered to dogs to determine if mines are present (Chapter 2, Part 2). Again, much remains to be learned about the processes here. However, of particular relevance to dog trainers is that TNT and related molecules will easily contaminate training tools, thus cleanliness and caution are essential when producing materials for training discrimination skills.

Central to the problem of learning more about the processes affecting the detection abilities of dogs is the mismatch between the extraordinary ability of dogs to detect mines, and the technical limits to current laboratory measurement techniques. The detection ability of dogs remains better than machines by some or even many orders of magnitude. Ultimately, the only available device against which the skills of a dog can be compared is another dog. Thus truly independent measurement of odour availability, allowing experimental determination of the limits to the skills of dogs, is not yet available. And there is no reason to expect it in the short to medium term. Despite that constraint, much is being learned because of support from the dogs themselves.

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