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Remote Explosive Scent Tracing REST

Geneva International Center for Humanitarian Demining

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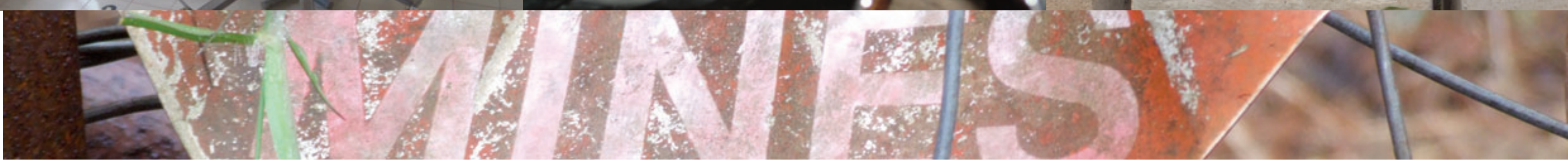
Remote Explosive

Scent Tracing

REST



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REMOTE EXPLOSIVE SCENT TRACING | REST

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FOREWORD

Remote Explosive Scent Tracing (REST) is essentially a survey methodology based on using dogs and rats to remotely detect landmines and explosive remnants of war (ERW). Systems similar to REST have been used in technical survey and mine clearance operations for 20 years, and have been subject to a study conducted by the Geneva International Centre for Humanitarian Demining (GICHD) since 2000.

At that time, REST was considered one of the most promising avenues for speeding up demining operations and making them more cost-efficient, very much in the spirit of the land release concept. The GICHD got involved in the REST project with the aim of developing a fully operational system, based on a well organised research process. It was hoped sufficient scientific evidence would enable operators to use it with a high level of reliability.

The use of animal detectors has increased rapidly, but the research to explore and understand the technology has not necessarily kept pace with this expansion, to the point where one can safely say that all variables between animals and their detection targets are fully understood. The REST project has contributed greatly to an increase in this understanding. Although the overall objective has not been reached, the increased knowledge gathered throughout the project has proved valuable in operations with dogs and rats. It has also had tremendous application for research findings outside of mine action.

The project brought together people from very different backgrounds, such as chemists, ethologists, psychologists and dog-training specialists. They worked side by side towards the same objective, ie the development of an operational REST concept.

This publication provides a summary of historical perspectives and empirical results for various research tracts explored through REST. This could not have been achieved without the support of cooperating partners, individuals, institutions and other supporters who assisted the GICHD and its contractors in our endeavours to better understand animal detection systems.

GICHD would like to thank the European Union, Germany, Japan (through the United Nations Voluntary Trust Fund for Assistance in Mine Action), Norway, Sweden, the United Kingdom, and the United States for their financial support to this programme.

We hope that it will be a useful resource for further developing and exploring this fascinating detection technology.

Ambassador Stephan Husy
Director
Geneva International Centre for Humanitarian Demining

CHAPTER 1

INTRODUCTION AND HISTORICAL OVERVIEW

by Alan Poling | Max Jones | Rune Fjellanger | Christophe Cox

INTRODUCTION AND HISTORICAL OVERVIEW

The concept of detecting explosive remnants of war (ERW) with the help of animals, known as Remote Explosives Scent Tracing (REST) is not a new one. As many as 20 years ago, a South African demining company, Mechem Consultants, began using a REST system with dogs (known as the Mechem Explosive and Drug Detection System – MEDDS) to search for ERW in Mozambique and Angola.

Mechem initially used a similar system to REST to detect explosives, illicit drugs, and weapons in enclosed vehicles or transport containers, during the years of conflict between southern African countries. The idea to use REST in humanitarian demining followed naturally. Reports of the system's accuracy and reliability were never published in the public domain. However, the method was used from 1990 to 1996, and Joynt reported it to be fast and inexpensive, and that mines which had been missed in prior searches were detected at this stage.[1]

In 1997, because of the apparent success of MEDDS, Norwegian Peoples Aid (NPA) sponsored the development of a REST programme to support their humanitarian demining activities in Angola. Mechem supplied detection dogs, sampling equipment, vehicles, and personnel, who developed the system for several months. NPA then asked the Geneva International Centre for Humanitarian Demining (GICHD) for assistance in evaluating the training of the dogs and the general methods used in the system. In response to this, the first major study of REST by dogs was conducted in 2000.

It was found that, for the most part, the accuracy with which the dogs detected samples taken from areas known to contain landmines was less than satisfactory when the system operators were blind to the number and temporal position of positive samples. Consequently, NPA suspended their planned operational use of the system in favour of conducting further research and development, and forged a relationship with the GICHD for that purpose.

The GICHD supplied the services of Dr. Ian McLean (an environmental biologist and ethologist) and Mr. Rune Fjellanger (an ethologist and dog-training specialist) to the project. This was with a view to developing more effective procedures; primarily for the analysis component of a REST system that uses animals as detectors (as opposed to a sampling component).

Fjellanger, McLean, and Anderson[3] designed and then evaluated a training programme to prepare dogs for this application. Their study demonstrated the feasibility of a defined training regime; after less than six months training, the four dogs involved learned to sit reliably while sniffing air filters containing concentrations of 2-4-6 trinitrotoluene (TNT), the explosive in most ERW. Fjellanger and his colleagues made TNT concentrations in the filters very low, as would be the case in an actual minefield.

Based on promising results with manufactured positive and negative filters, the functional utility of the system was assessed in a subsequent pilot study, using the same four dogs, but filters from test minefields in Bosnia. In this study, the dogs were presented with samples taken from areas known to contain mines, and areas that were considered mine-free. Specifically, positive samples were created by drawing air through filters with a vacuum pump in the near vicinity of landmines of three different types. These filters, together with air samples taken from mine-free areas, were then presented to the dogs in another location.

Overall, the dogs positively identified 60 of 88 of the positive filters, suggesting that their REST system was feasible, albeit in need of further improvement. This was the first data published on the practical feasibility of REST for ERW detection.

By the early years of the present century, the humanitarian demining community was in the middle of a paradigm shift, as it began to adopt the principles and practices of Land Cancellation and Release (which will hereafter be referred to as Land Release).[5] Land Release, which holds great potential for maximizing returns on the limited resources available for demining, describes "the process of applying all reasonable efforts [which are defined by the national mine-action authority] to identify or better define Confirmed Hazardous Areas and remove all suspicion of mines/ERW through Non-technical Survey, Technical Survey, and/or clearance."[6]

The promising results reported by Fjellanger and his associates, combined with the obvious appeal of REST for land release applications, generated significant interest. An accurate and reliable REST system would constitute a quick and relatively inexpensive strategy for distinguishing hazardous from non-hazardous areas, and would be a tool for quality assessment, and as such, be invaluable in Land Release operations.

In addition to cancelling non-hazardous areas rapidly, a REST system appeared quite feasible for two main reasons. Firstly, Mechem reported that they had already developed and were utilising an operational REST system.[1] Secondly, the animals in a REST system are required to perform a signal-detection task, which is fundamentally similar to the tasks done by dogs and rats in order to pin-point mines or UXO, and which have been used in known minefields (ie, direct-detection animals). Furthermore, several organisations had reported the successful use of direct-detection dogs.

The first REST workshop was held in Morogoro, Tanzania from February 8th -11th, 2002. APOPO, the sponsoring organisation, was exploring the use of giant African pouched rats for the direct detection of ERW, and wished to expand its work to REST applications. Most attendees of the conference were enthusiastic about the possibilities of REST, both in general and for minefield detection in particular. However, the challenges faced by remote ERW detection using animals were also discussed at length.

There are, however, broad and complex goals to be accomplished first, which are not easy to do. For example, as discussed in Chapter 4, researchers must establish safe and effective procedures for collecting, coding, storing, and transporting samples from the field to the laboratory, without either losing chemical traces of ERW from the positive samples, and without transferring those traces to the negative samples. They also must devise methods of presenting samples (often multiple times) to their animals. They also need to use training and testing procedures that will show the animals to be sensitive and accurate ERW detectors, when exposed to operational samples.

To be met, they require significant amounts of research where empirical evidence is sought for the utility of many procedural details. At the time of the first REST workshop, very little research had been conducted or reported, so little was known about how to achieve these goals. What was needed, it appeared, was a substantial and focused programme of research, where a number of experiments would be conducted in parallel, to optimise the various components of a REST system.

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Bach and McLean[2] summarised the recommendations of workshop delegates as follows:

"The Tanzania workshop was not in a position to make a formal list of recommendations, but it strongly supported the principle that REST will not be implemented on a broad scale, unless it is firmly founded on quality research. Not only is there still no properly structured research and development programme in place, but some of the few organisations with functioning detectors are working on shoestring budgets, and are in danger of being closed down irreversibly. Clearly, if REST is to be further developed, the industry needs to get behind it and support it at all levels, including explaining its value to the sponsors. On a more positive note, these four organisations could be encouraged to establish a coordinated analysis capacity, supporting the required research in the short to medium term, and then moving on to supporting demining operations."

In the mid-2000s, general optimism persisted in regard to the use of REST for ERW detection. For example, in 2004 McLean and Sargisson noted that, "Currently, it is being used operationally for mine detection in Afghanistan, and is likely to be implemented for road clearance in Sudan and Angola by the end of 2004."[7] They went on to describe general strategies for optimising REST, and stated that the technique could be used to ascertain the true contamination rate in a given area. Although provocative, their discussion was purely theoretical and they provided only hypothetical data.

Further evidence of enthusiasm for REST is evident in the GICHD's 2003 publication of International Mine Action Standards (IMAS) 09.43, "Remote Explosives Scent Tracing."[8] This document, and the revised version that came out in 2005, provide guidelines for an operational REST system for detecting ERW.

Regarding the detection accuracy of the animals, the 2005 Standards require each animal to achieve a minimum hit rate (HR) of 70 per cent and a maximum false alarm rate (FAR) of five per cent. The same set of samples should be inspected by at least three animals, and as a group they should achieve a cumulative HR of 100 per cent, and a cumulative FAR of less than 20 per cent. In other words, when the indications of three animals are collated, no positive samples should be missed, and no more than 20 per cent of negative samples should be indicated.

These standards clearly assume that it is possible to obtain high accuracy levels routinely, when REST is used to detect areas contaminated with ERW under operational conditions. However, in 2005, when the standards were drafted, to our knowledge there was no compelling, publicly available data that demonstrated that this level of accuracy was attainable. Despite the absence of such data, relevant research was planned and ongoing. In particular, NPA and the GICHD joined forces again to bolster research and development in regard to REST, using dogs and pouched rats.

In 2005, new facilities for studying REST with dogs were built adjacent to APOPO's rat facilities in Morogoro, and in early 2006, NPA moved its REST dogs and equipment from Lubango, Angola to the new facilities. Dr. Max Jones, a behavioural psychologist, was employed by the GICHD and appointed Director of the dog programme. Two expatriate research assistants, Ms. Yolande Dunn and Ms. Birgitte Lauritzen, and 17 local people, were also employed to staff the dog facility. Mr. Christophe Cox, a product developer, and the CEO of APOPO, together with Dr. Ron Verhagen (a biologist) headed the work with rats. In addition, a scientific Advisory Committee made up of chemists, ethologists, psychologists, and dog-training specialists, was assembled to oversee both projects.

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In 2006, Jones presented to the GICHD, NPA, and the Advisory Committee, a research proposal that offered a new and more scientific approach to the study of REST. The general aims of the proposed research were described as follows:

"First, the research aims to identify how best to develop a REST system that can be deployed for operational activity. This involves identifying best-practice methods of collecting sand/soil/dust samples from areas suspected of containing landmines, of training dogs to indicate the presence of odours emanating from landmines, of storing those samples, of presenting those samples to the dogs, and of feeding back the results of analysis to field operators. A second but related aim is to identify variables that affect the accuracy and reliability of a REST system, so as to optimise parameter values and produce a robust operational system. These variables will exist in both the sampling and analysis phases of REST, and in addition to assisting with prescribing best practice, could be cited as challenges that any organisation offering REST must address in their Standard Operating Procedures. The third aim is to conduct experiments that inform our understanding of the mechanisms underlying the effects of specific key variables."

Jones' proposal, which was readily accepted, drew on published literature regarding learning and behaviour in animals, and stressed the importance of conducting rigorous and carefully controlled research, using the methods characteristic of a field of psychology known as *Behavior Analysis*.[9] These methods, and the results of some REST studies using them, are summarised in Chapter 2.

NPA remained one of the sponsors of REST research until April 2007, when they withdrew from the project, and were replaced by the Swedish Rescue Service Agency (SRSA).

Another Morogoro REST workshop, attended by members of the Advisory Committee, took place in October of that same year. During the workshop, the Morogoro researchers described the results of various experiments they had conducted, their interpretation of those results, and their plans for further research. Attendees agreed that the project had made excellent progress in the previous 15 months, but that further and sustained progress was required, before REST could legitimately be viewed as a safe and validated method for detecting ERW.

To that end, members of the Advisory Committee and the Morogoro researchers drafted a set of recommendations for procedural changes. These changes moved the system closer to an operationally viable one, were to be evaluated for efficacy, and would be introduced singlularly, and in a timely manner. The workshop attendees also produced a prioritised list of phenomena to be investigated in experiments with dogs and/or rats. Overall, the goal of this further R&D was to "… develop procedures for training and testing animals to detect the odour of buried landmines based on scientific evidence, rather than simply experts' opinions, as has often been the case in the past."[11]

Although NPA had officially withdrawn from the project, the manager of their training centre for mine-detection dogs, Mr. Terje Berntsen, had remained on the Advisory Committee. In 2008, Berntsen (and thus NPA) provided further support for the REST project, by sending six additional dogs from its training centre in Sarajevo, Bosnia-Herzegovina. During that year, Jones and Dunn resigned from the dog project, SRSA reported financial difficulties in regard to sponsoring it, and research activities rapidly deteriorated.

Conditions actually became so bad that plans were being laid to make all local staff redundant, re-home the dogs, and donate the infrastructure to the Sokoine University of Agriculture, on whose grounds the buildings sat. However, various members of the Advisory Committee argued for the project's general worth, and in November of 2008, NPA unofficially resumed control of the dog project. With support from GICHD, the arrangement became official in April 2009. NPA retained Dr. Fjellanger to direct the project as an expatriate consultant, and Dr. Adee Schoon, who had recognised skill and experience in evaluating canine odour-detection programmes for the Netherlands police, joined as a consultant.

Fjellanger and Schoon developed a detailed plan of training and testing steps for the dogs and for APOPO's rats. Chapter 3 summarises the studies that were carried out and their findings. They also planned some analytical chemistry studies, that were to be conducted by Dr. Negussie Beyene, who was employed by the GICHD but worked in APOPO's laboratory. Chapter 5 examines how analytical chemicals can contribute to animals effectively detecting explosives.

CHALLENGES TO THE MOROGORO REST PROJECT

Looking back, various factors impeded the progress of research and development into REST, using animals. Firstly, securing long-term financial support for research was a recurrent challenge, but perhaps this isn't surprising in an industry such as humanitarian demining where immediate benefits of investments are sought, and money spent on research and development is often seen as money taken away from operational activity. Secondly, maintaining a critical mass of trained research technicians often proved difficult, and the uncertainty of project funding probably contributed to a high staff turn-over at times. Thirdly, the absence of stable, on-the-ground scientific leadership also impeded progress.

Odour-detection research with animals requires ongoing and uniform implementation of a large number of often very complex procedures. For some aspects of the research, seemingly minor departures from a detailed protocol such as sample preparation or presentation, animal training, or data recording can have a dramatic effect on the animal's performance, and as such, adds variability to those measures. This in turn makes the detection of performance changes (that come about due to changes in procedure) difficult or impossible to detect. Staff training and checks for procedural integrity are thus imperative.

In addition, careful analysis of each animal's performance measures, which are often beyond simply calculating accuracy scores, are required. These ensure that ongoing procedures can be closely monitored and altered quickly, if necessary.

However, those directing the research were either not in their positions for long periods, or else were not able to monitor activities on a day-to-day basis, because of other responsibilities. Therefore, the REST research, in regard to both dogs and rats, suffered from procedural inconsistency and more than occasional setbacks. Despite these setbacks, several studies were nonetheless conducted, producing valuable results, and are described in Chapters 2, 3, 5, and 10.

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In both remote and direct-detection applications, the training aims are to prepare animals to emit an easily observed, distinct and consistent response, known as, an indication, when, and only when, they smell ERW. This is accomplished by training them in a stimulus-discrimination task ie, *signal-detection*, in which a designated indication response, such as,stopping and scratching the ground by rats, or sitting by dogs, is rewarded only when it follows an encounter with a positive training sample, ie, that produces odours unique to ERW.

Indication responses for negative training samples, which should be identical to positive training samples except that they do not contain ERW odours, are not rewarded. Both positive and negative training samples are presented, intermixed in training sessions, so that their spatial and temporal locations are unpredictable to the animal. Various technical terms are used to describe the trial outcomes in signal-detection tasks. Animals can emit the following indication responses:

> A *hit*: an indication response in the presence of a positive sample
> A *miss*: failure to emit an indication response in the presence of a positive sample
> A *false alarm*: incorrect indication in the presence of a negative sample
> A *correct rejection*: correct withholding of an indication in the presence of a negative sample

The general aim of training and the operational system that follows is twofold:

1) to facilitate the highest possible hit rate (HR) when presented with samples that contain an operationally realistic amount of ERW residue and a variety of irrelevant odours
2) to facilitate the lowest possible false alarm rate (FAR) when presented with a range of negative samples that, by definition, contain no ERW residue

The higher the HR and the lower the FAR are, the greater the discrimination between positive and negative samples will be. This in turn means that control over the indication response by the target ERW odour will be stronger. Given that the potential to rapidly identify areas that are free from ERW is the most practical utility of REST, most prospective operators value a high HR (and thus a low miss rate) more than a low FAR.

Early into the work on REST, polyvinyl chloride (PVC) gauze filters that had been developed and supplied by Mechem, were used to collect and present samples to the dogs and rats that were being trained. These filters were placed at the front end of a vacuum pump and air from just above the ground surface was drawn through them.

Initially, APOPO personnel trained the rats with positive samples that had been created by drawing the air that was immediately above landmines through a filter. Samples were taken from a 28-hectare test minefield, which contained several different types of mines, about 1,200 in all, spaced at minimum distances of 40 m from each other. Negative samples were created by drawing air through a filter above an area of ground a known distance away from the test minefield.

At first, the test results appeared quite promising, as the rats reliably emitted indication responses to filters from APOPO's test-minefield, and didn't to filters from other locations, so HRs were high and FARs were low. However, when tested with positive samples from other locations where mines were present, the rats missed the vast majority of them. These were then treated as negative samples, because indication responses were not reliable.

These results were seen as a failure to establish stimulus control over indications, in regard to the intended target odour of landmines, during training. In other words, the training had allowed some other odour difference between positive and negative samples to serve as the basis for the rats' discrimination. It seems that, because all of the positive training samples came from the same general location, the rats had learned to emit the indication response in the presence of odours that were unique to that location, and not odours that were unique to landmines in general.

It was impossible to establish exactly what odours in the location were functioning as cues for the rats. However, because APOPO's minefield was routinely used to train rats for direct landmine detection, it is possible that odour cues left by humans or other rats controlled their responses. Alternatively, a particular type of plant may have been more common in the minefield than in the areas from which negative samples were taken.

A similar conclusion was reached about some test results obtained from NPA's REST project with dogs in Angola. There too, dogs seemed to have learned to reject negative samples that were taken from village markets, frequently travelled roads and other areas that were unlikely to be contaminated with ERW, and to make the indication response to the location-related odours on positive samples.

These findings illustrate two important points. First, they show the value of maintaining a healthy scepticism in regard to an apparently accurate performance by REST animals. Secondly, they show the value of undertaking tests, in order to assess whether or not an odour other than the target odour is controlling the indication response.

Consistent with this sceptical approach, Jones and Dunn developed a brief test methodology[11], in order to assess on a regular basis whether irrelevant odour features of positive training samples had acquired stimulus control. Their method involved manufacturing a small number of negative samples (ie, 15 of 93 per session) that shared a specific feature with positive samples, for example, had been stored with positives, had identical labels on the containers and/or had been touched equally often. They then assessed whether FARs on these test negatives were significantly higher than FARs on other negative samples.

On several occasions they discovered that odours inadvertently added to the positive samples, but not the negative ones, during the sample preparation, storage, and/or presentation phases were controlling the indications, sometimes at the expense of the TNT odour. Therefore, had these researchers not conducted tests with new positive and/or negative samples, they would have erroneously concluded that their training had produced the desired behaviour in their animals and perhaps have moved prematurely to operational status.

The second point illustrated by these results is that animals are opportunistic when learning to detect odour cues that signal the availability of a reward. In general, an animal will learn to use whichever odour cues, alone or in combination, are easiest to detect and which reliably predict that a reward will follow an indication response. Whether those cues are truly indicative of ERW is of no consequence whatsoever to the animal. Just as the famous counting horse "Clever Hans" responded to cues unknowingly provided by his handler[12], REST animals learn to respond in accordance with cues unintentionally provided by researchers.

Because of this, and the fact that a human is unable to smell the odours that rats and dogs can, considerable care should be taken to render the target odour of ERW the only reliable cue that distinguishes positive from negative samples. A description of the procedures to be followed by research technicians in all phases of sample preparation, transportation, storage, and presentation needs to be extremely detailed in order to minimise the risk of adding odours, as well as maximising the uniformity of procedures.

Considerable time and effort needs to be spent on training staff in order to implement those procedures, and procedural reliability checks are imperative.

However, even when such measures have been taken, one can never be sure that the intended difference between the odours of positive and negative training samples is in fact the only difference, and that which has been sensed and used by the animals. Carefully controlled tests also must be routinely conducted. This is in order to rule out stimulus control by any odour that might correlate with the target odour. For example, our confidence may grow when carrying out a control of the target odour, and this may be being picked up as a cue by the animals.

THE CURRENT STATUS OF REST

Since it began, the ultimate goal of the REST research at Morogoro was the development of an operational, empirically-validated system for ERW detection, that was made up of procedures which had been documented sufficiently enough for others to be able to replicate it.

When the Morogoro project started, NPA had a real need for such a system, especially for use in road clearance, and Mechem's reported success (and winning of UN contracts) with MEDDS suggested that the system was feasible. The GICHD also recognised the value of an operational REST system, and supported its development. However, such a system is still not yet available. Moreover, another, recently developed system, which uses long-leash mine-detection dogs, has reduced the current need for REST (see below).

At the 2010 workshop, representatives of NPA and the GICHD revealed, not unexpectedly, that neither organisation has further funds available to sponsor the research clearly necessary for REST for ERW detection to be ready for operational deployment. Their argument is simply that the project has not succeeded in proving the REST concept, nor being ready for operational activity, within the agreed deadline. Therefore, the Morogoro dog-training facility will close immediately.

If further funding can be obtained, an especially promising rat study will be completed, the prototype sampler will be finished, and the headspace analyser will be used, as part of projects related to, but separate from, REST. In recognition that REST for ERW detection research yielded results of potential significance to the humanitarian demining community, NPA and GICHD agreed to support a workshop dealing with the topic and a publication dedicated to it. The workshop was held in Geneva in early November.

Despite not producing an operational REST system, the knowledge obtained at Morogoro can be used to good advantage in training and testing dogs and rats for direct detection of landmines and UXO. For example, transfer tests with the animals and headspace analysis can be used to develop training aids that produce odour signatures, which very closely resemble those present in the vicinity of the mines and other explosives that dogs and rats ultimately will detect. Moreover, research at Morogoro has shown that some seemingly reasonable approaches to developing a REST system were problematic, and so provided information that should inform any future attempts to develop an operational system.

Developing an operational REST system for ERW detection is a very complex interdisciplinary undertaking, which poses significant challenges for product engineers, analytical chemists, and behavioural scientists. In the end, it may be impossible to overcome the challenges and develop a workable system, but it is still premature to assume this is the case.

Despite the fact that many of the researchers involved in the Morogoro project aspired to a progressive, scientific approach, the actual work conducted often involved attempts to produce an operational system as quickly as possible, largely because the sponsors of the project were never able to fund Research and Developement activities for an extended period of time.

The trial and error method of developing the technology often resulted in procedures being radically and fully changed when a problem was identified, resulting in "the baby being thrown out with the bathwater" on numerous occasions. It also meant that the researchers could not return easily to a set of formerly successful procedures when new problems were encountered with the radically changed procedures.

Finally, a result was that important behavioural patterns were inadequately evaluated, which in turn meant a more limited understanding. As described previously, inconsistent supervision played a factor in the research moving too slowly, and important procedures were not accurately or reliably implemented by staff. This reduced the productivity of the project, and compromised the scientific quality of its findings.

Workshop attendees have generally agreed that further research is still needed to determine whether or not REST for ERW detection is a viable concept. They have also agreed that the research should be carefully planned and adequately supervised, in order to produce data of sufficient quality to merit publication in peer-reviewed journals. Such publications are widely recognised as an indicator of research quality, and high-quality research is needed in order to understand complex phenomena such as REST for ERW detection. This in turn could be used for practical purposes, such as humanitarian demining.

Moreover, research findings and the acquired understanding they bring, when published, are made available to others working in related areas. This helps prevent redundant efforts, and should, ultimately lead to either a workable REST system for ERW detection, or at least a general consensus that such a system does not work.

To many people involved in humanitarian demining ten years ago, it seemed likely that an operational REST system for ERW detection would soon be developed and widely used. However, at the 2010 workshop, enthusiasm for REST as a tool for ERW detection was far from overwhelming. This was especially the case in light of the alternative to REST that was described by Mr. Terje Berntsen from NPA's Global Training Centre.

This alternative, involving direct searches by dogs, has been developed and used as a technical survey method to breach safe-lanes and check areas of specific threat. Although it has not been used in the context of land release or road/route clearance, it requires only proper standard operating procedures for use in such applications. There was widespread acknowledgement among workshop attendees that this "new" method is a more viable method than REST for determining whether areas contain ERW. However, some pointed out that the concept of remote-detection with animals is used operationally in a number of other areas, for example, in airport security, freight screening, and in tuberculosis detection, and so might yet prove viable for ERW detection.

APOPO's work with REST for ERW detection has been part of its general effort to become a centre of excellence for odour detection by pouched rats. The knowledge obtained from REST research has value in other areas, for example, in detecting disease in samples taken from patients and brought to the lab for analysis. This also works conversely; ie, work in areas such as studies of tuberculosis detection in rats is likely to be relevant to ERW detection.

Perhaps the best way to develop REST for ERW detection is to work from a broader perspective that focuses on generally understanding remote odour-detection, and the variables that affect it, while endeavouring to develop a variety of useful operational systems. ERW detection through the remote detection of target odours is an exceptionally difficult task for a variety of reasons, some of which have been described above. Therefore, simultaneously focusing on other, easier applications may establish a more sound empirical foundation for developing an ERW-detection application.

Moreover, envisioning remote odour-detection as a general concept, with a broad range of application, would open the possibility of securing funding from sources outside the humanitarian demining community, and would enlist the services of experts in a range of industries. Such a task has much to recommend it, and was endorsed by workshop attendees.

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CHAPTER 2

THE OLFACTORY SYSTEM AND OLFACTION: IMPLICATIONS FOR REST

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CHAPTER 2

THE OLFACTORY SYSTEM AND OLFACTION: IMPLICATIONS FOR REST

INTRODUCTION

As almost all detector dogs rely to some extent on olfaction, an understanding of olfaction is essential for dog trainers. The purpose of this chapter is to introduce the reader to the interaction between the science of olfaction and the art of training and utilising explosive detection dogs. This chapter will discuss the facts of olfaction that seem to be important for the training and maintenance of detector dogs. Special attention will be given to several current areas of research, which may cause a rethinking of training methodology. These areas are:

- The perception of mixtures
- The role of experience
- The role of adaptation
- The role of sniffing
- Species differences

The separation into the five areas is artificial and in actuality, none of these factors are orthogonal to the others. For example, the role of sniffing is intimately related to the role of adaptation, and the perception of mixtures is very dependent on the role of experience. In all of the areas, the differences in species may play an overriding role, limiting generalisation.

WHAT EVERY DOG TRAINER SHOULD KNOW ABOUT THE OLFACTORY SYSTEM

There is a tremendous body of literature on the genetics, structure and functioning of the olfactory system. Some of the relevant literature is cited in the text. Much of the material and organisation of this section is taken from a chapter titled Olfaction and Explosives Detector Dogs by Goldblatt, Gazit, and Terkel[19].

Olfaction is probably the oldest of the senses. It is found in some form or other in all living cells [5]. In basic terms, olfaction is the response of a living organism to chemicals in the environment. It is essential for the procurement of nutrients and avoidance of hazardous environmental conditions. To give an example, the primitive soil nematode shows the ability to learn to avoid odours associated with pathogenic bacteria [89].

All cells have the capability and the necessity of sensing the external chemical environment. During evolution, these chemical sensors evolved into concentrations of cells specialised enough to sense the external environment, ie, the olfactory system. The olfactory system is considered conservative and some of its features are common in diverse organisms such as round worms, invertebrates and vertebrates [11]. There is evidence of convergent evolutionary processes, showing that the various olfactory systems are more analogous than homologous [10;72]. In other words, there seem to be a limited number of ways to process odours, and widely varying species have evolved the same mechanisms [25].

The reason that most phyla process odours in a similar manner is due to the unique nature of olfaction. Unlike sight and sound, odours cannot be classified on the basis of a few physical parametres. Each and every odour is qualitatively different and there are hundreds of thousands of potentially important odours, which the organism must be capable of distinguishing between. In mammals, there are more genes devoted to olfaction than any other ethological system – which shows both the importance and genetic cost of olfaction.

GENETICS OF OLFACTION

More genes are involved in the sense of smell than in any other system. Each of these genes is coded for a specific receptor, which in turn is associated with a member of a "super-family" of G-proteins, coupled olfactory receptor proteins [13;15;46;88]. In other words, each gene codes for one protein, which is expressed by one type of olfactory receptor, which in turn, expresses only one specific receptor protein. It is thought that each receptor protein binds with some physiochemical characteristics of the odourous substance. These include features such as the length of the carbon chain, presence and type of cyclization, amount and type of bond saturation, and various functional groups [29].

To complicate matters, each receptor is capable of combining with more than one physical feature; ie, the receptors are broadband. A receptor that is activated by one odour may also be activated by others. If there is a high concentration of an odour, more olfactory receptor neurons are activated than if the same odour were presented in a lower concentration. To summarise, each olfactory gene codes for one type of receptor, which binds optimally with one physiochemical property of the olfactory molecule, and which can also bind with other related aspects.

The number of olfactory genes has been determined for a variety of mammalian species. However, it is essential to realize that there are a number of genes that seem to be non-functional. This is because of mutations and natural selection. If an olfactory gene is no longer selected for, it will undergo random mutations which render it non-functional. These non-functional genes are called pseudogenes.

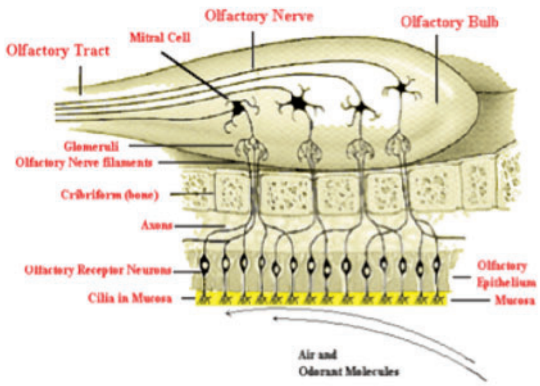
Regarding actual numbers of functional olfactory genes; dogs, rats and mice have approximately 1000 intact genes, humans have around 400 and dolphins have none. As dogs, rats and mice have a similar number of genes, this suggests that they are about equal in their ability to discriminate between odours. The number of genes probably does not determine the threshold for detection of an specific odour. However, the number of genes probably does influence the ability of the animal to make fine discriminations between very similar odours.

In all species studied, the olfactory system consists of:

- an odour input device (usually the nose)
- a layer of mucosa covering a bed of olfactory receptors (olfactory epithelium)
- communication lines between the olfactory epithelium and the olfactory bulb (olfactory tract or nerve)
- an olfactory bulb for initial processing of the olfactory information
- communication paths to the olfactory cortex and other brain areas that process olfactory information

These can be seen schematically in Figure 1.

FIGURE 1 | Schematic of the olfactory system [45]



All of the olfactory neurons that express the same type of receptor, send their axons to a specific complex of neurons, dendrites and axons known as a glomerulus. Current theory [4] maintains that each glomerulus receives input from all the olfactory receptor neurons expressing for one specific receptor protein. A glomerulus does not receive any inputs from any other type of olfactory receptor (coded by a different olfactory gene). One would then expect that the number of glomeruli is directly related to the number of olfactory genes expressed in the olfactory receptor neurons. This seems to be relatively true. There are 1800 glomeruli in mice and 2400 glomeruli in each olfactory bulb of rats [32].

The greater the number of olfactory genes, the better the ability to make fine olfactory discriminations. This is because each glomerulus responds to one physiochemical property of an odour. The more properties that can be coded for, the more accurate the discrimination between molecules that may differ by only one or few properties. Rats and mice for example can distinguish between stereoismers; these are molecules identical in structure and chemical formula, but which rotate in opposite directions. Since each glomerulus is activated by a unique physiochemical property, and since each of the glomeruli are activated by a different property of olfactory molecules, it is thought that the glomerulus is the functional unit of olfaction [33].

Therefore, the ability of dogs to discriminate between odours may be correlated with the number of glomeruli in the dogs nose. The only information on the number of glomeruli in the dog comes from a non-reviewed report by Morrison however[61]. He states that the dog has about 5000 glomeruli, however he does not provide a reference for these numbers, and some of his other data differs significantly from published articles [59;65].

Electrophysiological recordings and imaging studies of the olfactory bulb show that odours activate from few up to many glomeruli. Often, the number of glomeruli activated depends on the intensity of the odours. The outputs of the glomeruli are the axons of Mitral and Tufted cells. Mitral cell axons leave each glomerulus and go directly to the periform cortex, which is where information on the odours is processed and converted to the perception of them.

The mitral cell axon terminates on neurons in the periform cortex. This area of the brain is very rich in axons and dentrites and is an area of high interconnectivity. There is abundant evidence that the neurons of the periform cortex are plastic in regard to the odours that will activate them [82;90;91]. The extent and implications of this plasticity will be discussed later in the chapter.

The combinatorial theory explains the data on olfactory perception best. It is based on the fact that an odour activates many olfactory receptor neurons, which in turn activate their specific glomeruli. Each of these glomeruli in parallel send signals along their axons to the olfactory cortex. The olfactory cortex then responds to the sum total of activated glomeruli and, according to the combinatorial theory, this sum total of activity is translated into the perception of an odour.

This means that an odour, as we understand it, is the result of the simultaneous activation of many different glomeruli, meaning that there is no one olfactory receptor for any specific odour. There is no one receptor for the smell of a rose or vanilla, for example, and neither are there specific receptors for explosives, such as TNT, C4 and TATP. In each case, the olfactory system learns to associate a pattern of glomeruli activity with an odour in the environment. The odours become recognised by learning, and through previous exposures to the same combination of activated glomeruli [83;84].

The best way to conceptualise the working of the olfactory system is to imagine a piano with a key for each olfactory gene (or glomerulus). Each and every smell activates a different number and pattern of keys, producing a unique chord of activation, which becomes the perception of the odour. Although there may be only 1000 keys, the number of potential chords is huge. This is evolution's way of enabling animals to recognise and discriminate between hundreds of thousands of odours.

WHAT EVERY DOG TRAINER SHOULD KNOW ABOUT OLFACTORY PERCEPTION

It should now be apparent that olfaction is quite complex. The commonly accepted combinatorial theory suggests that the perception of olfaction occurs in the cortex of the brain and is, for a large part, a function of previous experience with the odour; a phenomenon called perceptual learning [20;83;84]. The combinatorial theory provides a framework for understanding how animals perceive mixed odours, and why adaptation is important for the perception of odours.

In the remainder of this chapter, we will discuss the:

- perception of mixtures
- role of experience, especially in regard to mixtures
- role of intensity
- role of adaptation
- importance of sniffing and its relationship to adaptation

It is important for trainers to understand these facts.

THE PERCEPTION OF MIXES

Trainers need to know how animals respond to mixtures of odours. This is a critical question since they are never in a vacuum but always in mixtures.

There are two types of mixtures which are relevant to trainers. The first is caused by the fact that the target smell is always mixed with a background of other odours. The second type is the odour itself, as most odours, especially explosive ones, are complex mixtures. It is important to understand how animals respond to this bouquet.

There are two extremes regarding the perception of a mixture. First, the mixture can be sensed analytically. This means that each component of the mixture can be detected irrespective of the other odours in the mixture. The other extreme is when the sum of the component odours makes a new odour which cannot be separated into its parts. This is called the configurational or synthetic view of the perception of odours.

The preponderance of research shows that the perception of complex mixtures is configurational. For example, coffee smells like coffee, and it is extremely difficult to detect the individual volatiles. Research using artificial mixtures has shown that humans [28;34], rats [70] and mice [73], cannot accurately identify the components of a mixture of three odours, even when each component is well known. When there are four or more odours together, it is very difficult to identify any of the components. Although each, when presented singularly, can be described as "woody", "smoky" or "like mint", these descriptors disappear when the odour is part of a mixture [28].

These results are compatible with the theory that odours are perceived as the sum total of glomerular activity as transmitted to the olfactory cortex. Wilson and his colleagues showed that in rats, following exposure to binary mixtures, some cortical cells fire only to the mixture and not to the individual components [82]. Boyle *et al*,[3] concluded that in humans, binary odour mixtures and their individual components are processed differently by the human brain. Stevenson and his colleagues showed that in humans, following exposure to a pair of odours, it is more difficult to separate them perceptually [71]. There is a lot of evidence that animals treat mixtures as a synthetic whole, and are not capable of discriminating the individual components, especially when there are three or more odours in the mixture.

In humans, it is easy to study the perception of mixtures by simply instructing someone to label the odours detected in a sample. In animals, this is much more difficult. Staubli *et al* [70] gives an example of a technique used to study an animal's perception of mixtures. They trained rats to respond to a mixture ABC and not a mixture ABD. Theoretically, the rat could learn either to respond to the mixture ABC and not to ABD, or else the rat could learn to respond when C is present and not respond when D is present.

Once the rat had learned the task, to see if the animal had learned the mixture as a configuration or analytically, they studied the rats' responses to odours C and D when presented alone, by training them to respond to D when it occurred alone and to not to respond to C when it occurred alone. Their reasoning was that if the rat had previously learned that odours C was paired with reinforcement and odour D was not (the analytic approach), then it would be more difficult to learn that odour D is now paired with reinforcement (therefore a reversal learning affect). The results showed that the rats had no trouble learning the reversal. This strongly supported the hypothesis that the rats learned the odours ABC and ABD as a configuration and they did not learn the separate components.

It can be concluded that rodents, primates and humans process mixtures of three or more odours configurationally. They respond to the mixture as a new odour and are not able to distinguish the individual components.

In spite of all of the research just cited showing that animals are very poor at analysing complex mixtures, anyone who works with dogs knows they can detect the target odour even in the presence of strong smells. Research shows that humans and animals are fairly good at identifying a smell against an odourous background and/or from within a mixture [83].

Therefore, how can these two conflicting results be reconciled? Wilson and Stevenson [83] suggest that whether an animal treats a mixture as a configuration that is not separable or whether it is treated analytically with each component being recognised, is a function of experience. The more experience an organism has with a specific odour, the easier it is to detect it in a mixture. This will be discussed in much more detail in the section concerning experience.

SALIENCE AND OVERSHADOWING

Kay and her colleagues suggested that the shift between configurational and analytic processing of binary mixtures is gradual and very much influenced by the relative salience of the two components of the mixture [31]. They maintain that in many odour pairs, the response of the animal to the individual components of complex mixtures can be explained by overshadowing, where a dominant stimulus component establishes control of the behaviour at the expense of the less dominant stimuli. They suggest that mixtures are processed synthetically only when the components are of similar intensities.

In addition to this research[31], other investigators such as Linster [58] and Laska [41] have also shown that the binary mixture is either treated as different from the individual components, or that one odour is dominant over the others (overshadowing). For example, Laska and Hudson [41] trained humans to discriminate between a 12-odour mixture, and the same mixture from which a variable number of components were removed. They found that when the odour of cineole (eucalyptus) was in both the sample and the comparison, it was very difficult to distinguish between the two samples, no matter how many of the other components were removed, showing that cineole overshadowed all the other odours. Similar results were found with mice [68]. Goyert *et al* [14] hypothesise that the odours of many common foods and fragrances appear to be dominated by notes of single compounds that impart characteristic, albeit crude, identities.

PREVIOUS EXPERIENCE WITH THE ODOURS

The olfactory system is designed to be flexible and is modified by experience. Throughout the lifespan of the individual, new neurons are formed in the olfactory bulb. This is contrary to what had been previously maintained - that once the brain developed, no new neurons were born. It is now known that olfactory sensory neurons have a lifetime of about three weeks. When they die they are replaced by newly born neurons. This permits environmental odours to have a major impact on the formation of new connections in the olfactory system [17]. It also allows for a type of modulation of the sensory neuron population in the olfactory epithelium.

Recent research has highlighted the role of previous experience in olfactory discrimination. It was found that experience with an odour sharpens the generalisation gradient. Mandairon et al found that naïve rats did not distinguish between closely related odours in a habituation test [54]. They used the odour pairs "+Limione" and "–Limione", "+terpin" and "– terpin", and pentanol versus butanol (the first two pairs are stereoisomers, which are identical in structure, but differ in the three dimensional arrangement of atoms. The "+" and "-" refer to the direction of rotation).

The rats were given several successive exposures to one of the pair, for example "+limione" and the amount of time investigating the odour was measured each time. Normally, the investigation time decreases with each exposure (habituation). If a new odour then substitutes the habituated one, the exploration time increases. If the animal perceives the old and new odours to be the same, there is no increase in time spent exploring the new odour.

After the rats were habituated to the first odour, ie, +Limione, they did not increase the exploration time when presented with the second odour, -Limione, showing that they did not distinguish between them. Mandairon then gave the rats twenty days of two hours per day exposure to the odours. They found that following the exposure, the rats now explored the -Limione even though they had habituated to the +Limione. The same effect was found for the other two odour pairs. Interestingly, animals exposed to the Limione pair were also able to discriminate between the other, non-exposed pairs.

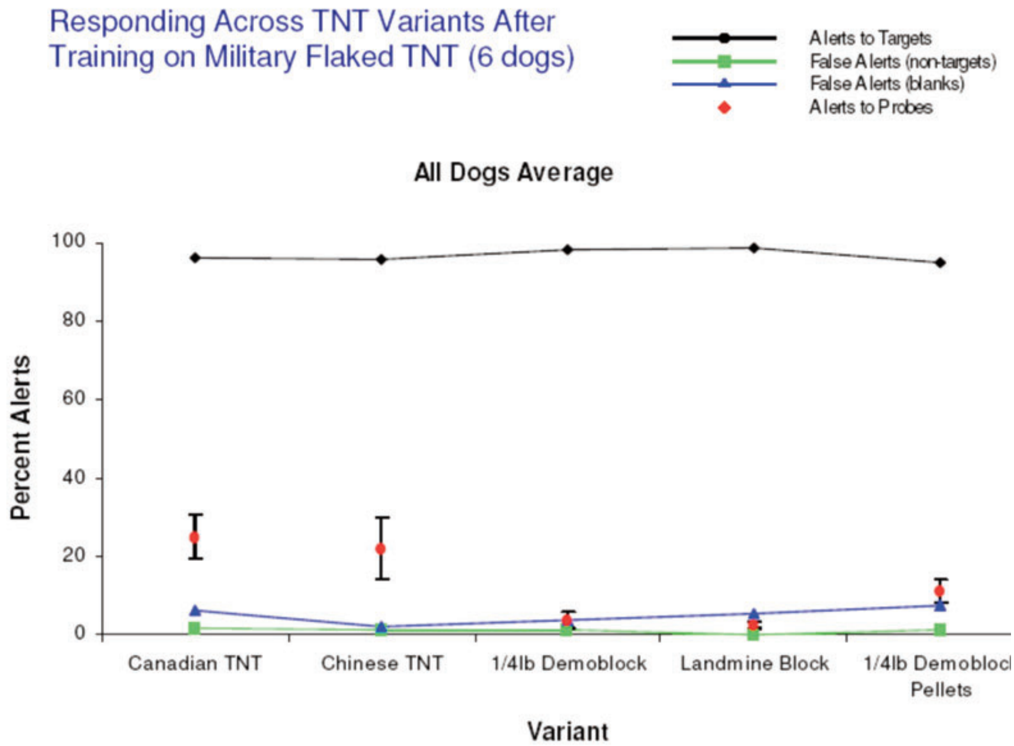
Mandairon and Lister [56] showed that the olfactory exposure can be either through learning, enrichment, or exposure. They argue that the olfactory bulb has evolved to be an adapting network, allowing animals to adjust to changing environments. Supporting this, Magavi *et al* [52] exposed mice to an odour for two to six weeks and found a greater number of newborn neurons which responded to that odour.

This adaptability is not limited to changes in the olfactory bulb. Yee and Wysocki [87] found evidence that the olfactory epithelium is also modified by experience. Supporting this, Wang *et al* [78] found that exposure to odours induced an increase in the electrical activity of the olfactory nerve, a function of olfactory sensory neuron activity providing more proof that experience can cause changes in the population of olfactory sensory neurons. This increased ability to discriminate as a result of exposure to the stimuli is a general phenomenon known as differentiation[20].

This process of differentiation, where continued training with a stimulus improves the ability to discriminate it from similar odours can pose a large problem for dog trainers. It is very important for dog trainers to recognise that continued training on one substance will reduce the amount of generalisation shown by the dog. This was well demonstrated by Paul Waggoner who found that following extensive training on either US Military flaked TNT, or on U.S. Military C4, dogs failed to respond to other forms of TNT or other forms of C4. Waggoner considers these results to be extreme because operational dogs can detect different types of TNT and C4.

His extreme results are probably due to the fact that the dogs in this laboratory setting were only trained on the military flaked TNT and on a specific type of C4. In fact, when Waggoner trained the dogs with a second type of TNT, they were more likely to indicate on the other types of TNT in the sample. It is therefore essential that dogs be trained on a variety of samples of any explosive. Otherwise, they will be much less likely to respond to explosives that are not identical to the explosive used as the training aid. This can be seen in Figure 2.

FIGURE 2 | This graph shows the probability of responding to the target odour (military flaked TNT) which was well trained, versus the probability of responding to other types of TNT. The results show that the "Alerts to Probes" (which is the probability of responding to the other types of TNT) was very low. Data is courtesy of Paul Waggoner of the biosensor center at Auburn University, from a presentation at the Detector Dog Conference held in Bergen Norway in 2007.



EXPERIENCE WITH COMPONENTS IN MIXTURES

As stated previously, there is abundant evidence that previous experience with an odour can improve the ability to detect it in a mixture. When an animal detects a single odour or a mixture, there is the simultaneous activation of all the glomeruli that respond to that odour. The olfactory cortex receives this pattern of activated glomeruli and as a result, forms new synapses. This results in neurons that respond only to that specific collection of glomeruli that we can now label as an odour, and which is different to all others. Thus, a mixture may differ from a single odour only by involving more glomeruli. Once these synapses are formed, a process that takes less than 90 seconds [83], the odour and/or mixture is defined by a population of cortical neurons that only fire to that unique collection of activated glomeruli. Once these connections are formed, it is more difficult for the animal to separate the mixture into its components.

However, if an animal or person has had experience with one component of the odour before encountering it as a component in a mixture, then there are already cortical cells that fire only to the experienced smell. Increased experience with that one component strengthens those synapses and makes it possible to recognise the odour even when it occurs in a mixture. The more experience an animal has with that odour, the easier it is to recognise it in a mixture or against an odourous background. This hypothesis is best expressed by Wilson and Stevenson:

"Thus, if the features contributing to 'dog' odour are experienced alone or against a variety of backgrounds, a unique representation of 'dog' odour will be formed within the piriform cortex. Once this representation, or template, has been formed, the odour can be more easily recognized against background odours or discriminated from dissimilar odours. However, if the odour has only been experienced in the context of a constant background or distracter odours (i.e. always in a similar mixture), or occurs in the presence of an overwhelming number of other features (complex mixtures) identification of the target odour within the mixture will be hindered due to the cortical synthesis of all the features together." [83].

An example of this is found in an experiment by Jinks and Laing [27]. They used a bank of 16 familiar odours, and tested humans on their ability to recognise each of them. They then picked the odour that was most familiar and most easily identifiable for each person and presented it again, either alone or in a mixture of two, four, eight, 12 or 16 familiar odours.

They found that, contrary to other experiments, where an individual component could not be recognised from a mixture of four, the well-known odour could be recognised even in a mixture of eight or 12. Thus, if the target smell is first encountered as a part of a mixture, it will not be identified as the target when encountered alone. However, if it is first learned alone, then it will be detectable within a mixture.

If follows from this section that explosives detector dogs should be trained on the odour that is most representative of a class of explosives before it is trained on each individual explosives. That is because each parent explosive is embedded inside a complex mixture of volatile chemicals. According to the way the olfactory system works, if the animal is first trained to detect a complex compound such as C4, it probably will not respond to the parent explosive, RDX when the dogs encounter it in a different mixture. However, if the animal is first trained on RDX, or on some other odour "X" that is always associated with RDX, then the animal should respond positively to RDX or that odour X whenever it is encountered and irrespective of any mixture. This raises a critical question, what are the key odours for training detector dogs?

WHAT IS THE KEY ODOUR FOR DETECTING AN EXPLOSIVE?

This question of mixtures and overshadowing is very important when training explosives detector animals. Because explosives are complex mixtures of many components, some more volatile than others, it is a real question as to what in the mixture the animals respond to. If there is a mixture of several salient odours, the animal has a choice regarding what odour it pays attention to. This is known as selective attention and it has been investigated in mice by [73].

Takiguchi *et al* trained mice to discriminate one type of red wine from water. They then tested their choice of a different type of red wine. They found that some of the rats did not respond to the second type of red wine, whereas other mice responded to the second type more than they responded to the original wine. They say that the results are due to selective attention for different volatiles found in red wine.

Williams *et al* [81] tested the response of dogs to various components of TNT, C4, and dynamite. They found that each dog trained to respond to C4 responded to a different salient odour as if it were the C4. Interestingly, they did not even include the parent explosive, RDX, as a potential odour, since it has such low vapour pressure that it was not even detected in their gas chromatograph. In fact, several prominent investigators such as Furton [23;49] and Waggoner [62] maintain that the dog does not detect the parent explosive but rather the more volatile by-products. Because of this, Furton recommends training TNT detectors on DNT which is a common and more salient component of TNT then the TNT itself [23].

The question of what odour(s) characterise explosives is very important to dog trainers. Many federal organisations and commercial companies invest significant amounts of money into finding the odour that characterizes each class of explosives. The ATF trains their dogs to respond to the smell of the parent explosive, TNT, RDX, nitroglycerin etc. They maintain that a dog trained to detect RDX will detect all explosives that contain RDX. A dog trained to detect TNT will detect all explosives containing TNT. However, the ATF has never published any research which proves this hypothesis.

A commercial product, “NESTT@”, which is sold as a trainer-aid for explosives, actually consists of the parent explosive embedded in an inert matrix [51]. This gives the aid the same chemical and biological signal as the parent explosive, but is not explosive. In blind tests to evaluate NESTT@, some investigators report that trained dogs respond to it as if it were the explosive, but other investigators report that dogs do not respond to it [23;49;51]. Another commercial product, “Explosniff@”, also consists of the parent explosive in an inert matrix. However, there are no published results to validate its effectiveness as a trainer aid.

Another approach has been championed by Ken Furton and his associates, they maintained that the key odour should be the most salient odour that is consistently associated with the commercial explosive. In view of the data supporting the configurational approach to mixtures, there is much validity in this approach. Explosive odours are complex mixtures and some components are much more volatile than the parent explosive, and probably overshadow the parent explosive. Therefore, it is logical to train the animal on the most salient scents commonly associated with the parent explosive.

Therefore, DNT is the key odour for the detection of TNT based explosives and 2 ehyl-1-hexanol is the key odour for the detection of RDX based explosives [50]. A commercial company, “Scentlogix@” also seems to choose this way of working. However, there are few published, peer-reviewed articles which systematically investigate the efficacy of these substitutes for explosives, and some of these articles contradict each other [23;49;50].

A problem with this approach is that explosives may or may not contain the salient odour that the dog was trained to detect. For example weathered TNT does not contain any DNT and there are many compositions of C4 which contain other volatiles. If animals could be trained to detect the parent explosive, and if they would respond to the parent explosive irrespective of the other odours in the mixture, we would have the ideal trainer aid. However, given that other odours in the explosives are much more salient, the dogs should not learn to detect the parent explosive.

We decided to test this with dogs undergoing a training programme for explosives detection. Dogs were well-trained to detect C4. Then, after they responded to C4 at high accuracy, they were presented with a wall containing many 15 cm holes. Behind and below the holes were holders where various scentss were placed. Four different types of stimuli were placed behind the holes: clean containers, containers with pure RDX, containers with RDX mixed with a salient (un-nameable) substance, the salient substance alone, and containers with all types of odours such as coffee grinds, grease, tobacco etc. Most of the samples were either empty or contained other, non-relevant odours.

The results were surprising. Dogs that were well-trained on C4, with all its extraneous plasticisers and other salient volatile odours, not only detected samples of C4 but also responded positively 60 per cent of the samples of pure RDX, without having had any training for it, and responded to only one per cent of irrelevant odours. Even more surprisingly, samples of RDX paired with a salient scent had 100 per cent detection! (We think that the dogs used the salient smell as a signal to investigate the hole in the wall).

This experiment was replicated with other dogs, and the same result was obtained. It seems that at least some of our explosives detection dogs not only are capable of analysing C4 and detecting the subtle odour of RDX, but they also responded positively to the RDX the first time they encounter it, provided that they had been previously trained to detect C4.

To summarise, it was previously known that mixtures were detected configurationally and that the individual components were not recognised. It was also known that animals learned salient smells that overshadowed more subtle odours. Overshadowed odours were not learned. Now, at least with our dogs, it seems that they do analyse the mixes and even learn to respond to subtle odours in the mixture. If others also find this to be true, it can have quite an influence on the future training of detector dogs. The critical experiment, which has not yet been done, would be to determine if it is possible to train different species of animals to detect a subtle target odour, irrespective of the mixture in which it appears.

SPECIES SPECIFICITY AND CONFIGURATIONAL PROCESSING

Although configurational processing has been tested on rodents [48], primates [40], humans,[28] lobsters [7] and bees[26;63], it may not be a universal truth. Some commercial dog training companies and some government agencies (eg US Border Patrol) initially train their dog to detect a bouquet of four drugs or a bouquet of four explosives. They maintain (but do not supply data) that this facilitates training since they say that the dog will now respond to each of the four odours originally trained in the mixture.

The dog does not have to learn each one separately. This analytic perception of odours is contrary to the scientific research discussed above. (These trainers explain the dogs' olfactory performance by evoking species differences. They say that when humans walk into a pizza parlour they smell pizza, whereas a dog smells the separate ingredients).

Our group decided to investigate this more carefully. We trained dogs to detect the odour of a mixture of three explosives. The samples were made by putting an amount of each of the three explosives together in a sealed metal container with some rags for several days. No attempt was made to equalise the odour intensities of the three explosives, although we were sure of these differences. At the end of the week, the dogs were trained to differentiate between the rag saturated with the three odours from clean ones, or rags that had been saturated with other odours.

Once the animals were performing well, we tested their responses to the individual components. The rags were prepared in the same way, but only one explosive was placed in each of the three containers. The dogs were only tested once or twice for their response to the component odours. We found that even on the first trial most of the dogs consistently responded to the individual components of the mixture they had previously learned.

Since this result was very surprising and contrary to the published data, we decided to run the experiment again with naive dogs instead of experienced dogs. Although the training on the mixture took longer because they were new to the experimental proc-edures, when tested on the individual components, most responded on the first trial to each of the three components of the mixture.

We then thought that maybe there was a problem with the specific explosives we used so we re-did the experiment with a third group of dogs using a different mixture of explosives. Again, we found that the dogs consistently responded to each of the individual components of the mixture. We concluded that, at least in mixtures of three, the dogs used an analytic approach and easily recognised all of the components. We do not know if the difference between our results and those published are due to species or methodological differences, but given the intense artificial selective pressure on dogs for olfactory detection over the last couple of thousand of years, it is quite possible that dogs do process odours differently to other species.

As a result of these data, there is more support for the notion that dogs do break down odours into its component parts (at least in mixtures of three). It must be emphasised that, contrary to the view of Wilson and Stevenson[83], most of the new dogs, which had never been trained on odour detection until they encountered a mixture of three odours, were still able to immediately identify each of the three components of the mixture on the first trial.

CHANGES IN THRESHOLDS AS A FUNCTION OF EXPERIENCE

Many studies on perceptual learning have shown that with experience, the threshold of detection decreases and the subject is able to detect at much lower thresholds than at the initial testing [18;20]. This has also been found with olfaction. For example, rats exposed to either amyl acetate or anderostenone (possibly a human pheromone) show a significant decrease in the detection threshold after exposure to the specific

odour.
This lowering of the threshold of detection is specific to the exposed odour and does not generalize to other odours. [79;87]. We also found that the probability of detecting TNT increases with experience of TNT [16]. Finally, Walker *et al* [77] intensively trained two dogs for six months to detect amyl acetate. Probably, because they used very intensive training, the behavioural threshold they obtained, (one part per trillion) was orders of magnitude better than previously reported for amyl acetate.

We can summarise this section by stating that olfactory experience is critical to olfactory perception because it changes the way the brain processes information. It reduces generalisation between similar odours, and increases sensitivity to those exposed odours. The third effect, possibly the most important, is to improve the ability of the animal to detect a well-known odour, even in a complex mixture.

THE ROLE OF ODOUR INTENSITY

Often, the affinity of the olfactory receptor protein for an odourant is not all or none. Rather, there seems to be graded, concentration dependent effect. This means that for many odours as the concentration of the odour increases, the perceived quality of it changes. This has been intensively studied in humans and is by now well-known [21]. Johnson and Leon have done imaging studies on rats regarding the effects of different intensities on glomerular recruitment. They found that there are obvious changes in the number of glomeruli activated by a given odour as the concentration increases [29].

McNamara *et al* [58] showed that the absolute concentration of the two odours in a mixture affect whether the mixture is treated synthetically or analytically. They found that when both odours are at low concentrations, the rats respond to the mixture synthetically, whereas at higher concentrations, they respond more analytically. Interestingly, Williams *et al* [81], in their study of which volatiles of C4 are the key odours, found that the results were also influenced by the relative concentration of the volatiles. At one concentration dog #7007 reported cyclohexanone to smell like C4, but at higher or lower concentrations, it no longer smelled like C4.

In humans, Gross-Isseroff *et al* [22] showed that often, odours are not ranked as similar if there are large differences in concentration. Laing *et al* [35] showed that humans describe the same odour at different concentrations differently.

These effects of intensity on the quality of the odour may have implications for explosives detector dogs. For example, dogs trained on small amounts of explosives sometimes have trouble responding to very large amounts. It was thought that the animal could recognise the higher intensity odour but could not go to source, therefore behaved as if there were something it should do but did not know what. It could be that at high concentrations, explosives smell differently than at low intensities. Therefore, all dogs should be trained and maintained on all the intensities it may encounter.

MASKING

It is a common conception that if a target odour is mixed with a highly salient mixture such as ground coffee, it is more difficult to detect. This was studied in a few experiments [36;69;76] and it was always found that the presence of other smells increased the threshold for the detection of the target odour, ie, that the target smell was more difficult to detect.

Laing *et al* [36] found that the detection threshold of the target odour was higher in the presence of a masker, and that the relationship was "all or none". The rat could detect the target odour as long as its intensity was gradually decreased, but at some point, there was an abrupt cessation in the ability to detect the odour. On the other hand, Waggoner [76] found that the threshold of detection decreased gradually as the intensity of either of two maskers increased, but one masker was much more effective than the other. Waggoner also showed that there were large individual differences between dogs, suggesting that training variables are important in determining the effectiveness of maskers.

We surmise that the more experience the animal has with the specific odour and masker, the less effective the masker will be. Therefore, if a trainer knows what types of maskers he might encounter, it would be very worthwhile to train the dog to detect odours in the presence of those maskers.

ADAPTATION TO ODOURS

Recently, much research has been devoted to adaptation to odours. This refers to the reduction in responsiveness of a sensory neuron, following exposure to a stimulus. This is different from habituation, which is a response reduction following exposure to a stimulus, due to activity of the central nervous system (the brain). A good way to remember the distinction is that habituation can be reversed if a novel stimulus appears just before the habituated stimulus. In habituation, the previous response will reappear (external disinhibition) but in the case of adaptation, there should be no reappearance of the inhibited response.

Sometimes, the term adaptation is used even though, in some experiments, it is more likely to be more accurately a case of investigating habituation. Adaptation can be considered as nature's way of improving the detection of odours in mixtures.

This research on adaptation is important for both understanding and training explosives detector dogs. For example, Linster *et al* [47] trained rats to discriminate eugenol from a binary mixture of eugenol and acetic acid. The rat was required to put its nose in an olfactory port and, if eugenol alone was present, the rat had to touch the water spout in order to receive a reward. If eugenol and acetic acid were present together, the nose poke would not be reinforced. Normally this task is not too difficult and the rats performed well.

In the second part of the experiment, acetic acid alone was continuously present in the olfactory port for a period of six minutes. After several minutes of exposure to acetic acid, the rats responded to the mixture as if it were only eugenol. In other words, the rats could no longer detect the acetic acid component of the mixture. The authors suggest that the presence of acetic acid in the background caused habituation to it, and facilitated the detection of eugenol.

Kadohisa and Wilson [30] studied the effects of olfactory adaptation electrophysiologically. While rats were exposed to two scents either individually or as a mixture, they recorded from cortical cells. They then presented one odour for 40 seconds, and then added a second one for ten seconds, thus creating a binary mixture. They found that neurons ceased to respond to the background odour (the odour presented for the first 40 seconds) but still were responsive to the novel odour. So, their electrophysiological results support the behavioural results of Linster et al [47]. Kadohisa and Wilson [28] concur with Linster that adaptation could be a mechanism for separating a target odour from the background.

The most interesting experiment was by Goyert *et al* [21], who studied olfactory adaptation in humans. First, they trained the subjects to identify all four odours used in the experiment. They confirmed that the subjects could not identify all of them in mixtures of three or four odours, and then allowed them to sniff a mixture of one, two or three odours. Immediately after sniffing the mixture, they were presented with the same mixture but with another odour added. The interval between the first and the second sample was only a few seconds, the time necessary to switch bottles.

They found that the ability to identify the added odour was greater following the few seconds spent sniffing the first bottle. This brief exposure enabled adaptation to the original scent, which meant the additional odour became more salient. In addition, they found that this improvement was irrespective of the number of odours in the mixture.

There is solid evidence that adaptation to a background odour greatly improves the ability to detect novel ones. We suggest that an intrinsic problem with REST is due to lack of inhibition of the background smells. Given that all mines are associated with significant background smells, which are usually much more salient that that of the mine, the role of adaptation to the background is extremely important.

A freely moving dog has ample time to adapt to the local background and can therefore more easily recognise and respond to the target odour. For a REST dog or rat however, there is no background similar to that of the field from which the odour was taken. When the animal sniffs the sample, it receives both the background and sample at the same time, meaning there is no adaptation to the background, which makes it much more difficult to detect the target odour. This is presently only a hypothesis, and should be tested.

SNIFFING

A major variable that influences inhibition is sniffing, which, until recently, was considered a simple mechanism of getting odours into the nose. Recent research shows that sniffing has a major influence on habituation, and consequently on separating the target smell from the background.

In simple olfactory discrimination tasks, the sniffing rate does not seem to be correlated with performance [80]. Using a preparation where rats had their heads fixed and scents brought to their noses, it was found that they showed individual differences in sniffing strategies, which had emerged during discrimination learning. Some rats showed brief bouts of rapid sniffing with the onset of the odour, and others showed little or no change in sniff frequency. Nevertheless all rats performed with high accuracy, indicating that rapid sniffing is not necessary for odour discrimination.

Surprisingly, Wesson *et al* found that sniffing strategies remained unchanged even when task difficulty was increased and the performance level decreased. They suggest that the major functional contribution of rapid sniffing is to enable the animal to acquire the stimulus more quickly once it is available, rather than to directly influence odour perception [73]. So, in normal laboratory olfactory discrimination tasks, rapid sniffing does not seem to be very important.

However, sniffing does seem to be very important in separating the background from the target odours. Verhagen *et al* [74] examined the relationship between the rate of sniffing and brain activity. They found that when the rat used high frequency sniffing, the brain activity was decoupled from the sniffs and there was a weakened response to the odour.

When the rat was sniffing slowly, the response to the odour was not weakened. Moreover, during low-frequency sniffing, smells encountered later in a sniffing bout were encoded as the combination of the first odour and those from the background. In comparison, smells encountered during high-frequency sniffing that were then encountered later in a sniffing bout were encoded as the difference between the two odours.

A rat sniffing at a high rate adapts quickly to the scent. When a new odour is introduced, it generates a pattern of brain activity that's different from that created by the background odour. When the rat is sniffing slowly, it is much more difficult to detect the activity of the new odour against the background activity. Unfortunately, there were no behavioural tests to determine if the ability to discriminate the new odour was enhanced when the rat was sniffing at a high rate.

Although this experiment should be replicated and extended to behavioural tests of the ability to separate the background from the target, it suggests that in tasks involving the detection of a subtle odour against a salient background, it is better if the animal sniffs at a high frequency. In observations of dogs and rats during REST trials, it is apparent that the amount of time spent sniffing is minimal. Perhaps if the animal could be trained to sample by sniffing at a high rate, there might be higher detection rates.

SUMMARY

The combinatorial theory is accepted as the way an animal processes olfactory information. There are no receptors for odours; rather each odour is represented by a pattern of activated glomeruli. For each scent, the pattern differs, and it also often differs as a function of the intensity of the odour. The neurons that respond to smells do so as a result of new synapses formed due to previous experience with specific odours.

Complex mixtures of odours cannot be separated into individual components. In order to improve the ability to detect a specific scent from its background, the animal must have first experienced it alone, away from the mixture. This gives the brain the opportunity to train neurons to recognise it, and facilitates being able to later detect it from a background of different odours.

Recent data with dogs suggests that they may be able to treat mixtures analytically and therefore can detect individual components. In addition, dogs seem to have the ability to learn subtle odours in the mixture, whereas other species seem to respond to salient odours, which overshadow more subtle ones.

An important feature of olfaction is its flexibility and responsiveness to experience. The more experience an animal has with an odour, the less likely it is to generalise, meaning that trainers should have many exemples of each explosive the dog is required to find. Also, the threshold for detecting the presence of odours also decreases as the animal becomes more sensitive to it, so it is easier for the dog to discriminate between the target scent and the background smells.

Finally, adaptation was discussed. Data indicates quite clearly that even a few seconds of exposure to an odour causes adaptation, facilitating the detection of any novel odours introduced later, following habituation to the background. Also, there is some indication that rapid sniffing contributes to adaptation and increases the salience of newly introduced target odours.

APPENDIX:

Species differences

Because of natural selection, every species has developed sensitivity to odours that facilitate survival and successful reproduction. In every generation, natural selection chooses those that can better use olfactory information, resulting in extremely good olfactory systems that detect and discriminate between scents important for the survival of that species. The threshold for detection of the same odour differs between species as well as within any given species. Each odour has its own threshold for detection, and each individual has a different threshold, which is a function of the physical properties of the odour, its importance for the species, the individual's genetic makeup, and previous experience of the scent.

Commonly, it has been convenient to divide the mammals into microsmatic and macrosmatic groups, based on the size of the olfactory system. Primates (especially humans) were considered classic examples of microsmatic species, and it was assumed that odours were not important and could not be detected at concentrations that macrosmatic animals (ie dogs) can. Recently, many studies have shown that microsmatic animals can detect some odours better than macrosmatic animals [24;37;39; 42;44]. These results, and other anatomical evidence, led several authors to suggest that the terms macro and microsmatic are misleading [43;67]. It should be noted that the odours that monkeys show a lower threshold to than dogs or rats, are often associated with fruit. This supports the role of natural selection in determining the thresholds of specific odours ([8;9]).

A more direct proof of the role of natural selection in determining odour thresholds is found in rats. Laska *et al* [38] found that the rats were able to discriminate concentrations between 0.04 and 0.10 ppt (parts per trillion) of fox faeces odour. Foxes are natural predators of rats. Other species, not predated by foxes, had much higher thresholds of detection of the smell of fox faeces. According to Laska *et al*, this is by far the lowest olfactory detection threshold reported in rats.

One of the basic tenets of olfaction is that all the axons of a specific olfactory receptor (OR) neuron converge on one glomerulus. Recently, research by Maresh *et al* [57] reexamined this principle in humans. They imagined that the human olfactory bulb (OB) would have 700 glomeruli, two for each of the 350 identified intact ORs in the human genome. However, the results were startling. The human OB has between

2,975 – 9,325 glomeruli in each OB, making an average of 5,568.
The large number of glomeruli is striking, both to the degree to which it deviates from the predicted model, as well as how it varies between individual human donors. The presence of large and variable numbers of glomeruli may reflect a fundamental difference in human olfactory bulb organisation, perhaps indicating divergence from the rodent model of odour processing.

Problems with the combinatorial theory

Even though most researchers totally adhere to this combinatorial theory of olfaction, there are still some problems and we don't have all the answers. One problem arises from research where part or all of the olfactory bulb is destroyed. For example, Slotnick and his colleagues destroyed over 90 per cent of the olfactory bulb in rats and then investigated if they could still perform olfactory discriminations [1;66]. There was no decline in their ability to discriminate, and it is difficult to reconcile the maintenance of discrimination after destruction of the olfactory bulb, with the combinatorial theory of olfaction discussed above.

Another problem with the combinatorial theory of olfaction is concerned with research on the fruitfly, Drosophila [6]. Using sophisticated genetic techniques, they were able to create a strain of Drosophila that had only one functional olfactory gene. The combinatorial theory of olfaction suggests that such a fly should not be able to discriminate between odours, yet they found that the flies could distinguish between odours without combinations of olfactory receptors in the antennal lobe.

There is also some evidence that timing of the activity may also be important when discriminating between smells[6].

The combinatorial theory of olfaction, where the perception of olfaction is due to the simultaneous firing of activated glomeruli, is supported by abundant evidence and is currently the best theory available. However, there is some evidence to suggest that it does not entirely answer every question.

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CHAPTER 3

ANALYTICAL AND PHYSICAL CHEMISTRY OF EXPLOSIVES IN REST

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CHAPTER 3

ANALYTICAL AND PHYSICAL CHEMISTRY OF EXPLOSIVES IN REST

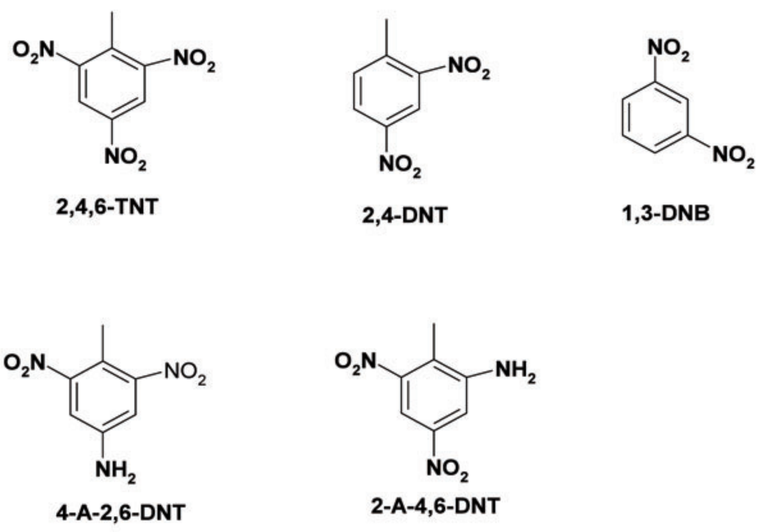
INTRODUCTION

Most military explosive compounds contain carbon, hydrogen, oxygen and nitrogen atoms and the oxygen usually exists in the form of nitro groups (NO_2). Depending on where the NO_2 is attached, explosives can be broadly categorised as nitroaromatics or nitroarenes (when NO_2 is attached to carbon, C-NO_2), nitramines (when NO_2 is attached to nitrogen, N-NO_2), and nitrate esters (when NO_2 is attached to oxygen, O-NO_2) [1].

2,4,6-Trinitrotoluene (TNT) is one of the nitroaromatics. It is widely studied because it is present in most kinds of landmines and other explosive devices. Military grade TNT contains impurities such as 1,3-dinitrobenzene (DNB) and the six dinitrotoluene (DNT) isomers, among which 2,4-DNT is the most significant (Fig. 1). These compounds remain present for several decades after manufacture. This was evidenced by an analysis of the vapour above very old TNT (35-55 years after production) and above TNT filled landmines [2, 3].

Analysis of soil samples collected from above buried landmines has shown that 2,4-DNT, TNT and two of its environmental degradation products, namely 2-amino-4, 6-dinitrotlouene (2-A-4,6-DNT) and 4-amino-2,6-dinitrotoluene (4-A-2,6-DNT) are detected most frequently [4].

FIGURE 1 | Chemical structure of selected nitroaromatic explosive compounds.



The various nitroaromatic explosive compounds differ in chemical structure as well as in physico-chemical properties (Table 1), which directly affects their "sorption" and "desorption" onto and from the environmental matrix.

"Sorption" (or absorption) is the process in which the environmental matrix takes up another substance, whereas "desorption" is the process in which a substance changes from an absorbed state to a gaseous or liquid state and is released from the matrix. Vapour pressure (one of the measures shown in Table 1) is the equilibrium concentration of a vapour generated from a sample of the pure material (liquid or solid) in a closed container, and exponentially increased with the temperature of the system.

This value can be taken as a rough indicator of the volatility of a chemical in its pure state and when it is sorbed to a matrix. As shown in Table 1, another measure - the octanol-water partition coefficient (Kow), is typically used as an indicator for sorption from water into soil (humic material). Thus, it serves as a measure of how quickly a compound can be transported with the water through soil and sediments. The higher the Kow value, the higher a chemical's tendency to sorb to humic material and the lower its tendency to travel through the soil with the water.

TABLE 1 | Physico-chemical properties of selected nitroaromatic explosive compounds (adapted from reference 5 and 6).

compound	MW, amu	m. point (°C)	b. point (°C)	Aqueous solubility (mg/L) at 25 °C	vapour pressure (torr, 20 °C)	[b]log Kow
2,4-DNT	182.14	70.5	300	199	2.2×10^{-4}[a]	1.98
1,3-DNB	168.11	90	300	500	3.9×10^{-3}	1.49
2,4,6-TNT	227.13	80.5	240	100	1.1×10^{-6}	1.73
4-A-2,6-DNT	197.17	171	N/A	2800	2×10^{-5}	1.91
2-A-4,6-DNT	197.17	176	N/A	2800	4×10^{-5}	1.94

a-at 25 °C | b-recommended values

Soil is a very complex matrix that may contain inorganic minerals, organic matter, microorganisms, water, air, vegetation, and natural or man-made debris and contaminants. Typically, the principle soil components that have a significant role in sorption of organic compounds are water and organic matter. Nitro-aromatic compounds have also been found to be special in that they may also significantly sorb clay minerals [7].

Depending on grain size, soil can be categorised as:

- fine earth (clay , silt and sand with grain diametre < 2 mm) OR
- coarse elements (gravel and stone with grain diametre > 2 mm)

The Soil Science Society of America has classified fine earth into 12 major soil textures. These are clay, silty clay, sandy clay, clay loam, silty clay loam, sandy clay loam, loam, sandy loam, loamy sand, sand, silt loam, and silt [8-10]. In general, the organic matter in the soil is considered as the determining factor for sorption of organic contaminants onto soil. However, recent studies demonstrated that the amount of clay mineral (ie minerals with a diametre smaller than two micrometres) in soil also plays an equally important role in sorption of nitroaromatic compounds. The higher the clay mineral, the better the sorption [11 and references therein].

Li *et al* demonstrated that sorption of nitroaromatic compounds increases as the ionic strength[1] of KCl increases. This was attributed to the formation of K-clay quasi-crystals [11]. Haderlein *et al* also observed that sorption of nitroaromatic explosive compounds increases when the exchangeable cations[2] of the clay contain K^+ and $NH4^+$. They concluded that the abundance and degree of K^+ and $NH4^+$ saturation of the clay minerals is a controlling factor for the mobility and availability of nitroaromatic compounds [7].

Therefore, depending on soil texture, mineral distribution, cation exchange capacity and organic matter content, the sorption strength varies, as observed experimentally [12]. Significantly sandy soil sorbs loosely and desorption is relatively easy, whereas clayey soil sorption is relatively strong and desorption relatively difficult. The same phenomenon has been observed with animal training; where rats and dogs identify the target easily in sandy soils but with difficulty in clay soil.

Besides the soil texture, organic matter, mineral and water content, there are other environmental factors affecting sorption and desorption of explosive compounds. These are:

- soil temperature
- vegetation (presence, type and density)
- rain events (intensity, duration, and direction of water overflow)
- wind (strength and direction)
- the depth of the explosive (landmine)

The type of landmine is another crucial factor, as some landmines have completely sealed metal casings that strongly limit the leakage of explosive vapours, whereas others, with plastic or wooden casings, leak substantially. All of the aforementioned factors can interact to influence the availability of detectable molecules and should be considered in REST sampling and in animal training and testing.

CHEMICAL ANALYSIS OF REST SAMPLES

Sampling dust or soil above suspected area is the preferred method for REST sampling. The dust/soil collected may need to be analysed chemically, for several reasons:

- to countercheck animal detection (ie for quality control)
- for research purposes
- to assist in best practice for animal training

Several techniques, summarised below, are available for this analysis.

Ion mobility spectrometry (IMS)

"Ion mobility spectrometry" (IMS) is an instrumental method of analysing explosive compounds in a REST sample. The steps involved are:

a) Fast solvent extraction of explosive compounds from dust/soil by shaking a certain amount (eg, 1 g) of the sample in a given volume of organic solvent (eg, 2 mL of acetone) for a few minutes and letting it settle for few minutes

b) Transferring a measured amount (eg, 50 microlitres) of the supernatant onto a filter (fibre trap) and letting the organic solvent evaporate

c) Placing the filter in a thermal desorption unit so that the trapped compounds are volatilised

d) Converting the sample vapours to ions (electrically charged molecules) at atmospheric pressure

e) Characterising/detecting the resulting ions by their gas phase mobility under a weak electric field

Some manufacturers of IMS for explosive detection declare detection limits in the range of few hundred picograms. For instance, for the Ionscan 400 (which APOPO has) from Smiths Detection, the company declared a detection limit of 300 pg for TNT. This may be achieved for standard solutions, but for soil extracts, this value can be higher for various reasons.

This is mainly because co-extraction of other compounds interferes with *step d* above, by competing with TNT in the ionisation process and reducing the likelihood of detecting TNT. Furthermore, the declared detection limit usually does not make sense to non-analysts and it may be necessary to convert it to a more sensible figure.

Take, for example, if a gramme of a REST sample and 2 mL of acetone are shaken for three minutes, and, after the particles settle down, 50 microlitres of the supernatant are taken and applied to an IMS filter for thermal desorption/vapourisation, ionisation and detection. Assume there are no compounds co-extracted that may interfere in the ionisation process, and that all the explosive compounds in the sample are transferred to the solvent (100 per cent extraction efficiency). The 300 pg signal from the IMS means we have 12 ng of TNT per gramme of REST sample, ie, the IMS gives a signal if we have at least 12 ng of TNT per gramme of sample. Considering the extraction efficiency, the interfering co-extractants and other factors not discussed here, the actual detection limit may go up to 100 ng per gramme of the sample.

HIGH PERFORMANCE LIQUID CHROMATOGRAPHIC (HPLC) (US-ENVIRONMENTAL PROTECTION, EPA, METHOD 8330)

The high performance liquid chromatographic (HPLC) method with an ultraviolet (UV) detector is one of the oldest and first methods recommended by US EPA (Method 8330) for the analysis of explosive compounds from soils and sediments.

As with IMS, the first step is extraction of the explosive compounds into a solvent. Method 8330 recommends extracting 10 g of soil sample in 20 mL of acetonitrile, with a platform shaker or cooled (<30 °C) ultrasonic bath for 18 hours. To understand the HPLC system, imagine a stream of solvent called "carrier" pumped through a long tube ending at a flow-through detector cell. Somewhere along the tubing there is an injection port at which the extracted sample is introduced into the flowing stream of the solvent. Before the flow goes into the detector cell, there is a tube packed with a solid separation material. It facilitates separation of the extracted mixture through the interaction of the different components, with the solvent and with the solid packing material.

Depending on the chemical nature (polarity, charge, size, etc) of the different components and the packing materials, individual compounds end up having different partition ratios. As a result, compounds with a high affinity for the solvent go fast to the detector with the flowing stream, whereas components with the highest affinity for the column packing stick take the longest and wash out last. The reported detection limit with this technique is 250 ng per gramme of soil. However, EPA cautioned that the detection limit is highly dependent on the sample type (matrix dependent) and may vary accordingly.

Although commonly used, the HPLC-UV method has the following disadvantages:

a) very long and tedious extraction procedure

b) poor selectivity of the UV detector prompting introduction of a secondary or confirmatory HPLC column which does not solve the problem completely

c) poor sensitivity and lengthy pre-concentration steps

GAS CHROMATOGRAPHY (GC) WITH ELECTRON CAPTURE DETECTOR (ECD) (US-EPA METHOD 8095)

As an alternative to HPLC, the US EPA introduced another recommended method (Method 8095). It is known as gas chromatography (GC) with electron capture detector (ECD) for the analysis of explosive compounds from environmental samples.

Again, the analysis starts by extracting the explosive compounds from the soil. The same lengthy extraction procedure is used. Unlike the HPLC, the carrier is a flowing stream of nitrogen, hydrogen, or helium gas through a long (typically 5-30 m) capillary tube, containing a stationary phase, usually a non-volatile liquid sorbed on the inner walls of the tube. At the injection port, the injected liquid sample is heated to convert it to vapour, and the vapour merges into the flowing gas.

Depending on the chemical nature of the different components in the vapourised sample and the stationary phase of the column, these components pass through the column at different speeds, because the difference in their interactions with the stationary phase affects separation. Some components may be strongly sorbed in the stationary phase. Increasing the column temperature desorbs them into the carrier gas and subsequently the detector.

In ECD, a radioactive source such as ^{63}Ni ionises the carrier gas, resulting in positive ions and electrons. In turn, the migration of the electrons produces background current. When electron capturing compounds are present in the carrier gas, some of the electrons produced by the ionisation of the carrier gas are captured by these compounds, reducing the intensity of the background current. The decrease in the background current is proportional to the concentration of electron capturing compounds.

When analysing 1 g of soil with the GC-ECD method, an amount of around 6 ng TNT is potentially detectable, but this value is matrix dependent and may not always be achievable.

The GC-ECD method suffers from the following drawbacks:

a) very lengthy and tedious extraction procedure

b) poor selectivity (low specificity) towards explosive compounds. This is because soil is a complex matrix that may contain other electron capturing compounds (nitroaromatics, carbonyls with double bonds, alkyl halides, organometallics, etc) that may reach the detector at the same time with the explosive compounds and interfere with their detection.

GC WITH NITROGEN PHOSPHORUS DETECTOR (GC-NPD)

To alleviate the problems associated with ECD, another detector called Nitrogen Phosphorus Detector (NPD) or Thermionic Detector is sometimes used.

It is termed thermionic because a heated solid surface or bead is used as an ion source. Often, the thermionic source is a rubidium ceramic bead which efficiently ionises compounds containing organic nitrogen and organic phosphorus. The resulting ions are then collected and measured. Although the NPD also responds to other hydrocarbons, the response to them is 100,000 times less than the response to compounds that contain nitrogen or phosphorous. Therefore it is considered an element-specific detector.

Using standard TNT solutions, a detection limit of 0.625 pg is routinely recorded, with APOPO's GC-NPD. When this is translated to a REST sample, at least 0.3 ng of TNT should be present in a gramme of the sample. Considering the issue of extraction efficiency and the matrix effect, the detection limit may be significantly higher than this value.

GC MASS SPECTROMETRY (GC-MS)

Recently, the trend has been to use GC with a mass spectrometric (MS) detector to analyse samples for the presence of explosives. This technique combines the power of the high resolution separation of the components by the GC, with a very selective and sensitive MS detection. The separated gaseous component from the GC is then transferred into the MS ion source before being ionised. It then produces different fragment ions which are mass resolved, using a filter, and detected. There are several ways of ionising the vapourised component from the GC that affects the sensitivity of the MS. The most widely used are the electron ionisation and the chemical ionisation methods.

Using GC-MS in the normal scanning mode (scanning in wide mass range) for the analysis of explosive compounds in soil, does not improve sensitivity relative to other detectors, such as NPD. The advantage, however, is the ability of GC-MS to identify other components separated by the GC that would not be detected by other methods, such as NPD. The detection limit with GC-MS can be improved in the Single Ion Monitoring (SIM) mode, if quantitative information about a component known to be present in the sample, is required.

The advantage of GC-MS is most pronounced when the sample introduction is done with Solid Phase Microextraction (SPME) or Headspace Sampler (HSS), rather than lengthy solvent extraction and concentration steps. Here, the volatile compounds in the sample are trapped with a SPME cartridge, that desorbs them at the GC injection port upon heating, or an automated HSS may directly sample the headspace vapour above the sample and transfer it to the GC injection port. The sensitivity of this system can be fine-tuned by;

- increasing the soil sample
- adding moisture
- heating the sample
- shaking or equilibrating the sample for some time

With this set up, it is possible to identify and analyse volatile compounds emanating from the explosive compounds, as well as from any casing material or additive in the landmines and the soil sample.

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REST SAMPLING FOR DETECTING LANDMINES

In a system containing various phases like water, air, soil minerals, humic matter, or a filter; any organic chemical will distribute itself so that a certain percentage of the chemical will eventually be found in any of these phases (ie, in an equilibrium situation). Volatile chemicals will mainly reside in the air and sorb only somewhat to the other phases. Less volatile chemicals will mainly sorb to the solid and liquid phases that are available, and only a small fraction will remain in the air.

The signature compounds characteristic to mines (dinitroluene, trinitrotoluene, TNT, and aminodinitrotoluene, ADNT) are less volatile. The fraction of those chemicals that sorbs to water, soil minerals and filters depends on the properties of the chemicals, temperature, humidity and the properties of those phases. The underlying relationships are complex but fairly well understood, so that we can typically estimate which fractions are sorbed to which phase. As an example, 1 g of dry soil will contain at least 10,000 times more 2,4-DNT than 1 litre of air that is in equilibrium with this soil. For TNT and ADNT the situation is even more extreme. Animals only have direct access to the few molecules that reside in the air that they sniff.

What does this mean for REST sampling? Different cases should be distinguished between:

1) **Filtering air in order to collect the airborne fraction of the signature compounds**
   In order to optimise this technique, the filter must be designed so that almost all signature molecules will be scavenged from the sampled air. This is not difficult to achieve but it has a severe drawback: if the filter is presented to the animals later, then only a small fraction of the collected molecules will go back into the air (because this was how the filter had to be designed for efficient sampling). Therefore, the animals sniffing at the filter will have access to only a small fraction of the concentration they would encounter in the field.

   The exact line of argument is more complex than shown here: filters could principally be optimised for a good performance in the sampling and presentation mode as outlined in (13). However, this would:

   a) be extremely tricky
   b) require different designs for each signature compound
   c) still not overcome the fact that air concentration above the presented samples is always much lower than in the field.

2) **Sampling the dust from the soil surface in order to collect a dust-bound fraction of the signature compounds**
   A small amount of dust contains much more of the signature molecules than even a large amount of adjacent air. Like a filter, soil generally doesn't release signature compounds to the air (which is why soil contains much more of them then the adjacent air in the field). However, a small amount of soil containing a high amount of signature compounds results in a much higher air concentration of signature molecules than a filter. A dust sample from above a mine is very similar to the air concentration above this mine that the animals would encounter in the field.

   However, in reality, dust collected into a single sample may only partly come from an area above a mine where signature molecules are present. If this is case, the clean dust collected above mine-free areas will scavenge some of the signature molecules from the "contaminated" dust during sample storage, so that the air concentration eventually presented to the animals will actually be smaller than what it was in the field in the vicinity of the mine.

This dilution effect also occurs in pure air sampling, so one can clearly conclude that the sampling and presentation of dust is much more efficient than the sampling of air. However, the concentration presented via a dust sample which has been partly collected from mine free areas, is always smaller than the concentration in the field in the vicinity of a mine. Therefore, REST with animals is always a less sensitive technique than the direct operation of animals in the field.

Technically, it is feasible to collect dust with or without filters. For REST it is advisable to collect dust without filters because the filter material would reduce the concentration of signature molecules. Also, animals can actively desorb the signature compounds from soil minerals by exhaling moist air onto the soil. This allows them to increase the available concentration in the inhaled air by about a factor 100. This effect only works on dry soil and not on typical filter material. Therefore only dry soil must be sampled (this will happen anyway because wet soil is too sticky to be collected with a vacuum pump).

From the known soil sorption constants of the signature molecules, one can conclude that collecting about 50 mg of dust per square metre of soil surface is enough to supply the maximum possible signal to the animal. More dust will not do any harm when collected representatively over the whole area, but neither will it bring any improvement.

STORAGE AND PRESENTATION OF DUST REST SAMPLES

Dust must be stored in dry, cool and dark conditions, to prevent any degradation. Dryness is especially important! Containers should be glass or metal - which are not penetrable to scent molecules - rather than plastic.

Animals should be able to get their noses close to the opening of the containers so that their exhaled air reaches the dust (see humidity effect described above). Therefore, the distance between the opening of the container and the dust should be less than 2 cm for dogs and 1 cm for rats. Humidification should not be attempted manually, because the optimal range of humidity is very narrow, and differs depending on soil texture and original moisture content. The animal will achieve optimal humidity with its exhaled breath.

In order to avoid misconceptions, it is necessary to note that:

- The best filter for REST of landmines must be designed completely differently to the optimal filter for sampling cargo. The requirements are different because in cargo, dust is typically not available, and air sampling can be focused on the contaminated air within the cargo. Also, dilution with uncontaminated air can be largely excluded. To the best of our knowledge, no systematic (scientifically based) optimisation of filters for cargo sampling has taken place so far.
- The best sampling method for subsequent analysis with animals is not necessarily the same for instruments. For example, the filter requirements of the gas phase of sampling are different to those needed the dust phase. In addition, the amount of dust in the sample doesn't matter for animal detection, but matters greatly in instrumental analysis.

ANALYTICAL AND PHYSICAL CHEMISTRY OF EXPLOSIVES IN REST

Several years ago, on testing the performance of filters used by MECHEM for REST sampling, we found that they proved to be very inefficient for collecting molecules from the air. This was not because of the material itself, but because the gauze had such a large mesh size, that the air passed through it too quickly for the airborne molecules to diffuse to the sorption sites. The reportedly satisfying performance of these filters in practice probably came from the additional collection of dust particles that occurred when the filters touched the ground during sampling.

VARIABLES THAT INFLUENCE THE AVAILABILITY OF DETECTABLE CHEMICALS

When searching for mines, detection of explosives on the soil surface above buried mines is one promising technique. However, there are limitations. Soil type and weather conditions affect the amount of explosive molecules on the surface, and there may not be enough to provide a signal to the animal. It is important to bear in mind the limitations that adverse environmental conditions can put on the ability of animals to detect the mines, including when replicating training conditions and samples.

Many factors influencing availability are interrelated, and their influence on the explosive concentration on the soil surface is often non-linear, resulting in an extremely complex situation. For example:

- On dry soil, an increase in temperature decreases the gas phase concentration of explosives above the soil. If the soil is wet the opposite happens
- If the soil is dry and the relative humidity in the air increases from 60 to 90 per cent, then the gas phase concentrations of explosives above this soil increase by about a factor ten or more. This is because the increasing number of water molecules in the air help replace explosive molecules from the soil surface. However, if it rains on dry soil, the gas phase concentration will be reduced to zero, because the desorbed explosive molecules will directly dissolve into the rain water rather than volatilise into the air
- On dry soils, the performance of dogs does not depend on the available gas phase concentrations, because they are able to actively desorb explosive molecules that are attached to the soil. Hence they “see” much higher concentrations than an analytical instrument that only analyses the gas phase above the soil. However, on wet soil this advantage does not exist
- While weather has a strong impact on the availability of scent on a soil surface, there is no simple correlation. This is because the current weather plays a role, and also the previous days’ weather, the soil type and moisture content are important (see below)

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BACKGROUND INFORMATION

Environmental chemists have a rather good qualitative understanding on how chemicals in general migrate through soils. Principally this movement happens in the soil pores either via the gas phase or in water. Based on the physico-chemical properties of the explosives, we expect that any significant transport in the soil for these molecules only occurs in and with the soil water (and not via the gas phase in air-filled pores). This is even true for extremely dry soils where a human would not be able to sense the presence of water. The fraction of molecules sorbed into the soil matrix does not travel at all. Therefore, the transport velocity and direction of the explosives is determined by the movement of the pore water.

The water-flow in the soil depends on several things. These are:

- the spatial moisture distribution in the soil
- solar irradiation
- wind-speed
- frequency
- intensity of rain
- temperature
- soil texture, and others

The better the prediction of the movement of water in the soil, the better our understanding on whether a mine search is generally feasible within a given climatic zone or specific situation will be. Water that infiltrates the soil during and after rain flushes the explosive molecules deeper into the soil, resulting with few or none remaining on the soil surface.

During a dry period following rain, evaporation from the soil surface occurs. This will cause the direction of water flow in the soil to reverse; therefore, the upward transport of the explosives is possible. However, a water divide develops underneath the soil, below which water still continues to infiltrate deeper into the soil. It is only above this that water will creep upwards as though in a sponge.

During rain, the water divide is located on top of the soil (ie, all water moves downwards). As evaporation occurs, the divide moves down into the soil. When it has reached the explosive molecules, either at the level of the mine or somewhere above, transport of the explosives to the surface re-starts. Obviously, a mine search before this point in time will fail.

When the explosives reach the soil surface with the water, then a fraction of them volatilise, and the rest stay on the soil surface. On dry soil surfaces, a large fraction of the signature molecules are sorbed into the soil, rather than volatilised along with the water. A dry surface layer then acts as an efficient trap for the explosives that have been transported upwards with the water.

A wet soil surface sorbs a much smaller fraction of the explosives and more is volatilised. Intuitively, one might think that this is more favourable for the animals because then the concentration in the air is higher. However, once in the air, the odours are quickly diluted and spread out so that the concentration available to the animals is actually quite low. In contrast, on a dry soil surface, the odours accumulate and large amounts are released when an animal exhales moist air.

We do not have an accurate mathematical model that predicts the concentrations of odour molecules at the soil surface as a function of weather, soil type and depth, the type of the mine and other factors. However, while working towards this goal we offer some preliminary advice based on our current understanding that might prove useful to practitioners. The following conclusions are hypotheses based on our current understanding and still need to be checked in practice:

TIME LAG AFTER RAIN BEFORE THE MINE SEARCH CAN BE RESUMED

After rain, the development of a dry soil surface layer indicates clearly that significant evaporation of water - and therefore upward transport has occurred (although it is not sure whether this process has reached the explosive molecules yet). As mentioned before, the dry soil acts as a trap and accumulates explosive molecules quite effectively.

The intensity of the rain, the type of soil, and the moisture content before the rain event will determine how long it takes until such a dry surface layer develops. Dew fall or very light rain will dislocate a significant amount of the odour molecules from a dry soil surface into the adjacent air layer but will not flush the odour molecules deep into the soil, so that the search can probably be resumed reasonably soon.

SOIL TYPE

Clayey soils take much longer to dry out than sandy soil, but this does not mean that clayey soil is less favourable than sandy soil for mine searches. During a rain event, water infiltrates much faster and deeper into sandy soil than clayey soil, which is why they dry out quicker.

While drying out, the upward water flow in sandy soils is much less effective than in clayey soils. During a very dry period, water in sandy soil does not move to the surface at all, but evaporates deep in the soil, which is where the explosives accumulate. In contrast, in clayey soil, upward water flow continues to the surface, even if the soil surface is already very dry.

Based on these features, one may expect clayey soils to be more favourable than sandy soils. However, in climates that are so humid that clay soils never become dry on the surface, a sandy soil might still show a better performance.

VEGETATION

Vegetation significantly slows down evaporation of water from the soil surface, which slows down the upward transport of explosive molecules. However, as long as vegetation does not completely prevent the soil surface from drying out, and as long as it does not prevent the dogs from getting their nose close to the ground, then a mine search should still be possible.

TEMPERATURE

The range of acceptable temperature conditions is probably rather wide and much less of a concern than the humidity conditions.

However, although elevated temperatures generally accelerate the transport of explosives to the soil surface, they also accelerate the degradation of TNT. Also, temperature effects on the physiology of the dogs and rats are likely to be more relevant or limiting than the direct effects on surface concentrations.

CLIMATE

Climates with long dry periods and little vegetation are the most favourable for the operation of mine detecting animals.

In humid climates, sufficiently dry periods may be so short that the work is not cost-effective. According to one field operator, a reliable mine search with mine detection dogs in Bosnia is restricted to two or three months each summer. In areas with an even more humid climate than Bosnia, the deployment of direct detection animals does not seem advisable. Note, though, that this also depends on the soil type.

LOCATING MINES

The explosive signature molecules can show a concentration a maximum of several metres from the mine and even up-hill from it. A plausible explanation for this may be that when water infiltrates soil, it does not necessarily flow straight downwards. Depending on the pore structure of the soil, it may also flow sideways, with only a small downward gradient. This flow could very well travel even up-hill.

When infiltration stops and evaporation starts, water transport always travels straight upwards, as does the transport of the explosives. Therefore the explosives will appear on the surface just above wherever they were transported underground during the infiltration process.

Soils rich in clay show a network of cracks when they dry out. In case of a heavy rain event, most of the water flows into these cracks, and so the explosives may be transported in all kinds of directions quickly and over rather large distances. This will not happen after a light rain however.

PREPARING TRAINING SAMPLES

Environmental conditions and the physico-chemical properties of the explosives also come into play when preparing training samples for animals. A comprehensive discussion of all the potential pitfalls that have to be considered when preparing training samples is beyond the scope of this text, but we suggest the following ideas:

(i) When the same amount of explosives is spiked into different soil samples of the same weight, the resulting scent can easily differ by a factor 100 or more, depending on the types of soil used and its moisture content. Soils with a high clay content sorb a higher fraction of explosives than sandy soils. Therefore, when spiked with the same amount of explosives, more scent molecules should be available from a sandy than a clayey soil. (Note that this is in contrast to the situation in the field; where clayey soil is likely to provide favourable conditions due to better water transport).

(ii) Moist soils sorb much less explosives than dry soils, but as explained above, this does not mean that the availability is better on wet soil samples, as long as the animals are allowed to use their moist breath for desorbing the odours from the dry soil.

(iii) The training of animals on pure military grade TNT will inevitably provide them with a different odour bouquet than they will encounter on the soil surface above a mine. This is because the various components of military grade TNT migrate through the soil at different velocities and are degraded to different extents. Therefore, training should not rely on using military grade TNT alone.

SUMMARY AND CONCLUSION

Analytical chemistry methods for detecting explosives in field samples are time consuming, laborious and costly, and typically the detection limit is lower than that of well-trained animals. Currently available methods cannot compete with animals when it comes to the quick scanning of large numbers of samples.

However, the advantage of instrumental analysis lies in the clear identification and quantification of the signature compounds (if a mass spectrometre is used). In comparison, animals only provide a yes/no answer and one can never be sure whether the answer was triggered by the presence/absence of an explosive signature compound or by something that is not originally connected to the presence of a mine.

From a physical-chemistry point of view, there are a number of clear conclusions that can be drawn regarding the use of REST for landmine detection:

a) the sampling strategy should aim for collecting dust without using filters

b) in the presentation mode, the animals should be allowed to get their nose close (within 1 or 2 cm) to the sample

c) the odour concentration found in a dust sample that comes from a section that was only partially contaminated with explosives will always be smaller to what is found in the field in the direct vicinity of a mine (dilution effect).

As a consequence of the latter, therefore, REST, despite having other advantages, cannot be more sensitive than a animal searching directly would be.

The environmental effects on the availability of signature compounds are very complex. There are many processes acting at the same time, and their effects are often interrelated and highly non-linear. The best and simplest hypothesis that allows for a successful mine search (directly or with REST), is a dry soil surface. It is an indicator of an upward-flow of water, and an effective trap for explosives transported to the surface. However, more research in this field is needed.

ENDNOTES

1 When ionic compounds such as KCl are dissolved in water they dissociate into ions and ionic strength is a measure of the concentration of the dissociated ions.

2 Cations are positively charged ions (K^+, $NH4^+$, Ca^{2+}, Fe^{2+}, etc.) which tend to attach to the negatively charged surface of soil particles and organic matter. The degree at which a soil adsorbs and exchange cations is termed cation exchange capacity.

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CHAPTER 4

STRATEGIES FOR THE RESEARCH AND DEVELOPMENTAL OF REST USING ANIMALS AS THE PRIMARY DETECTORS

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CHAPTER 4

STRATEGIES FOR THE RESEARCH AND DEVELOPMENTAL OF REST USING ANIMALS AS THE PRIMARY DETECTORS

INTRODUCTION

If an effective and reliable operational system of REST using animals were to exist, it would share at least two features with any system engineered to detect environmental compounds more accurately than an unaided human:

1) the systems would apply complex procedures (represented either in hardware or in an operator's behaviour)
2) those procedures would have been discovered by rigorous and replicable empirical research.

In the case of an electronic device operated by humans, few people would challenge the need for sophisticated research and development (R&D) by an appropriately qualified scientist/engineer; it would be assumed that various basic principles of physics and/or chemistry had been applied in novel ways before the scientist/engineer thoroughly tested the performance of his/her device. However, fewer people recognise a similar need for careful R&D in the preparation, operational use, and monitoring of animals in a system of REST. Perhaps this is because most people who use animals for their detection abilities are unaware that a science of learning and behaviour exists and is being used to generate training and behavioural-control technology in other domains.

A central theme of this chapter is that the complexity of procedures in an operationally-viable system of REST is equal to (if not greater than) the complexity of procedures that culminate in an electronic detection-device. The need for scientific research in the development and validation of procedures in REST should, therefore, be given equal recognition. I argue that a science of behaviour known as Applied Behaviour Analysis (ABA) is ideally suited to developing those procedures that involve preparing animals as the primary detectors in a REST system.

WHAT IS APPLIED BEHAVIOUR ANALYSIS?

Applied Behaviour Analysis (ABA) is a sub-discipline of psychology - the scientific study of behaviour in humans and animals - and is taught in most psychology departments at colleges or universities in western countries around the world. The Association for Behaviour Analysis International (ABAI) has a professional membership of around 6,000 and hosts various annual conferences. The Behaviour Analyst Certification Board provides professional licensing for those wishing to practice clinically as Behaviour Analysts, and behaviour-analytic work is published in a range of peer-reviewed journals including *Journal of Applied Behavior Analysis, Journal of the Experimental Analysis of Behavior, The Behavior Analyst, Behavioral Interventions*, and *Behavior Analysis in Practice*.

Behaviour Analysts practice and/or conduct research in a large number of domains. Currently, the most popular is the field of developmental disabilities - ABA offers an approach to special education for children with an Autism Spectrum Disorder, and, is recognised by the US National Institute of Health as the only empirically-validated treatment for this disability. ABA has also been applied in Clinical Psychology, General Education, Organisational Behaviour Management, Gerontology, Sports Psychology, Behavioural Medicine, Neuro-rehabilitation, government Policy Development, and the management of behaviour in domestic and captive-exotic animals (see *The Cambridge Center for Behavioral Studies* - www.behavior.org). It is a field that has numerous applications because it offers scientific methods with which to identify effective ways of changing the behaviour of any living organism, and many problems in human societies can be addressed by changing the behaviour of someone, some group, or some animal.

Cooper *et al* (1987) defined ABA as "*… the science in which interventions derived from the principles of learning & behaviour are applied to improve socially significant behaviour to a meaningful degree, and principles of single-subject research are used to demonstrate experimentally that the interventions employed were responsible for the improvement.*"

In other words, ABA involves devising interventions that utilise some of the basic principles of learning and behaviour that have been studied in laboratory research with animals – a field known as the Experimental Analysis of Behaviour. These interventions are applied, and assessed using various applied-research strategies, in order to develop techniques for effectively teaching new behaviour and maintaining behaviour changes. In the seminal article defining ABA, Baer *et al* (1968) wrote that "... analytic behavioral application is a self-examining, self-evaluating, discovery-oriented research procedure for studying behavior."

ABA differs from traditional approaches to psychological therapy in terms of its focus, goal, and methodology. It is based on the philosophy that a science of behaviour is possible and indeed desirable (a philosophy first described by B.F. Skinner, 1938). Its proponents advocate direct measurement of precisely defined and observable responses from the human/animal subjects being studied (patterns of behaviour called *target behaviours*) and emphasise the need for thorough and reliable measurement of target behaviours. In terms of methodology, those using ABA invariably strive to change the behaviour of the subject animal/person in the desired way, while also demonstrating convincingly that the procedures/interventions employed to do so were actually responsible for the behaviour change.

According to Baer, Wolf and Risley (1968, 1987), the seven key characteristics of ABA are that it:

- is applied
- is behavioural
- is analytic
- is technological
- is conceptually systematic
- is effective
- addresses generality

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It is also possible to consider these characteristics as criteria for behavioural research that seeks to develop procedures for establishing specific performances in animals and people. Because we see the development of training procedures as the primary mission of the animal component of REST R&D, we describe Baer et al's characteristics of ABA in some detail below.

1. ABA and REST R&D involve applied research

Baer *et al* argue that behaviour-analytic research is *applied* if the target behaviour of interest is socially significant and is, therefore, either directly beneficial for the animal/person emitting the behaviour or valued by the community in which the person/animal exists. This definition of *applied* was intended to distinguish ABA from the Experimental Analysis of Behaviour (EAB) where basic research involves studying a target behaviour that has been selected for measurement conveniences (eg, key pecking in pigeons, lever-pressing in rats).

Baer *et al* wrote "The differences between applied and basic research are not differences between that which "discovers" and that which merely "applies" what is already known." Instead, the purpose of both applied and basic research is the same - to discover lawful relations between an animal's experience with its environment and its current behaviour. Only the social significance of the behaviour being studied determines whether it is considered applied or basic research. Therefore, to the extent that an animal reliably emitting a specific response in the presence of UXO odour is of value to people seeking to remove that UXO from the environment, that behaviour is socially significant and research aimed at establishing it is applied.

This definition of applied research renders a distinction between research and development (the two arch enemies in many peoples' expressions) problematic because the two activities are seen as one–and-the-same; development of a behavioural technology for the animals serving in a REST system necessarily involves research activity.

2. ABA is, and REST R&D should be, behavioural research

Baer *et al* stated that ABA is *behavioural* to the extent that it involves a precise measurement of observable aspects of a person's/animal's behaviour and the environmental conditions (stimuli) under which a specific target behaviour occurs. Various strategies for recording target behaviours are available, but observation of the subject behaving over time is often the only method available when that target behaviour is socially significant.

In REST systems, the target behaviour is the indication response (dogs sitting or rats scratching), and it is detected, recorded and subsequently measured by human observers. REST with animals should, therefore, be viewed as two interacting signal-detection tasks – one being performed by the animal (the primary detector) and the other being performed by human observers (secondary detectors). This involvement of another agent's behaviour in the research implies a need to verify that it was the animal's behaviour, and not the observer's that changed when a change in the training procedure was introduced.

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The verification described above generally proceeds by quantitative assessments of the agreement (correlation) between behaviour recordings of two or more independent observers. Another method, and one that is suited to REST R&D, is to measure the agreement between a single observer's recordings before and after (s)he is given information regarding the placement of samples containing the target odour (termed *blind-testing*). Only when we have obtained high degrees of observer agreement can we be confident about the validity and reliability of the data we have recorded. As it happens, a significant investment in the documentation of procedures and the training of staff was required before the NPA/SRSA-GICHD REST project succeeded in obtaining high measures of agreement. Some of those assessments are described in the next chapter.

3. ABA is, and REST R&D should be, analytic

Baer *et al*'s third characteristic of ABA (ie that it is analytic) is perhaps the one which is most important for the behavioural component of R&D into REST with animals. There are three ways in which research should strive to be analytic. The first follows directly from Baer *et al*'s definition of the term. That is, the research should aim to demonstrate convincingly, and by way of carefully controlled experiments, that any change in measures of the subject's target behaviour was due to a specific change in the training procedure and not some other confounded variable. The second sense in which the research should be analytic involves seeking objective and empirical evidence for the behaviour of our subjects that we were trying to establish. The third meaning of analytic lies in paying careful attention to how the target behaviour is recorded, in order that later analyses of the data might suggest controlling variables that would otherwise not be detected. We will discuss separately each of these criteria for being analytic.

Requiring empirical evidence for a specific procedure having produced the desired behaviour change is important because only then can we develop an understanding of the variables controlling the target behaviour and hope to develop an optimal set of procedures. In the context of R&D into REST, a behaviour analyst will assume that the animal (rather than a human expert) knows best which procedures assist their detection accuracy and which are detrimental. (S)he will then design experiments that essentially ask the animals to sort procedures into those categories. Consequently, although REST researchers ought to make procedural changes that work toward those envisaged for operational activity, the final set of procedures should be approached systematically and by analyses of the effect (if any) of numerous single procedural changes. The importance of implementing, and then assessing the effects of, single and small changes to a procedure cannot be overstated. Allowing multiple changes to occur simultaneously makes it impossible to discern which specific change produced a behaviour change, and so limits our ability to replicate effective training later.

In addition to the value of seeking scientific evidence for the efficacy of training procedures, the actual research methods used in ABA to provide this evidence are ideally suited to preparing a small group of animals for operational REST activity. The methodology is called *single-subject* (or *within-subjects*) research. It was pioneered in the behavioural sciences by Skinner (1938), elaborated considerably by Sidman (1960), and continues to evolve. The basic principles of this methodology are as follows:

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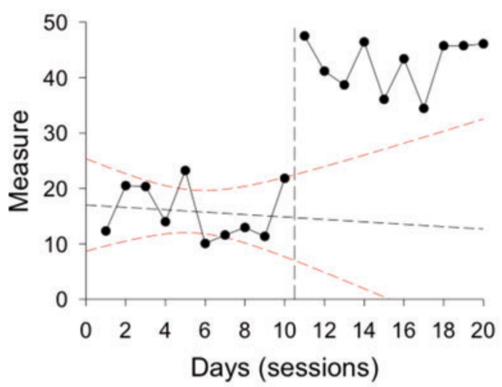
1. Some specific target behaviour of each of a small number of animals is first measured repeatedly in successive training sessions that involve an unchanging method of training – a period known as *baseline*.
2. Measures of the target behaviour of each individual are then plotted with session number on the horizontal axis in order that the stability of the target behaviour over time can be assessed.
3. Minimal variance in measures of the target behaviour is achieved by minimising the observer's measurement error and controlling (ie, keeping at a constant value) all those variables that have some effect on the probability of the target behaviour occurring.
4. Once the baseline measures are deemed stable and with acceptable variance, each of the individual animals receives the same procedural change and the monitoring of their behaviour continues.

An effect of the procedural change – anything from changing an animal's session time in a day to changing the reward delivered for hits – is claimed if the measures of the target behaviour after the procedural change fall in an area of the graph that is outside where they were predicted to fall if the initial training conditions had remained. This judgment is generally made by visual inspection of the graphed data rather than by applying inferential statistics. (Figure 1 illustrates this method of inductive reasoning).

In contrast to between-group designs, in single-subject research, each subject receives the control condition (the baseline phase) and the experimental condition (the intervention phase). This means that each subject constitutes an experiment in its own right and the value of having more than one subject is that it affords an opportunity to replicate the result of the experiment multiple times. Although it is possible that all the subjects shared some pre-experimental experience or some biological trait that modulated an effect of the procedural change, that possibility become less likely with each subject added and five subjects (ie, four replications of an effect) is generally considered sufficient to prove an intervention's effect.

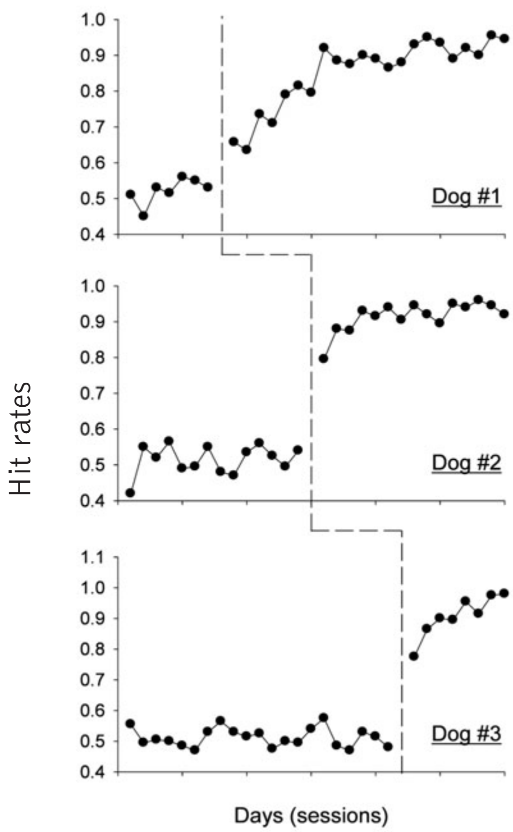
FIGURE 1 | An illustration of baseline logic. Measures of the target behaviour after some procedural change (data on the right of the vertical dashed-line) fall in a region that is outside the region where data would be predicted to fall if the procedural change had not been made. The red dashed-line indicates the edges of a 95 per cent confidence interval. .



The design illustrated in Figure 1 can be described as an *A-B design*, where A refers to a baseline phase and B to the intervention (ie, the change in procedure). Obviously, single-subject experimental designs are often considerably more complex than just replications of an A-B design across subjects. For example, evidence against the possibility that the mere passage of time was responsible for the behaviour change can be obtained by staggering in time across subjects the point at which the procedural change was made, a procedure known as *multiple-baseline-across-subjects* (see Figure 2).

In addition, more confidence in experimental control over the target behaviour and an accurate description of the variable responsible for the behaviour change is obtained if the baseline phase is reinstated (ie, the procedural change is removed) and measures of the target behaviour are seen to return to baseline levels: an A-B-A design (see Figure 3). Finally, at times, an alternating-treatments design (A-B-A-B-A-B…) where training switches at regular intervals between two procedures might be possible (Barlow & Hayes, 1979; see Figure 4).

FIGURE 2 | Hypothetical data from an experiment involving a multiple-baseline-across-subjects design. Subjects are kept in the baseline phase (left of the dashed line) for varying numbers of sessions before the procedure is changed and the intervention is introduced. This reduces the likelihood that some variable other than that manipulated in the procedure change produced the behaviour change.



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Several textbooks describe the details of many other single-subject experimental designs (eg, Cooper *et al*, 2007; Johnston & Pennypacker, 1993; Kazdin, 1982; Poling, Methot & LeSage, 1995; Sidman, 1960) and I will not review them here. However, two points are worth making. First, the various principles that underlie proving an effect of some procedural change can be applied in a wide variety of ways. This means that the methodology is conducive to improvised experiments that are designed on the fly and as data come to hand. Second, in order to easily compare data sets across conditions (sets of sessions) in a single animal, and judge accurately when a real change in behaviour has occurred, the variability in measures of behaviour across sessions within a condition must be minimised. This is achieved by minimising measurement error and experimental control of all those environmental variables that control the emission of the target behaviour (*cf*. group-design research where variability in treatment effects is considered noise and statistics are used to mask out the variability). However, controlling important variables across sessions requires knowing which variables affect the emission of the target behaviour and so requires that efforts to discover these variables are part of the research agenda. Examples of experiments aimed at identifying sources of variability in measures of detection accuracy in REST animals are described in the next chapter.

FIGURE 3 | Hypothetical data from one subject receiving an A-B-A design where the intervention is removed (and the baseline phase is reinstated) after the intervention has been in place for some number of sessions. Returning to the baseline phase and replicating the data path seen in the initial baseline phase increases our confidence in the intervention having a true effect on our subject's behaviour. Note that this return to baseline can be replicated across subjects to demonstrate an effect even more convincingly. (However, recovery of baseline data requires that intervention effects can be undone and sometimes they cannot.) In addition, a replication of the effect of the intervention can be arranged in an A-B-A-B design. This design has the added advantage of leaving the subject with the desired performance.

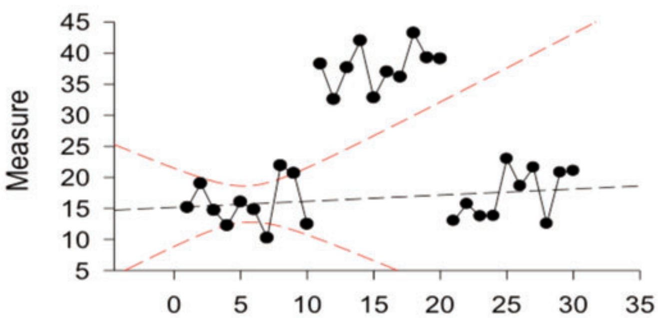
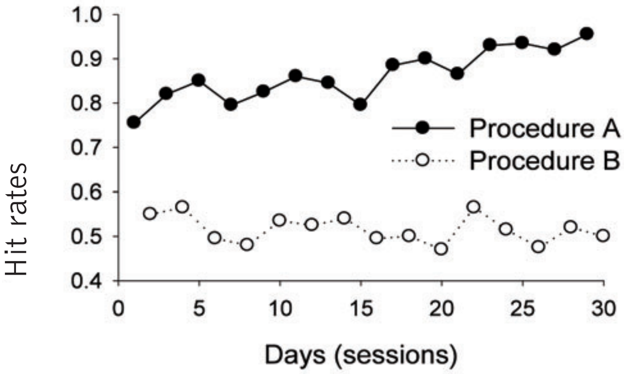


FIGURE 4 | Hypothetical data from one subject receiving an alternating-treatments design where Procedure A is applied on odd-numbered sessions and Procedure B is applied on even-numbered sessions. An effect of procedure is evident if there is clear separation between the two sets of data is minimal as in the example above. This design is appropriate only when minimal interference between the effects of either procedure on the efficacy of the other can be expected. Replicating a difference between two procedures across additional subjects increases our confidence in the difference being a real effect.



There is a second and equally important aspect to being analytic in the R&D of training procedures for REST animals. It concerns seeking experimental evidence that the target behaviour we are trying to establish in our animals (an ability to indicate the presence of UXO odour) is indeed the behaviour that we have trained. (Readers interested in a discussion of Stimulus Control Topography Coherence Theory – SCTCT – see McIlvane & Dube, 1992; 2003). Our goal is to have a specific response (eg, sitting) occur on every occasion that a sniffed sample contains UXO odour but never when it does not contain that odour. This is because other irrelevant odours can easily correlate with the intended target odour and cue the indication response (known as *overshadowing*) without the handler noticing that this has happened. (In terms of SCTCT, the topography of the stimulus-control that exists over the indication response might not be the topography that we intended).

The problem of inappropriate stimulus control arises because human trainers are trying to establish control over the response by a stimulus that they are unable to sense, which in turn reduces their ability to arrange differential reinforcement of the response with respect to the presence versus absence of the target odour. (A similar problem has been noted in the measurement of an animal's ultrasonic hearing although at least instruments capable of detecting some of those sounds in real time have been developed. See Dalland, 1970). It is not unlike the problem that a parent faces when trying to teach their child to label some emotion like pain, fear, anxiety, envy, etcetera; the stimulus that should control the response cannot be sensed by the parent (it is a private event for the child) in order that the parent can reinforce an appropriate corresponding verbal report by the child. Instead, the parent must be guided by collateral behaviour. The behavioural researcher attempting to train stimulus control by an odour that is beyond his/her ability to smell needs to have some degree of faith that the methods used to create positive samples have resulted in the target odour being present in those samples and absent in negative samples. We should not, however, rest easy with this faithfulness and instead should seek empirical evidence for stimulus control by our intended target odour. General strategies for seeking such evidence are described in the next chapter.

Finally, REST R&D will be analytic if it involves careful and thorough analyses of measures of the target behaviour (eg, sitting) with the intention of discovering variables that control that behaviour. Furthermore, such data analyses are possible only when the target behaviour is recorded with regard to many potentially important variables. For example, rather than recording simply how many times a subject emitted the indication response in the presence and in the absence of the target odour, indications should be recorded with respect to:

- the spatial position of a sample in a set
- the temporal position of a sample in a session
- the particular observer who judged the animal's behaviour
- the climactic conditions inside the laboratory where samples are presented
- the number of times those samples had been previously presented, etc

It is only once the values of many variables have been are recorded alongside records of the animal's behaviour that one can assess the significance of correlations between values of a variable and measures of the target behaviour. Therefore, at the SRSA/NPA-GICHD REST project, clear evidence was found of the following:

1) a *warm-up effect* where hit rates were consistently lower earlier in a session than they were later
2) higher hit rates in the second session of a day than in the first
3) higher hit rates when a dog was the first to inspect a set of samples

Although these effects were apparent only as correlations and so need not imply cause-effect relations, they point to potential sources of variance in measures of the target behaviour and can, therefore, guide experimental analyses of specific variables and/or strategies aimed at minimising that variance. Take the warm-up effect as an example. One can easily imagine how this contributed variability in session-by-session hit rates of the dogs. A computer programme was used to randomly allocate 12 positive and 84 negative samples to positions one to 96. Samples were then presented in that order, in sets of 12, on an apparatus called a carousel. If hit rates on the first 24 samples were always lower than the remaining sets, and the programme happened by chance to allocate many of the 12 positive samples to the first two sets, then the overall hit rate for the session would be lower than it was in a session where relatively few positive samples appeared in the first two sets. From a research perspective, discarding data from the first two sets of samples should reduce the variability in hit rates over sessions and allow researchers to assess more accurately whether a given procedural change affected the animal's performance. From an operational perspective, this effect implies that technicians arranging operational samples should re-present later in a session, those samples that were presented earlier in the session.

4. ABA is, and REST R&D should be, technological

That ABA is technological means that all important aspects of a specific procedure for changing behaviour (including procedures for establishing the appropriate stimulus control over some response) have been completely and accurately identified and described. When ABA research is published, complete and accurate descriptions of successful techniques allow others to apply those techniques and to achieve similar outcomes. Thus, teaching children with autism to speak or training animals to indicate the odour of UXO is not considered an art, or a skill possessed only by experts; it is a science and, as such, requires careful application of techniques that others have documented and found to be effective. Being technological should, however, be considered an objective of research rather than a dichotomous feature because the completeness and accuracy of procedural descriptions often evolves in the course of experimentation. In other words, much of what is learned in behaviour-analytic research is exactly what aspects of a procedure are critical, what aspects are important, and what aspects are superfluous.

The need for R&D into REST with animals to be technological warrants further emphasis. Aside from assisting others to establish an effective REST system, the identification and accurate description of procedures also helps technicians conducting the research because they need to replicate procedures across training sessions of a given condition. The importance of technicians precisely replicating procedures cannot be overstated because variability in procedure implementation is a known source of variability in measures of a subject's performance, and performance variability is the enemy of single-subject designs. Accurate descriptions of research procedures can be a formidable task however, because a large number of extremely complex procedures exist.

For example, there were five types of research technicians working on the NPA/SRSA-GICHD project: laboratory technicians, documenters, animal handlers, cleaners, and security guards. In order to promote uniform procedures across technicians and across time in a single technician, Standard Operating Procedures (SOPs) were written for each type of technician, and diligently updated before every procedural change that was a new condition in an experiment. Those written only for the laboratory technicians exceeded 45 pages and included details such as:

- the total number of times that an aluminium canister containing a sample was touched prior to presentation on the carousel
- when in a training session a technician should change his/her outer pair of plastic gloves
- how the lids from aluminium canisters should be stored while the open canister was on the carousel, etc

Documentation alone, however, was found to be insufficient and it was also necessary to:

- run regular SOP training sessions for each group of technicians
- examine their knowledge of current SOPs in short tests
- develop checklists for supervising technicians to assess the performance accuracy of others

Variability in the performance of even the security guards had the potential to add variability to the dogs' indication accuracies and hinder the progress of research. This was because food rewards were being used in training sessions and guards were tasked with feeding the dogs a measured amount of food each morning. If the time since the last meal determines the efficacy of food rewards in training sessions, then adding variability to meal times and meal sizes will add variability to reward efficacy and perhaps then to performance measures.

5. ABA is, and REST R&D should be, conceptually systematic

A conceptually systematic body of research is one in which methods are described, and results are discussed, in terms drawn from a conceptual framework (an accepted terminology) that has evolved with the body of research. In order for ABA to be conceptually systematic, effective procedures for establishing a specific behaviour and mechanisms underlying their efficacy should be described in terms of the basic principles of learning and behaviour involved. Such terms include *respondent conditioning*, *operant conditioning*, *positive reinforcement*, *establishing operation*, *stimulus control*, *discriminative stimulus*, *selective stimulus control*, and many others.

Baer *et al* (1968) argued that being conceptually systematic "… can have the effect of making a body of technology into a discipline rather than a collection of tricks" (p. 96). In addition, using an established scientific vocabulary (ie, a unified conceptual framework) to describe various phenomena enables similarities and differences between them to be identified.

The conceptual framework adopted in ABA has its roots in two domains:

1) basic research investigating the principles of learning, and the maintenance of learned behaviour in animals (the Experimental Analysis of Behaviour; EAB)
2) a philosophy of psychology known as Radical Behaviourism (Skinner, 1938)

I suggest that the conceptual framework adopted by researchers conducting R&D in REST with animals should also be guided by EAB and Radical Behaviourism. Only a brief description of both disciplines should suffice to support my argument. Readers interested in learning more about the EAB should refer initially to various textbooks (eg, Catania, 1998; Mazur, 2006; Donahoe & Palmer, 1994) and those interested in Radical Behaviourism should begin with texts written for undergraduate students of psychology (eg, Baum, 1994, 2005; Skinner, 1974).

Radical Behaviourism assumes that all aspects of an animal's behaviour are determined and that behaviour is lawful. This philosophy rejects the notion of behavioural causes residing in some non-physical realm such as the mind, and challenges the scientific value of so-called *mentalistic* explanations of behaviour which refer to thoughts, emotions, states and drives inside the animal. Instead, three sets of factors are assumed to determine the behaviour of an animal at any given time. These are:

1) its biological make-up, including what it has inherited from its ancestors
2) its learning history (or history of behavioural interactions with the environment)
3) the current state of the environment.

For example, rather than attributing a dog's false alarm to its *thinking* that it smelled explosives, a Radical Behaviourist might attribute the false alarm to the absence of rewards for correct rejections, and then conduct experiments to test that theory.

Another central concept in Radical Behaviourism is that the utility of a theory for how Variable X affects measures of Behaviour Y should be judged according to the degree to which that theory allows one to predict and control measures of Behaviour Y. Therefore, theories which invoke states within the animal rate abide poorly with this criterion, because one cannot easily predict when those states will exist in order to predict the observable behaviour. This is a philosophy of science known as *pragmatic epistemology* and its adoption suits any field of research that seeks real-world applications of principles discovered.

EAB has a long history in psychology. It is a field of research that is directly relevant to R&D into REST with animals because it has involves the study of learning in animals, and the behaviour analyst working on REST must discover (amidst other things) how best to train (ie, facilitate learning in) his/her animals. Although several authors have recently brought EAB to the attention of some animal trainers (most notably, Prior, 2004), few animal trainers appreciate just how pertinent the EAB research literature actually is. For example, only a small proportion of those aware of EAB will be aware of the research concerned with variables controlling how and at what speed animals learn to discriminate between environmental cues or stimuli. Amidst other questions, this research has examined the factors that predict which feature of a complex multi-featured stimulus earns an animal's attention and so acquires stimulus control over some response (see Johnson, 1970, for an early review). Termed *selective stimulus control*, various phenomena studied in this literature are relevant to the R&D of REST (eg, blocking, overshadowing, masking). This is because the odour of UXOs is probably a bouquet made up of many constituent odours, and being able to control exactly which one odour feature receives the animal's attention would be of great benefit when attempting to establish the appropriate performance of our animals.

Much of the research into selective stimulus control has involved pigeons learning to discriminate between visual stimuli (eg, Farthing & Hearst, 1970; Miles & Jenkins, 1973). However, research conducted with mammals and olfactory stimuli has also been carried out (eg, Laing, Panhuber & Slotnick, 1991; Slotnick & Katz, 1974) and the results of those studies have replicated many of the findings with pigeons. Therefore, numerous principles of selective stimulus control seem to apply across a range of animal species, and a REST researcher is safer to assume general principles of learning than he/she is to assume species-specific ones.

Although few animal trainers involved with animal-based REST are familiar with EAB, an even smaller group of professionals know about a sub-discipline within EAB called *Animal Psychophysics*. This field is concerned with research into methods for measuring the sensory abilities of various animal species (see Stebbins, 1970). As a matter of necessity, researchers in this field must be informed by findings from animal studies of discrimination learning because they need to establish and then maintain behaviour that is maximally sensitive to the strength of a specific stimulus.

STRATEGIES FOR THE RESEARCH AND DEVELOPMENTAL OF REST USING ANIMALS AS THE PRIMARY DETECTORS

Scientists attempting to develop animal-based REST should be informed by research in animal psychophysics because accurate determination of an animal's threshold for sensing an odour indicative of UXO should be one of the most important goals in their R&D agenda. That is, the concepts validated and the technical jargon used in EAB, studies of selective stimulus control, and animal psychophysics would ideally feature in the conceptual framework adopted by scientists conducting R&D into animal-based REST. Unfortunately, contemporary research in these areas is highly technical and requires considerable formal education. Therefore, scientists with expertise in animal psychophysics and EAB should, at the very least, serve on a Scientific Advisory Committee overseeing REST R&D. (It is noteworthy that various concepts in current use by animal trainers – such as the concept of *drive* –once appeared in the conceptual framework of EAB but have since been removed because their explanatory value has proven to be limited).

6. ABA is, and REST R&D should be, effective

Baer *et al* (1968) wrote that "if the application of behavioural techniques does not produce large enough effects for practical value, then application has failed". They argued that "in evaluating whether a given application has produced enough of a behavioural change to deserve the label (*effective*), a pertinent question can be, how much did that behaviour need to be changed?" This is a practical question, and its answer should be supplied by consumers of the research. In the case of animal-based REST, R&D efforts will be judged to have been effective if the minimum performance requirements specified in the International Mine Action Standards (IMAS: 09.43 - Remote Explosives Scent Tracing) have been met. The 2005 revised version of those standards specifies that:

1) each individual animal must achieve a minimum hit rate (HR) of 70 per cent and a maximum false alarm rate (FAR) of five per cent
2) at least three animals must be used to inspect the same set of operational samples
3) as a group, no positive samples should be missed and no more that 20 per cent of negative samples should be indicated

Although IMAS 09.43 describes clear criteria for judging whether R&D efforts into animal-based REST can be deemed effective, and being effective is an important component of those efforts being considered successful, several less obvious points warrant mention. First, given that an operational system of REST will involve a large number of complex procedures, the course of R&D should involve many comparisons between procedures, and no one procedural change should be expected to achieve the criteria for effectiveness. Instead, procedures in various domains (eg, sample collection, sample presentation, animal training, etc) will need to be optimised by way of empirical assessment, and a set of procedures (ie, a system) will evolve slowly and finally prove to be effective.

Secondly, the efficacy of a REST system should not be judged by accuracy criteria alone; rather, the efficiency of the system should also be considered and this requires comparing it to alternative technologies that exist for detecting UXO. (The resources required for any method of detection must themselves be evaluated against those required for simply clearing areas using mechanical devices). For example, we know that leading appropriately trained dogs to a known mine field results in their pin-pointing mine locations, at least down to the nearest square metre. It therefore follows that collecting the dust from a 1-m^2 area above the mine and presenting that dust to a trained dog in a remote laboratory will likely result in that dog indicating the presence of mine odour also. However, little efficiency will have been gained by the remote sensing system. Therefore, if REST is to be more efficient than any direct-detection method, the land area represented in a sample of dust must be considerably larger than 1 m^2, but exactly how large that area needs to be is yet to be specified by experts in humanitarian demining. (Efficiency does not increase as a linear function of collection-area size because more resources will be required to follow up on larger areas that the REST system deemed contaminated with UXO odour).

In addition to requiring minimum sampling areas before being able to judge efficiency, only once these areas have been specified can the feasibility of an animal-based REST system be properly assessed. The issue is simple but nevertheless requires an illustration. Suppose that we know the position of one mine in each of a number of minefields, that each minefield is 1024 m^2, and that we collect one sample of dust from each field. Suppose we always start a sample collection by collecting dust from immediately above the mine and then collect from increasingly larger uncontaminated areas across the minefields. If our smallest collection area is 1 m^2, then with each doubling of the area sampled (ie, 2 m^2, 4 m^2, 8 m^2, etc), the concentration of contaminated dust in our sample will have been halved. Thus, in a sample taken from an area of 1024 m^2 (ie, the entire minefield), the concentration of contaminated dust will be 0.510 (0.0009 = 0.09 %) of what it was in our sample from 1 m^2. Whether or not the animals in a REST system can detect the presence of mine-related odours in that sample amounts to asking whether it contains a signal strength that exceeds the animal's sensory threshold, because no amount of optimised training can render that threshold irrelevant.

7. ABA does, and REST R&D should, address the issue of generality

According to Baer *et al*, "a behavioral change may be said to have generality if it proves durable over time, if it appears in a wide variety of possible environments, or if it spreads to a wide variety of related behaviors" (Baer *et al*, 1968, p. 96). In most examples of ABA, the behaviour change will involve a person now behaving in closer accordance with societal/cultural norms, whereas in REST R&D, the behaviour change involves the animal now emitting the indication response only in the presence of the target odour. Despite this difference, in both ABA and REST R&D, a performance that has been established by training should be maintained across both time and situations in order to be useful. This maintenance, in turn, requires (among other things) that some degree of stimulus generalisation occurs. That is, stimuli that are similar to those which were presented as the target stimuli in training, but which were never actually presented in training, should evoke the taught performance.

In animal-based REST, stimulus generalisation circumvents the need to present in training all possible variants of the odour of UXO. In fact, given that the odour of UXO must always exist with the odour of irrelevant compounds in operational samples, presenting all possible variants of the target odour in training is probably impossible. Furthermore, attempting to minimise the requirement for stimulus generalisation by training animals with target odours that are as close as possible to those emanating from positive operational samples has many practical difficulties. For example, this approach requires that the R&D of the sampling component of REST is sufficiently mature to offer precise descriptions of collection, storage and presentation methods, but this may not be the case.

In addition, positive samples would have to come from actual minefields that were discovered by minimal use of detection technologies, and so are unlikely to contain extraneous odours that were added in the process of inspection. (Therefore, one could not use soil collected from minefields that were discovered by free-running or long-leash dogs because those areas are likely to contain some amount of odour left by the dogs). Similarly, negative samples would be required from many areas that were previously considered hazardous but which turned out to be entirely free of UXO. Given the difficulties faced in procuring such samples for training, it seems that we must rely on the animals' behaviour showing some amount of stimulus generalisation if the system is to be viable.

Once a researcher conducting REST R&D recognises the requirement for stimulus generalisation, he/she must then address how best to train and test the animals for maximal generalisation from the training stimuli. Again, principles discovered in EAB and ABA imply various strategies, some of which have been applied by professionals training detection dogs albeit in the absence of a conceptual framework. The first strategy involves attempting to identify the specific odour that is common to a range of UXOs, and training stimulus control by that odour in order that that control might later block (Johnson, 1970) stimulus control by odours that correlate with UXO but are actually irrelevant. Therefore, for a period of time, researchers at the SRSA/NPA-GICHD REST facility tried to establish stimulus control by the odour of TNT alone, as it is an ingredient in many types of UXO that differ in terms of other constituent compounds. However, an attempt to apply blocking will undoubtedly result in the greatest generalisation to operational samples, if the choice of a target odour is based on the results of *transfer tests* (Reynolds, 1961) with animals that have proven their ability to detect UXO in direct-detection scenarios.

A transfer test involves assessing the stimulus control exerted by each of a number of features of a compound stimulus by presenting each feature alone and measuring the degree to which the target behaviour is emitted. Therefore, a transfer test to assess which component of a specific landmine had stimulus control might involve separately burying the explosive content alone, the plastic casing alone, the metallic components alone, and the rubber seal alone, and then comparing the number of occasions that dogs correctly indicate the position of each component. Such tests are yet to be formally conducted and reported.

A second strategy for promoting stimulus generalisation is to train with multiple examples of the target stimulus (Stokes & Baer, 1970). In the context of REST, this involves training with positive samples that include odours of different types of UXO, at different strengths, and accompanied by a range of irrelevant odours. Similarly, negative samples should include a range of irrelevant odours to guard against an animal learning simply to reject a specific odour and indicate on all others (Williams & Johnston, 2002). Such training is likely to be effective because it essentially reduces the degree to which successful operational activity requires stimulus generalisation.

A third strategy is to consider the animals' task as one of learning to discriminate two large sets of stimuli - a set of odours that emanate from buried UXO and a set of odours that are unrelated to UXO - and so, a task that requires learning the *concept* of UXO. Concept- learning in animals has received considerable attention in the EAB. For example, pigeons have been able to learn to discriminate the presence versus absence of people in photographs (Herrnstein & Loveland, 1976), Bach's music versus

Stravinsky's music (Porter & Neuringer, 1984), and impressionist art versus cubist/abstract art (Watanabe, Sakamoto & Wakita, 1995).

In terms of REST, this strategy involves giving the animal more freedom to identify the odour feature that distinguishes the set of positive samples from the set of negative samples, and so circumvents the need to identify the particular feature of UXO odour that should have stimulus control (the blocking strategy). However, by relinquishing control over the feature of positive samples used by the animals, very large sets of positive and negative samples may be necessary before stimulus control by the concept of UXO (and not control by irrelevant odours correlating with UXO odours) develops. In addition, a very systematic approach to presenting those stimulus sets will probably be necessary to limit the degree to which stimulus control by irrelevant odours develops (Miles & Jenkins, 1973).

Although some progress toward developing methods for training stimulus generalisation was made at the SRSA/NPA-GICHD facility, significantly more R&D is necessary before specific protocols can be recommended. It is likely that the most effective and efficient strategy will be complex and involve a blend of the principles described above. Furthermore, the development of procedures with which to assess generalisation to *quasi-operational* samples (ie, those collected via an operationally-viable technique but for which the presence/absence of UXO odour has been independently verified) seems unavoidable, as does the repeated use of these procedures during the course of training. That said, solutions to these issues must exist and the sooner a researcher appreciates the extent to which *generality* should be addressed in his/her R&D, the sooner those solutions will be discovered.

SUMMARY

This chapter has described the key characteristics of a field of psychology known as Applied Behaviour Analysis, and argued that those characteristics are ideally suited to being used as criteria for the animal research component in the R&D of REST. An implication of this fit is that those conducting this R&D would benefit from using the research methods, philosophical positions and publishing conventions that are typical of ABA and its parent discipline, EAB. This in turn requires those conducting R&D to become familiar with some of the ABA and EAB research literature, while looking beyond the particular target behaviour or species of animal (eg, human, pigeon, rat, dog) being investigated in a published study.

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CHAPTER 5

A SAMPLE OF BEHAVIOUR-ANALYTIC RESEARCH AIMED AT DEVELOPING A SYSTEM OF REMOTELY DETECTING EXPLOSIVE REMNANTS OF WAR (ERW)

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CHAPTER 5

A SAMPLE OF BEHAVIOUR-ANALYTIC RESEARCH AIMED AT DEVELOPING A SYSTEM OF REMOTELY DETECTING EXPLOSIVE REMNANTS OF WAR (ERW)

As discussed in the previous chapter, if an operational system of Remote Explosive Scent Tracing (REST) using animals existed, it would be made up of complex procedures. These procedures would have been developed by rigorous and replicable empirical research, and comparisons between them would have aimed to identify the optimal quantity or quality of certain variables. In the chapter, it was argued that the research methods characteristic to Applied Behaviour Analysis (ABA) are ideally suited to developing procedures in REST in regard to preparing the animals for detection. In this chapter, some of those research methods are illustrated in a description of various experiments conducted at the NPA/SRSA-GICHD research facility in Morogoro (Tanzania) between July 2006 and 2008. By providing examples of how these methods were applied, we hope to inspire future scientists to adopt a similar approach. We also hope to demonstrate how developing new technologies requires research, and in doing so, dispel the common myth that conducting research is at the expense of developing the system.

A general principle applied in all of our research and development (R&D) activity was that the animals themselves know best which procedures assist their ability to indicate the presence of target odours, which reduce that ability, and which are innocuous. Our selection of procedures for assessment required considering the opinions of dog-training experts who had succeeded in preparing dogs for odour-detection roles, and formulating a draft plan of how an operational system that satisfied IMAS standards would look. Most of our research involved assessing the effects of discrete and single changes that took the entire set of procedures closer to one feasible for operational activity. Any one procedural change would be kept in the protocol if it was found either to improve detection accuracies or to improve the efficiency of the system with no decrease in accuracies. Many of the experiments, however, arranged procedures that constituted tests for whether some variable affected detection accuracy. Such procedures were usually arranged only temporarily and not preserved in the protocol used thereafter.

For the sake of descriptive clarity, the research that we conducted has been organised into four categories. Each category involved numerous experiments that were not necessarily conducted successively, but were related in terms of what was being assessed. They are:

1) assessments of the topography of stimulus control over indication responses
2) interventions aimed at reducing false alarm rates
3) investigations of sources of variance in detection accuracies
4) assessments of the reliability of our data

CHAPTER 5

A SAMPLE OF BEHAVIOUR-ANALYTIC RESEARCH AIMED AT DEVELOPING A SYSTEM OF REMOTELY DETECTING EXPLOSIVE REMNANTS OF WAR (ERW)

A. GENERAL METHODS

Before describing the procedures arranged in specific experiments within each category above, we will describe various methodological details that remained constant across the experiments.

1. Infrastructure

A research facility was purpose-built on the grounds of the Sokoine University of Agriculture adjacent to APOPO's facilities. One building served as kennels for up to 12 dogs and the other provided office space and laboratories (see Figure 1, left photograph). The floor area of the latter building was divided into two parts using wooden barriers and later a half-height wall; a public-access area and a restricted-access area. The restricted area included equipment-cleaning spaces, store rooms, two training rooms, and half of the foyer. This area was used only by designated staff (laboratory assistants & documenters) wearing dedicated footwear. The floors of the training rooms were tiled and sealed, and the walls had been painted with a thick coat of chalk that could easily be removed and replaced on a regular basis to remove any explosive compounds (see Figure 1, right photograph). Two doors provided access to the training room; one for the dog and its handler, and the other for laboratory assistants.

FIGURE 1 | **Left**: A photograph of the research facility built in Morogoro, Tanzania. The building containing offices and laboratories appears in the foreground and the kennels are in the background. **Right**: A training room (aka analysis room) containing a carousel and a hide that was used only for the first few experiments. The visible door was used for access by a dog and its handler, while another door was positioned where the photographer was standing.

2. Human Resources

Seventeen local people were hired as staff; six worked as dog handlers (DH), four as laboratory assistants (LA), two as documenters and data-entry operators (DO), and five as custodial/security staff. Two expatriates lived in Morogoro to work at the facility; one had mainly administrative duties (the project manager) whereas the other focused on research matters (the researcher, Yolande Dunn). The activity of both ex-patriots was directed by a scientist who was employed by GICHD (Max Jones) and spent around one week of each month at the facility. Finally, Jones and Dunn regularly reported their research activity to an advisory committee comprised of seven scientists (chemists, ethologists & behaviour analysts) and two professionals with experience training dogs for odour-detection roles.

3. Subjects

Eight dogs were available to serve as subjects in the research, but between five and seven were used at any one time and exactly which dogs served changed in the course of the research. Table 1 describes the relevant details of the dogs. Their ages ranged between 18 months (Debi & Dede) and four years, seven months. Furthermore, they had varying amounts of prior training with landmine/explosives detection, and the nature of that training varied considerably. Most notably, the first six dogs had served in a REST R&D project in Angola, whereas the last two were sourced from NPA GTC soon after the current project began. Some of the dogs from Angola had previously been trained by staff of Mechem®, whereas others had been trained by NOKSH (Norsk Kompetansesenter for Spesialsøkshund) in Norway.

TABLE 1 | The names, breed, sex, date of birth (DOB), and origin of the eight dogs that served as subjects. (NPA Norwegian Peoples Aid; GTC = Global Training Centre.)

Name	Breed	Sex	Approx. DOB	Source
Taz	Springer Spaniel	Male	29/11/02	NPA Angola
Zak	Black Labrador	Male	14/05/02	NPA Angola
Leeroy	Golden Labrador	Male	27/01/02	NPA Angola
Mia	Black Labrador	Female	03/02/02	NPA Angola
Baz	Springer Spaniel	Male	23/11/02	NPA Angola
Deb i	German Shepherd	Female	20/02/05	NPA GTC, Sarajevo
Dede	German Shepherd	Female	20/02/05	NPA GTC, Sarajevo

3. Apparatus

A 12-armed carousel was used to present samples to dogs inside the training room (see Figure 1; right photograph). The 12 arms were numbered with respect to their spatial position in the room. (Thus, Arm #10 was always closest to the exit door, Arm # 6 was always closest to the viewing window, etc.) A stainless-steel bowl was fixed at the end of each arm of the carousel and used to contain the samples. Samples consisted of aluminium pots (similar in size to film canisters) that contained 10 g of soil or sand and 10 ml of either military grade TNT dissolved in distilled water (positive samples) or distilled water alone (negative samples). Each pot had an adhesive label on its outside wall to code whether it was a positive or a negative sample. 75 per cent of the pots in a session had been used as negative samples in a previous session (all positive pots were destroyed after a single use), and positive and negative samples were equally likely to appear as new pots. All pots were fitted with screw-top lids after sand/soil/solution had been added and while they were in storage before being used in training sessions. LAs were provided with extremely detailed instructions on how to prepare samples.

4. Procedures

Each dog received two training sessions per day (separated by at least two hours), five days per week, and one session on a Saturday. Within a session, dogs received between six and nine sets of samples with 12 samples – one on each arm of the carousel – per set. (The actual number of sample sets per session increased gradually over the first month of research.) In experiments where there were 72 samples per session, ten samples were positive and 62 were negative. In experiments involving 108 samples per session, 15 were positive and 93 were negative. For each session, a computer programme used a random-number generator to assign samples to each of the 72 (or 108) positions, and generated a data-recording sheet that showed the sample type at each position (see Figure 3).

FIGURE 2 | **Left:** Left: A photograph of laboratory assistants loading samples from a storage tray onto the carousel. One assistant turns the carousel using a metal rod while the other retrieves the sample from the tray, removes the lid of the pot, places the pot in the bowl and places the lid in a designated container. **Right:** A photograph of a training session in progress. In the foreground, a documenter is seated outside the room and is recording the decisions of a laboratory assistant (out of photograph) who is viewing the session through a one-way mirrored window. The dog handler appears in the background and remains stationary in this position until either a clicker sounds or a light is illuminated on the wall he is facing.

Two sets of 72 (or 108) samples were manufactured and put in their designated positions in a storage tray approximately 18 hours before being presented to dogs. Up to three dogs were presented with the same set of samples, but the order in which those dogs received training sessions was rotated systematically across sessions so that each dog was equally likely to be the first, the second and the third to receive the sample set.

One DO, one DH, and two LAs were involved with running a session. Prior to a session starting, the selected dog received a 20-minute routine of being walked around a set circuit, resting in a designated area, and then resting in a holding pen immediately outside the training room. During this time, LAs loaded the first set of 12 samples from the sample tray onto the carousel (see Figure 2; left photograph). A lamp fixed to the outside wall of the training room and adjacent to the exit door was lit once the LAs and the DO were ready for the session to begin. Upon seeing the light illuminate, the DH led the dog into the room and released it to begin searching at Arm 1 and then

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move in an anti-clockwise direction around the carousel. The DH then took up a position either behind the hide or adjacent to and facing one wall of the room (see Figure 2; right photograph). The DH remained still in this position and watched another set of lights mounted on one wall of the room for further instructions from the LAs.

FIGURE 3 | An example of the data-recording sheet used by documenters in training sessions. Although this example denotes positive samples varying in the concentration of TNT they contain, the sheet used in most training sessions depicted a single concentration. That concentration was normally "+2".

Dog:	Date:	+ves	+1	+2	+3	+4	+5
Trainer:	Handler:	Documenter:					

Lab Assistant A: (loading samples & removing -ve samples)

Lab Assistant B : (removing +ve ssamples & calling samples searched)

+ve Samples prepared by:

Start time: | Start temp: | Start humidity:

Session remarks:

A	Run remarks:											Visit Remarks
Visit 1	A1	A2	A3	A4	A5	+3	A7	A8	A9	A10	A11	A12	
Visit 2	A1	A2	A3	A4	A5	+3	A7	A8	A9	A10	A11	A12	
Visit 3	A1	A2	A3	A4	A5	+3	A7	A8	A9	A10	A11	A12	
Visit 4	A1	A2	A3	A4	A5	+3	A7	A8	A9	A10	A11	A12	
Visit 5	A1	A2	A3	A4	A5	+3	A7	A8	A9	A10	A11	A12	
Visit 6	A1	A2	A3	A4	A5	+3	A7	A8	A9	A10	A11	A12	
B	Run remarks:												Visit Remarks
Visit 1	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	
Visit 2	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	
Visit 3	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	
Visit 4	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	
Visit 5	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	
Visit 6	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	
C	Run remarks:												Visit Remarks
Visit 1	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	+4	
Visit 2	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	+4	
Visit 3	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	+4	
Visit 4	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	+4	
Visit 5	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	+4	
Visit 6	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	+4	
D	Run remarks:												Visit Remarks
Visit 1	+1	D2	D3	D4	D5	D6	D7	D8	D9	+2	D11	D12	
Visit 2	+1	D2	D3	D4	D5	D6	D7	D8	D9	+2	D11	D12	
Visit 3	+1	D2	D3	D4	D5	D6	D7	D8	D9	+2	D11	D12	
Visit 4	+1	D2	D3	D4	D5	D6	D7	D8	D9	+2	D11	D12	
Visit 5	+1	D2	D3	D4	D5	D6	D7	D8	D9	+2	D11	D12	
Visit 6	+1	D2	D3	D4	D5	D6	D7	D8	D9	+2	D11	D12	
E	Run remarks:												Visit Remarks
Visit 1	E1	E2	E3	+2	E5	E6	E7	E8	E9	+1	E11	E12	
Visit 2	E1	E2	E3	+2	E5	E6	E7	E8	E9	+1	E11	E12	
Visit 3	E1	E2	E3	+2	E5	E6	E7	E8					
	E1	E2	E3	+2	E5	E6	E7	E8	E9	+1	E11	E12	
Visit 6	E1	E2	E3	+2	E5	E6	E7	E8	E9	+1	E11	E12	
F	Run remarks:												Visit Remarks
Visit 1	+4	F2	+5	F4	F5	+3	F7	F8	F9	F10	F11	+5	
Visit 2	+4	F2	+5	F4	F5	+3	F7	F8	F9	F10	F11	+5	
Visit 3	+4	F2	+5	F4	F5	+3	F7	F8	F9	F10	F11	+5	
Visit 4	+4	F2	+5	F4	F5	+3	F7	F8	F9	F10	F11	+5	
Visit 5	+4	F2	+5	F4	F5	+3	F7	F8	F9	F10	F11	+5	
Visit 6	+4	F2	+5	F4	F5	+3	F7	F8	F9	F10	F11	+5	

Finish time: | Finish temp: | Finish humidity:

The DO and LAs observed the session from outside the training room and through a one-way mirrored window. One LA judged two aspects of the dogs' behaviour: whether a sample had been sniffed (if the dog put its nose within 1 cm of the pot and kept its head there for at least 0.25 seconds) and whether the dog had sat immediately after sniffing a sample (ie, its hind quarters contacted the floor and it remained stationary for at least 1 s). Each time that a dog sniffed a sample, the LA called out the arm number associated with that sample, and when a dog emitted the indication response, the LA called out "kaka". The DO noted sniffed samples on the record sheet (Figure 3) by placing a tick in the appropriate cell, and noted indications by circling the appropriate cell.

In all training sessions, the DH was unaware of the position of any positive samples on the carousel but, in normal training sessions, the LAs had a copy of the record sheet and so knew these positions. If an indication immediately followed sniffing a positive sample, one LA would say "kaka" and then sound a clicker through a hole in the wall to signal to the DH that praise and a small piece of sausage (or cheese) should be delivered to the dog. A dog was removed from the room after every delivery of food. However, if an indication followed sniffing at a negative sample, "kaka" was again spoken but different consequences then ensued and these consequences varied across conditions (see I*nterventions aimed at reducing false alarm rates* below). If the dog had searched all 12 samples on the carousel without indicating, the DO would raise one hand to signal a completed set to the LA. The LA would then require that the dog searched between one and four more samples (varying across visits) before he/she threw a switch to illuminate a green lamp inside the training room.

Upon seeing this lamp lit, the DH called the dog's name and led it out of the room back to the holding pen. Because dogs frequently either indicated on a positive sample before sniffing at all 12 samples in the set, or failed to sniff all samples when they hadn't indicated, several visits to the room were usually necessary before all samples were judged to have been examined. Each visit was recorded on a separate line of the record sheet (see Figure 3) and, in most conditions, samples that had been examined were removed from the carousel for later visits. Removing samples after they had been examined ensured that each sample was examined only once and so simplified our analysis of the data.

A SAMPLE OF BEHAVIOUR-ANALYTIC RESEARCH AIMED AT DEVELOPING A SYSTEM OF REMOTELY DETECTING EXPLOSIVE REMNANTS OF WAR (ERW)

B. ASSESSING THE TOPOGRAPHY OF STIMULUS CONTROL OVER INDICATION RESPONSES

Establishing stimulus control over some aspect of a non-verbal animal's behaviour usually requires delivering a reward when the desired response occurs in the presence of the target stimulus and withholding that reward when the response occurs in the absence of the target stimulus; a procedure known as *discrimination training* (Lashley & Wade, 1946). Training a dog to cease searching and to indicate by sitting whenever it senses the odour of ERW requires rewarding it for sitting immediately after having sensed ERW odour, and not for sitting at other times. This task is fraught with difficulties, which arise mainly because a dog's ability to detect and sense differences between odours (ie, its olfactory acuity), far exceeds that of its human trainers. The trainer can never sense the stimulus correlated with reward delivery as accurately as the dog can sense it, and a difference between the trainer's definition of the target and the actual odour controlling the dog's indication response can easily emerge. In more technical terms, the topography of the stimulus control over the indication response can easily differ from the topography intended by the trainer (McIlvane & Dube, 2003).

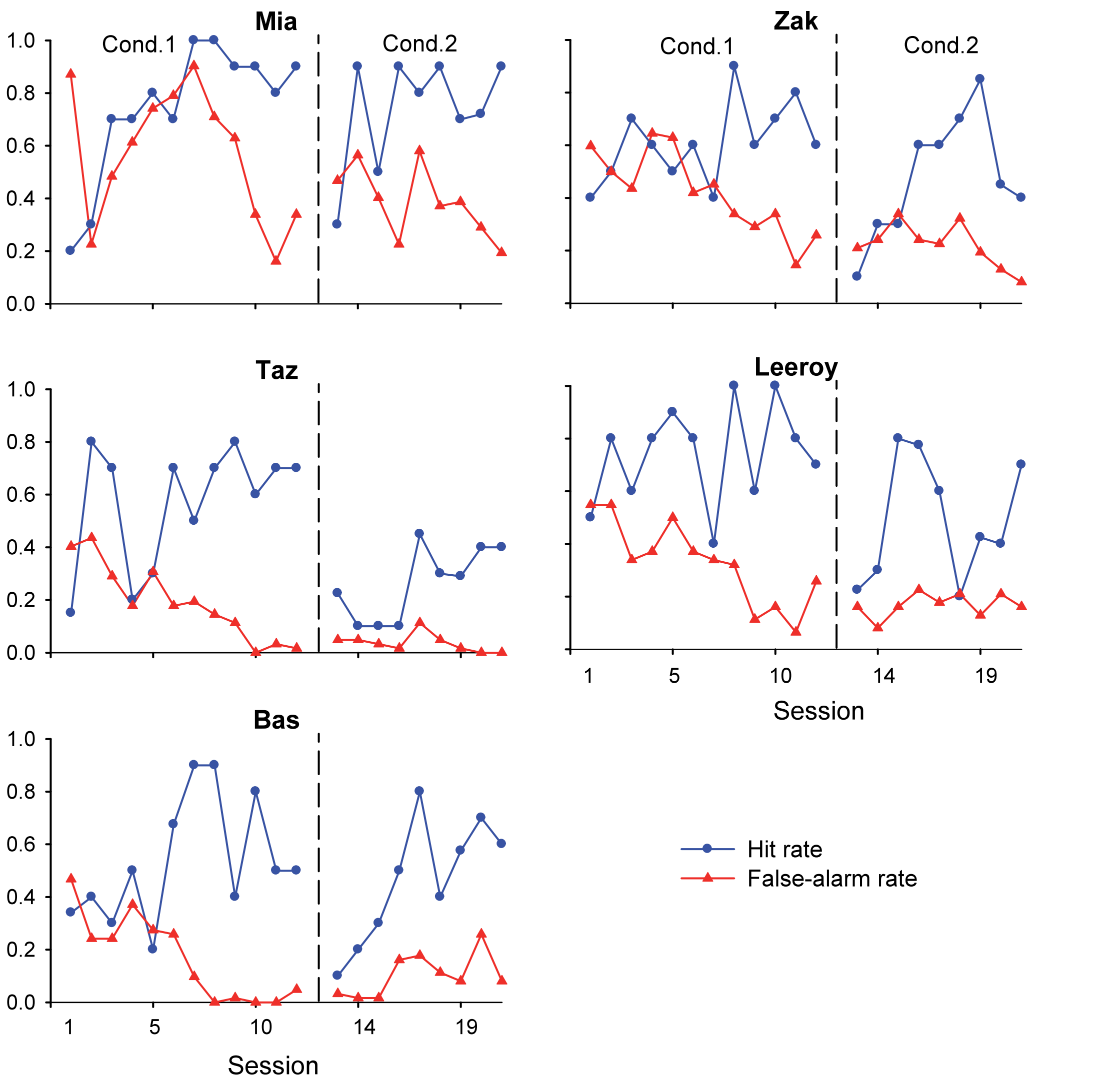
There can be no doubt that taking various precautions during the preparation, storage and presentation of samples will increase the likelihood of stimulus control by the intended target odour. However, the trainer cannot avoid assuming that the target odour was present at a uniform strength on all positive samples, that this odour was absent on all negative samples, and that no other odour distinguished positive from negative samples. More importantly, the trainer cannot assume that a dog's accurate detection of positive samples (ie, a high hit-rate) and its accurate rejection of negative samples (ie, a low false alarm rate) is evidence of having trained stimulus control by the target odour, because other features of positive samples might have mimicked that control. The trainer can never prove stimulus control by the target odour and can only demonstrate that alternative stimulus control is unlikely. Nevertheless, the more often that stimulus control by alternative features of positive samples is dismissed, the stronger the support for stimulus control by the target odour. Adopting this logic, numerous tests for stimulus control by odours other than the target one were conducted at our research facility. We describe some of those tests below.

Research at our facility began with five dogs that had been transported from NPA's REST R&D facility in Lubango, Angola. Just prior to leaving that facility, these dogs were being trained to indicate the odour of military-grade TNT on PVC gauze filters supplied by Mechem. Consequently, our resumption of their training also involved rewarding detections of TNT, albeit when it was dissolved in water and added to sand so that the concentration was approximately 10^{-5} gm TNT/gm sand. (This concentration was achieved by beginning with a "mother" solution that had a measured concentration of TNT and then titrating that solution in successive steps. 10 ml of the titrated solution was then added to 10 gms of sand in a pot.) We attempted to create a uniform set of negative samples in order that the only difference between positives and negatives in this initial training was that the former contained TNT.

Despite their previous experience, Figure 4 shows that all dogs began this training with hit rates that were not significantly higher than false alarm rates. Thus, emitting the indication response (sitting) was no more likely after positive samples than it was after negative samples, suggesting that no stimulus generalisation from the odour of TNT on PVC gauze to that of TNT in solution on sand had occurred. However, with successive training sessions, false alarm rates for all dogs fell and hit-rates for several dogs increased (see Figure 4).

A SAMPLE OF BEHAVIOUR-ANALYTIC RESEARCH AIMED AT DEVELOPING A SYSTEM OF REMOTELY DETECTING EXPLOSIVE REMNANTS OF WAR (ERW)

FIGURE 4 | Hit rates (filled circles, solid lines) and false alarm rates (unfilled circles, dotted lines) as a function of session number for each of five dogs. The vertical dashed lines show the point in time at which acetone was removed from sample preparation procedures.



After around a week of this training, we recognised that acetone was involved in the preparation process of positive, but not of negative samples. Specifically, the beakers used to titrate the mother solution of TNT were being wiped dry with a cloth soaked in acetone after use. Despite all laboratory equipment being subsequently washed with hot soapy water and left to drain and dry in the sun, there remained the possibility that traces of acetone appeared in positive samples made the next day. Consequently, our first experiment involved assessing whether stimulus control by the odour of acetone had overshadowed stimulus control by the odour of TNT. This test involved changing the SOPs in order to remove acetone from the cleaning process once hit rates appeared stable; an A-B experimental design (see previous chapter). The vertical dashed-line on Figure 4 separates sessions where acetone had been used from sessions where acetone had been dropped.

A SAMPLE OF BEHAVIOUR-ANALYTIC RESEARCH AIMED AT DEVELOPING A SYSTEM OF REMOTELY DETECTING EXPLOSIVE REMNANTS OF WAR (ERW)

Figure 4 shows that removing acetone from the sample-preparation process resulted in the hit rates of four of the five dogs suddenly dropping. If we assume that the only difference between the procedures across these two training phases was the presence versus absence of acetone in equipment cleaning, these results suggest that four of the five dogs had been indicating the presence of acetone on positive samples rather than the TNT.

In addition, the steady increase in hit rates for the four affected dogs suggested that stimulus control by some other odour feature of positive samples was developing. Although we hoped it was for TNT, the results of this experiment forced a thorough search of our LA SOPs for other sources of odour differences on positive and negative samples. We also designed an alternative method for assessing stimulus control by odours other than TNT in case the tested feature of our manufacturing, storage or presentation procedure was innocuous. (Every change to the SOPs required considerable time being invested in documentation and re-training of staff, and came with the risk of introducing further problems.)

Many aspects of our SOPs for LAs involved taking precautions to avoid contaminating negative samples, our equipment and our facilities with traces of TNT. One such precaution involved preparing positive and negative samples in different locations; negative samples were prepared in a dedicated space inside our building, whereas positive samples were prepared in a chemistry laboratory in one of APOPO's buildings. Consequently, the second assessment of stimulus control topography involved testing whether any location-related odours had acquired stimulus control over indications.

Rather than simply making all samples in a single location from that time forward, four test sessions were conducted. In each of these sessions, four of the 62 negative samples were prepared using the normal procedure, but in the same location as where positive samples were prepared; namely, the APOPO laboratory. These four test samples were then allocated randomly to positions in a session using the same procedure used to allocate positive samples. We reasoned as follows: If dogs were indicating the presence of location-related odours on positive samples, then false alarm rates on negative samples made in the same location as positives (ie, test samples) should be higher than false alarm rates on negatives made in a different location (ie, normal negative samples).

FIGURE 5 | The percentage of two types of negative samples that were indicated by each of the seven dogs serving at this point in the research. Black bars indicate negative samples that were prepared in a laboratory at our facility (ie, normal negatives) whereas grey bars indicate negatives that were prepared in the same location as that used to prepare positive samples (ie, the APOPO laboratory).

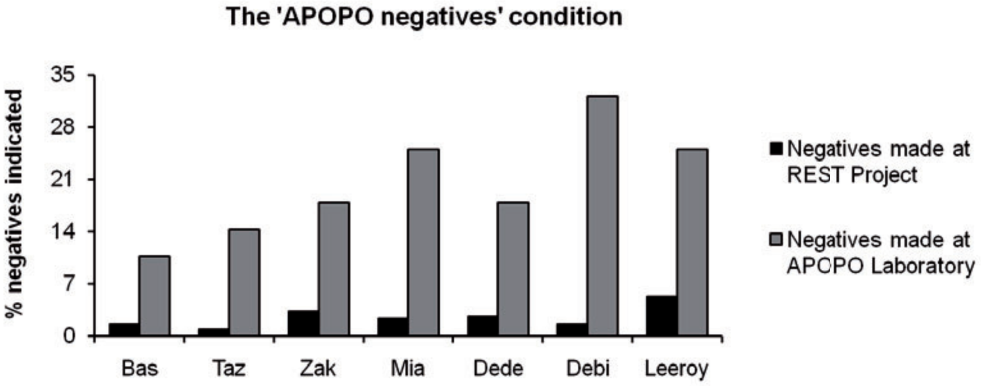


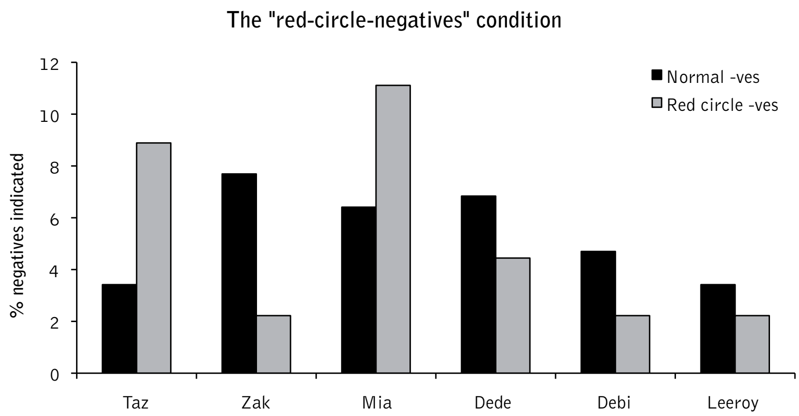
Figure 5 shows the false alarm rates on the two types of negative samples. To our dismay, false alarm rates on test samples were indeed higher than false alarm rates on the normal negative samples for all seven dogs, and this difference was statistically significant on a Chi-square test ($p<.05$). Therefore, assuming that the only difference between test negatives and normal negatives was where they were made, these results suggest that accurate detection of positive samples probably reflected some amount of stimulus control by odours that were added in the preparation location. (Exclusive stimulus control by location odours was unlikely, because false alarm rates on test negatives were considerably lower than hit rates on positives.) Although this might at first seem far-fetched, in retrospect, it seemed entirely plausible because APOPO's chemistry laboratory was accessible only via a room that housed around 20 African-giant-pouched rats, meaning that samples had to be carried through this room when being brought from and returned to our building. Thus, rather than training dogs to indicate the odour of TNT, we may well have also been training them to indicate the odour of rats.

In response to these results, we built another laboratory at our facility and used it for the production of both positive and negative samples. Known as the "outdoor laboratory", this construction consisted of a wire cage without a floor and a canvas awning for a roof (see Figure 6). It was designed to allow air to flow through it and be easily and regularly moved up and down the boundary of our facility to guard against contamination by traces of TNT.

FIGURE 6 | A photograph of the outdoor laboratory used to prepare samples. Wire-mesh walls and no floor provided good air flow and, therefore, rapid expulsion of TNT in gaseous form from the work area. The entire construction was also easily moved on a regular basis up and down a lane, in case any TNT in solution had been spilled on the ground.

Other assessments of the topography of stimulus control followed identification of two further differences between the procedures used to prepare positive and negative samples. The first involved how the lids placed on positive and negative pots during storage had been treated. As mentioned above, up to three dogs per session were presented with the same set of samples. This representation of samples required that the lids of sample pots were replaced after presentation to the first and second dogs. In order to reduce the risk of carrying traces of TNT from positive-pot lids to negative pots, and to allow LAs to quickly check the positions of samples in a tray, a "+" was drawn on the lids of positive pots using a red marker pen, but no markings were made on the lids of negative pots. This meant that it was possible that the odour of the marking ink had spilled over the pot during storage time and that dogs were sensing it on positive pots but not on negative ones. To assess whether ink odour had acquired stimulus control, we conducted an experiment in which 15 of the 93 negative samples in each of four sessions had a red circle drawn on the lid of the pot at the time when the red plus had been drawn on the lids of positive pots. As with the test for sample-preparation location, we reasoned that higher false alarm rates on red-circle negatives than on normal negatives would imply that dogs were indicating the presence of ink odours (rather than TNT odour) on positive samples. Figure 7 shows the results of this test. Fortunately, the false alarm rates on red-circle (ie, test) negatives were not significantly different from the false alarm rates on normal negatives, allowing us to dismiss the possibility of stimulus control by marker ink.

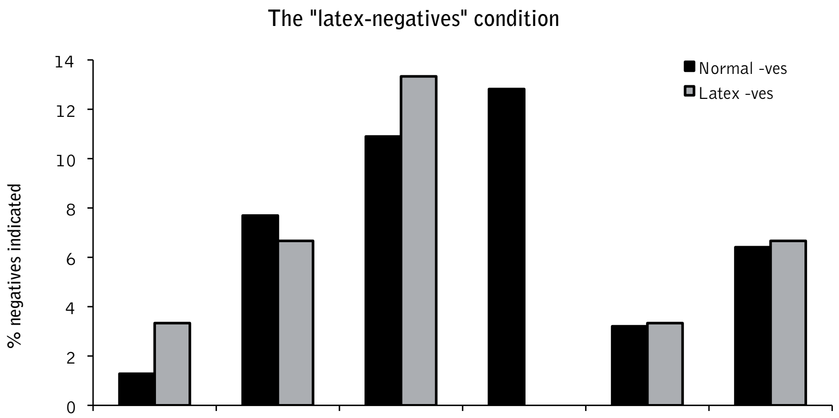
FIGURE 7 | The percentage of two types of negative samples that were indicated by each of the six dogs serving at this point in the research. Black bars indicate negative samples that had no makings on the lids used during storage (ie, normal negatives) whereas grey bars indicate negatives that had a circle drawn with a red marker pen on the lid used during storage (ie, red-circle negatives).



The second difference between positive and negative sample preparation techniques concerned how the pots were handled. Two LAs spent most of a day preparing the samples that were required for sessions scheduled for the next day. At the stage where a measured amount of water was added to the pots, negative samples were always made before positive samples. In addition, LAs wore a single pair of latex-rubber gloves while preparing all the negative samples, but they changed their gloves after having made a batch of ten positive samples and up to 60 positives were made per day. These frequent glove changes were again an attempt to reduce the risk of inadvertently contaminating with TNT the outside of sample pots, various pieces of equipment and the laboratory area. However, it also meant that the gloves touching positive pots had touched fewer previous pots than the gloves touching the majority of negative pots. Consequently, we speculated that the latex odour on positive pots might have been stronger than that on negative pots, and if this was true, the dogs may have been indicating samples from which a stronger odour of latex rubber emanated.

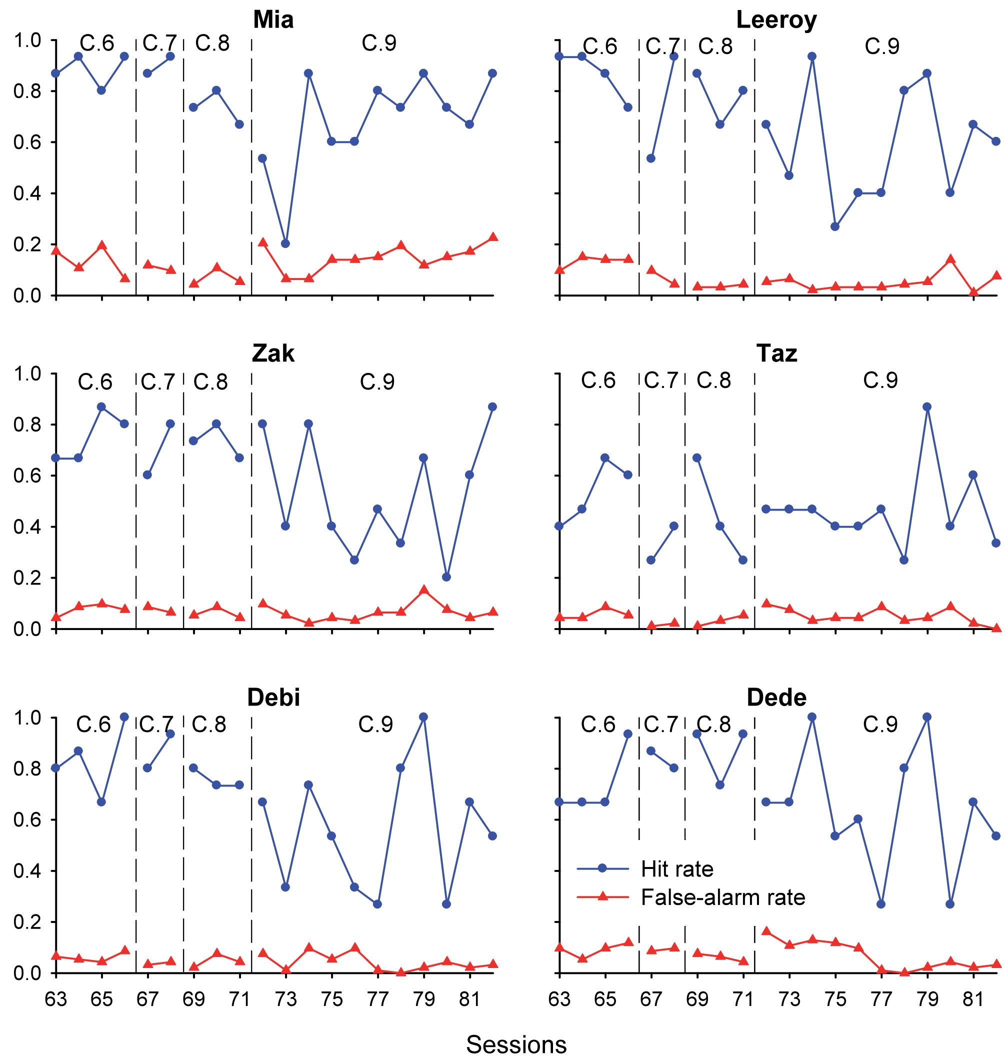
To test this possibility, 15 of the 93 negative samples per session were created while a LA wearing a fresh pair of gloves held the pot. Four sessions were conducted with these test negatives before we compared the false alarm rates on test negatives with the false alarm rates on normal negatives (see Figure 8). The false alarm rates on test and normal negatives were not significantly different from one another. Consequently, we could again dismiss the possibility of stimulus control by a possible feature of positives and, in so doing, claim further support for the theory that the odour of TNT was indeed the feature of positive samples that had stimulus control.

FIGURE 8 | The percentage of two types of negative samples that were indicated by each of the six dogs serving at this point in the research. Black bars indicate negative samples that were held with a single pair of gloves during the preparation process (ie, normal negatives), whereas grey bars indicate negatives that were held with a fresh pair of gloves while being prepared (ie, test/latex negatives).



Despite seeing no evidence for stimulus control by the strength of latex-rubber odour, we nevertheless opted to cease using rubber gloves in all procedures because they were coated with a powder and emitted an odour that was easily detected by humans and so likely to be very strong to dogs. In Condition 9, LAs began wearing two pairs of plastic gloves instead. Figure 9 shows the effect of switching to plastic gloves. To our surprise, five of the six dogs showed a clear decrease in hit rates, and two dogs showed an increase in false alarm rates. Furthermore, the variance in hit rates increased markedly with the change of glove type but did later return to baseline levels (data not shown here). These results are difficult to reconcile with the results of our latex-negatives test (Figure 8). Perhaps they indicate that, although the odour of latex rubber on positive samples was not cuing indications, this odour was nevertheless an important component of the stimulus context on both positive and negative trials such that when it was removed, stimulus control by TNT odour was temporarily lost. Such a phenomenon has previously been reported in the research literature on learning in animals, and is known as *masking* (Newman & Baron, 1965). Furthermore, it might be analogous to the decrease in detection accuracy that APOPO scientists reported when they shifted from one soil type on all samples to a different one.

FIGURE 9 | Hit rates (blue circles) and false alarm rates (red triangles) for each dog in each session of Conditions 6 through 9. Condition 6 served as a baseline condition. In Condition 7, a proportion of the negative samples were given extra latex-rubber odour (see Figure 8). Condition 8 was a return to Condition 6, and in Condition 9, latex-rubber gloves were replaced with two pairs of plastic gloves.



As well as attempting to rule out alternative topographies of stimulus control, we also developed a protocol for generating results that, if obtained, would be consistent with the notion that the odour of TNT was exerting stimulus control over indications. This protocol involved presenting different strengths of the target odour (TNT in solution) on positive samples. This was achieved by applying a set of successive titrations in order to produce five different concentrations of TNT dissolved in water, and then adding 10 ml of the titrated solution to 10 g of sand. The logic we applied was this: similar hit rates on samples with different TNT odour strengths need not imply that some odour feature other than TNT had stimulus control over indicating because all those odour strengths may be well above the dog's sensory threshold for TNT detection. However, if hit rates decrease with decreasing TNT concentration, then it is unlikely that some odour feature other than TNT on positive samples had stimulus control because the strength of that odour should be uniform across samples with different TNT concentrations.

We presented six (and sometimes seven) dogs with positive samples varying in TNT concentration on six separate occasions. The first test (Condition 10) involved 26 sessions where the 15 positive samples in each session involved concentrations of either 10^{-5}, 10^{-7}, 10^{-9}, 10^{-11} and 10^{-13} g of TNT per gramme of sand, with three samples at each concentration. These samples were allocated randomly to Positions 1 to 108 in a session (see Figure 3). After observing minimal improvement in hit rates on each concentration with extended training in Condition 10, subsequent tests involved the same concentrations but only two sessions per test (ie, six presentations of each concentration). Successive tests were separated by at least two weeks but usually by around two months, and various unrelated experiments were conducted between the tests. Figure 10 shows the cumulative hit rates across six dogs for each concentration of TNT. Although false alarm rates are not shown, they were low in all tests and did not differ systematically across tests for any of the dogs.

FIGURE 10 | The cumulative hit rate of the group of dogs as a function of concentration of TNT solution on positive samples for Condition 10, and each of five subsequent probe conditions. Data have been collated across sessions and subjects.

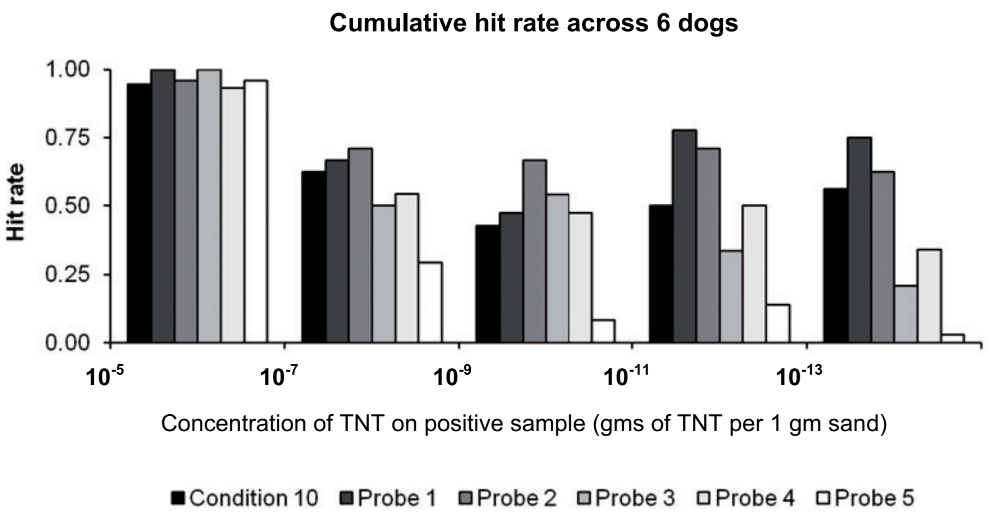


Figure 10 shows that the highest hit rates were obtained at the highest concentration of TNT in all six tests. In addition, hit rates were lowest on the lowest concentration in Probes 2 to 5. However, the trends in hit rates with decreasing concentration of TNT varied considerably across tests. Statistical analyses of monotonic trend (Ferguson, 1966), using the data from individual dogs, revealed no significant decrease in hit rates with decreasing TNT concentration in Condition 10, Probe 1 and Probe 2, but a significant decreasing trend in hit rates was apparent in Probes 3, 4 and 5.

These results paint a complex picture of the topography of stimulus control we had trained at various times in our research. First, they suggest that the degree of stimulus control by the odour of TNT increased with successive tests; this control seemed to exist to a limited degree on the first three tests, but was strong in the final test.

Second, the results suggest that stimulus control by some unknown feature of positive samples may have existed alongside control by TNT in the first three tests. In each of these tests, hit rates were highest for the highest concentration of TNT, and at intermediate levels at each of the four lower concentrations.

Therefore, it is possible that TNT odour controlled indications when its strength was high, but that control switched to the unknown odour feature when its strength was weaker. This unknown odour must have been less salient than the strongest odour of TNT (a concentration of 10^{-5}), and more salient than the weakest (concentrations of 10^{-11} & 10^{-13}), but of uniform salience across all TNT concentrations. Although this interpretation is purely speculative, learning to indicate the presence of either of two target odours is well within a dog's ability (Williams & Johnston, 2002).

C. INTERVENTIONS AIMED AT REDUCING FALSE ALARM RATES

REST systems have the potential to reduce significantly and quickly an area that a demining organisation needs to search thoroughly with more intensive and more expensive techniques. This potential is realised when a system can be shown to have a high hit rate and a low false alarm rate with operational samples. The high hit rate implies a low miss rate and a low false alarm rate means that follow-up resources are not being wasted on areas that are free of ERW. Thus, both measures of the system's performance accuracy are important. International Mine Action Standards for REST (IMAS 09.43; United Nations Mine Action Service, 2005) stipulate that the false alarm rate for an individual animal should not exceed five per cent. In addition, reducing false alarm rates, while maintaining hit rates, increases the overall discrimination accuracy of any detection system.

Several authors have noted that unacceptably high false alarm rates are quite likely in conventional detection tasks for animals (including REST) because there is an asymmetry in the reinforcement contingencies arranged in those tasks (eg, Sargisson & McLean, 2010). Specifically, although two responses are available to the animal upon presentation of each sample (ie, sitting versus moving to the next sample) and both are correct, depending on whether the sample was positive or negative, only one of the correct responses is explicitly reinforced; sitting in the presence of positive samples. Correctly rejecting negative samples by not sitting and moving past them is not reinforced because it does not constitute a discrete unit of behaviour. Despite this asymmetry, published guidelines for training REST and direct-detection animals (Fjellanger, Andersen & McLean, 2002; Fjellanger, McLean, & Bach, 2003) describe very few techniques for reducing false alarm rates, and these techniques have seldom been empirically tested.

Seemingly, the most common technique is simply to ignore false alarms and hope that withholding rewards for emitting the indication response when the target odour was absent will lead to a gradual decrease in the frequency of false alarms; a principle of learning known as *extinction* (Catania, 1998). This technique is also the least invasive. Consequently, it was the first technique that we assessed. Figure 11 shows the false alarm rates for three dogs over the first 50 sessions of training, during which time false alarms were simply ignored and so earned no specific consequence. (These were the three dogs showing the highest false alarm rates and only the first four conditions - 50 sessions - are shown, because no further change in false alarm rates was observed between Session 51 and Session 129 when an experiment assessing an alternative intervention for false alarms was conducted).

FIGURE 11 | The false alarm rates of three dogs in each of the first 50 sessions of training in the project. Although four procedural changes took place over this period, in all conditions, false alarms were recorded but simply ignored by the DH. The data from three dogs are shown because they showed the highest false alarm rates. False-alarm rate was calculated by dividing the number of examined negative samples by the number of indications made on examined negative samples. The blue dashed-line shows the five per cent criterion specified by IMAS.

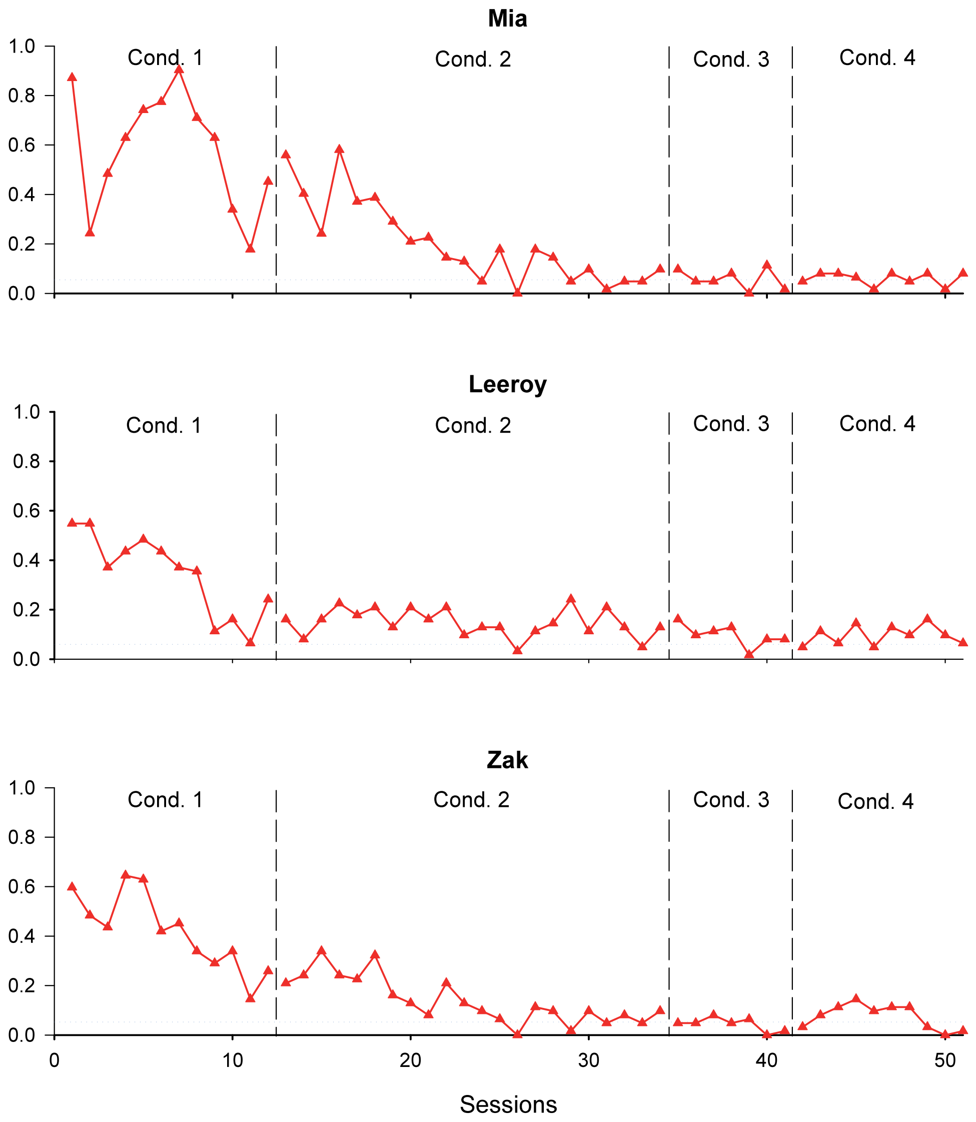


Figure 11 shows that simply ignoring false alarms resulted in a gradual decrease in their relative frequency. The degree of this reduction/extinction was not, however, sufficient in that false alarm rates stabilised at a level that exceeded the five per cent maximum specified in IMAS (.05 on Figure 11). In fact, false alarm rates consistently exceeded five per cent for five of the six dogs over the first 129 sessions (13 conditions contributing to various experiments).

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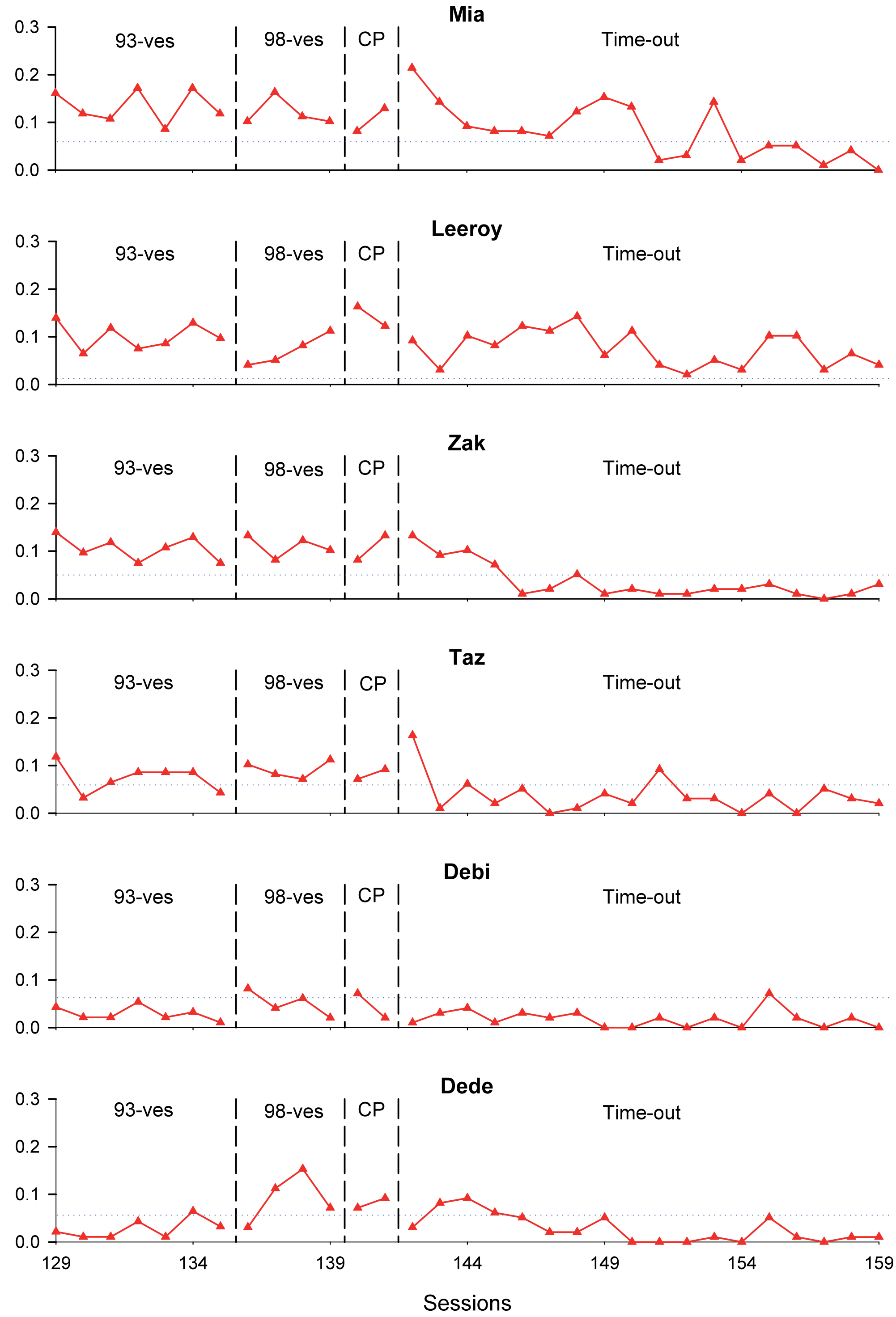
FIGURE 12 | The false alarm rates of each dog in each session of an experiment aimed at identifying a procedure that was effective in reducing these rates. The condition labelled "93 –ves" served as a baseline. "CP" is an acronym for correction procedure. The blue dashed-line shows the five per cent criterion specified by IMAS. See text for further details.



A SAMPLE OF BEHAVIOUR-ANALYTIC RESEARCH AIMED AT DEVELOPING A SYSTEM OF REMOTELY DETECTING EXPLOSIVE REMNANTS OF WAR (ERW)

Figure 12 shows the results of procedural changes that represented other attempts to reduce false alarm rates so that they were below five per cent. The condition denoted as "93 –ves" served as a baseline condition against which we compared the efficacy of several interventions involving procedural changes. Figure 12 shows that false alarm rates were consistently above five per cent for four of the six dogs during this baseline condition; only Dede and Debi showed acceptable false alarm rates.

The first intervention we assessed involved increasing the number of negative samples per session from 93 to 98 (and decreasing the number of positives from 15 to ten) so as to increase the opportunities for false alarms and so, increase the opportunities for them to extinguish when they were ignored. In retrospect, the degree of this increase was so small that it was very unlikely to be effective, and Figure 12 confirms that indeed it was ineffective. However, it is worth noting that the false alarm rates of one dog (ie, Dede) actually increased to above five per cent during this condition, although that increase looks to be a continuation of a trend in the earlier condition rather than being attributable to increasing the number of negative samples.

The second intervention aimed at reducing false alarm rates is labelled in Figure 12 as "CP" because it involved a type of error-correction procedure that was again designed to increase the opportunities for false alarms to extinguish. In this condition, on each occasion that a dog emitted a false alarm, a LA would sound a buzzer to signal to the DH that the dog should be led from the training room to the holding pen outside. Unlike his/her behaviour when a dog had correctly indicated a positive sample, the DH avoided eye contact and remained silent when leading the dog from the room after a false alarm. After spending 20 seconds in the holding pen, the dog was returned to the training room where the carousel contained the same set of samples that it contained on the prior visit but less any positives that had been missed on that visit. Thus, unlike all prior conditions, the negative sample associated with the false alarm remained on the carousel in a subsequent visit.

This removal from the room followed by re-presentation of the samples was repeated until a dog either:

a) made five successive false alarms on the same set of samples
b) refrained from false alarming and thus, correctly rejected a set of negative samples
c) correctly indicated a positive sample on the carousel

Any negative sample that was associated with three successive false alarms was removed from the carousel and replaced with a negative sample from a set of spares. It is noteworthy that dogs very seldom made three false alarms on the same negative and that different dogs seldom false alarmed on the same negative. These results suggest that false alarms were not stimulus specific and instead reflected only a response bias; namely, a bias for indicating. Therefore, it is unlikely that some number of negative samples had been contaminated with the odour feature of positive samples that controlled indications, or that dogs were indicating samples that had earlier been indicated by other dogs.

Despite increasing dramatically the opportunities for false alarms to extinguish, Figure 12 shows that the correction procedure did not decrease the false alarm rates of the five dogs showing rates greater than five per cent. That said, our assessment of this intervention was conducted for only two sessions and it is possible that extended training with this procedure is necessary before a reductive effect is seen. The reason we didn't run this correction procedure for more sessions was that it resulted in considerably longer sessions than previous conditions and staff were struggling to complete the planned 12 training sessions within a seven-hour working day.

The reluctance of staff to continue running this procedure highlighted for us an important criterion for any feature of training; not only does that feature need to promote the desired behaviour in our animals but it also needs to be acceptable to the staff who are asked to implement it. After all, irrespective of the potential efficacy of a procedure, if staff feel inconvenienced by that procedure, the integrity with which it is implemented is likely to deteriorate, perhaps to a point where it will not be effective.

The third intervention we assessed was the most invasive. This intervention also involved sounding a buzzer and removing the dog from the training immediately after a false alarm was emitted. However, there were two important differences between this intervention and the correction procedure. First, rather than being secured in the normal holding pen before being returned to the room, dogs were now kept for 20 seconds in a pen that had a solid front door, a wooden-grilled ceiling, and stones on the floor. While in this pen, dogs were unlikely to lie down, were denied the usual access to water, and could not interact with the DH. We considered that this procedure imposed a cost for false alarms (namely, time-out from a rewarding environment) that could conceivably serve to punish false alarms. Secondly, unlike the correction procedure, all those samples that were judged to have been sniffed prior to the false alarm were now removed from the carousel prior to the dog being returned to examine any remaining samples.

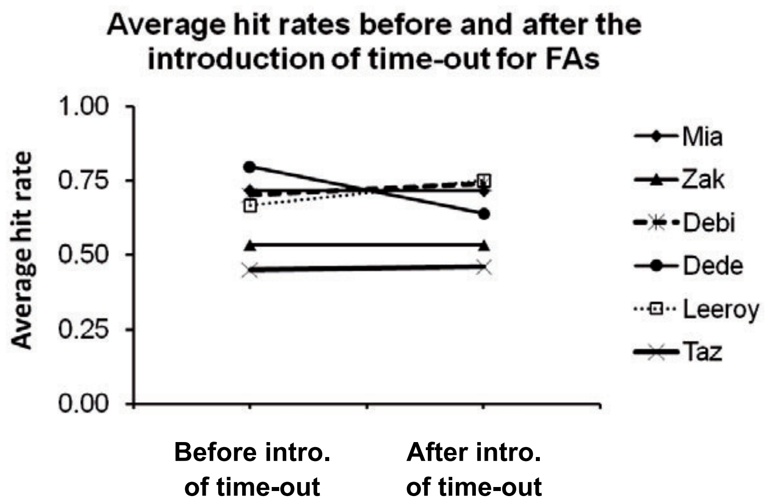
Figure 12 shows that following each false alarm with a brief period of time-out was effective in reducing to below five per cent the false alarm rates of four of the five dogs that required some reduction (Mia, Taz, Dede & Zak). Furthermore, for three of these four dogs, the decrease in the false alarm rate was gradual, suggesting that they required repeated false alarm/time-out pairings before the time-out punished false alarming as ought to be the case if learning was involved. Leeroy was the only dog whose false alarm rates did not decrease to below five per cent. However, this dog's false alarm rates still showed some decrease with the introduction of the time-out procedure. Prior to time-out, Leeroy's false alarm rate was at or below five per cent on only two of 13 sessions (15 per cent). However, after the introduction of time-out, his false alarm rates were at or below five per cent on nine of the 18 sessions (50 per cent). These results suggest that our inability to reinforce correct rejections of negative samples could, to some extent, be compensated for by arranging a penalty for false alarms on those samples.

Time-out was assessed only after attempts to accelerate the extinction of false alarms failed, because applying time-out came with a serious risk. If a high false alarm rate reflected a bias toward indicating what was independent of sample type, and time-out for false alarms effectively reduced this bias, then this intervention might well reduce hit rates in addition to reducing false alarm rates. Put simply, arranging time-out for false alarms might reduce the overall frequency of indicating, including when the sample is positive.

A SAMPLE OF BEHAVIOUR-ANALYTIC RESEARCH AIMED AT DEVELOPING A SYSTEM OF REMOTELY DETECTING EXPLOSIVE REMNANTS OF WAR (ERW)

To assess whether the application of time-out affected hit rates, we compared the average hit rate for each dog in conditions immediately preceding the introduction of time-out (Condition 14-16; 13 sessions) with the average hit rate in sessions following the introduction of time-out (Condition 17; 17 sessions) - see Figure 13. It is clear in this figure that the application of time-out did not decrease hit rates for the majority of dogs; only one of the six dogs (Dede) showed a lower mean hit rate after its introduction. Thus, arranging time-out for false alarms appears to have selectively punished indications on negative samples. This was the result we had hoped for.

FIGURE 13 | The average hit rates of each dog before and after the introduction of time-out for false alarms. The average hit rates before time-out were calculated from Session 129 through 141 (Conditions 14, 15 & 16), whereas the means after the introduction of time-out were calculated from Session 142 through 159 (Condition 17) - see Figure 12.



A SAMPLE OF BEHAVIOUR-ANALYTIC RESEARCH AIMED AT DEVELOPING A SYSTEM OF REMOTELY DETECTING EXPLOSIVE REMNANTS OF WAR (ERW)

D. INVESTIGATIONS OF SOURCES OF VARIANCE IN DETECTION ACCURACIES

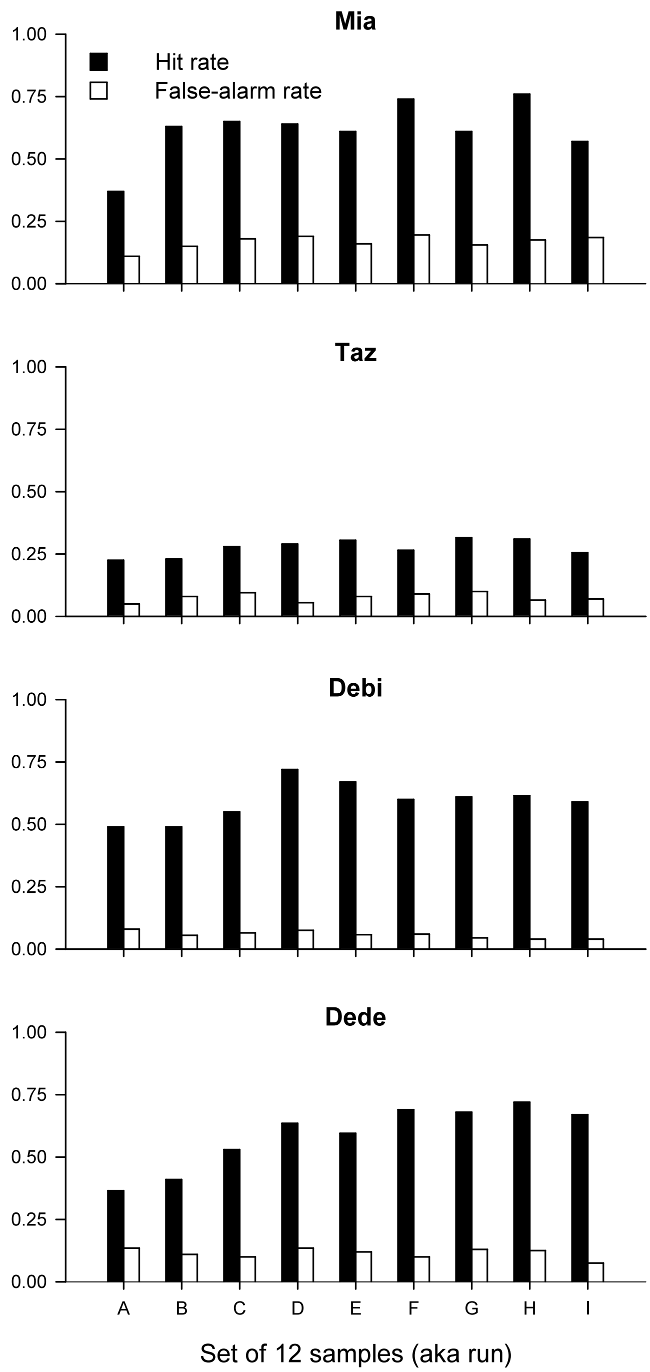
Although the primary aim of our project was to develop an operational REST system, we believed that such development required research that sought to identify variables which affected our dogs' detection accuracies. This identification of controlling variables would be important because it might allow some of those variables to be kept constant at values that promote the highest accuracies. The control of variables affecting the occurrence of target behaviour is also an important objective in behavioural research that applies principles of single-subject (or small-N) research designs and we wanted to use those designs. Single-subject designs involving comparing repeated measures of a subject's behaviour before and after some procedural change. Consequently, the smaller the variation in behaviour measures across sessions within each condition (ie, pre- and post-change), the more easily an effect of the procedural change will be detected. In so far as making no attempt to control important variables might mean that the values of those variables vary across sessions. Explicitly controlling them ought to minimise the variance in measures of the behaviour and so aid the assessment of procedure changes.

Our search for variables affecting the detection accuracies of our dogs involved analyses of both the dogs' performance and the status of potential variables recorded for individual training sessions. These analyses involved drawing graphs and calculating statistics using data that had been entered from the record sheets for each session (see Figure 3) into a computerised database. We investigated the effect, if any, of the following variables:

1. Climactic conditions inside the training room (ranging from approx. 25 to 30 °C, and 53 to 81 % humidity)
2. Which LAs had prepared the sample set being presented in training
3. Which LAs were judging indications and sniffs in a training session
4. Which DH was involved in a training session
5. Which run number (ie, set of 12 samples) samples appeared on within a session
6. Which training session of a day it was (ie, the morning or the afternoon session)
7. Which of the 12 arms of the carousel samples appeared on
8. Whether the dog was the first, second or third in each group sharing a set of samples

These analyses revealed that detection accuracies did not correlate significantly with either climactic conditions inside the training room or the identity of a staff person serving a particular role. However, effects of the latter four variables were observed.

FIGURE 14 | The hit and false alarm rates on each of the nine sets of samples (runs) presented per session for four of the six dogs. Hit rates are shown as black bars whereas false alarm rates are shown as white bars. The data from the remaining two dogs are not shown because there was no effect of run number in those data. This data was calculated using response frequencies summed across sessions of a ten-week block of training, during which time condition changes had minimal effects on accuracies.



A SAMPLE OF BEHAVIOUR-ANALYTIC RESEARCH AIMED AT DEVELOPING A SYSTEM OF REMOTELY DETECTING EXPLOSIVE REMNANTS OF WAR (ERW)

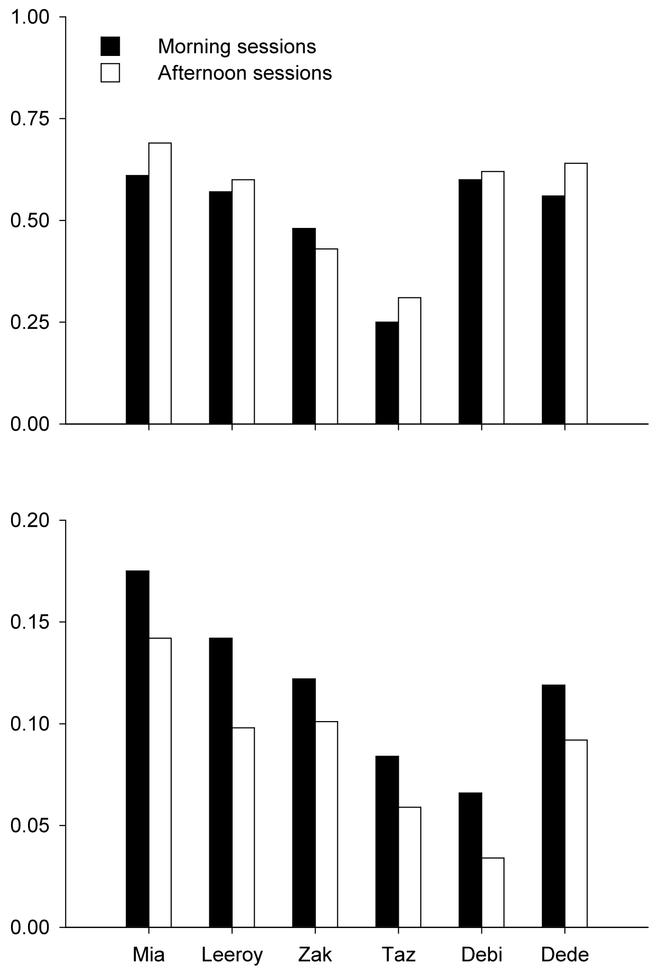
Figure 14 shows the hit and false alarm rates of four dogs on each of the nine sets of samples (*aka* runs) presented in a session. These data were calculated by summing response frequencies across sessions in a ten-week block of training, during which time condition changes that had minimal effects on accuracies were conducted. For each of the four dogs, Figure 14 shows that hit rates were lowest on the first set of samples presented in a session (ie, Run A). In addition, three of the four dogs showed a systematic increase in hit rates across the first four sample sets (ie, Debi, Taz & Dede).

These hit-rate changes were not, however, accompanied by systematic changes in false alarm rates, which remained relatively stable over the sample sets. Therefore, an increase in hit rates as the training session progressed represents a real increase in how accurately positive and negative samples were discriminated. Similar improvements in an animal's detection (or discrimination) accuracy have been reported in the research literature on animal learning, and have become known as the *warm-up effect* (Sidman, 1958). More importantly, an effect of run number on detection accuracy suggests that the position of positive samples within a session is a variable that contributes variance to detection accuracies across sessions.

For example, consider two hypothetical cases: one in which our computer programme allocated no positive samples to the first three runs in the session, and the other in which the majority of samples happened to appear on the first three runs. Given that detection accuracy improves with successive runs in a session, hit rates will be considerably lower in the second session than in the first.

Do the implications of the warm-up effect imply that we should skew the distribution of positive samples so that relatively fewer appear on the first several runs of a session? After all, such an intervention ought to increase hit rates. We argue that such an intervention would be foolish because dogs would probably soon learn that positives never appear on the early runs and so cease searching intensively on these runs. Consequently, if positives should happen to appear on early runs when dogs are presented with operational samples, those samples will likely be missed. Rather than trying to eliminate the warm-up effect, we argue that it should simply be accommodated and the position of positive samples in a session should continue varying in an entirely random manner. Such accommodation might involve re-presenting later in a session, any operational samples that were presented on the first few runs.

FIGURE 15 | The average hit rate (top panel) and false alarm rate (bottom panel) of each dog in the morning (filled bars) and afternoon (unfilled bars) sessions of a ten week blok of training, during which time condition changes had minimal effects on accuracies.



Each dog received two training sessions per day: one in the morning between 8:00am and 12:00am, and the other in the afternoon between 1:00pm and 5:00pm. Figure 15 compares detection accuracies from morning sessions with detection accuracies from afternoon sessions. The top panel shows the average hit rate, and the bottom panel shows the average false alarm rate of each of the six dogs in the morning and afternoon sessions over the same block of conditions analysed in Figure 14. Hit rates were higher in afternoon sessions than morning sessions for five of the six dogs, and false alarm rates were lower in afternoon sessions than morning sessions for all six dogs. Thus, five of the six dogs showed more accurate discrimination between positive and negative samples in the afternoon session implying that the time (or position) of a training session within a day is another variable that contributes variance to detection accuracies across sessions.

The reasons for this are unclear, because numerous mechanisms could underlie it, for example:

- samples were older in the afternoon than in the morning session due to all samples being manufactured at a similar time on the previous day.
- the amount of food earned as rewards in training sessions was significantly less than the daily ration of food delivered at 5:30am, and the afternoon session was conducted after a longer delay since this meal than the morning session, meaning that the dogs may have been more motivated to earn food rewards in afternoon sessions than in morning sessions.
- it is possible that rhythmic changes in a dog's metabolic and/or physiological state throughout the day provide it with greater olfactory acuity in the afternoon.
- this phenomenon may be a first- versus second-session effect that is analogous to the warm-up effect but over a larger temporal window.

Clearly, experimental manipulations would be necessary to ascertain exactly why this occurred. (For example, one such experiment might involve conducting both training sessions either in the morning or in the afternoon so as to control for time-of-day differences. Another experiment might present older samples in the morning than in the afternoon so as to control for sample age.) Whether such experimentation is necessary for the development of an operational system is, however, an issue that requires consideration because – as with the warm-up effect – accommodation of the phenomenon in operational activity may well be a simple matter (eg, represent in an afternoon/second session a proportion of the operational samples that were analysed in the morning/first session).

FIGURE 16 | The relative frequency of indications (both hits and false alarms) at each of the 12 arms of the carousel made by each dog. This data was calculated using response frequencies summed across sessions of a ten week block of training; during which time condition changes had minimal effects on accuracies. The red-dashed line shows the arranged relative frequency of positive samples at each arm.

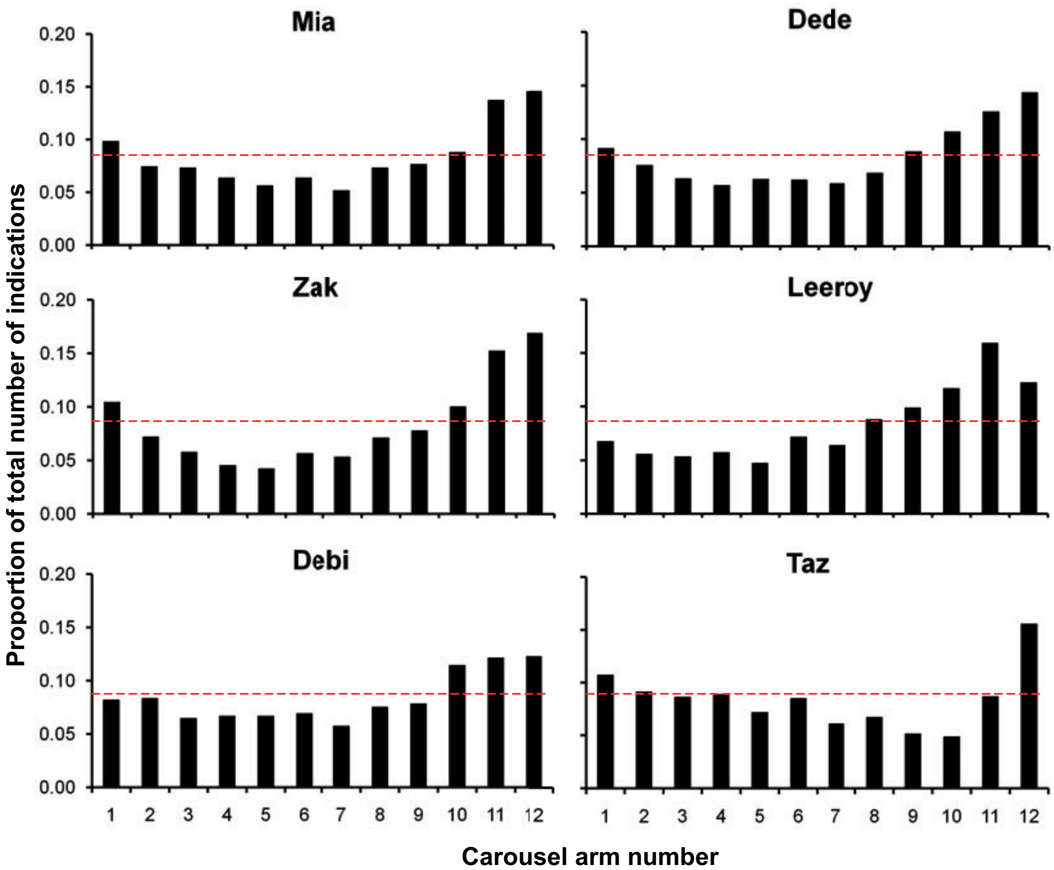
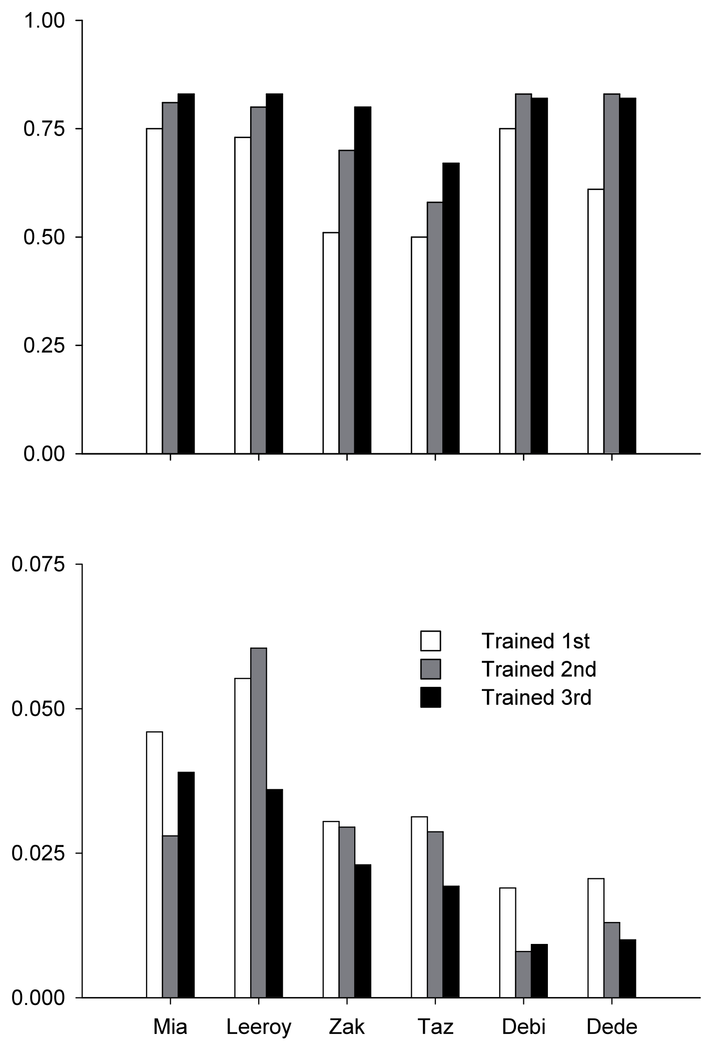


Figure 16 shows the distribution of indications around arms of the carousel. Here, the relative frequency of indications at each arm is shown for each of the six dogs using the same set of sessions that were analysed above. Although positive samples were equally likely to appear in each of the nine runs per session and in each of the 12 positions of the carousel, Figure 16 shows that dogs were not equally likely to indicate at the 12 carousel arms. Instead, all dogs were more likely to indicate at the first, second, eleventh and twelfth arms (ie, a set of four adjacent arms), than they were to indicate at the others. Consequently, they were more likely to score a hit on these arms than on other arms if positive samples appeared there, and to score a false alarm on these arms if negative samples appeared there.

Given such tendencies, accuracies calculated for sessions where numerous positives appeared on these arms would be higher than accuracies from sessions where relatively few positives appeared there. The position of positives on the carousel is, therefore, another source of variance in detection accuracies across sessions. However, as with the effect of run number within a session and number within a day, the reasons for an effect of arm number on indication bias are unclear and experimental manipulations are necessary to identify those reasons. For example, this bias might have been due to Arms 1, 2, 11 and 12 being closest to where the DH stood while the dog was searching the carousel and, therefore, the dog receiving a reward more immediately for correct indications on these arms. Alternatively, given that these arms were usually the final arms searched on a visit to the room, they represented the final opportunities to obtain a reward on that visit and this feature of those arms may have induced a bias to indicate. One final possibility is that the bias resulted in part from our practice of removing samples from the carousel once they had been examined on a visit to the room. Although this practice was convenient for data analyses, it meant that there were more visits where samples appeared at later arms than there were visits where samples appeared at earlier arms. If there was any tendency for dogs to indicate once per visit, then our removal of samples will make indications more likely on later arms.

FIGURE 17 | Hit rates (top panel) and false alarm rates (bottom panel) for each dog as a function of the order in which they received a training session and so examined the same set of samples.



The final source of variance in detection accuracies that we identified was a dog's position in the group examining the same set of samples. Figure 17 shows each dog's average hit rate (top panel) and average false alarm rate (bottom panel) when it was the first, second and third dog to be trained in the group. (These data were calculated from the same ten-week training period used in the above analyses). For all six dogs, hit rates were lowest when the dog was the first to be trained, and for five of the six dogs, false alarm rates were highest when it was trained first. Furthermore, hit rates generally increased and false alarm rates generally decreased as a dog's position in the group moved back, although only the change in hit rates was statistically significant on a trend test ($p<.01$). These results suggest that a dog's ability to discriminate positive and negative samples increased as more dogs had examined the set of samples.

Further analyses of these data were conducted in an attempt to understand the reason for detection accuracies increasing with position in the group. Of particular concern was that dogs were leaving odour cues on samples they had indicated, and that these odour cues exerted some amount of stimulus control over the indications of dogs that later examined those samples. (Not only would this constitute an unintended stimulus-control topography but it would also compromise our use of three dogs to examine samples in operational activity because they would not be independent examinations). If this was the case, then we should see dogs being trained second or third making false alarms to the same negatives that an earlier dog false alarmed on, but no such correlations were detected.

In addition, the detection accuracy of a dog should depend to some extent on the detection accuracy of the dog that immediately preceded it. Therefore, the accuracy of the dog with the intermediate accuracy in a group should be higher when it follows the dog with the highest accuracy than when it follows the dog with the lowest accuracy. Again, though, no such dependencies were observed. Unfortunately, the reasons for this effect of position within the group remain unclear to us but they are clearly worth pursuing with further research. Ideally, this effect of position would turn out to be no more than an effect of the time of day at which training was conducted (or sample age at training) because training time did after all co-vary with training position, and there is reason to believe that the former was a variable controlling accuracies (see Figure 15).

If all the sources of variance identified above are considered together, the detection accuracy of a dog will likely be lowest in a session a) that was conducted in the morning, b) where the dog was the first to be presented with a set of samples, c) where relatively more positives occurred on the first few runs than later runs, and d) where relatively few positives appeared at Arms #1, 2, 11 and 12 of the carousel.

E. ASSESSMENTS OF THE RELIABILITY OF OUR DATA

Numerous textbooks on ABA describe the concept of measurement (or data) reliability along with various methods for assessing it (eg, Cooper, Heron & Heward, 1987; Johnston & Pennypacker, 1983; Kazdin, 1982). Briefly, *reliability* refers to the extent to which the measurements of some aspect of behaviour remain consistent over repeated measurements of the same subject under identical conditions. (The principle is not unlike the principle of reliably measuring physical phenomena. For example, a surveyor measuring a plot of land will probably prefer a metallic tape measure to one that is made of plastic - and so likely to stretch with repeated use - because the former will provide more reliable measurements of lineal length than the latter).

A SAMPLE OF BEHAVIOUR-ANALYTIC RESEARCH AIMED AT DEVELOPING A SYSTEM OF REMOTELY DETECTING EXPLOSIVE REMNANTS OF WAR (ERW)

Establishing that reliable measures of behaviour were obtained is particularly important when the measurement system involves human observers/recorders judging the occurrence versus non-occurrence of the behaviour. (The previous chapter described how using human observers in REST with animals actually involves two interacting detection systems: the animals are detecting the target odour whereas the humans are detecting the animals' indications). Without such reliability, one is unable to ascertain whether a difference in measures of behaviour (eg, detection accuracy) across conditions arranging different procedures reflects an effect of the procedural change or some difference in the observers' behaviour. Therefore, reliability of measurement (and of the data obtained) is a necessary, although not sufficient, condition for claiming to have conducted a valid experiment. Furthermore, a measurement system that has low reliability will be another source of variability in repeated measures of the animal's performance. Therefore, data variability due to measurement error will add to the variability that already exists and is due to uncontrolled variables, and make the already difficult comparisons even more difficult.

We assessed the reliability of our data using two approaches. The first involved measuring the degree of correlation between the data recorded by two independent observers. Such tests are known as inter-observer agreement (IOA) checks. The second approach involved assessing the effect on detection-accuracy scores (if any) of denying the observers/recorders knowledge of where any positive samples were located on the carousel. These tests will be called blind tests because those judging the behaviour of our dogs were blind as to the nature of the samples being examined.

IOA checks were conducted for both sessions in a day over two successive days, and two such checks were conducted approximately three months apart. In each session of an IOA check, we issued data-record sheets to the two LAs and required both of them to mark which samples were sniffed, and which were associated with a dog indicating (sitting), by applying the normal definitions of these two responses (see *General Methods: Procedures*). We also erected a temporary screen between the LAs so that neither could see the data-record sheet of the other. Although both LAs were judging sniffs and sits, the decisions of only one of them determined the consequences delivered by the DH inside the training room.

TABLE 2 | The results of two tests for inter-observer agreement - regarding when a dog examined a sample (sniffs) and when it emitted the indication response (sits).

Dog	IOA Test#1		IOA Test#2	
	Sniffs (%IOA)	Sits (kappa)	Sniffs (%IOA)	Sits (kappa)
Taz	98.2	0.97	98.2	0.97
Zak	91.7	0.68	99.1	0.92
Leeroy	96.3	1.00	100	1.00
Mia	96.8	1.00	97.2	0.97
Debi	99.5	0.90	99.5	0.90
Dede	97.3	0.96	97.3	0.96

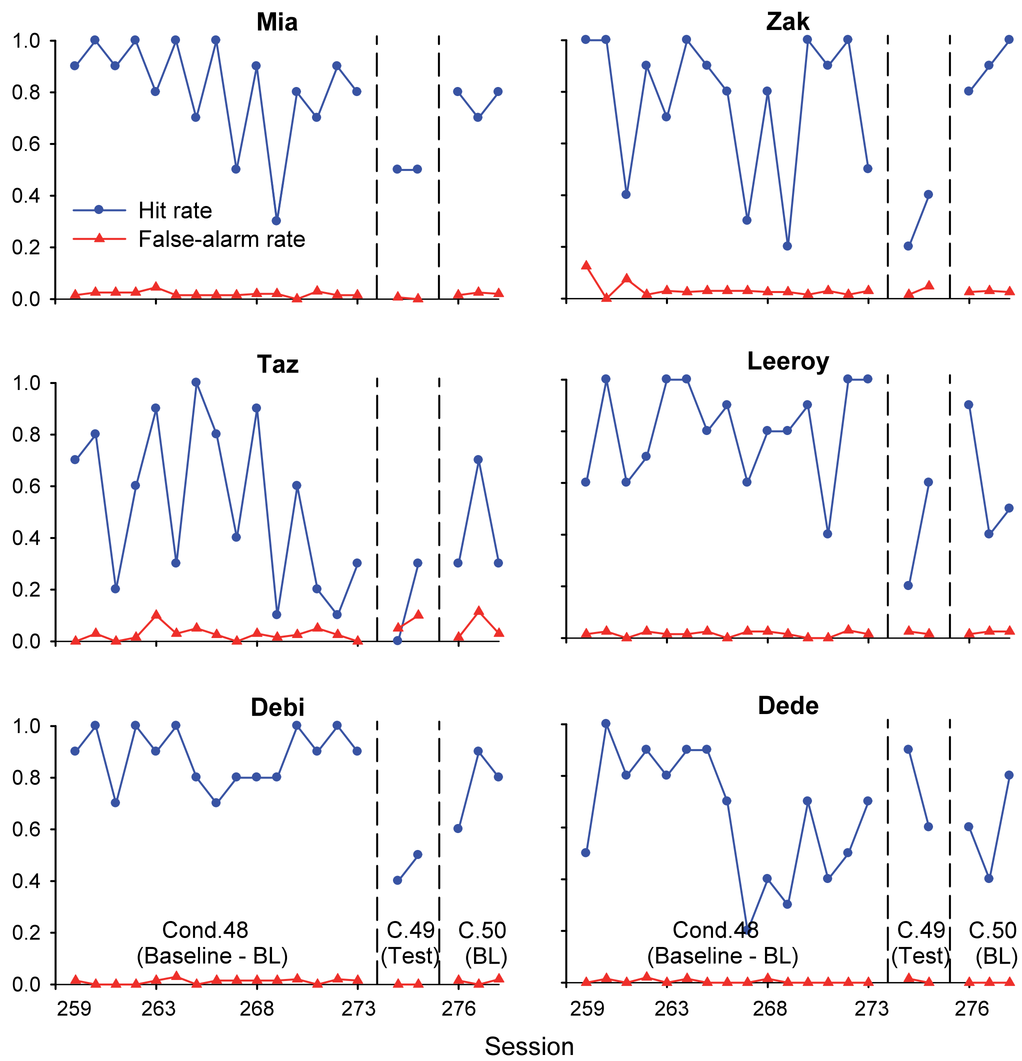
A SAMPLE OF BEHAVIOUR-ANALYTIC RESEARCH AIMED AT DEVELOPING A SYSTEM OF REMOTELY DETECTING EXPLOSIVE REMNANTS OF WAR (ERW)

Table 2 shows the results of our two assessments of IOA. The degree of IOA regarding which samples were associated with the dog sitting was measured by calculating a correlation coefficient called *kappa* (Watkins & Pacheco, 2001). This statistic takes into account the frequency of agreements that would be expected by chance and ranges between zero (agreement no better than chance) and 1.0 (complete agreement). In contrast, agreement regarding which samples a dog had sniffed required (for technical reasons) using the percentage agreement measure. The results of these IOA checks pleased us because high agreement scores were obtained for both responses in both assessments. In all but one case (Zak, Test #1, sits), these measures were also well above the minimum level of reliability demanded by editors of the Journal of Applied Behavior Analysis.

That said, two factors might have contributed to the high measures of agreement regarding sits. First, the LA controlling consequences in the training room might have influenced the decisions of the other LA when he/she operated either the clicker or the buzzer. Second, both LAs had knowledge of where any positive samples were positioned on the carousel, and this knowledge might have caused them to anticipate the dog sitting on some samples but not others. Only blind tests can prevent such expectancy effects from occurring.

Blind tests were conducted in both sessions of a day, and three blind-test days were arranged. The first and second test days were separated by three months, and the second and third by one month. The procedures arranged in each test were identical so that their results would be comparable. On the day before the test, LAs manufactured the required numbers of samples (ie, two sets of 98 negatives and 10 positives), labelled each of them as if they were negative samples, and organised them in a box so that one of the authors could load them secretively into their designated positions in the storage tray. During the training sessions, only we and the DO had information about the positions of the positives, one LA would call “kaka” when they judged a dog to have sat, and we sounded the clicker or the buzzer depending on which sample had been examined prior to the sitting. The DO recorded sniffs and sits as normal.

FIGURE 18 | Hit rates and false alarm rates for each dog in each session of the condition preceding the first blind test (Condition 48), during the blind test (Condition 49), and the condition following the blind test (Condition 50).

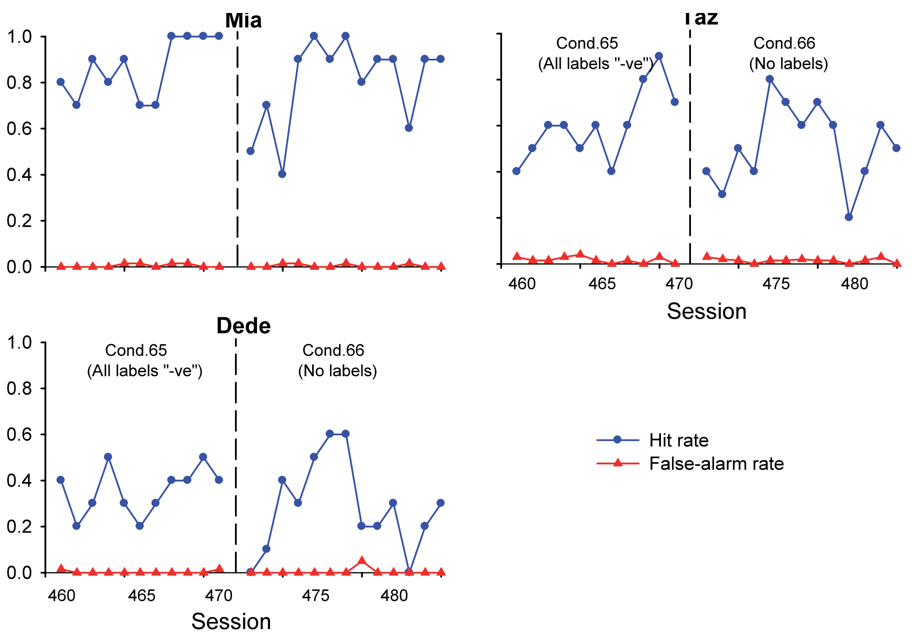


The hit and false alarm rates recorded in sessions prior to, during, and after the first blind test are shown in Figure 18 for each of the six dogs. (This experiment applies an A-B-A design - see previous chapter). Although false alarm rates during the test were similar to those before and after the test, hit rates were clearly different. For four of the six dogs, hit rates during the test were appreciably lower than hit rates in the baseline conditions on either side of the test. Therefore, for these dogs, LAs declared fewer indications during the test than during normal sessions; they seemed to have been considerably more conservative with what constituted a sit when they did not know whether the associated sample was positive or negative. This in turn implies that, in previous conditions, their decisions regarding when a dog had sat had been influenced by knowledge of the sample associated with the response.

This is not, however, the only explanation possible for lower hit rates during the test, because rendering the LAs blind to the positions of positive samples required several other procedural changes and any one of these could have caused the drop in hit rates. First, in normal sessions, one LA removed positive samples from the carousel and the other removed negative samples, so as to reduce the risk of cross-contamination. In contrast, one LA removed both types of sample from the carousel in the blind test. Second, in normal sessions, the lids from positive and negative pots were kept in different trays while the associated pot was on the carousel. However, in test sessions, the lids of positive and negative pots were kept in the same tray. This meant that lids from positive pots could well be returned to negative pots and vice versa during the test but not in normal sessions. Third, in normal sessions, positive and negative pots were given adhesive labels with different text on them (eg, "-ve" versus "+2") whereas in test sessions, all pots were given labels with "-ve" printed on them. Given that we printed considerably fewer labels for positive pots, these labels were usually older than the labels printed for negative pots raising the possibility that label age could have acquired some degree of stimulus control.

To assess whether any of the above procedural differences had caused the lower hit rates in the blind test, each difference was introduced alone after a baseline of normal training sessions and using either an A-B-A or an A-B-A-B design (see earlier chapter). The results of these experiments showed no effect of any of the procedural changes although applying the same labels to all pots reduced dramatically the hit rates for one dog (Taz). In response to this latter finding, we decided some time later to eliminate pot labels altogether. To our surprise, this procedural change reduced the hit rates of three of the six dogs (see Figure 19). Further training without labels was necessary before hit rates returned to their pre-change levels. This finding seems similar to that obtained when we switched from latex-rubber gloves to plastic gloves (see Figure 9) and may well be another example of masking.

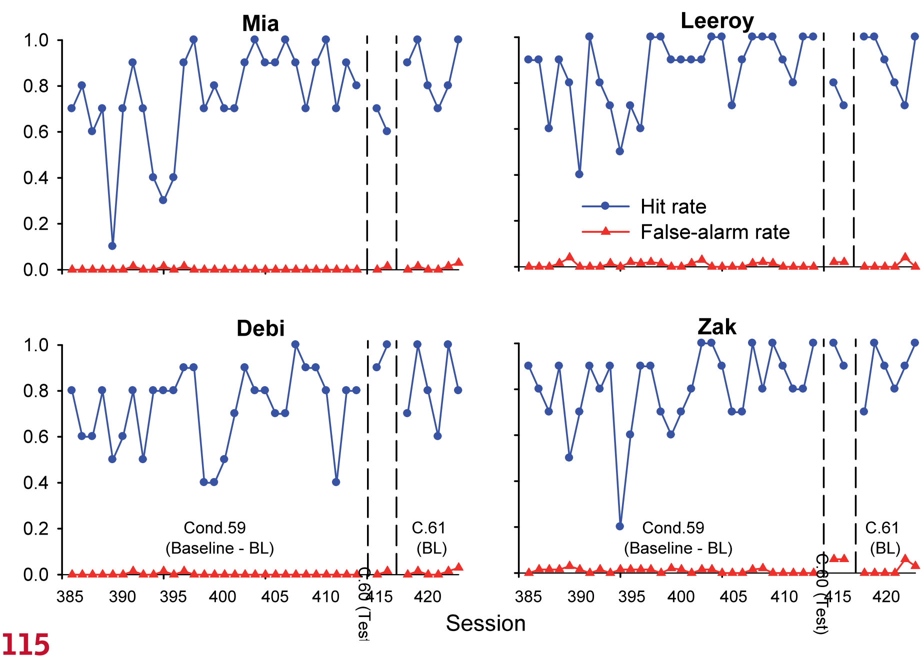
FIGURE 19 | Hit and false alarm rates of three dogs in each session of a condition where an adhesive label with "-ve" printed on it was put on all sample pots (Condition 65), and a condition where no pots had adhesive labels (Condition 66). The data from only these three dogs are shown because they were the only dogs that showed a difference in accuracy scores across the two conditions.



Our second blind test was conducted once the above experiments were completed, except the one assessing effects of removing pot labels. Figure 20 shows the results of this second blind test using the same format as Figure 18. We have presented the results of only those dogs that showed some change in hit or false alarm rates during the test. Although this blind test had less effect on detection accuracies than Test #1 (Figure 18), two dogs (Mia & Leeroy) still showed a decrease in hit rates and another dog (Zak) showed a clear increase in false alarm rates. We were bewildered by these results and so spent more time observing live and video-recorded training sessions of these dogs. This focused observation proved extremely useful because it revealed that these dogs sat for very brief periods when indicating. Moreover, in normal training sessions, LAs were frequently sounding the clicker after a short-duration sit and while the dog was moving toward the DH, so, sitting briefly and then approaching the DH seemed to have been reinforced.

Consequently, when these LAs were asked in the blind test to apply the strict definition of an indication described in their SOPs (ie, hind quarters making contact with floor for at least one second), several indications that would previously have been recorded as such were disqualified because sitting was too brief. Our solution to this problem was to give all dogs a 30-min session in which only one sample was presented on the carousel (a positive) and they were trained to sniff that sample and then remain sitting for longer and longer durations. By the end of this session, all dogs were sitting for up to five seconds and until the clicker sounded. The definition of an indication in the SOPs was changed from that point forward; dogs would now have to remain sitting for the time that it took a LA to say a short phrase in Kiswahili – approximately three seconds. Any episodes of sitting for shorter durations were not scored as indications and, therefore, earned no consequences. The absence of any change in the hit or false alarm rates of all dogs during the third blind test immediately following this training confirmed that we had rectified the problem. We had succeeded in improving the reliability of our data and perhaps also in eliminating a source of variance in detection accuracies across sessions.

FIGURE 20 | Hit rates and false alarm rates for each dog in each session of the condition preceding the first blind test (Condition 48), during the blind test (Condition 49), and the condition following the blind test (Condition 50).



A SAMPLE OF BEHAVIOUR-ANALYTIC RESEARCH AIMED AT DEVELOPING A SYSTEM OF REMOTELY DETECTING EXPLOSIVE REMNANTS OF WAR (ERW)

F. SUMMARY

Various methods for detecting areas of contaminated with ERW are currently being used by operators in the humanitarian demining industry. There can be no doubt though that the development of more efficient methods will aid efforts to reduce the lingering impact of armed conflicts in many countries. If larger areas of land can be examined at a lower cost, the return on resource investment will be greater and more people will benefit sooner. In addition, the principles underlying REST seem to offer such an efficiency gain, and the use of animals in such a system seems feasible given their proven success in direct-detection roles. However, whether or not REST using animals can actually be engineered, and scientifically proven to be effective, remains an unanswered question because our research never matured to the extent necessary to address it, and our research generated more new questions than answers. It also pointed to the need for considerably more rigorous experimentation before one could claim to understand fully the effects of the procedures required in a REST system.

The R&D efforts described here did nevertheless make significant progress toward assessing the feasibility of REST. Our dogs taught us the following principles:

- establishing, maintaining and subsequently proving stimulus control by an odour is a complex matter that demands the consistent application of carefully constructed procedures and an inherently sceptical interpretation of the animals' performance. Animals will use whatever odour cue is the most salient and predictive of rewards for emitting the indication response.
- numerous variables control the accuracy with which a target odour is indicated by an animal, and many of those variables cannot (or should not) be controlled. Identifying those variables is useful because it allows us to understand the sources of variability in detection accuracies from one session to the next. However, when we are unable (or unwilling) to control those variables, the noise that exists in our data increases the difficulty of ascertaining whether some procedural change affected the data.
- frequently assessing the reliability of the measurement system generating behavioural data is imperative and such reliability should never be assumed. Reliability assessments require carefully designed procedures and data-analysis methods, but ought to be applied as often as is practically possible.
- applying the research methods prominent in ABA was an extremely fruitful approach. In fact, we cannot imagine how else the R&D of a behavioural technology such as REST using animals might better be conducted.

REFERENCE LIST

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CHAPTER 6

DOCUMENTATION ON THE TRAINING OF NORWEGIAN PEOPLE'S AID DOGS FOR REST IN MOROGORO, TANZANIA

by Adee Schoon |

CHAPTER 6

DOCUMENTATION ON THE TRAINING OF NORWEGIAN PEOPLE'S AID DOGS FOR REST IN MOROGORO, TANZANIA

INTRODUCTION

The training of dogs in the REST Morogoro project focused on the approach of the training of dogs for REST. This paper describes the way in which this was done, using the Rest Information Management System (RIMS) computer programme developed for this purpose.

1. Starting point

Prior to the start of the Norwegian People's Aid (NPA)-leg of the project, the six Belgian Malinois shepherds had been trained to detect pieces of Kong (a hard, rubber, bouncy toy) inside containers on a 12-armed carousel (fig 1). This training was conducted from May to October 2008.

FIGURES 1 & 2 | Left: A picture of the 12 armed carousel and Right: A number of filled containers

The pieces of Kong had been put on a background consisting of different types of soils to which various material (both organic and inorganic) had been added (so-called additives). This ensured stimulus control on the pieces of Kong , since everything else varied (fig 2). The dogs were trained during two sessions on weekdays, and one on Saturday.

Every session consisted of a number of runs. In a run, each of the 12 containers had to be sniffed by the dog once. The dogs were started at position one, and if they made no indication at all they were taken away after they had sniffed all the 12 containers. If they indicated a container, they were either rewarded by a click that was immediately followed by a play game with a Kong if the indication was correct, or they were taken away out of the room if the indication was false. All the containers that had been sniffed were subsequently removed. The dog was brought back into the room for a second, third and possibly a fourth visit, until all the containers were smelled. Then new containers were put into the carousel for a new run.

In gradual steps, the number of runs per session was increased, and in general approximately one positive was used per run. The dogs initially searched on a lead, but this was gradually faded out. After a dog responded to a container, all the containers it had smelled were removed. A number of problems emerged in the training on the carousel.

The two major people involved differed in their view of the required training protocol, particularly whether the dogs should be prevented from completing a false response or if this should be broken off. The dogs were not searching intensely enough, passing by the "empty" containers very fast and regularly missing the relatively large pieces of Kong. They made a relatively large number of false alarms in the last arms of the carousel.

2. Pre-project advice

Prior to the start of the NPA REST project, some changes were discussed among the future project partners and implemented, as they were foreseen to increase the detection capability of the dogs and to lower the number of false alarms.

From October 2008, some changes were introduced. To intensify the searching, the dogs were trained outdoors in the morning. They searched for pieces of Kong stuck in holes in a wall, other holes were filled with other material (fig 3 and 4). The size of the Kong pieces to search for was gradually decreased, and following that, the pieces they had to detect indoors in containers on the carousel were decreased too.

FIGURES 3 & 4 | Left: Example of search on brick wall Right: Detail of filled brick holes

The results of the dogs were now reported weekly. All the dogs improved: the detection rates went up to almost consistently 100 per cent in December, and the false alarm rate was generally below one per cent (see appendix A).

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In January 2009, after the initial visit of the current project participants, some additional changes were put into place. In the carousel room, eight runs per session with eight positives became the standard. More additives were introduced per session, as well as more variety in soil types. A part of the list of soils and additives is given in Appendix B. Smaller sizes of Kong were introduced in gradual steps:

1. One smaller piece and seven "standard" sizes until the smaller one is indicated
2. Two of these smaller pieces, six "standard" sizes, until consistent hits on the smaller ones
3. Four smaller pieces and four "standard"
4. Smaller piece becomes the new standard

The position of the positives was randomised again (this had not been so since October 2008 since the computer programme was out of use). A procedure was put in place to counteract the observed position preference for the last arms in the carousel. Any container responded to was removed, as well as positive containers that had been missed. After a false indication, the dog was started in the same position again without any other changes. After a correct hit, the carousel was spun so the position that the dog started on was a new one. This was done to counteract the expectancy of the dogs: the first containers were familiar after a first visit, and the dogs tended to pass over these first containers very quickly on their way to the last pots where there could be another positive.

The results of the training of these weeks (weeks 32-36) was followed by weekly reports on the detection and false alarm rates. The results are summarised in the table in Appendix A.

3. Training from FEBRUARY to May 2009: decreasing from pieces of Kong to Kong contamination

At the project start, a number of training aspects were reviewed, adjusted and described in more detail.

3.1 Brick training

Every morning, the dogs were trained on detecting small pieces of Kong in a brick wall. On average they were given three to four searches, locating two to four pieces of Kong. Each search consisted of between 20-30 metres of brick wall: the bricks are 45 x 24 x 15cm, and have six holes in them (figs 1 and 2 above). They were stacked two bricks high.

The purpose of the training was to get the dogs to search systematically and slowly: the dog was on lead and the handler walked backward very slowly and steadily, allowing the dog to sniff at all the holes in the brick wall. The handler continued making stepping motions stationary if the dog began to move more slowly or came to a standstill, until the dog made a sit response. The dog was rewarded with a Kong for a correct sit. The Kong should be aimed at the location of the target and the throw timed in such a way that the dog is focusing on the target location, but the handling skills of the local staff were not high enough to maintain this. The handler should then play with the dog for some time. This has to be really playing, and must not end up as a fight for the Kong. Unfortunately, here again the handling skills of the local staff with the Malinois was not up to a high enough standard to ensure that this was always the case.

The exercise was resumed until all the planned searches had been conducted. The positive spots were never pointed out to the dog: at most, a wall can be searched again if the handler did not know for sure if the dog had been close enough to the piece for detection. Blank searches, ie searches without a target piece of Kong, were also conducted on purpose. False alarms were usually interrupted by the handler (who doesn't usually know, but is given a cue from a helper who does know where the targets have been hidden).

3.2 Carousel training

Every afternoon on weekdays and on Saturday morning, each dog was given carousel training. Each training session consisted of eight runs, each run consisted of the evaluation of 12 samples, in several visits if necessary. The samples for the training had been prepared in the morning of the day before. Three sets of samples were prepared, and each set was used for two dogs. The dogs and the order in which they were presented with the set were rotated to prevent any systematic additional cueing for the second dog.

3.2.1 Record sheets

Prior to the sample preparation, a record sheet was filled in. In this record sheet the soil types, additives and location for the positives were marked. Initially two different soil types were selected more or less randomly from the library of soils, later this was increased to five. Twelve different additives from the additive library were selected and distributed over the different soil types and runs (all these aspects were later randomised properly in the computer programme implemented in May 2009). The position of the positive samples was randomised using a list and marked on the session sheet. Details about the sample preparation date and lab assistants were filled in at the designated places.

3.2.2 Basic sample preparation

Samples were prepared every morning for use the next day. Ninety-six containers were placed in trays. Initially, aluminium containers were used, then in week 19 a switch was made to plastic containers. A spoon of soil (approx six grammes - in week 23 this was changed to one gramme to match the amount of soil used for the training of the rats) was scooped into each container in such a way that the distribution of the soil types was distributed over the eight runs. Next, 12 different additives from the additive library were selected and distributed over the different soil types and runs (all these aspects were later randomised properly in the computer programme implemented in May).

All handling of containers was conducted while wearing gloves. Care was taken to handle each container the same number of times to prevent additional handling cues.

3.2.3 Making positive samples

Kong had been cut into pieces of different sizes. The smallest amount that the scale could register was 0,020 grammes. This was then cut in half, and these further into halves, leading to the pieces of 0,010 – 0,005 – 0,0025 – 0,00125.

To create a positive, a piece of Kong would be put into a container on top of the soil and additive directly after it had been prepared. For "Kong" positives, it was left there until it was used in the carousel. To create a "Kong contamination" positive, the piece was removed. In this stage of the training this was done with a 0,00125 size piece that was removed early in the morning, therefore having contaminated the sample for approximately 17 hours. The sample was then left uncovered without the piece for a minimum of four hours before being presented to the dog.

3.2.4 Sequence of training steps

The general build-up of the training was as follows:

1. Eight "standard" pieces in each of the eight positive containers
2. Seven "standard"pieces and one next size smaller,
3. Six "standard" and two next size smaller,
4. Four "standard" and four next size smaller;
5. Eight next size smaller which has then become the new "standard" and back to step one.

In gradual steps, the size of the Kong piece was reduced, and then removed as the next step going down in the amount of target odour available for the dog.

3.2.5 Carousel procedures

The documenter noted the necessary session details on the record sheet at the beginning of the session. The LA's loaded the carousel with 12 samples for the first run, always wearing gloves while handling the containers and the rod to move the carousel. One LA loaded the carousel from one position and the other moved the arms of the carousel to facilitate this. After having left the room, the LA would signal with a light that the dog could enter. The LA and the documenter were outside of the room and could observe through a one-way window. The handler brought the dog into the room to one corner, unleashed it and directed it to search. The dog worked the carousel clockwise.

The LA observed the dog and read out the numbers of the carousel arms the dog had sniffed. The documenter noted every sniff on the record sheet. Every visit could end in one of three ways:

1. If the dog indicated on a sample by sitting, the documenter would note this on the session sheet and the LA would respond appropriately. If the sit was at a positive sample, the LA would say a Swahili phrase (ameka, ameka) and then sound the clicker. The dog was then rewarded with a Kong by the handler in the room.

2. If the sit was at a negative sample, the LA would wave his hand against the upper part of the window which could be seen by the handler. The dog would be taken away out of the room without praise.
3. If the dog did not respond to any sample, the handler would call it off after it had completed the full carousel and had begun the second round. He would take the dog out of the room in a cheerful way for having worked well.

The removal of the dog from the room indicated the end of a visit.

In the case that after a first visit not all samples had been sniffed at yet (as would be the case if the dog indicated on samples 1-11 in the carousel), the sample that the dog had indicated on and any missed positive samples were removed from the carousel by the LA. If the dog had made a false indication, it was called in again for the next visit. If the dog had made a correct indication, the carousel was spun a variable number of positions before the dog was called in again for the next visit.

A second visit would be marked separately on the record sheet. A run ended after all samples had been sniffed by the dog. The second run would be prepared by the two LA's in the same manner as described above: any containers still present in the carousel would be removed and the new containers put into place by one LA while the other moved the carousel arms to facilitate this. After all eight runs were completed the session was completed. The same sample set would then be used for a second dog.

3.3 Results

The results of the training of these weeks (weeks 39 in 2008 to week 18 in 2009) was followed by weekly reports on the detection and false alarm rates. The results are summarised in the table in Appendix A.

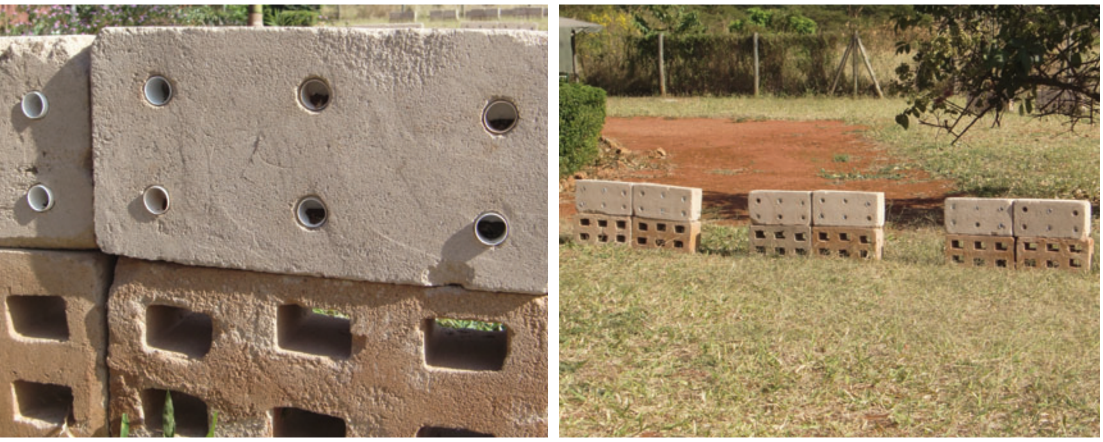
4. Training from May to October 2009: change from Kong contamination to mine solution

The shift from Kong contamination to Mine solution was conducted by first shortening the period of Kong contamination, then adding mine solution to the Kong contamination, and then fading out the Kong contamination in gradual steps.

4.1 Brick training

To prevent contamination with explosives, the brick training needed to be modified. Containers that contained negative samples that had been used in the carousel procedure, and that no dog had hit on, were saved for this purpose. These containers were mounted in specially prepared bricks (see figs. 5 and 6).

FIGURES 5 & 6 | Left: brick with holes for containers Right: example of search line with bricks



Daily, seven to eight containers in a line of bricks with 60 containers were refreshed, one of these having have been made a positive sample. The positives were chosen in a manner to facilitate the transition of the stimulus control from the odour of Kong to the odour of mine-water from a PMR2 mine:

1. Kong contamination long (overnight, at least 12 hours)
2. Kong contamination short (four hours, decreasing to three)
3. Kong contamination with mine-water (from a PMR2 mine, control water was added to the negatives)
4. Mine water (from a PMR2 mine, control water was added to the negatives).

The objective of these search exercises was to stimulate the dogs to search for the designated target in a different manner from the carousel procedure to stimulate their search drive and to provide an opportunity for a big play reward increasing the dogs' motivation. This training was terminated early August when it led to specific handling and training problems that were not easy nor important enough (since they were not relevant to the detection work on the carousel) to solve.

4.2 Carousel training

Every afternoon on weekdays and on Saturday morning, each dog was given carousel training. Each training session consisted of eight runs, each run consisted of the evaluation of 12 samples, if necessary in several visits. The samples for the training had been prepared in the morning of the day before. Three sets of samples were prepared and each set was used for two dogs. The dogs and the order in which they were presented with the set were rotated to prevent any systematic additional cueing for the second dog.

4.2.1 Session sheets

Each session was generated using a designated computer programme called RIMS (Rest Information Management System). The variables to be filled in were the number of runs that were to be conducted (usually eight), the number of different soil types desired for a session (usually five), the number of different additives to be used (usually 12), which control was to be used (control water or control mine-water), which targets were to be used and how many of each.

Appendix B illustrates the soil, additive and target/control libraries used by RIMS. Based on these variables, the programme generated a session:

- the programme divided the soils and additives randomly over the sample containers
- spread out the targets randomly over these filled containers
- the controls were added to the non-target sample containers

Sample preparation lists were then printed for the laboratory assistants, labels were printed for the samples, and a session sheet was printed on which to note the results. Based on this a detailed record sheet (similar to the one used before) for recording the dogs' actions during the session was filled in. An example of a sample preparation list and session sheet can be found in Appendix C. From week 34, the number of soils and additives to be used in a training session were brought down to one each, based on the results obtained with the dogs up to that point.

4.2.2 Sample preparation

From week 19, plastic containers such as were used in the rat training at Apopo's were used. All containers were first labelled in sequence. First the soils were added to the samples, after that the additives were added to the specific samples specified in the sample preparation list. In week 23, the amount of soil was dropped from six to seven grammes to just one gramme to fit in with the procedures at the rats and in view of the probably low amounts of dust that could be sampled operationally. The basic sample preparation was done as was described under 3.2.2.

In a similar series of steps as described for the brick training, the targets for the dogs went from a decreasing period of Kong contamination to a combination of Kong contamination with mine-water (PMR2 mine), to only mine-water (MW). After the Kong contamination had been reached, all samples were spiked starting from week 28 when MW was introduced. Spiking was conducted in the morning before the training began in an outside facility to prevent contamination (see figs. 7 and 8 below). Care was taken to touch each of the samples equally often, and to prepare positive samples midway in the procedure to prevent handling odour or temporal cues.

FIGURES 7 & 8 | Left: Outside spiking facility Right: LA's spiking training samples

4.2.3 Sequence of training steps

In gradual steps, the amount of available Kong target odour was reduced by shortening the period of contamination and then adding mine-water to it:

1. Kong contamination "long" which meant overnight (put in at 4 pm and taken out at 8 am next morning)
2. Kong contamination "short": four hours in the morning; later this was shortened to three and two hours
3. Kong contamination long and short with two to three mine-water (PMR2 mine) drops added, at the same time introducing two to three drops of control water on all of the negative samples
4. Two to three drops of mine-water (PMR 2 mine) only
5. Reducing amount of soil to match Apopo procedures and operational requirements

4.2.4 Carousel procedures

The same procedures as described above in 3.2.5 were followed with a few differences. Lights were installed for communication between the LA and the dog handler. When the handler entered the room with the dog, a small green light would be on. If the dog made a mistake, this light was switched off. A second change: to prevent the dog from favouring a certain part of the room to sit, the handler would walk to a different corner every day, and start the dog from there.

4.3 Results

The results of the training up to week 43 are summarised in Appendix A.

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5. Training from October to December 2009: Going down in Mine-Water concentration

In this stage, there was no more brick-training with the dogs. Instead of a single long session, two shorter ones were conducted daily with the dogs, using just one soil type and no additives, going down in Mine-Water concentration.

5.1 Session sheets

Using RIMS, two sessions were generated per couple of dogs per day. The procedure has been described above in 4.2.1.

5.2 Sample preparation

The basic sample preparation has been described before. After labelling the containers, soil was added to them. Spiking was conducted in the outside spiking facility. As targets, diluted mine-water concentrations were used mixed in with normal concentrations; and the mine-water concentration that was used was treated similarly as the target solutions.

5.3 Sequence in training steps

All the dogs were given a mix of the standard and the lower concentration during two to three weeks, but the FAR increased dramatically so for four dogs, only the high concentration was used, the other two were given a lower concentration.

5.4 Results

The results of the training are described in Appendix A. The detection rate went down from the onset of the lowering of the concentration of the mine-water, and the false alarm rate increased. For two dogs that seemed to be coping best, the mine-water concentration was kept lower. All dogs seemed to recover in detection rate but the false alarm rate remained higher than desired.

6 Training from January 1010 to March 2010: a radically different approach

Analysis of dogs on the different soil types had revealed that the dogs (and the rats) responded quite well when the MW was spiked on certain soils, but very poorly when spiked on other soils. There seemed to be a significant interaction between the soil type and the MW, confirmed by chemical analysis of MW on different soils in different conditions (Negussie, this volume).

To focus the dogs and the rats more on the odour of the mine itself, we decided on a radically different approach. Instead of spiking soil with mine-water, we allowed the odour of mine-water, and the odour of the mine itself, to "soak" into different neutral absorbents such as cotton wool and filter papers, and train the animals on these. In view of a possible first operational situation, we also decided to switch to a PMN mine.

This training was not foreseen in the planning, and required strict supervision from staff members so as to progress as quickly as possible through training steps. However, the key members could not be there enough, so not enough progress was made to really be able to judge the results or to test the effect of this training in the usual "transfer of training" tests used for this purpose. In the table below, the training steps are briefly summarised.

TABLE 1 | Samples prepared for the training of dogs and rats. If only prepared for one species, this is noted. In general, the first samples presented to the animals were on the top left of the table, the last ones we presented at the bottom right, but to prevent the animals from becoming too rigidly focused on a particular target they were intermixed.

Spiked MW	Decrease in drops	Scented MW	Scented mine
Empty containers			
Cotton balls	4 to 1		
Filter papers	1		
		Cottonwool; 48 hours	
		Filter paper; 48 hours	
		Filter paper, 48 hrs, soil added	Cotton balls
		Rats: filter paper,decrease to 2 hrs	
		Rats: filterpaper, 2 hrs, soil added	
Dogs: filter paper, soil added	4 to 1		
			Cotton balls,soil added
			Filter papers, soil added

The basic training philosophy that was followed in this period was to vary the soaking substrate, vary the target odour (MW and the mine itself), lowering the available odour by lowering the number of drops or shortening the soaking time, and adding soil without the interaction between soil and MW. Observing the behaviour and analysing the results would have dictated further training steps to achieve a transfer of training to field samples.

Appendices

Appendix A: overview of results

Appendix B: soil, additive, target and control libraries

Appendix C: example of sample prep list and session sheet used from May 2009

Percentage correct positives per weekper dog

<table>
<tr><th></th><th colspan="2">MUSA</th><th colspan="2">CHASER</th><th colspan="2">HANNA</th><th colspan="2">HOPA</th><th colspan="2">HULDRA</th><th colspan="2">YALA</th></tr>
<tr><td>Week 32: 0.015</td><td colspan="2">95,45</td><td colspan="2">78,79</td><td colspan="2">93,94</td><td colspan="2">89,39</td><td colspan="2">87,88</td><td colspan="2">96,97</td></tr>
<tr><td>Week 33: 0.015</td><td colspan="2">94,44</td><td colspan="2">88,89</td><td colspan="2">90,74</td><td colspan="2">90,74</td><td colspan="2">98,15</td><td colspan="2">98,15</td></tr>
<tr><td>Week 34: 0.0375</td><td colspan="2">84,85</td><td colspan="2">78,79</td><td colspan="2">78,79</td><td colspan="2">89,39</td><td colspan="2">95,45</td><td colspan="2">89,39</td></tr>
<tr><td>Week 35: 0.0375</td><td colspan="2">87,50</td><td colspan="2">78,41</td><td colspan="2">84,09</td><td colspan="2">93,18</td><td colspan="2">94,32</td><td colspan="2">94,32</td></tr>
<tr><td>Week 36: 0.025</td><td colspan="2">85,23</td><td colspan="2">84,09</td><td colspan="2">79,55</td><td colspan="2">92,05</td><td colspan="2">80,68</td><td colspan="2">90,91</td></tr>
<tr><td>Week 39: 0.020</td><td colspan="2">95,00</td><td colspan="2">87,50</td><td colspan="2">87,50</td><td colspan="2">92,50</td><td colspan="2">87,50</td><td colspan="2">97,50</td></tr>
<tr><td>Week 40: 0.020</td><td colspan="2">93,75</td><td colspan="2">93,75</td><td colspan="2">79,17</td><td colspan="2">93,75</td><td colspan="2">91,67</td><td colspan="2">100,00</td></tr>
<tr><td>Week 41: 0.020</td><td colspan="2">96,43</td><td colspan="2">85,71</td><td colspan="2">89,29</td><td colspan="2">94,64</td><td colspan="2">96,43</td><td colspan="2">98,21</td></tr>
<tr><td>Week 42: 0.020</td><td colspan="2">97,50</td><td colspan="2">100,00</td><td colspan="2">95,00</td><td colspan="2">90,00</td><td colspan="2">95,00</td><td colspan="2">100,00</td></tr>
<tr><td>Wk 43: 0.02/0.015</td><td colspan="2">100,00</td><td colspan="2">100,00</td><td colspan="2">100,00</td><td colspan="2">100,00</td><td colspan="2">100,00</td><td colspan="2">100,00</td></tr>
<tr><td>Wk 44: 0.015</td><td colspan="2">100,00</td><td colspan="2">97,92</td><td colspan="2">100,00</td><td colspan="2">95,83</td><td colspan="2">97,92</td><td colspan="2">100,00</td></tr>
<tr><td>WK 50: 0.020</td><td colspan="2">100,00</td><td colspan="2">95,83</td><td colspan="2">100,00</td><td colspan="2">100,00</td><td colspan="2">100,00</td><td colspan="2">100,00</td></tr>
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<tr><td>Wk 52: 0.020</td><td colspan="2">100,00</td><td colspan="2">100,00</td><td colspan="2">100,00</td><td colspan="2">100,00</td><td colspan="2">100,00</td><td colspan="2">100,00</td></tr>
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<tr><td>Wk 03: 0.015</td><td colspan="2">97,92</td><td colspan="2">81,25</td><td colspan="2">91,67</td><td colspan="2">93,75</td><td colspan="2">95,83</td><td colspan="2">91,67</td></tr>
<tr><td>Wk 04: 0.010/0.005</td><td>100,00</td><td>100,00</td><td>87,50</td><td>100,00</td><td>96,88</td><td>100,00</td><td>92,50</td><td>80,00</td><td>100,00</td><td>100,00</td><td>100,00</td><td>100,00</td></tr>
<tr><td>Wk05:0.005/0.0025</td><td>97,92</td><td>100,00</td><td>83,33</td><td>83,33</td><td>96,88</td><td>100,00</td><td>100,00</td><td>83,33</td><td>97,92</td><td>100,00</td><td>95,83</td><td>83,33</td></tr>
<tr><td>Wk06:.005/.0025</td><td>95,83</td><td>91,67</td><td>95,83</td><td>83,33</td><td>91,67</td><td>100,00</td><td>100,00</td><td>95,83</td><td>91,67</td><td>95,83</td><td>87,50</td><td>100,00</td></tr>
</table>

WK07:.005/.0025	90,00	70,00	70,00	90,00	90,00	90,00	100,00	90,00	100,00	100,00	95,00	100,00
WK08:.005/.0025	100,00	100,00	95,83	91,67	87,50	91,67	100,00	100,00	91,67	100,00	100,00	100,00
Wk09:.005/.0025	91,67	95,83	91,67	91,67	100,00	95,83	100,00	87,50	83,33	100,00	100,00	100,00
Wk10:.005/.0025	70,00	85,00	100,00	80,00	80,00	90,00	100,00	93,75	90,00	95,00	100,00	100,00
Wk11:0025/000125	93,75	100,00	87,50	100,00	97,92	100,00	89,58	100,00	95,83	100,00	95,83	100,00
Wk12:0025	93,75		87,50		83,33		95,83		95,83		97,92	
Wk14:0025	85,42		93,75		81,25		89,58		85,42		89,58	
Wk15:0025/00125	83,33	91,67	58,33	75,00	41,67	83,33	75,00	75,00	66,67	83,33	75,00	41,67
Wk16:0025/00125	100,00	85,00	95,00	90,00	90,00	80,00	95,00	95,00	95,00	95,00	95,00	85,00
WK17:0025/00125	93,75	100,00	100,00	87,50	87,50	68,75	93,75	81,25	93,75	87,50	75,00	81,25
WK18:0025/00125	93,75	75,00	75,00	75,00	81,25	81,25	87,50	93,75	100,00	100,00	93,75	87,50
WK19:00125/cont	91,43	100,00	68,57	80,00	82,86	100,00	94,29	100,00	82,86	100,00	85,71	100,00
WK20:00125/cont	92,86	100,00	95,24	83,33	76,19	100,00	95,24	100,00	100,00	100,00	92,86	83,33
Wk21:00125/cont	93,18	100,00	95,24	75,00	92,86	100,00	95,24	100,00	92,86	100,00	97,62	100,00
WK22:00125/cont	100,00	93,75	93,75	75,00	81,25	100,00	100,00	100,00	100,00	87,50	87,50	93,75
Wk23:00125/cont	91,67	92,86	91,67	75,00	91,67	85,71	91,67	85,71	100,00	92,86	100,00	89,29
Wk24: cont	75,00		89,58		75,00		81,25		79,17		91,67	
Wk25: cont	81,25		81,25		83,33		85,42		75,00		77,08	
Wk26:Kc long/short	57,14	58,33	57,14	75,00	81,25	25,00	57,14	58,33	60,71	75,00	64,29	50,00
Wk27:Kc long/short	66,67	41,67	70,83	66,67	70,83	58,33	70,83	66,67	79,17	70,83	58,33	58,33
Wk28:Kc/Kc+MW	75,00	81,25	54,17	62,50	70,83	100,00	83,33	68,75	91,67	93,75	75,00	68,75
Wk29:Kc+MW/MW	72,73	50,00	75,00	0,00	68,18	25,00	90,91	0,00	86,36	0,00	79,55	50,00

Wk30:Kc+MW/MW	88,89	50,00	88,89	16,67	91,67	8,33	86,11	16,67	72,22	58,33	80,56	8,33
Wk31:Kc+MW/MW	85,19	42,86	87,50	62,50	71,88	31,25	93,94	68,75	90,63	62,50	75,00	37,50
Wk32:Kc+MW/MW	75,00	37,50	77,78	54,17	83,33	16,67	80,56	58,33	83,33	62,50	86,11	54,17
Wk33:Kc+MW/MW	90,91	30,00	90,91	30,00	81,82	20,00	100,00	50,00	86,36	40,00	81,82	50,00
Wk34:KcMW/MW		68,75		45,83		45,83		85,42		35,42		46,88
WK35:KcMW/MW		58,82	58,33	22,73	83,33	0,00		47,06	83,33	22,73		
Wk36:KcMW/MW		60,42	90,00	33,33	88,24	58,06		66,67	58,82	83,87		
WK37:KcMW/MW		43,75	86,36	20,59	100,00	50,00		62,50	100,00	64,29	91,67	31,25
Wk38:KcMW/MW	35,71	50,00	81,82	50,00	59,09	42,31	57,14	44,12	59,09	46,15	77,27	55,56
Wk 39: MW	77,08		66,67		52,08		72,92		70,83		83,33	
Wk 40: MW-test	47,50		75,00		52,50		52,50		57,50		75,00	
Wk41: MW-test	75,00		82,50		67,50		65,00		77,50		85,00	
Wk 42: MW	68,75		47,92		56,25		60,42		58,33		47,92	
Wk 43: MW	87,50		68,75		81,25		85,42		75,00		87,50	
Wk 44:MW/MWh	75,00	29,17	62,50	8,33	79,17	20,83	75,00	33,33	79,17	20,83	66,67	12,50
Wk45:MW/MWless	50,00	20,00	25,00	22,50	50,00	62,50	62,50	12,50	25,00	40,00	25,00	17,50
Wk46:MW/MWless	58,33		37,50		54,17	50,00	62,50		33,33	45,83	43,75	
Wk47:MW/MWless	56.25		54.17			na	45.83			na	56.25	
WK48:MW/MWless	42.50		45.00			22.50	52.50			20.00	37.50	

Significant changes:
Week 37: beginning of brick training
Week 15: no plastic gloves
Week 19: change to plastic containers

Week 23:change from 6-7 grams of soil to 1 grams of soil
Week 31, 32 and 33: regular prevention false positives all dogs
Week 34 onwards: 1 soil, 1 additive (before: 5 soils, 12 additives)
Week 40: 2 shorter sessions a day, 1 soil, no additives
Week 43: switch to MW lower concentrations

Percentage false positives per week per dog

DOG NAME:	MUSA	CHASER	HANNA	HOPA	HULDRA	YALA
Week 32: 0.015	0,83	1,10	0,41	0,55	0,28	0,14
Week 33: 0.015	0,00	2,19	0,17	0,34	0,34	1,01
Week 34: 0.0375	0,14	0,96	0,55	0,28	0,41	0,55
Week 35: 0.0375	1,45	2,38	2,48	2,07	2,38	2,38
Week 36: 0.025	0,62	0,93	1,14	0,62	0,52	1,34
Week 39: 0.020	0,45	0,91	0,91	1,14	2,95	1,14
Week 40: 0.020	0,57	0,76	1,70	1,52	3,03	1,70
Week 41: 0.020	0,49	0,65	0,32	1,30	1,79	0,49
Week 42: 0.020	0,68	0,23	0,68	0,91	1,82	0,45
Wk 43: 0.02/0.015	0,19	0,57	0,38	2,27	1,52	0,38
Wk 44: 0.015	0,19	0,19	0,19	0,19	0,38	0,19
WK 50: 0.020	0,00	0,38	1,89	0,00	0,00	1,52
Wk 51: 0.020	0,00	0,00	0,19	0,00	0,57	0,19
Wk 52: 0.020	0,00	0,00	0,00	0,00	0,00	0,00
Wk 01: 0.020	0,00	0,00	0,00	0,00	0,00	0,23
Wk 03: 0.015	1,14	1,70	2,27	3,03	4,55	0,76
Wk 04: 0.010/0.005	0,69	0,00	0,29	0,23	1,61	0,46
Wk05:0.005/0.0025	0,57	0,00	0,86	0,77	0,19	0,77
Wk06:.005/.0025	0,95	0,57	2,98	0,38	0,38	0,38
WK07:.005/.0025	1,56	0,00	2,44	0,89	0,67	0,89

WK08:.005/.0025	0,00	0,37	0,56	0,37	0,19	0,56
Wk09:.005/.0025	0,19	0,93	1,11	1,30	0,00	0,93
Wk10:.005/.0025	1,11	0,67	2,22	3,06	0,22	2,00
Wk11:0025/000125	0,19	0,76	0,95	1,14	0,38	0,19
Wk12:0025	0,76	0,76	0,76	0,19	0,57	0,57
Wk14:0025	1,52	1,33	0,00	1,70	0,76	1,89
Wk15:0025/00125	4,92	3,03	1,52	3,41	1,54	3,41
Wk16:0025/00125	1,14	1,36	0,68	1,14	0,91	1,14
WK17:0025/00125	1,14	1,14	0,00	1,42	0,28	0,57
WK18:0025/00125	0,57	0,57	0,00	0,00	0,00	0,00
Wk19:00125/cont	0,68	0,45	1,14	0,45	0,23	2,95
Wk20: 00125/cont	0,76	0,19	0,00	0,19	0,76	0,95
Wk21: 00125/cont	1,89	0,19	1,70	0,75	0,19	1,70
Wk22: 00125/cont	0,28	0,85	1,14	0,85	1,14	1,70
Wk23:00125/cont	2,73	2,27	1,82	2,27	1,59	2,05
Wk24: cont	1,14	1,14	1,52	1,89	1,70	2,84
Wk25: cont	1,89	0,38	1,14	0,76	2,08	3,79
Wk26:Kc long/short	3,18	1,59	1,69	2,27	2,73	1,36
Wk27:Kc long/short	3,03	1,52	0,95	2,08	2,65	1,33
Wk28:Kc/Kc+MW	2,50	5,00	1,14	5,68	5,45	3,18
Wk29:Kc+MW/MW	2,46	4,36	1,70	2,84	2,84	2,46
Wk30:Kc+MW/MW	2,27	2,46	1,14	3,79	3,79	1,14

Wk31:Kc+MW/MW	1,82	1,33	2,27	2,47	3,98	3,60
Wk32:Kc+MW/MW	0,97	1,74	0,97	2,33	3,29	2,91
Wk33:Kc+MW/MW	6,16	3,20	2,05	6,39	5,94	3,65
Wk34:KcMW/MW	4,17	4,92	4,92	8,33	8,71	6,82
WK35:KcMW/MW	2,29	2,00	2,00	4,00	6,57	
Wk36:KcMW/MW	4,36	2,47	2,27	4,55	3,98	
WK37:KcMW/MW	4,36	2,50	3,41	6,63	3,41	7,31
Wk38:KcMW/MW	5,49	5,02	3,41	5,30	3,22	7,92
Wk39: MW	2,46	5,11	4,36	3,03	4,92	8,14
Wk 40: MWtest	4,32	4,77	4,09	3,41	4,77	5,68
Wk 41:MW-test	3,86	2,95	3,86	3,86	2,05	4,09
Wk 42: MW	3,03	4,17	5,11	4,73	1,89	5,30
WK 43	1,14	1,52	1,89	1,70	0,57	0,57
Wk 44: MW/MWh	3,79	3,98	5,11	5,87	3,22	6,06
Wk45:MW/MWless	8,14	4,92	9,66	7,20	8,90	12,12
Wk46:MW/MWless	8,71	3,98	9,85	5,68	5,11	5,68
Wk47:MW/MWless	8.71	4.36	na	5.49	na	8.52
Wk48:MW/MWless	13.41	9.32	6.82	10.23	8.41	10.68

Significant changes:
Week 37: beginning of brick training
Week 15: no plastic gloves
Week 19: change to plastic containers
Week 23:change from 6-7 grams of soil to 1 grams of soil
Week 31, 32 and 33regular prevention false positives all dogs

Week 34 onwards: 1 soil, 1 additive (before: 5 soils, 12 additives)
Week 40: 2 shorter sessions a day, 1 soil, no additives
Week 43: switch to MW lower concentrations

APPENDIX B

Example report of soils in stock in RIMS (Rest Information Management System)

Library of Soils in stock

Soil Code	Name	Date Collected	Location	Soil Type	Use of Land	Is current?	Remark
S101	James Kuya	12/11/2009	Kola Hill	clay soil	Agriculture	☑	
S102	James Kuya	12/11/2009	Kilakala Second	clay soil	Agriculture	☑	
S103	James Kuya	12/11/2009	Forest Morogoro	clay soil	Agriculture	☑	
S104	James Kuya	09/12/2009	Magadu rat field	clay soil	Agriculture	☐	
S105	James Kuya	09/12/2009	Inside Magadu r	clay soil	Agriculture	☐	
S106	James Kuya	09/12/2009	Behind of the fa	clay soil	Agriculture	☐	
S107	James Kuya	09/12/2009	Behind the fence	clay soil	Agriculture	☐	
S109	Said Abdallah	20/01/2010	Bigwa	sand soil	Agriculture	☐	
S110	Said Abdallah	20/01/2010	Francisco Kola	clay soil	Agriculture	☐	
S111	Said Abdallah	20/01/2010	Folkland	sand soil	road	☐	
S113	James Kuya	25/02/2010	Darajani football	Sand soil	football	☐	
S114	Thomasi Elias	25/02/2010	Darajani football	Sand Soil	football	☐	
S116	Violeth Mangesho	25/02/2010	Darajani football	Sand soil	Football	☐	
S117	Ruth Msuya	25/02/2010	Darajani football	Sand soil	Football	☐	
S118	Eustachius Sezary Ko	25/02/2010	Darajani football	Sand soil	Football	☐	
S18	Majenda Mhutila	03/01/2008	Mindu Darajani	On road soil	Not described	☐	
S25	Patrick Mbuna	08/05/2009	Mkundi farms	Red soil	Not described	☐	in stock
S51	James Kuya	08/07/2009	Msata Tanga Ro	Red Soil	Not Described	☐	
S58	Majenda Mhutila	29/07/2009	Magadu	Undergroun	Not described	☐	in stock
S59	Majenda Mhutila	29/07/2009	Magadu	underground	Not described	☐	in stock
S63	Thomasi Elias	05/08/2009	Mtego wa simba	Sand soil	Not described	☑	in stock
S75	Patrick Mbuna	02/09/2009	Dakawa	Black soil	Not described	☑	in stock
S77	Patrick Mbuna	02/09/2009	Dakawa darajani	Sand mixed	Not described	☑	in stock
S79	Patrick Mbuna	02/09/2009	Sokoine	Black soil	Not described	☑	in stock

Example report of additives in stock in RIMS (Rest Information Management System)

Library of Additives in stock

Add Code	Name	Date Collected	Location	Description	Current?	OdourStrength	In Minefield?
A0000	Yolande Dunne	01/10/2009	NOTHING	NO ADDITIVE	☑		☐
A0799	James Kuya	24/09/2009	SUA Dumple	Ashes	☐		☐
A0801	James Kuya	24/09/2009	SUA Farm	Soil Kichuguu	☐		☐
A0803	James Kuya	24/09/2009	Apopo	Flower dry leaf	☐		☐
A0805	James Kuya	24/09/2009	APOPO	Xmas dry leaf	☐		☐
A0807	James Kuya	01/10/2009	Jaraoat lunch gr	Cowpool	☐		☐
A0809	James Kuya	01/10/2009	Fockland	Mbirit leaf	☐		☐
A0810	Thomasi Elias	01/10/2009	Tiba road	Light dust of wood	☐		☐
A0811	Thomasi Elias	01/10/2009	Fockland	Dumped box	☐		☐
A0812	Eustachius Sezary Ko	13/10/2009	Mtoni street	Zed Alcohol box	☐		☐
A0813	Thomasi Elias	16/10/2009	Boma road stree	Banana leaves	☐		☐
A0814	Violeth Mangesho	27/11/2009	NPA Office	Sample preparation rec	☐		☐
A0815	Thomasi Elias	01/12/2009	Mtoni street	Sweet methol cigarate p	☐		☐
A0816	Thomasi Elias	15/12/2009	Mtoni street	Azam Mango juice	☐		☐
A0817	Thomasi Elias	15/12/2009	Vibandani CCM	Box	☐		☐
A0818	James Kuya	23/02/2010	SUA Damp	Gift paper	☐		☐
A0819	James Kuya	23/02/2010	SUA Bank	Pure Hebiscus box	☐		☐
A0820	James Kuya	23/02/2010	SUA Damp	Boya	☐		☐
A0821	James Kuya	23/02/2010	NPA Toilet	Toilet paper	☐		☐
A0822	James Kuya	24/02/2010	NPA Dog house	Dog' hair/feather	☐		☐
A0823	James Kuya	24/09/2009	NPA Compound	Majani ya Maua	☐		☐
A0824	James Kuya	23/09/2009	SUA Dampo	Leaves of Mwarubaini tr	☐		☐
A0825	James Kuya	23/02/2010	SUA Dampo	Newpaper	☐		☐
A0826	James Kuya	23/02/2010	Apopo Dampo	Plastic Bag	☐		☐
A0827	James Kuya	23/02/2010	Fockland	Box Soap	☐		☐

APPENDIX B

Example report of targets and controls in RIMS

Library of All Target/Control

Target	Name	Date Collected	Source	Concentration	Mother Sol.	Target?	Current?
K-00125	James Kuya	01/01/2009	Kong	00125 m		Yes	No
Kc-00125	James Kuya	01/01/2009	Kong	00125 removed		Yes	No
Kc4001	James Kuya	15/06/2009	Kong			Yes	No
None	James Kuya	01/01/2009	Nothing			No	No
KcMW000	James Kuya	07/07/2009	Kong cont long and MWpmr2-00			Yes	No
K4MW000	James Kuya	07/07/2009	Kong cont short and MWpmr2-0			Yes	No
Kc3MW00	James Kuya	30/07/2009	Kong cont short and MWpmr2-0			Yes	No
Kc2MW00	James Kuya	30/07/2009	Kong cont short and MWpmr2-0			Yes	No
Kc1MW00	James Kuya	30/07/2009	Kong cont short and MWpmr2-0			Yes	No
Kc0.5MW0	James Kuya	30/07/2009	Kong cont short and MWpmr2-0			Yes	No
Kc0.25MW	James Kuya	08/09/2009	Kong contamination and MWpmr			Yes	No
MWpmn s	James Kuya	15/02/2010	Mine Water			Yes	Yes
MWpmr sc	James Kuya	15/02/2010	Mine Water			Yes	Yes
MWC scen	James Kuya	15/02/2010	Water			No	Yes
MWpmn s	James Kuya	01/03/2010	Mine Water			Yes	Yes
MWpmr sc	James Kuya	01/03/2010	Mine Water			Yes	Yes
MWC scen	James Kuya	01/03/2010	Water			No	Yes
MWpmn s	James Kuya	20/03/2010	Mine Water			Yes	Yes
MWpmr sp	James Kuya	20/03/2010	Mine Water			Yes	Yes
MWC spik	James Kuya	20/03/2010	Water			No	Yes
MWC0001	Negussie	13/07/2009	water			No	No
MWC0002	Negussie	13/07/2009	water			No	No
MWC0003	Negussie	13/07/2009	water			No	No
MWC0004	Negussie	13/07/2009	water			No	No
MWC0005	Negussie	13/07/2009	water			No	No
MWC0006	Negussie	13/07/2009	water			No	No
MWC0007	Negussie	13/07/2009	water			No	No

APPENDIX C

Example of a sample preparation list and session list generated by RIMS.
Each container is labelled, the soil type and number of additive is specified, and how the sample should be spiked (with control water or with a target solution). Finally, the position this container should take in training session is given. In the session list the targets are marked with different colours.

Training Session Sample Preparation List

Session ID	212	Prepare Date	08/08/2009 10:00:00
Configuration	Carroussel	Lab Assistant	James Kuya
Remarks			

Label	Field Sample	Soil	Additive	Target/Control	Amount	Position
1		S24	A0046	MWC0023		A10
2		S24	A0094	MWC0023		E5
3		S24	A0094	MWC0023		H1
4		S24	A0282	MWC0023		G3
5		S24	A0297	MWC0023		C5
6		S24	A0297	MWC0023		G6
7		S24	A0297	MWC0023		F11
8		S24	A0322	MWC0023		A1
9		S24	A0322	Kc3MW0001		E9
10		S24	A0322	MWpmr2-005		G12
11		S24	A0322	MWC0023		A9
12		S24	A0358	MWC0023		A3
13		S24	A0358	MWC0023		H12
14		S24	A0358	Kc3MW0001		D4
15		S24	A0486	MWC0023		G7
16		S24	A0486	MWC0023		F7
17		S24	A0486	MWC0023		F9
18		S24	A0486	MWC0023		E11
19		S24	A0653	MWC0023		B1
20		S24	A0743	MWC0023		C6
21		S42	A0046	MWC0023		B10
22		S42	A0046	MWC0023		C2
23		S42	A0046	MWC0023		F1
24		S42	A0094	MWC0023		C10
25		S42	A0282	MWC0023		F8
26		S42	A0297	MWpmr2-005		H5
27		S42	A0297	MWC0023		B12
28		S42	A0297	MWC0023		G1
29		S42	A0322	MWC0023		E7
30		S42	A0486	MWC0023		F6
31		S42	A0486	MWC0023		D10
32		S42	A0631	MWC0023		E2
33		S42	A0631	MWC0023		C11

22/10/2010 21:00:19 Training Session Sample Preparation List Page 1 of 3

Session number : 139

Animal Name: Handler:
Lab Ass't: Documenter:
Start Time: End Time:
Temp.(ºC): Humidity:

Targets	W	MWpmr	MWC	MWSC	KcMW	Kc4MW	MWC-SKF	SCF-MWC	FP

Session Execution plan

A1	B1	C1	D1	E1	F1	G1	H1
A2	B2	C2	D2	E2	F2	G2	H2
A3	B3	C3	D3	E3	F3	G3	H3
A4	B4	C4	D4	E4	F4	G4	H4
A5	B5	C5	D5	E5	F5	G5	H5
A6	B6	C6	D6	E6	F6	G6	H6
A7	B7	C7	D7	E7	F7	G7	H7
A8	B8	C8	D8	E8	F8	G8	H8
A9	B9	C9	D9	E9	F9	G9	H9
A10	B10	C10	D10	E10	F10	G10	H10
A11	B11	C11	D11	E11	F11	G11	H11
A12	B12	C12	D12	E12	F12	G12	H12

CHAPTER 7

THE MOROGORO PROJECT | 2009-2010

by Adee Schoon and Negussie Beyene

CHAPTER 7

THE MOROGORO PROJECT | 2009-2010

INTRODUCTION

In any remote scent tracing application, the major challenge in training the animals is in devising a methodology to enable them to detect new odour samples directly. Real-life samples to be investigated come in endless variations. Training the animals should be geared towards them responding only to samples containing the relevant odour, but not only to the exact composition that the animal encountered in the training samples. In other words, the animal needs to have formed a “concept” of the relevant odour.

This is difficult in a controlled laboratory environment as animals are much more sensitive to odours than our instruments are. Even if all the instruments are in perfect order and there are no mechanical issues, temperature, moisture, or concentration differences, and no contamination problems, there may still be something that causes the training odour samples to differ systematically from the ones that have been used in tests. Small differences in base materials, production procedures or storage cannot be detected with the best technology, but can by animals trained long enough.

Using remote scent tracing applications in the field creates even more difficulties, and some of these are discussed elsewhere in this publication. However, there are still advantages to using such extremely sensitive detectors: for example, at the right sensitivity and specificity, it is not necessary to know what component they are using for detection. Also, properly-trained animals are easier, versatile, and much cheaper than the best headspace technology.

This is why remote scent tracing for landmines seemed a perfect solution for a major humanitarian problem. Dogs have long had a proven track record as direct detectors of mines. The rat was subsequently also considered, since they are also capable of direct landmine detection. However the training of both rats and dogs is not easy.

The purpose of this paper is to describe the approach and results obtained from 2009 to 2010. Goldblatt gives an overview of scent perception in general, and all of the difficulties that emerge from this for the training of animals in a remote scent tracing setup are apparent. Fjellanger and Jones give overviews of the training of dogs up to 2009.

2. APPROACH

2.1. Starting point 2009

In the course of 2008, in the REST programme at Morogoro, Tanzania, rats and dogs were trained on TNT spiked soil. Although the results were variable, it was clear that both species could detect TNT. However, it also faced the following problems:

- not knowing which odour components dogs or rats use when directly detecting landmines, except that it is probably not only TNT, since animals trained on TNT landmines also readily detect RDX-landmines
- not knowing if these components could be collected in soil or air. In the end, based on what was known about the TNT components leaking from landmines the decision was to collect soil
- no idea of the thresholds at which rats or dogs can detect these components

Dogs and rats readily detect buried mines in the field, but the limited data available at the time suggested that training them on a TNT solution would not suffice for them to detect soil collected above a mine in a REST setup. In the field, rats and dogs are free to "choose" any part of the odour signature a mine produces to indicate on. In controlled studies it had been shown that dogs often do not use the full odour signature of a complex odour but that they focus on a number of components. They need not choose the parent explosive when being trained on explosives but instead may use another component of the explosive. To further complicate matters, individual dogs can differ in their choice of components to indicate on, even if they have been trained in the same manner.

Since the chemistry instrumentation available at the time was insufficient to detect more than a limited set of explosives in the soil (either spiked in the laboratory or leaked from landmines in samples from the field), the choices that were made on how to create target scents for the animals were based on the available knowledge of how mines weather and age in soil. This is described in more detail below (3.2). The main goal of the training was to train animals on laboratory prepared samples that would lead them to develop a "target concept", which would include soil samples collected in the field so they would indicate without further training.

2.2. Broad lines of project plan 2009-2010

The team working on the REST programme from 2009 described their plans in a project plan, according to which there were two main lines:

- field tests
- laboratory tests

In the field tests, the plan was to use accredited field animals (both mine detection rats (MDR) and mine detection dogs (MDD) that had already formed a search image of mines in the field in a REST setting. This would provide a "proof of concept", even though it would not be precisely clear which odours the animals were focusing on. If they could transfer search images formed outside in the field into indicating on field samples in a laboratory setting, it would indicate that REST could be done.

In the laboratory tests, each training step was to be terminated by a "transfer of training" test to see if the search image the animals had developed in the training up to that point led directly to the detection of samples taken from the earth above a mine. The first step of the training was TNT solution for the rats, since this is what they had been trained on up to that point, and pieces of Kong for the dogs. This followed the training strategy set out by the Global Training Centre (GTC) of the Norwegian People's Aid, where dogs are trained to detect gradually decreasing pieces of Kong until their search pattern and indication is up to standard, and are then trained on the relevant mine-odours, so they can detect the mines they are likely to encounter in a particular area.

The second step of the training was to train on a target that we hoped mimicked what happens to mines in the field: the mines were soaked in water in a "hot pot", and this "mine-water" was then used to spike soil samples. In the field, water is the main transport mechanism of components that leak out of mines. The third step was to let the water evaporate, before the fourth step - to train animals on soil collected from directly around a mine.

The laboratory tests were stopped on the second step due to unforeseen interaction between soil types and mine-water spiking solutions. An intermediate step was designed to train the animals on the odour of the mine-water and the mine itself, by allowing different filter materials to soak up the mine-water or mine-odour in a dry "hot pot". However, time did not allow the transfer of training tests to field samples.

3. SAMPLE PREPARATION

3.1. Field samples

Field samples were prepared by the Apopo chemistry laboratory on the Morogoro mine field. The soil above the mines chosen for this purpose had been cleared of vegetation using a weed killer some months prior to the sampling and kept clear of plants by hand. The soil was brushed up in a circle with 50 cm diametre from the centre of the mine. Three mines of each mine type were selected and the total soil was pooled, and from this composite 2 g samples were taken for analysis by the animals in both the field tests and in the laboratory "transfer of training" tests. Control field samples were taken from empty boxes in the vicinity of the boxes with mines: the nearest mine was at least 10 m away from the spot where the control field soil sample was taken. All field samples were stored in the deep freezer when not used.

3.2. Training samples

Training samples were prepared by Apopo and NPA laboratory assistants for training sessions generated by a computer programme written for this purpose. In general, the variables entered into the programme were the number and type of positive training targets, and the number of different soil type additives that were to be used. Soils and additives to be used were selected from databases, generating a sample preparation list for the laboratory assistants, and data entry sheets for the experiments.

All the containers were labelled, then soil was added to the containers, then the additives, and finally all samples were spiked. First half the controls, then the training targets, and then the other half of the controls. The standard operating procedures (SOPs) were adjusted when necessary, but mainly, to prevent contamination they were:

- that all samples (positives and negatives) were always handled equally often
- that the positive samples could not differ in any systematic way from the negatives

Although every effort was taken to ensure that the laboratory assistants understood the steps, without supervision they cut corners to make the sample preparation quicker or easier. This had the effect of creating a systematic difference between positive and negative samples.

As described in 2.2 above, spiking the positive training targets was first done with a TNT solution, and then later with mine-water (MW) where we tried to mimic the full bouquet of the odour of a mine. To make mine-water, we tried to simulate the outside process of where mine-components first dissolve in rainwater, and then come to the surface with the evaporation of the water, by soaking a PMR-2 mine in a stainless steel bucket for a number of weeks until the water is saturated with TNT, the only measurable component at that time. This we called mine-water. Spiking of the controls was done with water that had undergone the same procedures as the target solutions, except for the TNT or mine component.

However, we found systematic differences in spiking between the samples prepared for the rats and for the dogs - the drop size for the rats was bigger because of the way the pipette was held, and the accuracy of the number of drops being spiked was more variable in the rat samples than in the dog samples. This made a direct comparison of the performance between rats and dogs complicated.

4. ANIMAL TRAINING

4.1. Rats

4.1.1. Pre-training

Rats were trained to detect TNT following a training protocol developed by Apopo. Training starts when the rats are very young. An overview of this training procedure has been described by Poling and others:

They learn to stick their nose in a hole for a period up to five seconds, and are rewarded with a click and some banana mash. Below the hole is a soil sample spiked with TNT. When they were performing well in a one-hole cage, they were moved to a three-hole cage with one TNT positive and two negative soil samples which are wet with the same number of drops as the positive. Their positions are then changed, and if they keep their noses in the holes containing the positive sample, they are rewarded. Once the animals are performing well here, they are shifted either to field or laboratory training.

4.1.2. Field training

The rats are shifted to a sandbox, trained to wear a harness, search in lanes, and detect buried tea-eggs (stainless steel perforated container) containing TNT (see Fig. 1). Later they are moved to the field to a specially prepared regularly dug-up sandy area, where the same search methodology was used and the rats are still learning to detect tea-eggs. Gradually they are moved to areas containing real mines and the search lanes became longer (up to 10 m) (see Fig. 2).

FIGURES 1 & 2 | **Left:** Rat trained to detect TNT in buried tea eggs **Right:** Rat trained on a mine field

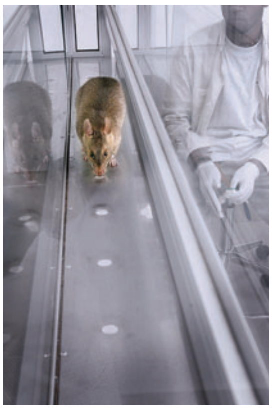
4.1.3. Laboratory cage training

For the laboratory training, the rats were moved to cages that were configured differently: in lines, rectangular, square, or semi-automated. In this project we predominantly worked with rats in line, square and rectangular cages.

Rats in the line cage were confronted with ten sets of ten samples in a row, where they smelled all holes once, and moved back to the beginning of the line in a corridor parallel to the corridor with the holes (Fig 3). Each sample was smelled once, and if a rat made a correct hit, a click was sounded and they ran to the end of the line for their banana mash reward in a syringe. The remainder of the samples were smelled in a second passage over the same set of samples, but during this second run the samples already smelled by the rats were covered up which maintained the single smelling rule. Rats in the rectangular and square cage did not run up and down, but continued on in their rectangular or square "circle". Samples were removed after they had been smelled, then replaced with new ones.

The rectangular cage had 22 holes, and rats were given four sets of 22 samples. The square cage had 25 holes, and rats were given four sets of 25 samples. When the rats made a correct hit in these two cages, the click led to a reward given through the wire mesh of the cage in proximity of the hole where the rat indicated.

FIGURE 3 | Rat working in a line cage



4.1.4. Specific training problems

In all the setups used, the trainer observed the rats' behaviour and stated when he thought the rat was indicating. The documenter confirmed or denied, and subsequently the trainer rewarded a correct hit or ignored a false alarm.

Most importantly, the trainer should be completely unaware of the position of the positives in the array. The behaviour of the rats changed over time, first pausing at the hole for five seconds, then biting the rim or scratching. In the square and rectangular cages they reared up to the place where they expected their reward and moved back down to the hole again to wait a little longer. Each rat developed its own characteristic behaviour pattern, that was recognised by the trainer as an indication. As the trainer's reaction could clinch an indication, it was imperative the trainer did not know where the positive samples were.

The documenter was in the same room as the handler, and often had the notebook containing the clearly marked positions of the positives in full view. The trainers were not always working blind - an important influence on performance. We tried to counter this by increasing the awareness of the importance of this point and supervision.

Using the same set several times for different rats influenced the results too. While only two line cage rats worked with the same set of samples, initially all six rectangular cage rats worked with the same set. With ten positives in a series of 100 samples, in the line cage almost all positions would be "positive" at some time. This was not the case in the rectangular cage: eight positives were distributed over 22 positions.

Analysis of the mistakes showed that in contrast to the line cage, the rectangular cage rats were making significantly more mistakes on positions that had been rewarded previously that day. This could have been a result of either the rat marking such a position, or that traces of the reward (soft banana mash in the syringe) were noticeable at such a position. By changing the reward to dry banana pellets that did not spill and leave tell-tale traces, using only using three rats per sample set, and cleaning the cage in between training, these problems were overcome.

4.2. Dogs

4.2.1 Background

The dogs used for the experiments described here were initially brought in from GTC, however they were not good enough to become MDD. They had not been given adequate training for a long time, since the local handlers were not acquainted with working with highly strung Malinois. A special trainer was then brought in and the dogs were trained extensively on Kong® detection in a carousel setup.

4.2.2 Carousel procedure

A 12-arm carousel was used in a room with two doors and a one-way window (Fig. 4). The laboratory assistant would enter through one door with the samples, prepare the carousel, and leave. The handler and the dog would enter through the other door, move to the starting position, the dog would be unleashed and it would search the carousel. The handler would follow slowly, at some distance.

FIGURE 4 | Carousel being loaded with samples

The dog was trained to sit to indicate. Once he sat, the laboratory assistant observing the dog through the one way window would utter a Kiswahili phrase to allow a two second delay, and then click to signal a correct hit. Following SOPs, lights were used to communicate with the handler re correct and incorrect indications. Normally a Kong was thrown as a reward, but at one point we introduced an incidental verbal reward instead, known as the "praise off". This was done to prepare introduction of operational samples: a call off was used as a "punishment", the Kong as a reward, and the "praise off" to indicate a neutral state.

The documenter would note all the indications of the dog. Although he knew the position of the positives, he was never in contact with the dog nor the handler and could not communicate this knowledge. The "two second sit" indication of the dogs was clear, allowing no misinterpretations.

4.2.3 Training

Each dog was initially confronted with eight sets of 12 samples daily, later this was split into two times four sets of 12 samples daily, to allow for quicker adaptation, to adjust training problems and to prevent attention sagging during long sessions.

Initially pieces of Kong were used as a target odour. These gradually decreased in size, until a piece of Kong that had been in the positive sample for hours was removed and the sample was presented to the dog; known as Kong-contamination. When mine-water was introduced as new target odour, it was first offered together with the Kong contamination, and the Kong contamination was subsequently gradually faded out.

4.2.4 Specific training problems

All the samples smelled before a hit (correct or false) were initially removed from the carousel. The dogs were then brought back in to analyse the remainder of the samples. The result of this was that the dogs would speed up past the empty holders, smell the last ones and tend to make more false alarms on these last samples.

Starting in the same position every time led to them favouring a certain place in the room. When the starting position was rotated, the dogs tended to favour the last positions in the carousel before they came upon the arm that they had started from. It proved to be extremely difficult to combine a random placing of the positives in the carousel and in the room with trying to keep the pace of the dog slow enough so it would smell all the samples intensely, so to prevent the dog from building up any expectation about where positive samples were.

5. BRIEF OVERVIEW OF EXPERIMENTS AND RESULTS

5.1. Field experiments (Appendix A)

In an effort to establish a "proof of concept" for REST, trained field rats were tested on their ability to recognise samples taken from the field. For the first test, five rats were re-trained in a line cage and then tested on their ability to recognise samples taken from the field. These rats did not detect the field samples, although they performed well enough on the training samples. However, later chemical analysis of field samples revealed that the training samples contained approximately 1000 times more TNT than the field, explaining this result.

In a second test, we tried to use a more natural habituation paradigm, where the assumption was that if the trained field rats recognised the field odour sample, they would spend more time in its vicinity, expecting to be rewarded there as they were in the field. The rats did not respond well to the experimental setup we devised for this: a box of 2 m long and 1 m wide placed in an "empty box" without mines in their normal training area containing two samples (field sample and a control) at opposite ends. Instead of examining the samples, they just moved around the sides of the box, hesitating to go inwards, and no differences in time were found between the half-box containing the field sample and the half-box containing the control.

Rats are probably too context-sensitive to use to prove a concept in this way. This is not to say that field rats cannot be used for REST, but that it would require a carefully balanced training regime to transfer the field-developed stimulus control to a REST setup. It was expected that dogs would transfer this knowledge more easily, but we did not have field dogs available for this study.

5.2. Laboratory tests with rats

5.2.1 Stage 1: training on TNT (Appendix B)

Training the rats on TNT solution was the strategy chosen to get the animals to detect field samples. This approach is called 'blocking'. The TNT is added to a variety of backgrounds in order to gain stimulus control. In this method, the critical step is the generalisation from the spiked or 'artificial' training sample to the real environmental samples. This was done three times in different cages in different situations.

The rats trained in the line cage were tested twice. The first time their training was limited in terms of background material: a limited number of soil types and no additives. In the transfer of training test the rats only indicated their TNT training samples, showing that they were under TNT stimulus control, but did not "generalise" this automatically to the detection of mines.

The second time the line cage rats were tested, the training was expanded to include more background odours, by using more soils and introducing additives. In the transfer of training test, the results obtained with the training samples had dropped (less detection, more false alerts) and the rats still did not respond to the field samples.

The third transfer of the training test was conducted with rats trained in the rectangular cage. The training of these rats included different soil types and additives, so these rats were comparable to the line cage rats in the second test. These rats seemed to respond to the field samples, but subsequent analysis of the results revealed a number of procedural effects that influenced these results.

The general conclusion of these experiments was that training on only TNT (at 12000-17000 ng per 2 g sample, the result of four drops of 100 ppm concentration), even against varying background odours, does not lead to the detection of field samples (that have only 15-40 ng per sample). Lowering the amount of TNT in combination with the varying backgrounds to the level expected in field samples was not attempted since the detection level at 100 ppm was too low for this to be realistic.

Based on these experiments, the conclusion is that "blocking" with TNT as a strategy for landmine detection does not work.

5.2.2 Stage 2: training on "mine-water" bouquet (Appendix C)

Rats trained in the rectangular cage on a combination of TNT solution and MW solution participated in a transfer of training tests where field samples as described in 3.2 were used. We had doubts about the amount of TNT available in those samples, so we did another transfer of training test with both line cage and rectangular cage rats on soil that was collected directly around a PMR2 mine that had been dug up. Lastly, a number of line cage rats were trained extensively on MW alone to see if their results stabilised. The rats in the rectangular cage used in stage 1 were trained on a mix of TNT and MW using an improved procedure. During the transfer of training test, it appeared that the change in procedures had not affected their detection level of the training samples, but it had increased their false alarm rate (FAR). These rats did not detect the field samples.

In the transfer of training test to soil from around a mine, neither the line cage rats nor the rectangular cage rats responded reliably to the soil collected around the mine. This soil was found to contain between 30 and 300 ng TNT, which was more than what was found in the dust field samples used so far, but still less than the amount found in training samples.

Extended training on the MW solution in the line cage led to an average FAR below five per cent, but the hit rate (HR) for the training samples did not stabilise: weekly averages varied from below 30 per cent to occasionally over 90 per cent. This was subject for further analysis described in 5.4 below.

At the end of the project, rats that were trained in the square cage were also added to the project since they were working reliably on low levels of TNT against various backgrounds. A slightly different approach was chosen here: continuing to train on TNT, and then adding in mine-water from first a PMR-2 mine, and then a PMN mine. Although the HR seemed good, there were major problems with the rats hitting on the control mine-water, and review of the spiking procedures revealed systematic differences in treatment of the positives leading to the positive samples being touched more frequently. The project ended before this could be remedied and the animals tested.

5.3. Laboratory tests with dogs (Appendix D)

5.3.1 Stage 1: training on the odour of Kong

As described in 4.2, the dogs used for this test were first extensively trained on progressively smaller pieces of Kong against a variety of soils and background odours (see Schoon this volume for more information on training procedures). A "transfer of training" test was conducted as a control: we did not expect the dogs to be able to detect field samples based on this training and the results justified this.

5.3.2 Stage 2: training on the odour of Kong and "mine-water" (MW)

In the next stage of the training, the Kong was gradually faded out and replaced with MW, as described in 4.2. During this training when the dogs were already responding to MW, a second "transfer of training" test was conducted. Once again, the dogs did not indicate the field samples from the three different mine types.

5.3.3 Stage 3: training on "mine-water"

The dogs were trained for a longer period of time on only mine-water in a more operationally realistic scenario: one soil type per session and no additional additives mixed in. These dogs were tested twice in a transfer of training test to soil collected immediately around a PMR2 mine that had been dug up. The first test results were very odd since the dogs responded strongly to the control field sample soil, even overriding their usual response to their usual training samples. This soil sample was analysed for the presence of explosives but none was found. In a second test conducted a week later, the dogs performed normally but did not respond to the field sample of the soil collected around the mine.

Prolonged training on mine-water and lowering the concentration was conducted for a period of a few weeks to prepare the dogs more realistically for a transfer of training test. Up to the point where the concentration was dropped, the dogs were performing well. However, when concentration dropped, so did the performance.

Two dogs seemed to be coping, so the training with a lower concentration was continued. For the other four dogs, the concentration was increased to the former level. However, the level of detection never recovered and the FA rate gradually increased. We could not find an explanation for this, other than perhaps the interaction between the soil and the spiking solution led to such a variation in the target odour that it became an unclear stimulus for the animals. An analysis of the results of the interaction between soil and "mine-water" is given in chapter 5.4 below.

5.3.4 Stage 4: training on "mine-water" and "mine-odour" without soil interaction

In an effort to eliminate the interaction between soil and spiking solution, a drastically different approach was used a short period before the project term expired. Instead of directly spiking soil, the odour of mine-water and of mines themselves was "soaked" onto different (neutral) backgrounds such as cotton wool and filter papers. This was done by allowing this material to sit in a closed container together with either a few drops of mine-water, or with a whole mine. The time of this "soaking" was gradually reduced. In the beginning, the material was presented without soil, and later, it was presented on top of soil. Controls were always also prepared and used.

The training progressed steadily but was impeded by lack of staff for necessary continuous supervision and leadership, and it was not continued long enough to conduct a transfer of training test.

5.4. Soil/Mine-water (MW) interaction analysis (Appendix E)

In an attempt to understand the variability of the training results obtained with both the rats and the dogs, a number of factors were looked at critically. Besides the training issues described above, we also reviewed the data we had collected over the year. During the year, different soils were collected on different dates, then given a number and a short description. These soils were subsequently used in training for both the dogs and the rats. The amount of soil gathered varied from a lot to only a small amount. This resulted in some soils being used more often than others. For all analyses, only training sessions where MW was used as a target odour were selected. The data was analysed for differences between soils with respect to detection and false alarm rates.

5.4.1 Analysis of results obtained with rats

The variation of the detection and false alarm rates fluctuated throughout the period and differed significantly depending on soil type. The HR was not correlated with the number of times the soil was used, indicating that experience did not lead to improvement. The HR and the FAR were not correlated, indicating that rats did not respond more readily to certain soil types than to others.

5.4.2 Analysis of results obtained with dogs

For the dogs, the variation of the detection and false alarm rates fluctuated throughout the period and differed significantly per soil type. The HR was not correlated to the number of times a soil was used in training and the HR and FAR were not correlated. The dogs did not respond more to particular soils than others.

5.4.3 Comparison of rats and dogs

Since both the detection and false alarm rates fluctuated significantly between soils for both the dogs and the rats, the question arose whether the results of the animals were similar across soils. The data collected for the dogs and rats above, was compared with each other for the 34 soils that both groups of animals had worked on. The HR and FAR were compared. The correlation coefficient for the HRs was not significant; the correlation coefficient for the FARs however was.

With respect to the HRs, the groups cannot be directly compared since pre-training differed; as did the MW concentrations they were trained on and the amount of spiking solution used, which could have led to a different “odour signature” for each group. Regarding the FARs, it is impossible to find any plausible reason for this without a full headspace analysis of the spiked and unspiked soil, other than that there may have been a more interesting odour in the soil for each species.

5.5 Chemistry research at APOPO

5.5.1 Comparison of soils

As discussed in Chapter 3, knowing the characteristics of the soil around the suspected area from which REST sample is to be collected, helps to predict the potentially available odour molecules in those samples.

Soil samples from the eastern, western and central part of APOPO's test minefield were collected at different depths. Different soil textures, organic content, cation-exchange capacity and other properties were analysed. These analyses were conducted at the Soil Science Department of Sokoine University of Agriculture, and they indicated that the proportion of clay particles increases as depth increases, reaching more than 70 per cent at a depth of 30 cm. In contrast, the organic matter content decreases as the depth increases (Table 1, Appendix A). Similarly, the dryness of the soils collected at different depth from APOPO's test field was evaluated and the dryness decreases as the depth increases (Table 2, Appendix F).Therefore, one can safely assume that the soil at APOPO's test field is mostly clay.

5.5.2 Comparison of extraction techniques

The microwave assisted extraction of nitro-aromatic explosive compounds from soil (developed by the Swedish Defence Research Agency, FOI) has been in use at APOPO since 2006. However, its efficiency, especially for clayey and dry soil like that of Morogoro, has been a point of discussion for some time.

Theory dictates that microwave activity of aqueous solutions is much less than that of organic solvents such as methanol and ethanol [2, 3 and references therein]. Comparison of efficiency of 25 solvent systems for the extraction of nitro-aromatic explosive compounds from soil (5 g soil in 10 mL solvent with a platform shaker at 150 rpm for one hour) revealed that methanol:water mixture (1:1) was the best followed by ethanol:water (1:1) and water:acetone (3:1). It was also observed that there was no difference in the result obtained by using phosphate buffer or deionised water (Table 3, Appendix F). A pilot experiment was done to compare the performance of micro-wave assisted extraction with platform shaker (for one hour) using phosphate buffer and methanol: water (1:1) mixture. The result indicated that microwave-assisted extraction leads to a larger amount of analyte concentration (Table 4, Appendix F). However, the recommended extraction time with the platform shaker is 18 hours (4). This pilot experiment used it for one hour.

A recent study at Masaryk University of the Czech Republic showed that the efficiency of microwave assisted extraction of nitro-aromatic explosive compounds ranges between 28 - 65 per cent using methanol, a solvent with better microwave activity than aqueous solution (5). However, this study is far from complete, and a comprehensive study of all extraction method is highly recommended.

5.5.3 Comparison of procedures for producing training samples

One of the problems in REST animal training is obtaining a training material which closely mimics the material that constitutes the operational target. Initially, REST filters were used to sample the vapour above landmines, and training was aided by filters contaminated from a dynamic vapour generator that pumps air over TNT crystals, trapping the resulting vapour in the filters.

As well as having the disadvantages of sampling air discussed in Chapter 3, this training sample preparation resulted in contaminating the whole training area. As the sampling strategy shifted to soil sampling, the training sample preparation was also shifted to using soils spiked with aqueous TNT solution. However, analysis of soil samples collected above buried landmines indicated that 2,4-DNT, TNT, 2-A-4,6-DNT, and 4-A-2,6-DNT are the most common compounds identified (6). Depending on the type of landmine, soil properties and other factors discussed in Chapter 5, several other impurities and degradation products may be detected. Therefore, spiking with aqueous TNT solution in no way produces a sample that best represents the field sample.

To circumvent this problem, another approach was sought. Different landmines were dug up from APOPO's test field; the soil was removed with running water and then the landmine was completely immersed in water in separate hotpots. As a control, a number of hotpots were filled with water only and all hotpots were kept in shade at APOPO's compound. After four months the leachates (mine-water) and the corres-ponding controls (mine-water control) were used to spike soils as training targets and neutrals respectively.

For a laboratory analysis, sample fractions were taken, explosive compounds were concentrated on Solid Phase Extraction (SPE) cartridge as per the FOI procedure, and the extracts were analysed with GC-NPD (Table 5, Appendix F). The results showed that landmines with tight cases and hard cases (Table 6, Appendix F) do not leach detectable amounts of explosive compounds.

However, other landmines leached 2,4-DNT, TNT, TNB, and amino DNTs, suggesting that this approach better represents field conditions than simply spiking with aqueous TNT solutions does. However, significant variation in TNT concentrations in mine-water from three different No. 4 landmines and PMR2 landmines also suggests that the degree and intensity of the transport of explosive compounds emanating from the same type of mine may differ significantly.

In another approach, sand, black and clayey soils were soaked with mine-water and mine-water control to produce target and neutral training soils. The soaking experiment was done in four duplicates by taking 500 g of soil and adding 300 ml of PMR2 leachate for the targets and 300 ml of mine-water control for the neutrals. Then two of the duplicates from each soil type were allowed to dry in the sun and the other two were dried in the dark. When the soil looked dry to the naked eye, 2 g was taken from each duplicate and extracted with the microwave assisted extraction procedure using methanol: water (1:1) instead of the phosphate buffer.

The GC-NPD analysis showed that 2,4-DNT was not detected in all of the soils that had been kept in the dark, whereas TNB was, but not in most of the soils that had been dried in the sun. Furthermore, TNT was the major component in all soils followed by the amino DNTs (Table 7, Appendix F). In both the sun-dried and room-dried cases, the controls were negative with respect to all explosive compounds. This mode of prep-aration apparently results in high concentrations of explosive compounds, and further study of the preparation, stability and storage condition of soils with low concentration is highly recommended.

In a slightly different approach, pieces of cotton pad and/or filter papers were put in the hotpot (containing a landmine) instead of water, so that the vapour emanating from the landmine was trapped in the cotton/filter papers. Both rats and dogs performed well with these materials, suggesting that further chemical analysis should be done and the profile of trapped explosive compounds should be mapped.

When the mine-water and the corresponding mine-water controls were used to spike REST training samples for the dogs and rats, there was a significant difference in the performance of the dogs and rats, despite an attempt to use the same training protocol. To answer why this happened, the training samples were analysed (after training) and significant differences were found in the amount of explosive compounds extracted from samples used for the dogs and the rats (Table 8, Appendix F).

Further investigation of the sample preparation procedure revealed that the training samples for the rats were prepared the morning of a training day, and the day before a training day for the dogs. We then analysed the training samples, first after preparation and then after they were presented to the animals. The lengthy extraction procedure did not allow immediate extraction, so the samples were stored at freezing temperature until the next morning, when microwave assisted extraction with methanol: water (1:1) was made according to the FOI procedure, followed by GC-NPD analysis.

There was no significant difference between the explosive compounds extracted from training samples immediately after preparation and those after presentation to the animals. However, there was a significant difference between explosives compounds in the samples in those prepared for the dogs to those prepared for the rats (Table 9, Appendix F). Further analysis of sample preparation led to the hypothesis that drop-size could be one of the reasons for the observed difference. To check if that was the case, four sample preparing personnel from APOPO and four others from NPA were selected to participate in this side experiment that involved weighing drops made by each of them.

First the personnel were allowed to get used to putting drops in a plastic pot placed on an analytical balance without affecting the stability of the balance. Once they are comfortable with this exercise, an empty plastic pot was placed on a balance that was adjusted to zero, and the personnel were allowed to make a drop in the pot while the laboratory assistant registered the weight reading. Then, the balance was re-adjusted to zero and the personnel put another drop in the pot. This cycle continued until a total of ten drops had been deposited and weighed. This experiment allowed differences in the weights of drops deposited by different personnel to be quantified.

In the second experiment, a plastic pot was placed on the balance which was adjusted to zero, and the personnel were allowed to apply the same number of drops as they were applying to spike their training samples (four drops for APOPO personnel and three drops for NPA personnel) while the laboratory assistant registered the weight after the number of drops were finished. This exercise was repeated for ten different pots. For the combined group the drop size varied between 20.5 to 44.5 μl (water was used in this experiment and a density of 1 mg/mL was assumed). For APOPO personnel the volume of four drops varied between 121.8 and 173.5 μl, whereas for NPA personnel it varied between 68.5 and 101.0 μL (Tables 10 and 11, Appendix F). Assuming concentration 100 (100 ng/μl) is used for spiking the 2 g of soil, the variation at APOPO was between 12,180 and 17,350 ng per 2 g soil while it was between 6,850 and 10,100 ng per 2 g soil at NPA.

An APOPO staff member with more than six years experience at the chemistry lab was asked to participate in this experiment and his drops varied between 21.5 and 47.3 µl and the four drops varied between 122.4 and 169.6 µl., - ie, in terms of concentration between 12,240 and 16,960 ng. This suggests that the variation is due to the inherent problem associated with the pipette.

During the 2007 REST workshop held in Morogoro, it was suggested to use an automatic eppendorf multi-pipette for sample preparation so that the amount of solution could be uniform throughout. This procedure may also minimise the time required to spike the soil samples. However the suggestion was not followed.

6. SUMMARY AND CONCLUSIONS

The project plan was ambitious, and in spite of very hard work, we did not complete all we set out to do. We did achieve a number of goals and a few conclusions are apparent.

Training animals solely on TNT does not prepare them well for mine-detection in the field. Although it is useful for pre-training, it cannot be used as a single guiding training odour in a REST setup where the goal is to find TNT-based "bombs" with more complex odour signatures. When possible, laboratory-prepared training odours should be augmented with training samples containing "field odours", in order to provide detector animals with the most appropriate odour signature.

Laboratory analysis is necessary every step of the way. For any future remote scent tracing project, a fully-equipped laboratory that can routinely perform headspace analysis is a pre-requisite. Not being able to fully understand the field samples we were training the animals to detect, nor being able to adjust training samples in a measured way impeded progress. The switch from soil analysis to headspace analysis, and from a limited explosive detection to a more broad analysis was too cumbersome and was realized too late into the project.

Supervision of both the sample preparation and the training by a qualified behaviour scientist was needed more frequently than it was possible to have in this project. Therefore, during every visit a number of errors that needed to be fixed were discovered. This hindered consistency while training of the animals, limiting progress.

With clear odour signatures, the HR and FAR set by GICHD for individual animals (>70% HR, <5% FAR) seem feasible for both rats and dogs. However, in this study, the concentrations necessary for the "clear signature" seemed to be higher for the rats than for the dogs. The 100 per cent detection level at "group level" seemed more difficult to achieve as a result of the clustering of detections and misses observed. The <20% FAR at group level is feasible since false alarms were not clustered in a correct test setup.

The unsuspected interaction between the soil type and the mine-water spiking solution impeded a fluent gradual training on decreasing concentrations. Within the time period of the project, we were unable to find a transfer of training to field samples based on the "mine-water bouquet" strategy. A second strategy was devised to exclude this interaction effect but due to time constraints this was not tested. This left the research team slightly frustrated.

When the Morogoro REST project in its entirety is examined, some more general conclusions are warranted. Among them are the following:

- An operational REST system for landmine detection is possible in principle, but not easy to produce in reality, and such a system did not result from the Morogoro research and development activities
- Any proposed REST system for landmine detection should be adequately evaluated by sceptical and expert scent-detection scientists
- Adequate sampling is extremely challenging. Large-scale filter sampling of air does not appear to produce detectable levels of explosive-related chemicals. Sampling dust may be better but this strategy poses vexing challenges with respect to the homogeneity of samples and the concentration of detectable chemicals
- Ensuring that positive training samples closely match positive operational samples is critical but very difficult
- Frequent changes in management and project orientation, pressure to produce an operational system rapidly, and frequent confounding of experiments compromised the project's success
- Remote Scent Tracing (RST) has many current and conceivable applications, including the detection of drugs, diseases, environmental contaminants, allergens, cargo-screening, and forensics. Perhaps other RST applications will pose fewer and more easily-solved problems that REST for landmine detection. Nonetheless, a carefully conducted, adequately supervised, and comprehensive long-term management plan is needed to ensure that research and development of any RST application is successful
- The environmental variables that affect scent detection are complex and interactive and have not been adequately evaluated. They merit attention in the context of both RST and direct scent detection. The Odour Signature Project, which is related in many ways to the REST for landmine detection project, should continue to a reasonable terminus and be promulgated in a detailed and comprehensive report readily available to the public

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Appendices

Appendix A: Field tests

Appendix B: Does training rats on TNT lead to the detection of field samples?

Appendix C: Does training rats on "mine-water" (water in which a mine has soaked) spiked on soil lead to the detection of field samples?

Appendix D: Does training dogs on "mine-water" (water in which a mine has soaked) spiked on soil lead to the detection of field samples?

Appendix E: Does the kind of soil that is used influence the performance of the animals?

Appendix F: Summary of REST Chemistry Results

Appendix A: Field tests

Introduction
In an effort to establish a "proof of concept" for REST, trained field rats were tested on their ability to recognise samples taken from the field. For the first test, five rats were re-trained in a line cage and then tested on their ability to recognise samples taken from the field. In a second test, we tried to use a more natural habituation paradigm, where the assumption was that if the trained field rats recognised the field odour sample, they would spend more time in its vicinity expecting to be rewarded there as they were in the field.

Experiment 1: using field rats in a line cage

Method: Field samples were collected on the 26th May, 2009 at the Apopo minefield following a procedure previously developed by Apopo. Samples were collected both above mines and in "empty" boxes, at least ten meters away from any other mine. The PMR2 and the nr 4 mines contain TNT as main explosive charge, the M14 is a RDX-based mine.
five internally accredited field-rats were trained to work in the line cage. They were trained using a relatively high concentration of TNT (100 ppm) solution. This was spiked on different types of soil. Four rats performed well enough in the cage to conduct the test (last week detection on average 93.3 per cent, FA rate 1.8 per cent).

Results: Chemical analysis of the field samples used for this test showed 15 ng TNT and 80 ng TNB per 2 g soil for the PMR2 mine, which was thought to leak the most TNT into the surrounding soil. No TNT was found in the field samples collected over the other mines.
In the table below, the results of the test held in the last week of May 2009 are given.

	Field samples				Training samples	
	PMR2	nr 4	M14	controls	TNT	controls
Field rats	**1**	**1**	**1**	**9**	**8**	**80**
Yasin	0	0	0	0	7	6
Karume	0	1	0	0	3	0
Ziko	0	1	0	1	7	1
Biaza	1	0	0	2	7	22
avg field	25.00%	50.00%	0.00%	8.33%	75.00%	9.06%

The rats do not respond differently to field samples than to training samples per se: the FAR's on the controls of the training samples and the field samples do not differ significantly (χ^2, NS at p <.05). However, they detect the field mine samples less well than the TNT training samples (χ^2, p <.05).

Discussion: The amount of TNT in the training samples of the rats was chosen to be quite high so as to facilitate their transition from the field back to the line cage setup. Four drops of the 100 ppm concentration that was used to train the rats on, would have led to 12,000 to 17,000 ng of TNT in these 2 g training samples. However, rats are very context sensitive. The discrepancy between the amount of TNT in the training samples and in the field sample, combined with this high concentration being consistent with the "line cage" setup, was probably the reason for the rats not detecting the field samples taken from the PMR2 and nr. 4 mines.

Experiment 2: using field rats in a "field" setup

Method: A movable arena of 1 x 2 meter was created using plywood. This was set down in an empty box with little vegetation in the Apopo minefield. In the centre of one half, a small aluminium tray containing a field sample collected above a PMR2 mine was placed. In the centre of other half, a similar dish containing a neutral field sample was placed.
Six rats were each tested on a new area (so there were no traces from the rat before on the ground) with new samples. They were put down in the middle of the arena, and filmed during ten minutes. The time they spent on each half was later calculated watching the video.

Results: The rats did not differ in the amount of time they spent on each side of the arena. They spent a lot of time trying to get out, or just moving along the side of the arena, scarcely venturing out into the middle.

Discussion: The test setup was not optimal for these rats. It is Apopo's experience that the rats usually take some days to weeks to adapt to new situations. To do this also allows for learning to occur, which was not intended for this experiment.
!
Conclusion
Rats are probably too context sensitive to use for a proof of concept in this way. This does not mean that field-rats cannot be used for REST, but it would require a carefully balanced training regime to transfer the field-developed stimulus control to a REST setup. It was expected that dogs would transfer this knowledge more easily, but we did not have field dogs available for this study.

Appendix B: Does training rats on TNT lead to detection of field samples?

Introduction
The training of the rats on TNT solution was the strategy chosen to get the animals to detect field samples. This approach is called 'blocking'. The TNT is added to a variety of backgrounds in order to gain stimulus control. In this method, the critical step is the generalisation from the spiked or 'artificial' training sample to the real environmental samples. This was done several times in the project period with different results.

Experiment 1: Line cage rats with limited stimulus control.

Methods. Four rats had been in training in a line cage where they are offered ten lines of ten samples daily. They were trained on TNT in a water solution (100 ppm), spiked on a limited number of soil types. Per training session they were given two different soil types sequentially.
Field samples were collected on May 26th, 2009. The PMR2 and nr. 4 mines are TNT based, the M14 is a RDX mine. The soil above three different mines and from nine empty boxes (nearest mine was at least ten meters away) was sampled following a protocol developed earlier by Apopo.
In the test, the field samples and the neutral samples were mixed with the usual TNT and water spiked training samples. Two rats were run on the same sample set. The test was given twice at the end of May 2009.

Results. The results of these rats are given in the table below.

	Field samples				Training samples	
	PMR2	nr 4	M14	controls	TNT	controls
	2	**2**	**2**	**18**	**16**	**160**
Aboe	1	1	0	0	12	1
Chantel	1	0	0	0	15	0
Lulu	0	0	0	0	14	4
Samira	1	1	1	0	16	3
Average	37.50%	25.00%	12.50%	0.00%	89.06%	1.25%

These results indicate that the rats are under clear control of the TNT solution against the limited backgrounds since they do not respond to the field mine samples in the same way (χ^2, $p < .05$). They do not react differently to the control samples from the field (χ^2, $p > .05$), which also demonstrates stimulus control on the TNT solution. There were no major procedural issues in this cage.

Experiment 2: Line cage rats with expanded stimulus control.

Methods. The four rats from experiment 1 were trained during two months to be more fully under stimulus control. To this end, the number of soils was more varied and offered randomised instead of grouped, up to five different soil types within a session. Different additives were added to the soil for even greater variation of the background in order for the TNT to become the controlling stimulus, up to eight different additives per training session, distributed over the different soil types. Two rats were run on the same sample set. The rats were then subjected to the same test again in July 2009.

Results. The result of the test are given in the table below.

	Field samples				Training samples	
	PMR2	nr 4	M14	controls	TNT	controls
	1	**1**	**1**	**9**	**10**	**78**
Aboe	1	1	1	0	5	2
Chantel	1	0	0	1	6	2
Lulu	0	0	0	1	6	1
Samira	0	0	0	0	3	4
Average	50.00%	25.00%	25.00%	5.56%	50.00%	2.88%

The HR on the training TNT samples had dropped as a result of the training, and the FAR had increased. Aboe seemed to respond to the field samples but the other rats did not.

Experiment 3: Rectangular cage rats with expanded stimulus control.
Methods: Six rats had been trained to detect TNT on a limited number of soil types in a rectangular tunnel-shaped cage. In this cage they walk four rounds per daily session, during each round they are confronted with 22 samples. These six rats were given further training on TNT (100 ppm), but now spiked on a more versatile background of soils and additives (different substances that were added in a random manner to the soils). All six rats were run on the same sample set. These rats were tested on detecting the field samples described in experiment 1 in May 2009.
Results. The results of this test are given in the table below.

	Field samples				Training samples	
	PMR2	nr 4	M14	controls	TNT	controls
	1	**1**	**1**	**9**	**12**	**64**
Chapakazi	0	1	1	0	6	2
Allan	1	1	1	1	7	5
Lewis	0	1	1	3	7	2
Ngwale	1	1	1	0	4	4
Levis	0	1	1	1	4	3
Jurasic	1	1	1	1	4	5
Average	50.00%	100.00%	100.00%	11.11%	44.44%	5.47%

The rats did not react differently to the controls from the field in comparison to the training control samples, indicating that they are not responding to field samples per se. However, they responded significantly more (χ^2, $p < .05$) to the field mine samples than to their training samples! Reviewing the sessions, it appeared that the rats were responding more often to a position in run if an indication had been rewarded in that position in the previous run. This could have been the result of marking that position (the surface is not cleaned in between runs), or the result of remaining odour cues from the banana reward. Since six rats were being run consecutively on the same set of samples, this effect was cumulative.

The procedures were changed in order to prevent this effect: no more than two rats were run consecutively on the same sample set, and the reward was changed from banana paste to banana pellets that do not leave a mess.

Appendix C: Does training rats on a "mine-water" (water in which a mine has soaked) spiked on soil lead to the detection of field samples?

Introduction
Rats (and dogs) readily detect buried mines in the field, but training them on a TNT solution did not suffice for them to detect soil collected above a mine in a REST setup. In the field, rats and dogs are free to "choose" any part of the odour signature a mine produces to indicate on. In controlled studies it has been shown that dogs often do not use the full odour signature but a number of components, they need not choose the parent explosive when being trained on explosives but they may use another component of the explosive, and individual dogs can differ in their choice of components to indicate on, even if they have been trained in the same manner. To better mimic the full bouquet of the odour of a mine, we tried to simulate the process outside where mine-components first dissolve in rainwater, and then come to the surface with the evaporation of the water. We soaked a PMR2 mine in a stainless steel bucket for a number of weeks until the water was saturated with TNT, which was the only component we could measure at that time. This we called "mine-water (MW)". At the same time other stainless steel buckets were filled with the same water and left to be used as controls level (MWC).

Experiment 1: Rectangular cage rats trained on mix of TNT and MW

Methods. The rats that had been trained in the rectangular cage on soil spiked with a TNT solution were used, and the target was shifted to MW. After they started to indicate on the MW, the controls were changed from simple water to MWC. Care was taken that all samples were spiked with an equal amount of drops so there was no systematic difference in humidity. In comparison to experiment 3 in the TNT training, only two rats used the same set of samples and the reward was changed from banana paste in a syringe to banana flavoured pellets. At an intermediate stage in their training (the rats were trained on a mix of TNT and MW spiked soil and on water controls), a test was conducted with four rats that were working well in August 2009 to see if the procedural changes had any effect. The results of the chemical analysis of the MW spiked training samples is described by Negussie, this volume. The field samples used for this test had been collected over the PMR2 mine, above a nr. 4 mine (TNT-based mine) and a M14 mine (RDX based). Only the samples collected above the PMR2 mine contained TNT (see Negussie, this volume).

Results. The results of this test are given in the table below:

	Field samples				Training samples	
	PMR2	nr 4	M14	Controls	TNT/MW	controls
	1	**1**	**1**	**9**	**8**	**68**
Chapakazi	1	0	0	1	3	1
Allan	0	0	0	0	5	2
Lewis	0	0	1	0	6	2
Ngwale	1	1	0	1	1	2
average	50.00%	25.00%	25.00%	5.56%	46.88%	2.57%

The procedural changes led to the same HR of the training samples on average (44.4 vs 46.9 per cent) but decreased the FAR level by half (5.5 vs 2.6 per cent). The rats hit on the TNT and the MW equally well. But they did not seem to detect the field samples reliably.

Experiment 2: Rectangular and line cage rats tested on soil from around a mine

Methods. The rats working in line cage 3, who had been trained exclusively on TNT up to this stage, and rats trained in the rectangular cage described above who had already been trained on a combination of TNT and MW, continued training on both TNT and MW. The training was slightly changed to mimic an operational setting more closely to using just a single soil type per training session and additives that were more realistic (previously, the most diverse smelly additives had been used to obtain stimulus control).
These two groups of rats were tested in October 2009 on their ability to detect what we considered an enhanced field sample: soil collected directly around a PMR2 mine.

Results. In the table below, the results of the last week of training before the test are given together with the results of the test.

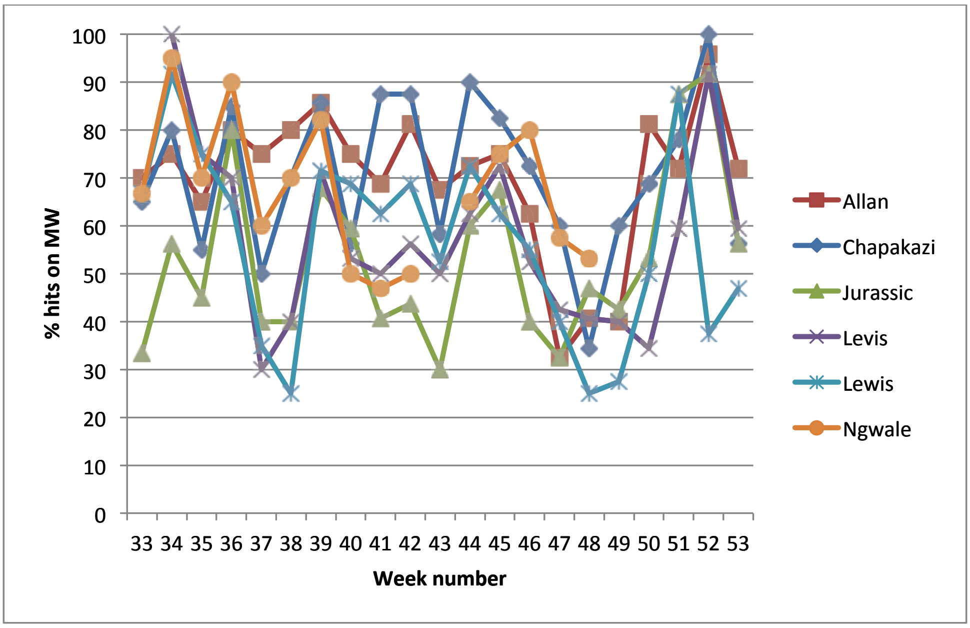
	week prior to test		test			
	detection on MW	FA rate	detection on MW	FA rate	detection on PMR2 soil	FA on control soil
average line cage	69.0%	2.0%	37.5%	3.9%	12.5%	7.5%
average rectangular	77.0%	2.7%	64.9%	4.6%	8.3%	13.3%

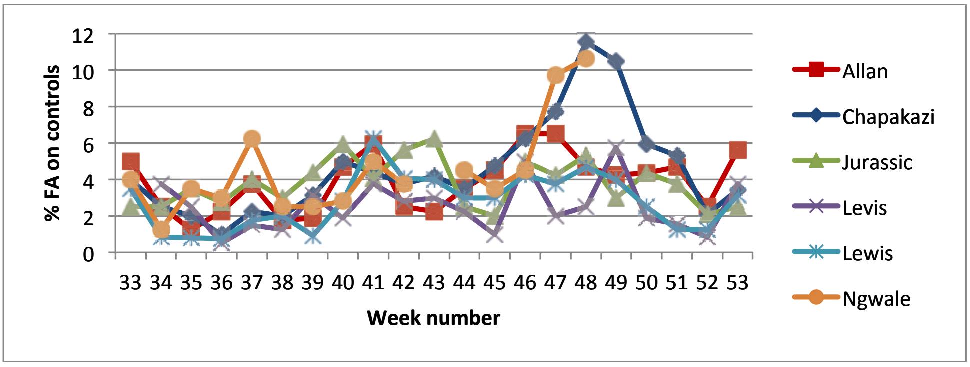
Although the HR on the MW spiked soil samples was lower during the test and the FAR's were up in comparison to the training situation, it was clear that the rats did not detect the soil collected around the PMR2 mine. When this soil was analysed, it did contained TNT and DNT in the range of 30 to 300 ng, but far less than the training samples (see Negussie, this volume). This meant that there was a marked difference in strength of the stimulus (based on the components from the explosives), which probably led to the PMR2 soil not being detected by the rats.

Experiment 3: Line cage rats extended training

Methods. The rats working in line cage 3 were trained on one soil type and one additive from week 34 onwards. From week 41, they were only trained on MW spiked soil. The training was continued to see how stable their performance would become.

Results. In the graphs below, the HR (% hits) on MW and the FAR (% FA) per week are given (usually five sessions per week). The two rats that gave the most FA, Ngwale and Chapakazi, were taken out of the project due to bad health.



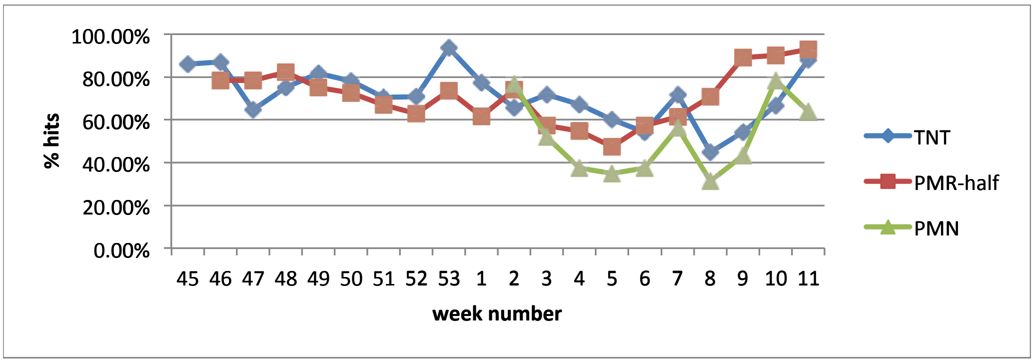


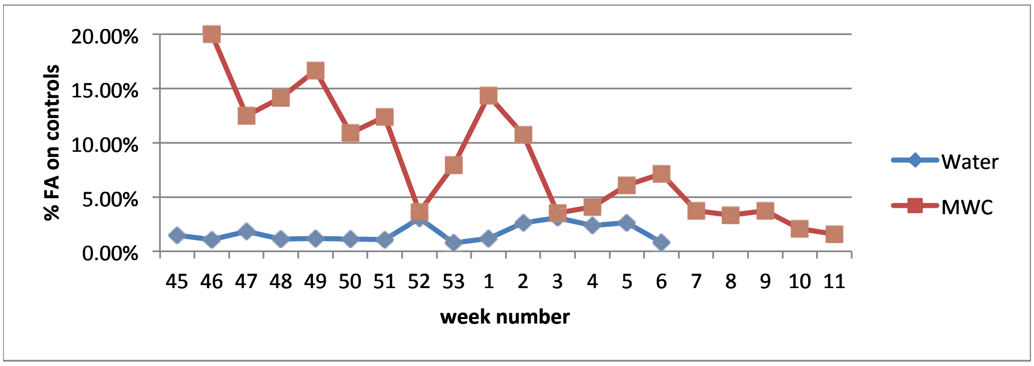
The results show that although the FAR stayed below five per cent on average, the rats did not stabilise in their HR. Further analysis on the interaction between the spiking solution and the soil type was done to find explanations for this. (see appendix E)

Experiment 4: Square cage rats on mixed training

Methods: Rats working in the square cage and trained on a lower level of TNT (1 ppm instead of 100 ppm) against different soil backgrounds, were used in this experiment. Mine water from a PMR2 mine and later from a PMN mine were added as positive stimuli, and mine water control was added as a negative control stimulus.

Results: In the graphs below, the HR and FAR are given over the training weeks.





Appendix D: Does training dogs on a "mine-water" (water in which a mine has soaked) spiked on soil lead to the detection of field samples?

Introduction

Dogs (and rats) readily detect buried mines in the field. In the field, the animals are free to "choose" any part of the odour signature a mine produces to indicate on. In controlled studies it has been shown that dogs often do not use the full odour signature but a number of components, they need not choose the parent explosive when being trained on explosives but they may use another components of the explosive, and individual dogs can differ in their choice of components to indicate on, even if they have been trained in the same manner.

To better mimic the full bouquet of the odour of a mine, we tried to simulate the process outside where mine-components first dissolve in rainwater, and then come to the surface with the evaporation of the water. We soaked a PMR2 mine in a stainless steel bucket for a number of weeks until the water was saturated with TNT, which was the only component we could measure at that time. This we called "mine-water (MW)". At the same time other stainless steel buckets were filled with the same water and left to be used as controls level (MWC). Procedures and results of chemical analysis are described by Negussie (this volume).

As a first step, dogs were trained to detect slivers of Kong in a 12 arm carousel. Later this target odour was decreased to just the odour of Kong by removing the piece of Kong prior to the dog working with the samples. Still later, the stimulus control was shifted from Kong odour to mine water by gradually fading out the Kong odour.

Experiment 1: First test of the dogs trained on pieces of Kong

Methods: Six dogs were trained to detect slivers of Kong that gradually decreased in size in a 12 arm carousel in containers that were filled with four different types of soil and 12 different "additives" (substances added to the soil, varying from plant material to household products). Field samples were collected on May 26th, 2009. The soil above three different mines and from nine empty boxes (nearest mine was at least ten meters away) was sampled following a protocol developed earlier by Apopo. The PMR2 and the nr 4 mines contain TNT as main explosive charge, the M14 is a RDX-based mine. The sample from the PMR2 mine was found to contain TNT, chemical analysis of the other samples failed to detect TNT.

In the test, the field samples and the neutral samples were mixed with the usual training samples that contained the small Kong slivers. The test was conducted at the end of May 2009.

Results: The results of the dogs are given in the table below.

	Field samples				Training samples	
	PMR2	nr 4	M14	controls	Kong	Controls
	1	**1**	**1**	**9**	**8**	**76**
Chaser	0	0	0	0	6	0
Hoppa	0	0	0	0	7	1
Huldra	0	0	0	0	8	1
Jalla	0	0	0	0	6	5
Hannah	0	0	0	0	6	0
Mussa	0	0	0	0	7	0
Average	0.00%	0.00%	0.00%	0.00%	83.33%	1.54%

The results indicate that the dogs were under clear stimulus control of the Kong sliver against the different backgrounds since they do not respond to the field mine samples in the same way (χ^2, p <.05). They do not react differently to the control samples from the field (χ^2, p <.05), which also demonstrates stimulus control on the Kong pieces. Training the dogs on Kong does not lead them to detect field samples.

Experiment 2: Second test of dogs trained on Kong and on mine water

Methods: The training of the six dogs continued, gradually exchanging Kong pieces for just the odour of the Kong (Kong contamination: kong was put into the container on the top of the soil for increasingly shorter times up to 1/4 hour), then combined with MW. When this test was done in August, the dogs were at an intermediate stage in their training on MW: they were given four targets of MW in combination with kong contamination, and four targets containing only MW in a session.

Results: The results of this test are given in the table below:

	Field samples					Training samples	
	PMR2	nr 4	M14	controls		Kc+MW/MW	controls
	1	**1**	**1**	**9**		**8**	**76**
Chaser	0	0	0	0		6	7
Hoppa	1	0	1	0		7	11
Huldra	0	0	0	4		7	3
Jalla	0	0	0	0		5	4
Hannah	0	0	0	0		4	2
Mussa	0	0	0	2		6	5
avg project	16.67%	0.00%	16.67%	11.11%		72.92%	7.02%

The results indicate that the dogs did not detect the mines based on their training so far, since they did not react to the field samples in the same way as they did to their training samples (χ^2, p <.05). They also do not react differently to the controls from the field than to their own control training samples (χ^2, p <.05), demonstrating that they are under stimulus control of their target odours.

Experiment 3. Test of dogs trained on MW on soil from around a mine

Methods: The six dogs continued to be trained on soil spiked with MW. The training was slightly changed to mimic an operational setting more closely to using just a single soil type per training session and additives that were more realistic (previously, the most diverse smelly additives had been used to obtain stimulus control).
The dogs were tested twice in October 2009 on their ability to detect what we considered an enhanced field sample: soil collected directly around a PMR2 mine. The control soil for the first test was taken from the Apopo soil stock, the control soil for the second test from the NPA stock.

Results. In the table below, the results of the last week of training before the first test are given together with the results of the tests.

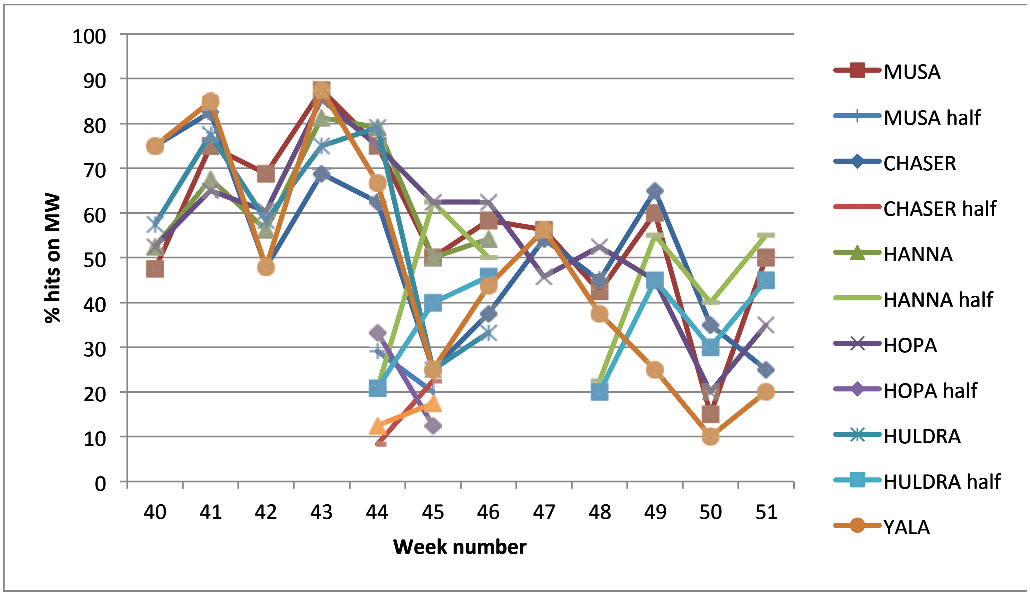
	Week prior to first test		Test			
	Training samples		Training samples		Field samples	
	MW	control	MW	control	PMR2 soil	control soil
October 1	70.0%	4.70%	10.4%	1.6%	25.0%	88.33%
October 7			79.2%	2.3%	8.3%	0.0%

In the first test, the dogs responded strongly to the control soil from the Apopo stock. The rats had been tested with the same soil, but they did not respond to this soil. Ionscan analysis of the control soil and the PMR2 soil did not reveal contamination with TNT or related products. But the response of the dogs was very firm, and in spite of the fact that these responses were not rewarded in any way, the dogs remained consistent, and even did not respond to their training samples any more. The second test with similar control soil from the NPA stock indicated that the dogs were responding to their training samples as usual, but not detecting the field samples at all (χ^2, $p < .05$), and also not responding to the control soil in any unusual manner.
The soil from around the PMR2 mine did not contain any TNT related products when analysed with an ionscan, but contained 30-300 ng TNT as well as DNT when analysed with a GC (see Negussie, this volume). The training samples contained much more. This meant that there was a marked difference in strength of the stimulus (based on the components from the explosives), which probably led to the PMR2 soil not being detected by the dogs.

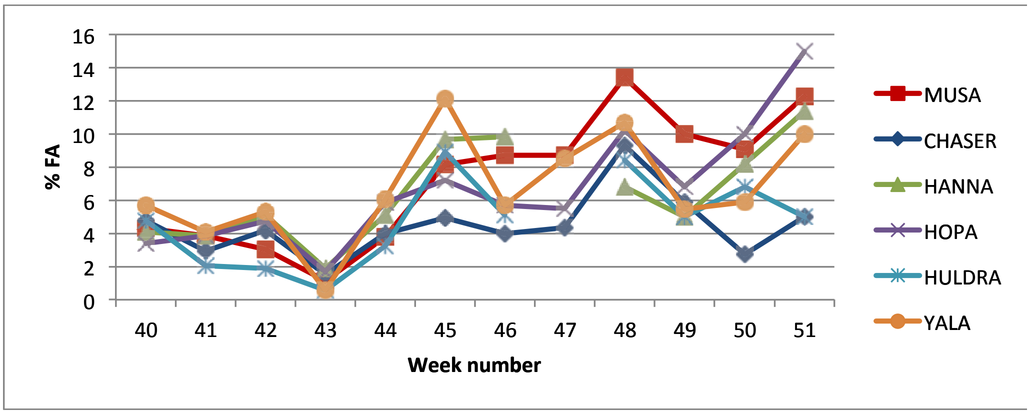
Experiment 4. Training the dogs on lower concentrations.

Methods: The training of the six dogs continued in the same manner as before using different soil types each day, focusing on soil types that were similar to the Morogoro mine field, not using additives anymore, with the goal to lower the concentration of MW to make the training samples more similar to the field samples. The training results were analysed to see if the performance stabilised.

Results: In the graphs below, the HR (% hits) on MW and the FAR (% false alarms) per week are given (usually six sessions per week).



APPENDIX D



The figures show that up to week 43, the dogs were all performing well on MW with very a low FAR. In week 44 the lower concentrations MW (half) were introduced. For four dogs (Musa, Chaser, Hopa and Yala) this was discontinued after two weeks since even the hits on the high concentration MW went down and the FAR started to go up. These four dogs did not recover: their HR remained lower and their FAR higher than before. Two dogs (Huldra and Hanna) were continued on only the half concentration MW, they performed equally well as the other four dogs. We could not find a simple reason for this gradually declining performance.

Appendix E:
Does the kind of soil that is used influence the performance of the animals?

Introduction
During the year, different soils were collected, given a number and a short description. These soils were subsequently used in training for both the dogs and the rats. Sometimes a lot of a particular soil was gathered, at other times only a small amount. This resulted in some soils being used more often than others. The data was analysed for differences between soils with respect to HR and FAR (detection and false alarm rates).

Results of the analysis for the dogs

Methods: For the dogs, all training sessions were used where the only target was mine water from a PMR2 mine. The results from different concentrations was pooled. The number of controls presented and the number of erroneous hits (% false alarm or FAR) was calculated per dog and per soil number, as was the number of targets presented and number of correct hits (% detection or HR). The results were summarized per soil type if four or more dogs had worked on that specific soil number.

Results: In the graph below, the HR and FAR are given per soil number. Since soils were collected continuously, the increasing soil numbers reflect the continuing training of the dogs.

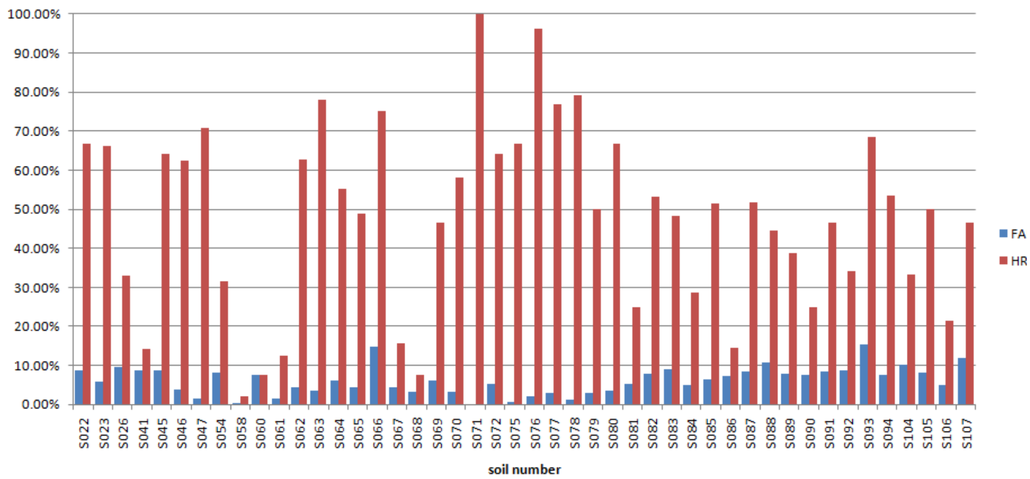


Fig. 1. HR and FAR obtained by dogs per soil.

It is clear that there is no general training effect since the HR and the FAR continue to fluctuate. Some soils were used much more often than others, soil S062 was used most often (>4000 samples presented in total) and soils S061 and S066 least (<150 samples presented in total). In the graph below, the relationship between the number of times a soil was presented and the hit rate is illustrated (the outlying result for soil 62 has been left out).

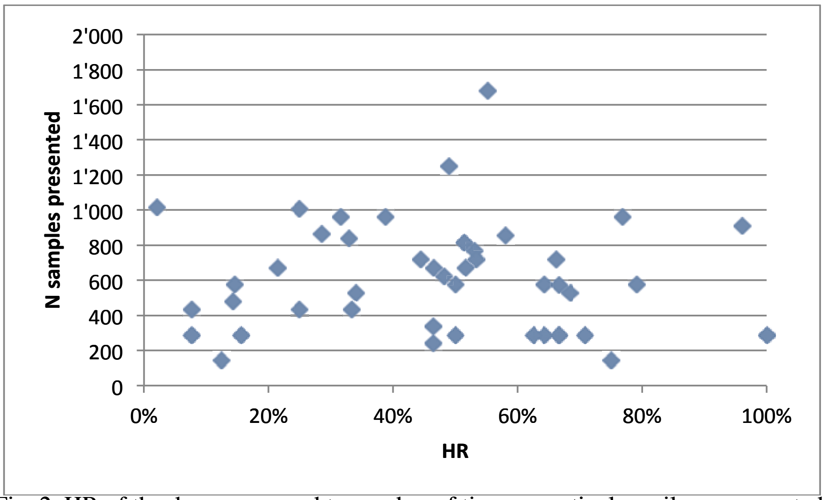


Fig. 2. HR of the dogs compared to number of times a particular soil was presented.

There was no significant correlation between number of times the soil was used and the detection rate (correlation coefficient 0,1339, NS), indicating that the difference in performance is also not a result of experience with a particular soil.

The HR were not evenly distributed over the different soil types (Chi square = 265,49, df=45, p<.005), nor were the FAR's (Chi-Square = 467,026 df= 44, p<0.005). The relationship between the HR and FAR is illustrated in the figure below. This is not a significant correlation (correlation coefficient -0.108; p>.05). So it does not seem that some soils are responded to more often than others by the dogs.

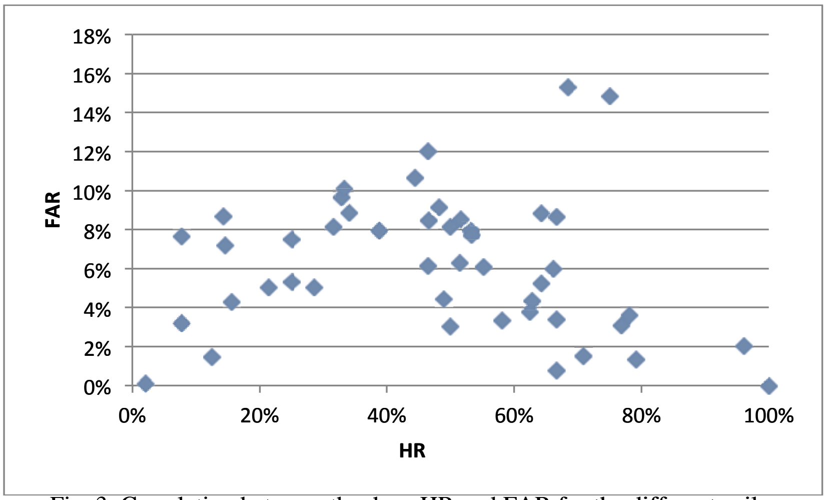


Fig. 3. Correlation between the dogs HR and FAR for the different soils.

Results of the analysis for the rats

Methods: For the rats, all training sessions were used where the only target was mine water from a PMR-2 mine. The results from different concentrations was pooled. The number of controls presented and the number of erroneous hits (FAR) was calculated per rat and per soil number, as was the number of targets presented and number of correct hits (HR). The results were summarised per soil type if three or more rats had worked on that specific soil number.

Results: In the graph below, the HR and the FAR are given per soil number. Since soils were collected continuously, the increasing soil numbers reflect the continuing training of the rats.

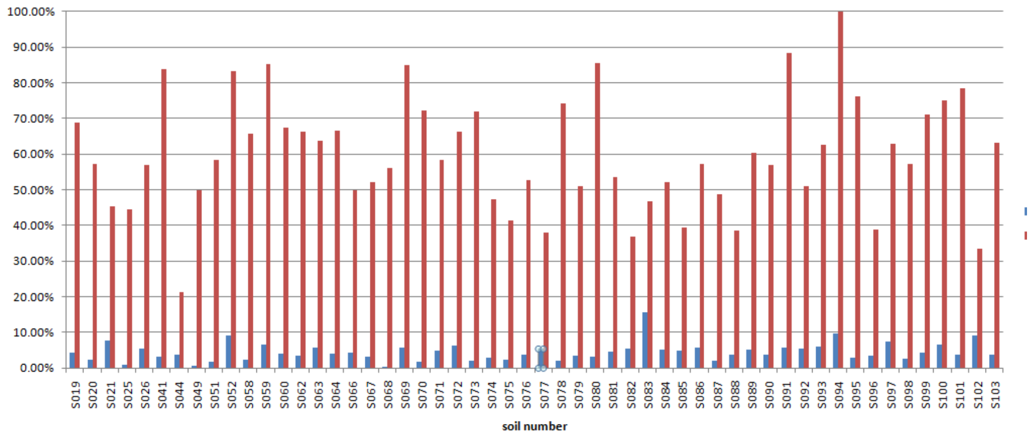


Fig. 4. HR and FAR obtained by rats per soil.

It is clear that there is no general training effect since the HR and the FAR continue to fluctuate. Some soils were used much more often than others, soil S060 was used most often (>1100 samples presented in total) and soil S020 least (132 samples presented in total). In the graph below, the relationship between the number of times a soil was presented and the hit rate is illustrated .

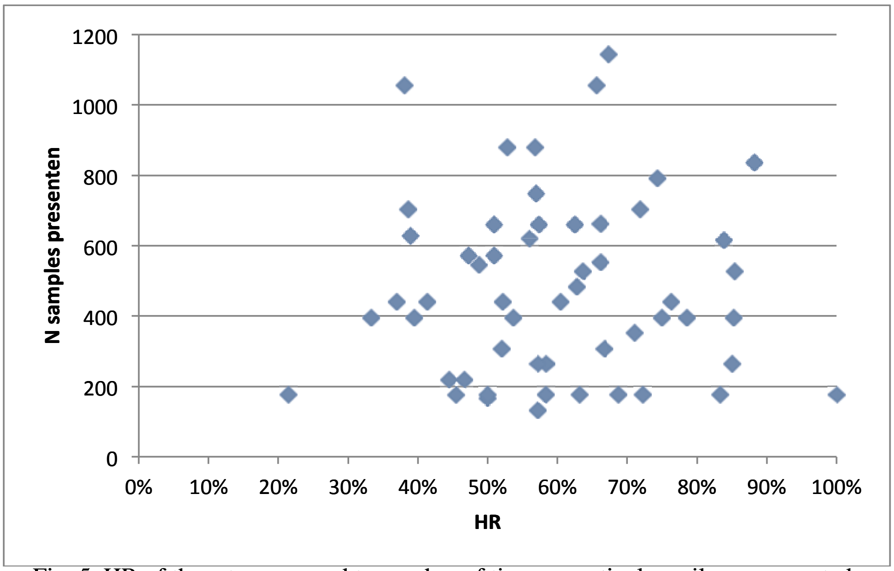


Fig. 5. HR of the rats compared to number of times a particular soil was presented.

There was no significant correlation between number of times the soil was used and the detection rate (correlation coefficient 0.0045, NS), indicating that the difference in performance is also not a result of experience with a particular soil.

The HR's were not evenly distributed over the different soil types (Chi square = 84.96, df=52, $p<.005$), nor were the FAR's (Chi-Square = 234.19, df= 52, $p<0.005$). The relationship between HR and FAR is illustrated in the figure below. There is no significant correlation between them (correlation coefficient 0.089; $p>.05$). So it does not seem that the rats respond to some soils more than others.

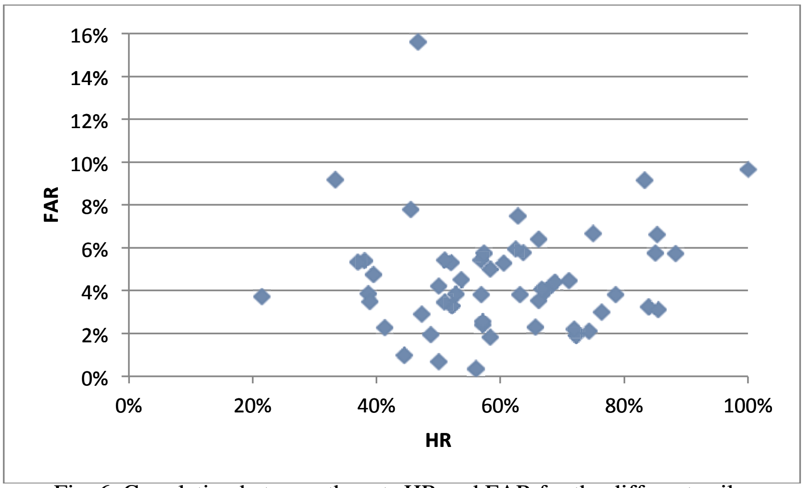
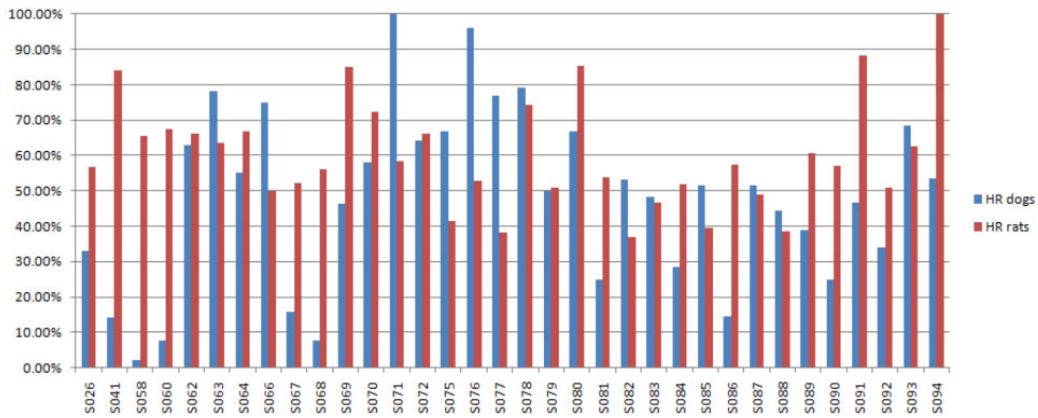


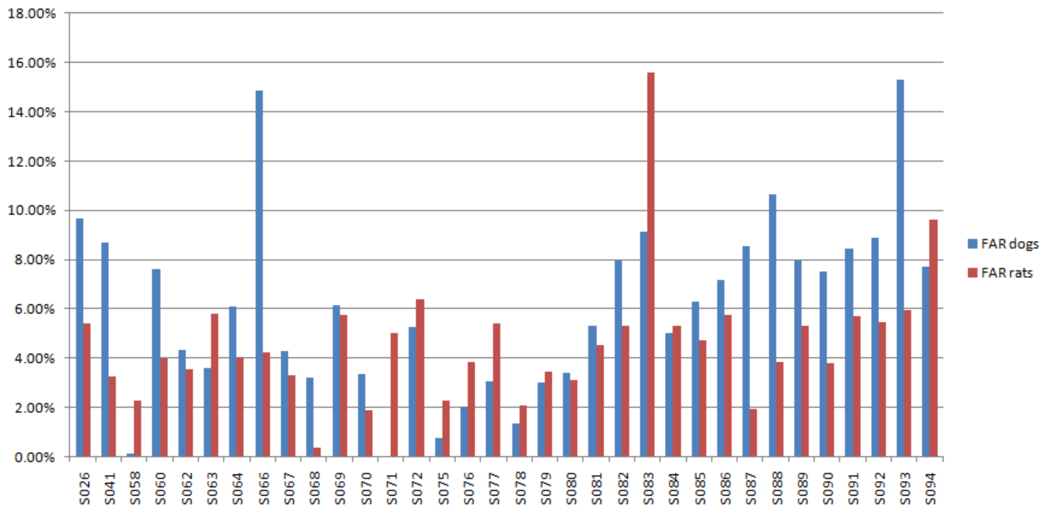
Fig. 6. Correlation between the rats HR and FAR for the different soils.

Comparison between dogs and rats
Since both the detection and false alarm rates fluctuated significantly between soils for both the dogs and the rats, the question arose whether the results of the animals were similar across soils.

Methods: The data collected for the dogs and rats above, was compared with each other for the 34 soils that both groups of animals had worked on. The HR and FAR were compared.

Results: In the graphs below, the HR and FAR for the dogs and rats are compared. The correlation coefficient for the detection rate is -0.04644 is not significant; the correlation coefficient for the false alarm rate is 0.353187, which is significant ($p<.05$).





Before drawing any further conclusions, two points need to be noted. First, the data on the dogs and the rats also include the efforts to decrease the concentration of the spiking solution. The concentration was decreased for both species relative to what they were used to. For the rats, only about eight of such target samples are included in the data, but for the dogs a much higher amount of the samples were a lower concentration. Two dogs received the lower concentration for more than 50 per cent of the target samples presented in this data. A second point is that in the course of the sessions, the mine water from the first "hotpot" was finished and the animals were switched to the second "hotpot". It appeared that the TNT concentration in this second hotpot was higher than that in the first hotpot even though the level in the first hotpot had been at the normal saturation level of TNT in water. The other components in the mine that also dissolved into the water probably increased its carrying capacity for TNT. This switch happened for both the groups at more or less the same time.

Bearing this in mind while evaluating the results in the graphs above, a tentative conclusion could be that the odour signature the animals are looking for differs between the two species. A possible cause for this may be that for the majority of the sessions presented here, the rats were given a higher amount of spiking solution than the dogs. Besides the rats not being given the lower concentrations as much as the dogs, as described above, the rats were also given more drops per sample. The rats were given four drops of a particular concentration per sample, while the dogs were given three drops of the same concentration. It also appeared that differences between the sample preparation for the dogs and the rats led to the drop size being larger for the rats than the dogs, leading to an even larger amount of mine water solution being spiked onto the rat samples than onto the dog samples (see Negussie, this volume). This may have had an effect on the perceived odour signature. A second reason could lie in the different initial training between the species. The dogs had been trained on detecting slivers of Kong placed on the soil. The rats had initially been trained on a TNT solution that was spiked onto soil. This may have led to the two species focusing on different aspects of the mine water odour signature.

Without full headspace analysis of the soils – with and without spiking solution - it is impossible to find any plausible reason why the false alarm rates correlate between the dogs and the rats, other than that there may be some –for both species – "interesting" odour in those soils. It is unlikely that the animals are responding to "landmine" related odours in the soils, since dogs and rats do not correlate in their HR on positive samples."

APPENDIX F

APPENDIX-F
Summary of REST Chemistry Results

Table 1. Soil property of soil samples collected from different corners of APOPO test field at different depths.

Field reference	Soil pH (1:2.5) H2O	EC mS/cm	Particle size distribution (PSD)[1]			Texture class	Total nitrogen (%)[2]	Organic matter (%)[3]	CEC (cmol/kg)[4]
			Clay %	Silt %	Sand %				
Eastern part-1 cm depth	6.20	0.06	51	5	44	C	0.20	1.99	15.2
Eastern part-5 cm depth	5.84	0.03	55	7	38	C	0.18	2.23	14.2
Eastern part-12 cm depth	5.59	0.03	57	3	40	C	0.19	1.78	11.8
Eastern part-30 cm depth	5.21	0.07	71	3	26	C	0.15	1.06	14.0
Western part-1 cm depth	6.24	0.05	49	3	48	SC	0.24	2.57	9.8
Western part-5 cm depth	5.70	0.02	49	3	48	SC	0.21	2.37	12.4
Western part-12 cm depth	5.48	0.03	49	3	48	SC	0.20	1.92	11.2
Western part-30 cm depth	5.15	0.02	73	1	26	C	0.19	1.41	15.2
Weather station-1 cm depth	6.24	0.14	51	5	44	C	0.31	2.92	12.0
Weather station-5 cm depth	5.40	0.03	57	5	38	C	0.20	2.51	12.4
Weather station-12 cm depth	5.28	0.02	57	1	42	C	0.16	1.82	12.4
Weather station-30 cm depth	5.04	0.03	71	1	28	C	0.13	1.30	14.4

KEY: C-clay; SC-sandy clay
1-hydrometer method
2-Kjeldahl method
3-Walkley-**Black method**
4-ammonium acetate saturation method

Table 2. Dryness of soil collected at different depth from APOPO test field.

Depth at which soil was collected, cm	Weight lost after 24 hrs drying at 105^{0}C, g	Percentage dryness*
5	0.116	88.7
10	0.113	88.2
25	0.148	85.2
35	0.161	84.1

* calculated as: 1-(amount lost after drying divided by the weight before drying) times 100

Table 3. Comparison of 25 selected solvent systems on their extraction efficiency towards nitroaromatic explosive compounds.

No.	solvent	Amount of explosive compound (ng/g)						
		2,6-DNT	2,4-DNT	2,3-DNT	TNT	2,4-DA-6-NT	4-A-2,6-DNT	2-A-4,6-DNT
1	Deionized water		20.4		2420.7		1106.9	938.0
2	Phosphate buffer pH 8.0		31.3		2452.5		1893.0	1363.3
3	Cyclohexane*		8.0	15.9	573.0		20.2	29.1
4	Hexane				4099.1		337.0	357.7
5	t-butyl methyl ether		1.0		528.9		94.5	149.6
6	Methanol				71.5		34.0	31.5
7	Water: methanol (1:3)		4.8		2084.7		443.0	442.8
8	Water: methanol (1:1)	5.0	75.5		3923.2	42.5	9350.2	3860.0
9	Water: methanol (3:1)		33.1		2374.6		3107.0	1678.0
10	Ethanol				264.4		56.2	68.3
11	Water: ethanol (1:3)		1.6		1721.7		176.6	294.2
12	Water: ethanol (1:1)	22.3	47.3		4209.2		4852.4	2084.8
13	Water: ethanol (3:1)		29.1		2241.8		2759.3	1402.3
14	Isopropanol				1004.9		79.4	169.3
15	Water: isopropanol (1:3)	43.7	4.8		1236.6		54.2	68.6
16	Water: isopropanol (1:1)		8.3		3007.8		963.1	711.8
17	Water: isopropanol (3:1)		27.4		2745.7		2602.7	1552.6
18	Acetone				28.5		9.1	9.6
19	Water: acetone (1:3)				54.3		28.0	20.8
20	Water: acetone (1:1)				599.4		91.2	129.5
21	Water: acetone (3:1)	11.0	78.5		4176.4		8620.0	3717.6
22	Acetonitrile				11.5		97.3	2.1
23	Water: acetonitrile (1:3)		0.7		16.7		9.1	7.8
24	Water: acetonitrile (1:1)		0.5		163.0		167.3	72.5
25	Water: acetonitrile (3:1)		0.7		82.3		9.3	9.7

Table 4. Comparison of the efficiency of microwave assisted extraction and platform shaker.

Method of extraction	Amount of explosive compound (ng/g), mean ± SD for triplicate samples			
	2,4-DNT	TNT	4-A-2,6-DNT	2-A-4,6-DNT

Buffer, microwave	155.3 ± 24.6	10046.5 ± 464.5	18494.8 ± 3222.0	11228.6 ± 1262.4
Buffer, Platform shaker	87.6 ± 28.4	7154.2 ± 717.8	4954.4 ± 626.5	4751.4 ± 426.1
Water: methanol (1:1), microwave	295.3 ± 40.6	23686.4 ± 6753.6	27681.3 ± 3297.6	20166.0 ± 2624.6
Water: methanol (1:1), Platform shaker	139.3 ± 1.8	16918.6 ± 1169.0	9405.7 ± 854.2	9699.7 ± 623.5

Table 5. GC-NPD analysis of 'mine water' produced by immersing the landmine in water filled hotpots.

Sample from	2,5-DNT, ng	2,4-DNT, ng	TNT, ng	TNB, ng	2,4-DA-6-NT, ng	4-A-2,6-DNT, ng	2-A-4,6-DNT, ng
No. 4A, 1 mL MW	18	392	1965	-	-	296	122
No. 4B, 1mL MW	24	565	3429	-	-	382	156
No. 4C, 1 mL MW	17	319	5044	-	-	315	134
MK5, 1 mL MW	-	-	8	-	-	-	-
TM57, 1 mL MW	-	-	-	-	-	-	-
T59, 1 mL MW	-	-	-	-	-	-	-
M16, 1 mL MW	-	-	-	-	-	-	-
PMN, 1 mL MW	-	40	1592	553	-	507	1024
PMR1, 0.5 mL MW	-	450	11482	746	-	525	1040
PMR2B, 0.5 mL MW	-	42	4612	601	139	598	1137
PMR2C, 0.5 mL MW	-	43	21643	397	-	806	1731
PMR2A*, 1 mL MW	-	-	3214	200	-	137	242
Spiking solution, apopo 1 mL	-	59	10134	206	-	848	907
Spiking solution, apopo 1 mL		66	11116	760	-	763	734
Spiking solution, apopo 1 mL	-	70	1053	886	-	687	618
Spiking solution, NPA 1 mL	-	63	11506	641	-	669	598
PMR2 mother solution-1	-	69	13932	661	-	662	507
PMR2 mother solution-1	-	70	13484	714	-	656	490

Table 6. Properties of different landmines (adapted from of Jane's mines and mine clearance, King, C. eds., second edition, US. 1997)

mine	type	casing	explosive
T59	Anti-tank	metal	TNT
TM57	Anti-tank	metal	TNT
MK5	Anti-tank	metal	TNT
M16	Anti-personnel	steel	TNT
PMR1	Anti-personnel	Cast-steel	TNT
PMR2	Anti-personnel	concrete	TNT
PMN	Anti-personnel	Bakelite with rubber plate	TNT
No.4	Anti-personnel	plastic	TNT

Table 7. GC-NPD analysis results of soils soaked with 'mine water' and dried in the dark and in the sun.

Sample from	2,4-DNT, ng	TNT, µg	TNB, µg	4-A-2,6-DNT, µg	2-A-4,6-DNT, µg
		Sun dried			
Sand 1	94	24.5	1.3	0.4	0.8
Sand 2	84	22.5	1.4	0.4	0.7
Black soil 1	143	49.7	-	8.8	3.2
Black soil 2	116	45.9	-	8.3	2.9
Clay soil 1	109	65.6	-	1.8	1.8
Clay soil 2	93	65.3	-	1.9	1.7
		Room dried (in the dark)			
Sand 1	-	59.9	2.0	1.8	3.9
Sand 2	-	56.1	2.2	2.0	4.0
Black soil 1	-	42.9	2.2	16.8	10.8
Black soil 2	-	34.3	1.9	13.8	8.6
Clay soil 1	-	10.9	2.8	4.4	8.8
Clay soil 2	-	10.1	4.0	4.8	8.5

Table 8. GC-NPD analysis of target samples used for rats and dogs training (2 g soil spiked with 4 drops of PMR2 leachate).

Sample from	2,4-DNT, ng	TNT, ng	2,4-DA-6-NT, ng	4-A-2,6-DNT, ng	2-A-4,6-DNT, ng
Rats-1	68	964		4694	1039
Rats-2	70	1410	1272	6585	1325
Rats-3	18	435	606	2486	522
Dogs-1		125	903	731	197
Dogs-2		312		507	201
Dogs-3		406		904	315

Table 9. GC-NPD analysis of target samples immediately after preparation (those with B) and immediately after presentation to the animals (those with A). The samples were prepared by taking 2 g of soil and spiking with 4 drops of PMR2 leacahte).

sample	2,4-DNT, ng	TNT, ng	TNB, ng	4-A-2,6-DNT, ng	2-A-4,6-DNT, ng
RB-1	47	17749	594	639	502
RB-2	47	16372	612	591	461
RB-3	59	20036	718	754	561
RA-1	26	10182	375	456	340
RA-2	52	45423	664	722	560
RA-3	26	10347	357	415	335
DB-1	13	3091	113	191	168
DB-2	9	2994	121	195	165
DB-3	13	2353	98	161	143
DA-1	14	2359	109	399	254
DA-2	16	2319	92	454	254
DA-3	15	2194	105	517	262

APPENDIX F

Table 10. Drop size experiment among APOPO personnel involved in sample preparation.

personnel	Range of wt of single drop, g	Mean Wt of single drop ± SD, n=10	Range of wt of four drops, g	Mean Wt of four drop ± SD, n=10
A	0.0314 - 0.0445	0.0388 ± 0.004	0.1435 – 0.1667	0.1595 ± 0.007
B	0.0265 – 0.0383	0.0318 ± 0.003	0.1218 – 0.1492	0.1390 ± 0.008
C	0.0205 – 0.0382	0.0297 ± 0.007	0.1307 – 0.1735	0.1532 ± 0.005
D	0.0258 – 0.0348	0.0304 ± 0.003	0.1303 – 0.1493	0.1427 ± 0.007
experienced	0.0215 – 0.0473	0.0330 ± 0.009	0.1224 – 0.1696	0.1422 ± 0.0127

Table 11. Drop size experiment among NPA personnel involved in sample preparation.

personnel	Range of wt of single drop, g	Mean Wt of single drop ± SD, n=10	Range of wt of three drops, g	Mean Wt of three drop ± SD, n=10
A	0.0241 - 0.0316	0.0279 ± 0.003	0.0801 – 0.1010	0.0908 ± 0.006
B	0.0214 – 0.0296	0.0249 ± 0.003	0.0762 – 0.0914	0.0832 ± 0.006
C	0.0218 – 0.0379	0.0288 ± 0.005	0.0685 – 0.0976	0.0783 ± 0.009
D	0.0250 – 0.0373	0.0307 ± 0.005	0.0726 – 0.0904	0.0803 ± 0.005

CHAPTER 8

SAMPLING

by Christophe Cox and Morten Kjeldsen

CHAPTER 8

SAMPLING

INTRODUCTION

The main objective for sampling in the REST project is:

To provide a soil or dust sample for animal detection that is representative of underground conditions in mine susceptible areas and at the location where the sample was taken.

In order to fulfill this, a series of activities were initiated for sampler development and sampling strategies. This section provides a summary of experiences from the activities completed during the REST project, and recommendations for future sample development.

CHARACTERISTICS OF EFFECTIVE SAMPLING

As already stated, the success of the sampler depends on capturing material that contains traces of underground mines. The general model is that moisture and water in the soil transport trace material of both the explosive chemical and the mine construction material to the surface. As water evaporates at the surface level, the trace material is left behind, and can be found attached to dust particles. For REST applications it can be of value to establish if a characteristic particle containing the trace material exists. Finally the probable distribution of particles containing surface scent traces will be of significance when establishing a proper sampling routine for a given location.

The general sampler will include a suction flow for particle entrainment and a solution to collect particles or the sample. Large objects can enter the inlet of the sampler, which could cause clogging with foreign objects, which will degrade overall performance.

Cross-contamination of samples pose a significant uncertainty with regard to the relevance of subsequent samples. In principle, the material usage and the flow design of pipes, together with cleaning techniques are all important in minimising cross-contamination.

The suction flow of the sampler will be based on a system containing a power source and a pump or fan solution. Since the sampler is likely to be mobile, limitation on weight and requirements on handling will be of high priority.

To summarise, the following objectives are important in achieving effective sampling:

1. Understanding properties of particles containing typical mine scent trace
2. Sample collection system
3. Solutions to avoid unwanted objects entering sampler unit
4. Procedures and solutions, both in design and operation, that prevent cross-contamination of subsequent samples
5. Selection of power source, and technical arrangements for creating suction flows
6. Effective manual handling of equipment, and procedures for achieving a given sample

In the following sections, the development of the sampler in APOPO and in the REST project is described, with special attention to the objectives listed above. Logistics, such as storage and transport of samples, or filter based techniques tested in the REST project, are not covered in this chapter.

CHAPTER 8

SAMPLING

SAMPLING DEVICES USED BY APOPO

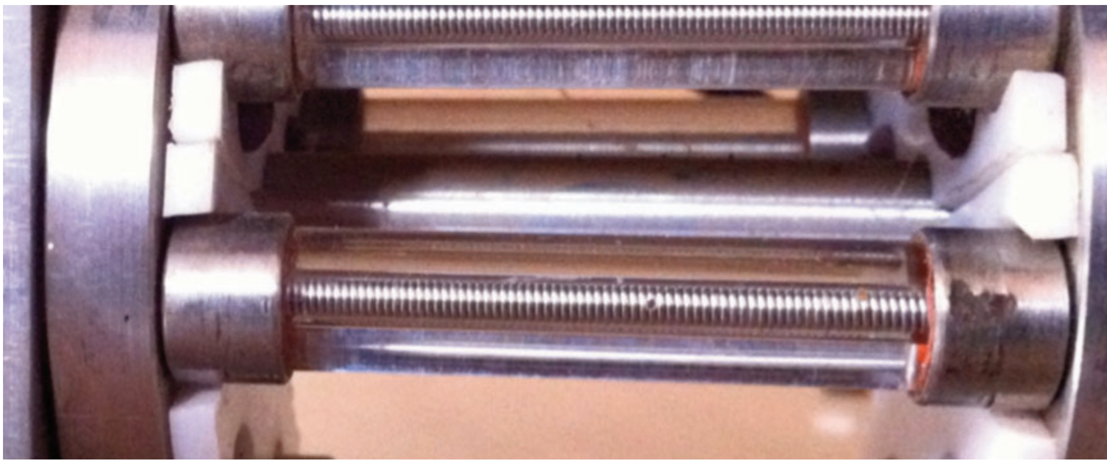
Since APOPO started its research on landmine detection, it has developed a series of sampling units and concepts, some of which are outlined below.

TNT Pre-concentrator

The initial idea was to develop a TNT pre-concentrator that could be used for field sampling and subsequently increase the vapour concentration during evaluation by heat flashing it to the rat (see description of this below).

APOPO started with the development of a fully-automated rat-training system for which it developed a vapour delivery system in collaboration with Jenel TVD, a Canadian company specialised in Trace Vapour Detection. The device consisted of a glass tube with a central coiled metal wire through which the air was drawn. The TNT vapours were adsorbed by the metal coil which was coated with a TNT adsorbent (see Figure 2). Upon presentation to the rat, an electrical current heated up the metal coil, sending off a concentration of TNT in a light airflow in a sniffing chamber. The rat would respond by pressing a left or right lever in a typical Skinner box setting. After the sample was heated, it could be re-used. The system would use a light, handheld pump for sampling < 2litres/min. The materials and technology used was similar to those used in instrumental analysis, such as Gas Chromatography. Although the system might still be useful for explosive sampling in a different context, it could not function for REST because mineral dust would negatively interfere with the adsorption mechanism.

FIGURE 1 | Vapour sampling tubes loaded in the automated training carousel



The MEDDS system

After this initial experiment, APOPO established a training centre in Tanzania, which included a test field for REST research with widely (40 m) spaced mines. APOPO started using and testing the equipment developed by MECHEM, which was also being used by NPA in Angola. Initially, Husqvarna petrol engine driven fans were used, but were later replaced by Honda fan. The sample consisted of a PVC gauze coiled around a plastic centre piece and kept in an outside plastic tube, as shown in Figure 2.

FIGURE 2 | Sampling tubes developed by MECHEM

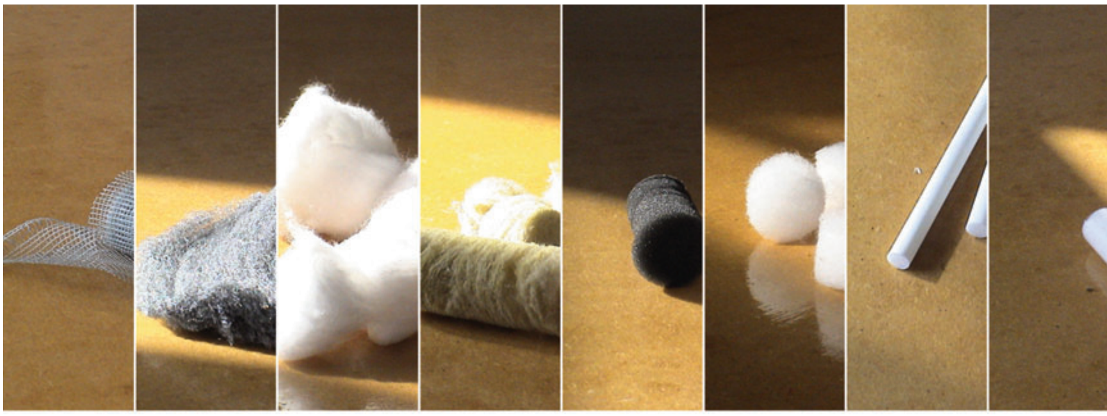
After repeated training on positive versus negative samples from the REST training field in Morogoro, the rats would discriminate quite reliably between the samples which were drawn from above the five by five metre boxes containing the landmines. In general results were significantly better in the dry season than the rainy season, though not always.

Observations by APOPO revealed that the PVC samples varied considerably in weight, and length of the PVC mesh, and sometimes the mesh was double folded causing air gaps. Considering these inconsistencies, APOPO tried alternative sampling materials which could improve REST sampling.

FILTER STUDY

APOPO tried commercially available materials that could be considered for REST sampling. This study was considered as a short brainstorm in which several materials would be used for sampling and submitted to the rats for evaluation. A series of seven new materials were evaluated for the application of REST by trained rats (see Figure 3 for different filter material and Figure 3 for evaluation results). As climate and other factors influenced day-to-day results, APOPO did the daily evaluation in two different cages, with two different groups of rats. One group of rats was used as a reference, and was evaluating the known PVC gauze filters sold by IVEMA. The average scores of these two cages had before proven to be almost equal.

FIGURE 3 | Different sample materials tested, from left to right respectively: PVC gauze, steel wool, cotton balls, rock wool, Polyurethane, Polypropylene, cigarette filters and Polyester fibre



Samples for both cages were taken at the same time and location from the REST test fields of APOPO in Morogoro. The majority of the materials were being tested using the IVEMA sampler. In the beginning of the test, some samples were taken by an electric pump, with a lower airflow, but this didn't seem to interfere with the results.

TABLE 1 | Average hit rate for 5 days testing of the rats

Overall results in %	Experimental filter	PVC Gauze filter
Steel wool	49,7	61,5
Cotton Balls	59,1	52,1
Rock wool (Glass fibres)	53,1	65,6
PPI (Polyurethane)	72,1	70,2
PP Dust filter (Polypropylene)	70,9	78,3
Cigarette filters (Cellulose)	67,4	76,9
Marker fillings (Polyester fibres)	77,3	65,2
TOTAL average	**65,4 %**	**64,9 %**

Based on this experiment, APOPO started using the Polyester fibre filters for further REST training. These were in fact Polyester wool reservoirs for ink used in colour markers. They were cheap, consistent and mass produced.

DEVELOPMENT OF PUMPS

The petrol engines were rather unpleasant to use, being heavy, noisy and letting out smoke. The air drawn through the PVC samples was typically in the range of 130 L/min, and this high flow would allow a relatively fast sampling pace (walking speed), but would cause the collection of surface dust and plant materials into the filter.

APOPO was therefore looking into battery powered electric pumps which would reduce unwanted issues such as noise, weight and exhaust fumes. Classic rotor pumps could do well, as long as the filter resistance was low. Biosens had developed pumps that were available off the shelf with batteries and had also developed particle filters for dust collection which had very low resistance. The final configuration is shown in Figure 4.

For the use of the PVC or Polyester Filters, both with high flow resistance, it was necessary to use membrane pumps to achieve sufficient suction. However, if a filter got clogged with dust, the power consumption would raise exponentially, depleting the battery pack in a matter of minutes.

FIGURE 4 | Electric sampling pump developed by APOPO.

SOIL VERSUS AIR SAMPLING

All the filter types tested by APOPO worked to a certain extent, as well as the chemical analysis studies carried out by FOI, APOPO and Sandia Laboratories. This showed that the rats were reacting to the soil rather than to the collection of explosive vapours emanating from the mines.

Moreover, repeated independent test showed that the rats and dogs in Angola were trained on the specific environments of the positive areas of the test fields, rather than on the explosives in the soil.

The calculations provided by Kai Uwe Goss and the publications by Gary S. Setlles[1], demonstrated that the quantities of explosives found in the soil or surface dust above a mine, are both much higher and more stable compared to explosive vapours found in the boundary layer of air above the surface.

The focus shifted to developing a sampler for collecting surface dust, rather than air. After further consultations with Kai Uwe Goss, it was decided to try to develop a sampler which would only collect surface dust in its pure form, rather than collecting it on a filter. This option would have a series of advantages, such as the reduction of consumable costs, no extra sorption by the filter element, easier spiking and chemical analysis of training and operational filters, and less requirements on the power of the sampling pump.

A few initial prototypes were developed by APOPO for surface dust sampling. One of the main challenges immediately noted was the ability to provide comparable samples over areas with different levels of vegetation, different soil types, and different ranges of humidity.

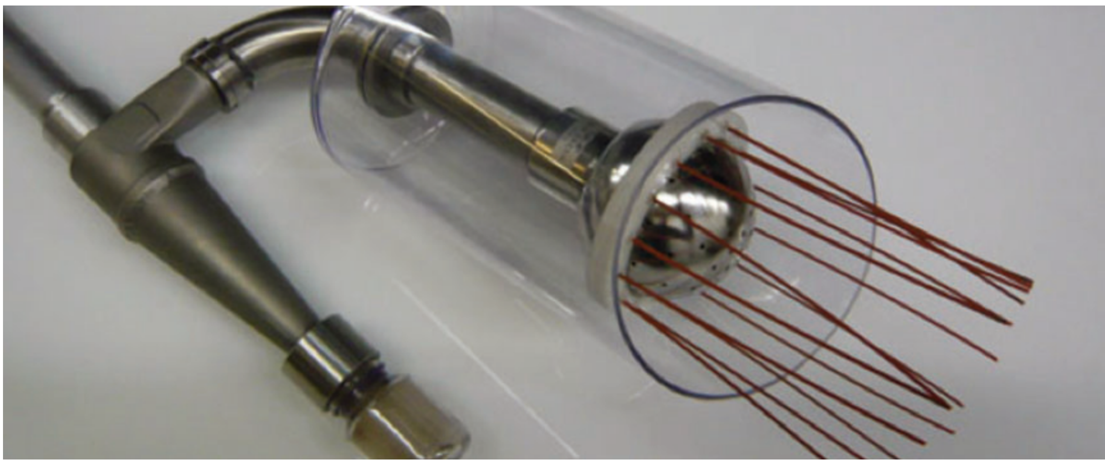
Several pump and collection mechanism concepts were tested and prototyped. For overcoming the collection efficiency difference between vegetated and non-vegetated areas, two principles were tested out. These were both stirring up the surface dust using a jet flow with compressed air, and using light brushes to do the same.

In Figure 5, the system to generate an intermittent jet flow to blow up the dust from between vegetated patches is shown. A balance was sought between the frequency and pressure of the jet flow without depleting the available pressurised air too fast.

FIGURE 5 | System for generating burst air jet flow for soil stirring. A rapid control valve allowed to set the burst jet rate/ frequency.

The pump shown in Figure 6 below uses light brushes to stir up the dust. A conic cap protects the fine dust particles from being blown away by the wind and the pump uses a particle separator which collects the heavier dust particles below in a sample bottle, and removes the very fine dust particles through a pump.

FIGURE 6 | System that uses light brushes to stir up the dust.



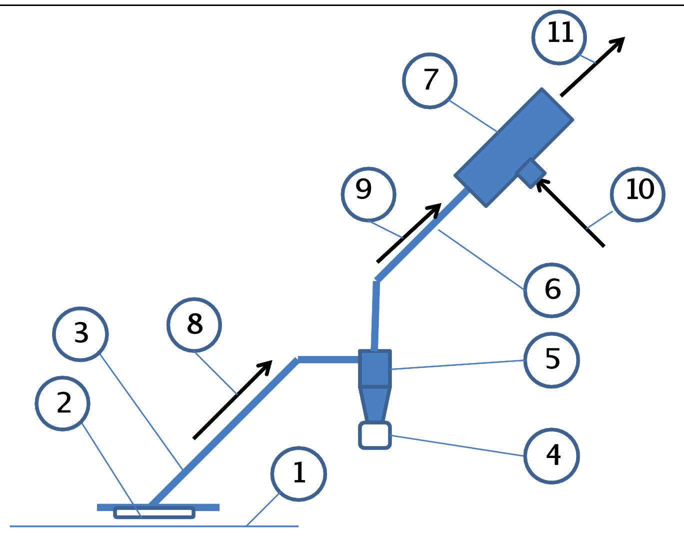
While the brush element was more efficient in stirring up dust particles, it was considered too hazardous to use in mine suspected areas. However, the particle separator was used as the central collection mechanism for the further development of the pump by Dr. Morten Kjeldsen, and his team of engineer students, Anette Uddqvist and Ida Roberthson.

FINAL SAMPLER OF THE REST PROJECT

The final sampler completed in the REST project was made as a joint project between the Norwegian University of Science and Technology and the University of Skövde. A project report was written on the later stage development of the REST sampler by Uddqvist and Roberthson[2].

The final sampler solution was based on a number of elements that were brought forward by the REST participants. This included a vacuum pump based on an ejector principle. With such a pump solution, compressed air can be used as the driving fluid for the pumping action. In addition, filter techniques had been abandoned in favour of a cyclone separation solution. Figure *7* provides schematic overview of elements included in the REST sampler.

FIGURE 7 | Overview of design elements in the REST sampler unit.

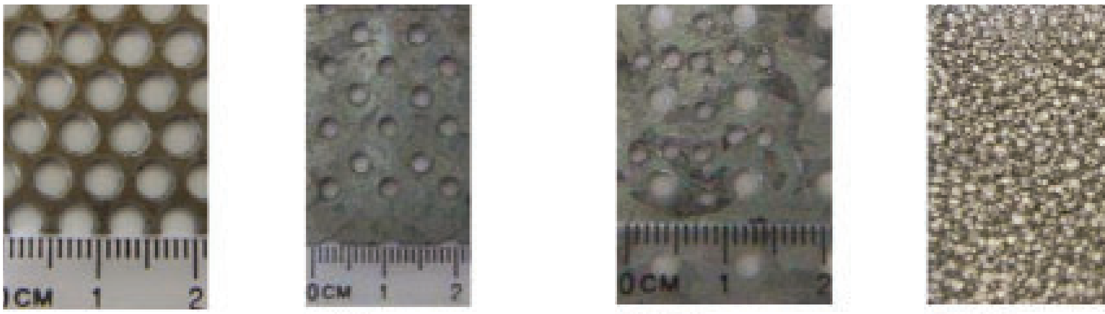


1: Soil
2: Inlet grid/ Coarse filter
3: Mouth piece.
4: Collector
5: Cyclone
6: Air ducts
7: Vacuum pump (ejector pump)
8: Suction flow (particle loaded air)
9: Reject flow (clean air)
10: Driving, high pressure, flow.
11: Exhaust gas flow.

The main purpose of the inlet grid, see (2) in Figure *7*, is to avoid dragging larger objects in the flow as if they enter the sampler they will obstruct passages and reduce the performance of the cyclone and the efficiency of the suction.

For the final sampler a number of inlet grids were tested, see Figure 8. The use of Grid 1 and 4 gave small increases in pressure drops. Grid 2 and 3 gave a measurable increase in pressure drop. Later the effect of increased pressure drop is discussed with regard to pump power requirements.

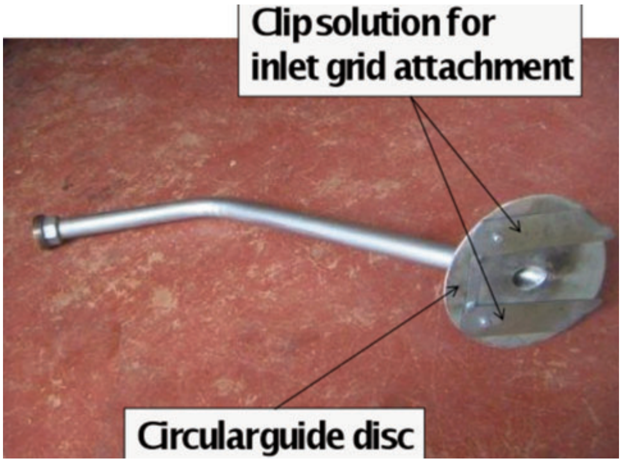
FIGURE 8 | Inlet grid tested in the REST project. After Uddqvist and Roberthson.



Grid 1 Grid 2 Grid 3 Grid 4

A sampler operational requirement is that the inlet grid should be easily replaceable, as dirt and dust can attach itself, providing a source for cross-contamination between samples. For the latest sampler version a clip solution, as depicted in Figure 9, was introduced to allow fast and easy replacement of the inlet grid.

FIGURE 9 | The mouth piece of the REST sampler consists of a guide disc, piping and a clip solution for attaching the inlet grids. After Uddqvist and Roberthson.



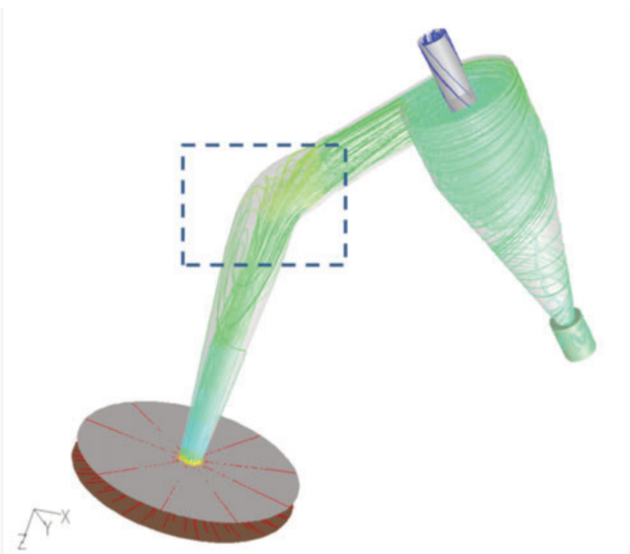
The mouth piece, see Figure 9, of the sampler is defined as the part between the soil and the cyclone, see (3) in Figure 7. The circular guide disc was included to serve a number of purposes: Ease the manoeuvring of the device, ensure that only particles between the soil and the disc are entrained by the suction flow and allow for secondary flow solutions if needed. A typical secondary flow application would be to stir up the top soil layer using air jets. This method was applied by APOPO but not together with the final REST sampler.

As the mouth piece could also be a potential cause of cross-contamination between samples, as it is not replaced between sampling of different areas, a number of approaches to minimise this can be taken:

- Careful initial design of inlet tubes to minimise the chance of particle sedimentation
- use of tubes surface treatment for reduction of the probability for sedimentation of particles on pipe walls
- a design that allows an efficient cleaning of the sampler between sampling different areas

Computational fluid dynamics (CFD) can be useful for detecting areas where the likelihood of sedimentation is large, see Figure 10. The REST project didn't conclude on material usage or specification of cleaning procedures between different sampling areas.

FIGURE 10 | **Left**: CFD calculation of a variation of the REST sampler mouth piece and cyclone. The flow field is visualised using path lines, and an area dominated by back-flows, hence susceptible to particle sedimentation, is highlighted. **Right**: A short introduction to CFD is given.



Computational Fluid Dynamics (CFD) is a term used for the collection of methods that numerically solve the governing equations for fluid dynamics.

For most CFD problems, challenges are associated with the setting of proper boundary condition, resolution for the numerical algorithms and correct physical models, including the use of turbulence models.

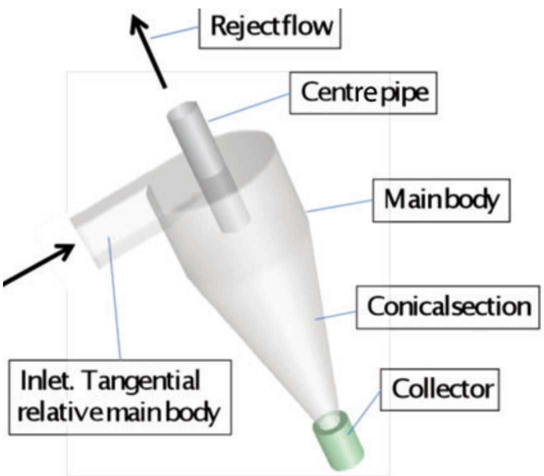
Post-processing of CFD results provides both qualitative, eg, graphical impressions of the flow, and quantitative information such as overall performance of a system.

CFD software is available both commercially and as open source. A huge number of companies worldwide provides CFD consultancy.

The cyclone particle separator and the collector (see Figure 12 and (4) and (5) in Figure 7) are responsible for separating and storing particles respectively. Ideally, all particles should be removed from the suction flow (8), such that the reject flow (9) is clean. Cyclones are commercially available, and cyclone design flow rates, associated pressure drop and separation efficiencies for given particles characteristics is usually given or specified. In Figure 11, a brief description of a cyclone is given.

The collector should be easily replaceable, and of a quality material that has little if any impact on the scent traces contained by the particles. For the REST sampler, threaded glass bottles are used. However, cross-contamination due to particles residue found in the thread parts is possible.

FIGURE 11 | **Left**: Components of a cyclone used for particle separation. **Right**: A qualitative description of the working principle of the cyclone component.



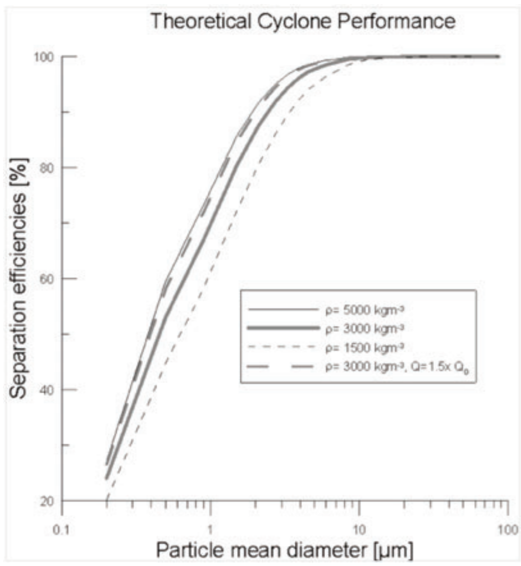
At the inlet, both air and entrained particles are introduced tangentially.

The particles with densities higher than air will move toward the cyclone wall. This migration is due to the fact that the centrifugal force significantly exceeds the gravity forces due to the strong acceleration of the flow in the radial direction.

Due to turbulence, short residence time within the cyclone and drag forces, smaller particles are likely to be entrained by the reject flow. The efficiency of a cyclone is often determined by the smallest particle (of a given shape) that, with a high certainty, is captured by the collector.

The performance of the cyclone can be determined using CFD (see Figure 12 for predicted performance for the REST sampler). The cited evaluation is using spherical particles in the calculations. Larger particles can easily be entrained by the reject flow if they are irregular in shape and have a larger drag coefficient. When designing the total system, it's necessary to match the pump performance with the cyclone performance. For the current REST sampler, lifting of settled particles in the collector is observed for high flow rates. This suggests that there is an upper threshold for suction flow.

FIGURE 12 | Calculation of cyclone performance modelled for the REST sampler cyclone. From the graphics it can be seen that for (spherical) particles larger than 10 µm, close to 100 per cent separation is achieved. For the calculation, spherical particles are assumed, as irregularly-shaped particles can introduce a significant reduction in performance. For the actual calculations, the exact geometry of cyclone internals was not known.



Regarding Figure 7, the components subsequent to the cyclone are the air ducts (6) and the vacuum pump (7). The design of the air duct is trivial because the contribution of this component to cross-contamination between different sampling areas is probably non-existant. Accumulation or sedimentation of dust within the pipes is possible, as is drop-out of said accumulation during handling between different sampling. For the REST sampler, none of these concerns were addressed.

The vacuum pump of choice for the REST sampler is of the ejector-pump type, the working principle of which is depicted in Figure 13. A significant benefit for such pumps is the lack of rotating or moving parts, which makes the pump unit more robust and reliable in field applications. As noticed in Figure 13, the power required to drive the pump is due to a high energy/velocity jet introduced in a mixing chamber. Through conservation of impulse, it can easily be found that the mixing chamber will exert a pull on the suction flow. The diffuser section will dramatically improve the performance of the pump unit. In Figure 14 a, a comparative study between ejector pumps is presented.

One significant difference between the two pumps was the lack of an expanding section for the basic pump - this fact alone is believed to explain most of the differences between the two. The REST sampler performance was mostly measured against mass flow consumption by the drive flow of the ejector pump.

FIGURE 13 | Schematic on the principle of vacuum pumps. The power required to drive the pump is provided by the high energy/high velocity drive flow.

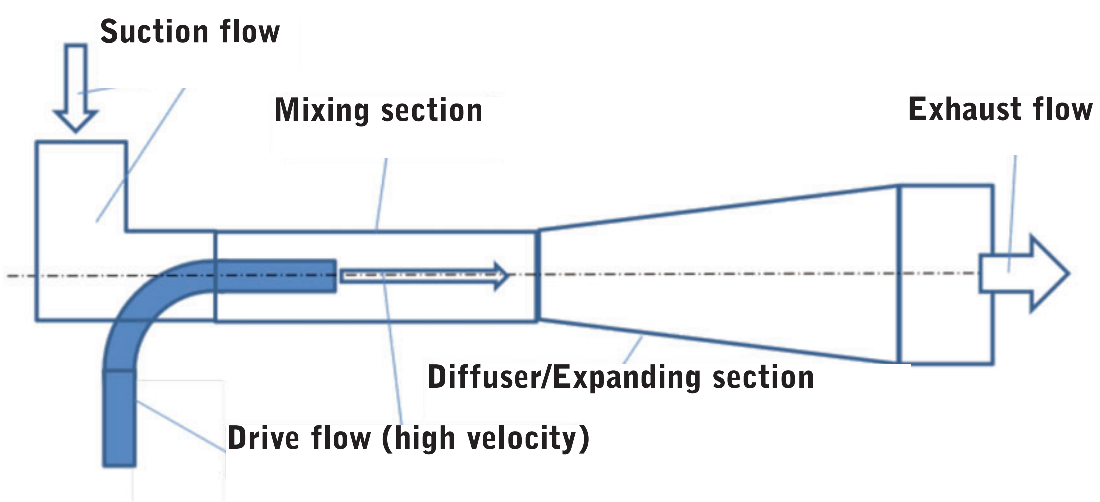
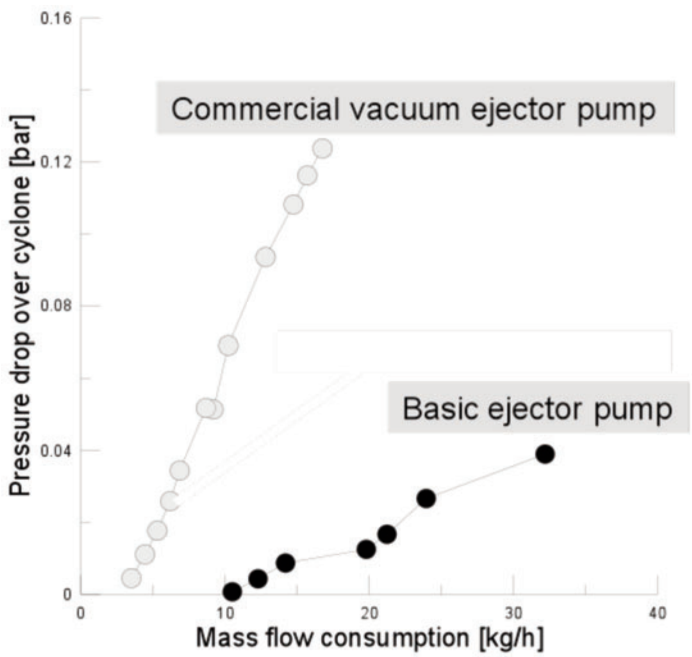


FIGURE 14 | Performance behaviour comparison between two ejector pumps. The mass flow consumption refers to the required flow through the high velocity/energy drive flow. The pressure drop over the cyclone is roughly proportional to the suction flow velocity squared.



When composing the REST sampler system, the pump characteristics must match those required by the cyclone. Commercial suppliers of vacuum ejector pumps will provide pump characteristics that allow a proper sizing of components.

One important component of the REST sampler system is the device that provides the necessary power to drive the vacuum pump. Currently, the preferred method to provide the power is through a pressurised vessel, as used by scuba-divers. One benefit of this is that the operator of the sampler has no need to carry a compressor, which reduces the noise level significantly. The weight of the vessels reduces the versatility of the total system. For the REST sampler, and with the current vacuum pump- cyclone configuration, the useful operation time with one vessel is in the range 15- 30 minutes. This is considered too short, and discussions on improving this will be given in the section “Suggestions for future sampler development” below.

EXPERIENCES USING THE REST SAMPLER

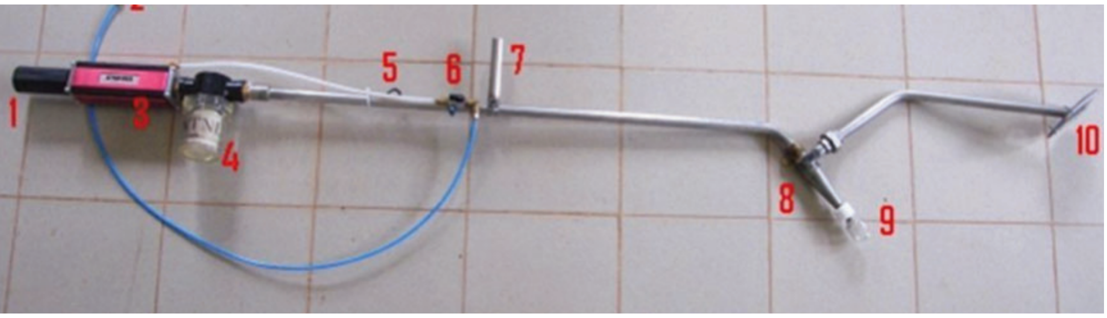
The final sampler in the REST project was completed by Anette Uddqvist and Ida Roberthson. In addition to the requirements and specifications put forward in the previous section, emphasis was also given to the ease of operation.

Figure 15 shows the sampler, minus the air pressure vessel kit. It is well-balanced enough to ease strain on the operator, while still enabling good control of motion over the soil surface, and maintaining the distance between the circular disc of the mouth piece and the soil.

FIGURE 15 | REST sampler carried by operator.

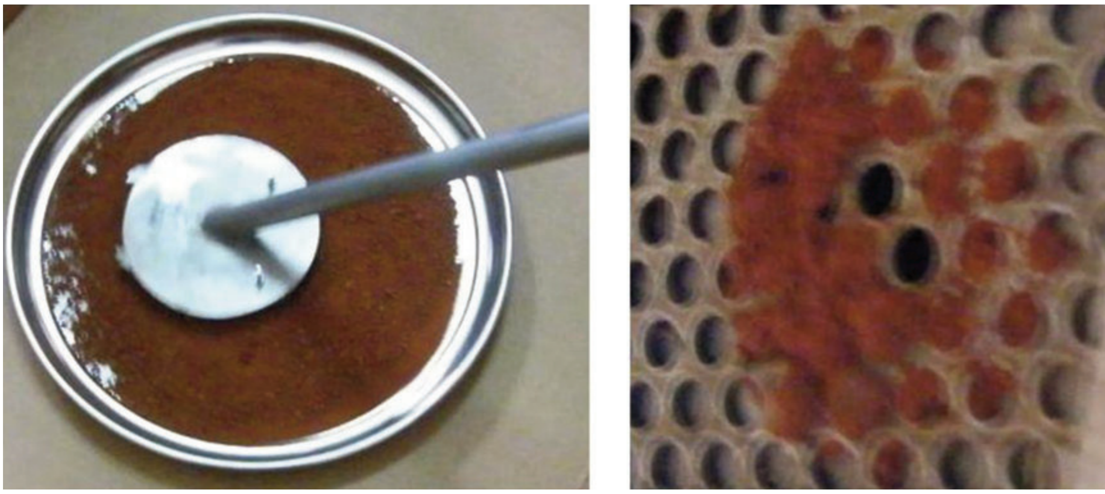
The final version of the REST sampler is seen in Figure 16. In addition to the components already discussed, the final sampler has a hinge point, see (5) in Figure 16, where the weight of the sampler is transferred to the operator suit. A handle (7) is mounted for sampler motion control, and finally an on-off valve is installed (6) for operation of the vacuum pump.

FIGURE 16 | Final version of the REST sampler as developed by Uddqvist and Roberthson. (1) is a silencer that reduces noise emission from the vacuum pump, while (4) is a filter protecting the vacuum pump internals.



With experience. it was found that Grid 3, see Figure 8, reduced the entrainment of unwanted objects or waste compared to the other. The penalty for using Grid 3 was a higher pressure drop, and therefore less operation time for one pressure vessel. As can be seen in Figure 17, a significant amount of soil can settle on the inlet grid. In the REST project, no specific investigation on settlement of soil/dust elsewhere in the mouth piece was made.

FIGURE 17 | Sample sampling and contamination inlet grid.



Using light microscopy, it was found that when inspecting particles collected by the system, particles less than 50 µm were separated from the suction flow. A particle or dust residue in the threaded joint between the collector and the cyclone was also observed. As Figure 18 suggests, significant amounts of particles must have exited together with the reject flow and been captured by the vacuum pump filter. In the project, the characteristics of particles trapped by the vacuum pump filter weren't quantified. The REST project didn't include an analysis of the consequence on the pump when removing the filter.

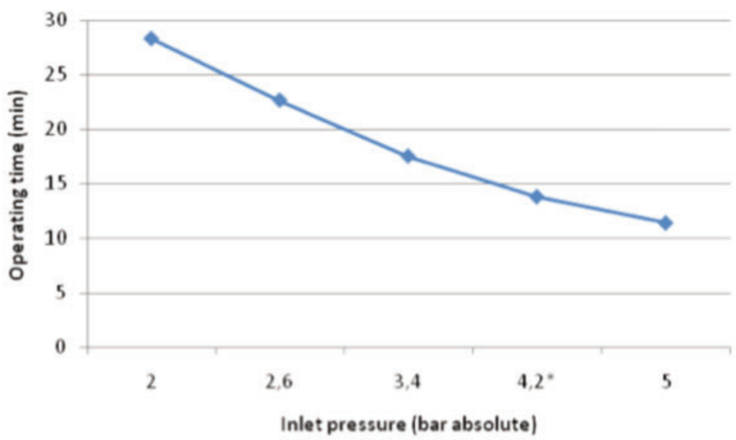
FIGURE 18 | Vacuum pump filter elements, see (4) in Figure 16, before and after usage.

Test sampling for various drive flow pressures were made, and the total weight of the captured samples were measured to be as shown in Figure 19. Typically, the sampling distance between the circular disc of the mouth piece and the soil is four cm. Now, the different drive pressures cited in Figure 19 will determine the efficient operation time of a filled pressure vessel, see Figure 20

FIGURE 19 | Performance of sampler as a function of drive pressure, and hence suction flow velocity.

Pressure (bar)	Amount sampled (g) 1 min	Amount sampled (g) 30 s
1	0,0464	(–)
2	1,6181*	0,0112
3	0,1356*	0,0141
4	0,0759	0,0056
5	0,0032**	0,0149
* Touched the ground		
** Ran out of air		

FIGURE 20 | Operation time for one pressure vessel for various vacuum pump drive pressures.



As a final test, a field sampling was performed by Uddqvist and Roberthson over a distance along a dirt road outside of the REST offices in Morogoro. The distance was roughly 50 m, covering a width of roughly 2 m and with an average speed of about 0.5 m/s. The experience from this testing was summarised by Uddqvist and Roberthson as:

The road tests showed that samples can be collected both when the sampler is moved fast and at an overgrown area.

SUGGESTIONS FOR FUTURE SAMPLER DEVELOPMENT

The REST sampler is based on design elements that are well-proven, but the system and its components allow for improvement. A number of suggestions aimed at increasing versatility and performance of a future REST sampler is given below.

When completing the system, a match between the vacuum pump and cyclone specifications must be ensured. Furthermore, the cyclone should always fit the current sampling conditions. One way to adjust the sampler is to have replaceable cyclones and a flexible vacuum pump. For the latter, a pump containing two mixing chambers could be made to enable serial or parallel operation between the two.

The inlet grid will be a significant source for cross-contamination between different sampling areas, however, with the current configuration, can be easily removed. The clamp-on/ attachment devices, see Figure 9, will still be prone to contamination. Uddqvist and Roberthson suggest using a grid that covers the whole circular disk of the mouth piece, ie, attached on the side of the disc not facing the soil. One variation of such a solution is shown in Figure 21.

FIGURE 21 | Suggested inlet grid solution covers the whole circular disc of the mouthpiece facing the soil. After Uddqvist and Roberthson.

For reducing cross-contamination risks between different sampling areas, an effective cleaning technique should be developed for the inlet mouth piece. This could be "gun barrel" type cleaning devices soaked in acetone.

As mentioned, the effective operational time for a filled pressure vessel is limited (see Figure 20). It's also evident that a significant part of the initial energy is throttled from vessel pressure, typically at 60 bar, to vacuum pump operation pressure, roughly at four bars. The air pressure source should therefore always be considered fed from other sources, such as a battery powered or combustion engine driven compressors replacing the pressure vessels. In the REST project, battery powered solutions were tested early in the project but then dismissed due to a short duration of battery life. Development has increased performance of batteries, but also the efficiency of the REST sampler, so that batteries, together with a portable electric motor-driven compressor should again be considered.

ENDNOTES

1 Aerodynamic sampling for landmine trace detection, SPIE AEROSENSE, Vol. 4394,0paper 108, April 2001

2 Anette Uddqvist & Ida Roberthson " Improvement of sampling system for remote explosive scent tracing", B.Sc. thesis, University of Skövde, Sweden, 2010.

CHAPTER 9

THE ODOUR SIGNATURE PROJECT (OSP)

by Conny Aakerblom

CHAPTER 9

THE ODOUR SIGNATURE PROJECT (OSP)

INTRODUCTION

The Geneva International Centre for Humanitarian Demining (GICHD) has been involved with support for mine detection dog training and research since 1999, when the Centre was asked to act as the focal point for mine dog development. Since then, the Centre has carried out mine detection dog studies on training, standards for mine dog training and operations, test and licensing, and research.

In 2003, the Centre was tasked by the United Nations Mine Action Centre Afghanistan (UNMACA) to carry out a performance and needs assessment of mine dog operations in Afghanistan, which led to the creation of a support programme under contract from UNMAS through the United Nations Office for Project Services (UNOPS). The programme of support for mine detection dogs in Afghanistan has continued to the present, although it is planned to end in March 2011. The aim of this programme has been to develop improved ways in which mine detection dogs (MDD) can be trained, which can be applied to any national programme using them. The GICHD programme has also studied basic subjects, including how explosive vapours migrate through soils, and knowledge of how dogs pick up the scent of mines, exactly what scents and odours they smell, and how their scent detection capability can be affected by the many environmental factors found in the field. This knowledge has been a necessary background to the Centre's assessments of how MDD can best be trained, and has led to modified training methods and equipment specially designed for the Afghan MDD programme.

During the support programme, the GICHD team noted that there were increasing difficulties in establishing and reliably maintaining high quality training, and high quality testing to confirm this training. Basic training and passing the license test are not enough - the ability of the dogs and handlers to consistently search for targets without missing any target-related odours over time has to be maintained and regularly tested. Dogs need to be tested daily to check their search capability, and both the dogs and the handlers need weekly remedial training to prevent bad habits developing.

In both training and testing, dogs should be presented with targets to detect, which should be as similar to real mines as possible. In the past, real mines were almost universally used, but they can pose problems. Mines for training are not always available, there are security implications using them. Also, avoiding non-target related cues and cross-contamination between target odours and non-target related odours (such as ground disturbance and human scent from handling the training materials) can cause problems.

The availability of mines for field training became influenced by two external factors, the increasing universality of the Anti-Personnel Mine Ban Convention (APMBC - also known as the Ottawa Treaty), and the introduction of International Mine Action Standards (IMAS). The APMBC requires all its signatory nations to destroy all anti-personnel mine stockpiles, and severely limits the number of mines that nations can declare as for use in training and research. IMAS strongly recommends that any mines detected during clearance should be destroyed where they are, or removed from the minefield for destruction as soon as possible. In practice, these two factors have reduced the availability of mines and other explosive targets, and increased their cost and scarcity value.

THE ODOUR SIGNATURE PROJECT (OSP)

Another and more dangerous factor influencing the use of real mines has been the increasing value of mines as terrorist weapons, and real mines without fuses can easily be turned into active mines, or used as a source of explosives for improvised explosive devices (IEDs). Therefore, training and test sites are fully fenced off and guarded 24 hours a day. Transportation of mines between one worksite and another for field training of dogs is a more hazardous process. However, even fencing and guarding has not protected some test sites, including the main Afghan mine dog test and licensing site at Charasiab between Kabul and the Logar province, which was attacked and burnt out in August 2008, resulting in the loss of many mines.

These security problems accelerated the need to develop targets that could not be moved, and many ideas were tried, such as setting mines in concrete and metal cages to make them more difficult to shift. However, this solution complicated and corrupted the odour signature of the mines and UXO targets, and made the carriage of such mines for field use impractical.

Well before the attack on the Charasiab site, the GICHD recognised that the problems of using live mines for training and testing could only be addressed if a target system could be developed which had no value as an explosive, but would still smell like a specific mine or UXO to the dog. In early 2006, the GICHD let a contract on the Swedish Defence Research Agency (FOI) to examine the possibility of creating such a scent as part of a study into odour signatures. This became the Odour Signature Project (OSP).

The starting point for this study was examination of solvents for TNT and other explosives, and water was found to be the best, because it is present in most soils, and is the most natural and strongest conduit for the transportation of explosive-related vapour from a buried target to soil surface. It was therefore decided to use aqueous solutions, but these still needed checking to determine whether these solutions would make suitable odour signatures to mimic real targets.

The OSP project was valuable and carried out through a series of sub-studies. It developed the exact methodology for preparing and using aqueous explosive solutions as targets, and provided kits with all the syringes and handling equipment needed to prepare targets by "spiking", preferably using the explosive from a local mine. The spiking material needed to be made up on site by local dog training staff. Parallel to this, storage conditions for solutions of TNT were developed (sub-study 2), as well as the training of MDDs, using the locally prepared spiked samples (sub-study 3). The development study then introduced the concept of copied signatures of the buried mines, such as:

- mine-case, cover and explosive filling (sub-studies 4 and 5)
- different spiking odour concentrations (sub-study 7)
- different manufactured types of the same explosives (sub-study 8)

The results of the spiking study were used in the REST programme in Tanzania, where some interesting results were obtained.

This OSP study provided the basic information on the preparation of target solutions, which were then applied to compressed soil targets, which were chosen because:

- they can be seen and handled the same way as a mine
- they can be stored and transported as easily as liquids
- placing solid targets is similar to setting mines and a simpler process than injection of liquids

The design of the soil target was carried out as a joint operation. The GICHD developed the concept of compressing spiked soil and the production equipment. The FOI provided recipes for water-based explosive solutions, and carried out trials to check that the odour signatures produced by the soil mine was as near as possible identical to a real mine.

The production of soil mines was simple in concept, but needed close attention to detail. The soil targets are produced by taking soil from the appropriate local minefield or test area, and mixing it with a water solution produced in a similar way to the spiking study, using explosives taken from local mines. The mixture has a soil to liquid ratio that depends on the type of the soil, and the wanted concentration level for mimicking a real target. The mixture is then put into a hand-pumped hydraulic press specially designed by the GICHD. Since then, extensive trials have been carried out to ensure that the correct compression is applied in each case, to produce a target that is solid, easy to handle and without any unwanted contamination.

The shape and size of the resulting target (82 mm x 20 - 30 mm) closely resembles an average anti-personnel mine or a large ice-hockey puck, so the targets are locally known as pucks. The amount and concentration of explosive liquid can be varied, and the following pucks can be produced:

- neutral pucks with no explosives, only water.
- pucks that have non-target related materials such as plastic, metal or any disturbing odour from frequently found items
- soil with purified TNT (producing only the TNT scent)
- soil with solutions of military grade explosives as found in mines
- soils with as much target material as possible, including powder or bits of case where possible

Each type of target has a specific role to play, as a search in a real minefield results with few real targets being found. Pure explosives such as TNT is common to most mines; military grade explosives always have impurities from the manufacturing process; and a puck with the full target material will probably represent the target mines more fully. Each puck takes about three to four minutes to produce, but this time will be reduced when full production starts in March 2011. There are two puck presses currently in Afghanistan, and several MDC staff members are already fully trained and qualified to use them for puck production.

FIGURE 1 | MDC staff collecting soil for production of harmless targets

Smaller versions of the pucks, called target pellets (10 mm x 2-6 mm) have been developed for the training and establishment of stimuli control. Producing target pellets uses the same basic materials, and these are small enough to be used on the surface for field training. The puck presses can produce 24 pellets at each compression.

FIGURE 2 | MDC staff producing Soil/mine-signature targets

Process

Although the manufacturing of pucks appears to be simple, absolute cleanliness is necessary to avoid any kind of unwanted cross-contamination during the production process. That is why the press operators wear gloves, laboratory coats and face masks to prevent them from contaminating the puck materials. During and after production, the pucks are handled with decontaminated stainless steel tongs, and stored in special stainless steel containers. While being set in the ground, they should also be handled with clean stainless steel tools that have been decontaminated to remove all traces of explosive material or odours providing possible cues. The need for this cleanliness is often difficult to explain to the production staff, who are more used to using gloves to protect themselves from pollution rather than the other way round.

Pucks are then moved in the special containers to where they are to be set, and buried about 1 mm below the prevailing ground level. This allows the vapour to start percolating outwards quickly, and prevents the need of long "soak times" required for actual mines (three to six months, depending on soil condition and environmental factors).

ADVANTAGES OF PUCKS

The puck characteristics can be tuned to meet the requirements of almost any minefield or training area. The amount and concentration of target liquid can be varied, as can the pressure applied. Development is still in the process of making the pucks more versatile and easy to tune. Provided that simple rules for avoidance of cross contamination and soil compatibility are obeyed, pucks can be made in any mine clearance area. Unlimited numbers and sizes of on-site training fields can be developed, allowing dogs to receive realistic continual training. This is instead of actual mines or lumps of explosive from different mines which have been handled by trainers and are heavily contaminated with various explosive and human smells. This could truly be a major step forward.

Pucks are safe to use and set in the ground, and easy to transport and store. They will last at least one year in the ground while still producing vapour, and it is expected that this time will be extended as the trials continue. When they are no longer needed, they will revert to the basic soil from which they came. As a source of explosive they are completely useless – the few cubic centimetres of liquid contain miniscule amounts of explosive compounds and can be transported on ordinary airliners without any danger. The certificate for air transport within Sweden has already been obtained.

Research and development of the pucks have been matched by an increase in the capability of the analysis capability in FOI. During the trials of pucks, soils samples were taken and sent to Swedish FOI for analysis, to check that the vapour and the fine dust particles on top of the soil surface contain the same chemical compounds as mines. Further techniques and equipment have been developed by the REST project, allowing the air above the pucks and mines to be sampled and analysed, a process that more closely imitates what the dog actually smells. This equipment will be further developed and used in the OSP project.

The pucks are subjected to rigorous testing both in Sweden and Afghanistan, alone and in conjunction with real mines. This form of "double blind" trial allows direct comparisons to be made during the search process. The Mine Detection Centre of Afghanistan (MDC) recently carried out its own independent trial, as a result of which it is now confident that the new targets can be used, and is anxious to get them put in test boxes outside the perimetre of the MDC guarded compound. The Mine Action Coordination Centre (MACCA) in Kabul is keen to get puck targets in place to prevent further theft or attacks on their mine dog test and licensing facilities, and to allow proper maintenance training to take place in MDD field operations all over Afghanistan.

FIGURE 3 | Target as it looks like when it comes out of the "puck press"

FIGURE 4 | Mine-signature targets after production

Therefore, harmless nil-value soil targets are essential for many aspects of mine detection dog training and testing. However, further development work is still in progress to further tune target specific odour signatures, puck production and the associated equipment, and to familiarise the MDC and MACCA staffs with the routines of laying and checking soil target test fields. The work will be done in close cooperation the MDC staffs, who are currently the leaders in this area of expertise in Afghanistan. The knowledge of making and using the harmless nil-value targets system will be transferred to all MDD using organisations in Afghanistan, and it is then up to each organisation to decide whether or not to adopt and use it.

It is clear that the test and training regime that has been created in Afghanistan could also be transferred to other countries, such as Cambodia and Yemen. Programmes in Tajikistan and its neighbours have also shown great interest. That said, success will only be fully achieved when Mine Action Coordination Centres trust and use soil targets for testing and licensing, and every organisation using MDD is willing to accept spiked soil targets for field continuation and remedial training.

FIGURE 5 | MDC staff planting training targets in a training field

CHAPTER 10

AN ALTERNATIVE TO REST FOR LANDMINE DETECTION

by Terje Groth Berntsen

AN ALTERNATIVE TO REST FOR LANDMINE DETECTION

THE LAND RELEASE CONCEPT

In land release, land that is suspected of having mines is subjected to a non-technical survey (NTS). This results in either proving areas to be free of mines and releasing them, or in confirming areas that need to be cleared (Confirmed Hazardous Areas/CHA) or further surveyed through technical methods (technical survey/TS). This will then result in proving these areas free of mines and releasing them for human use.

This process leads to an evidence-based decision process to release land. An essential part of this process is that all reasonable effort is applied to ensure there are no mines/ERW in the area that is to be released. For better understanding of land release, please refer to Bach (this volume).

DEVELOPMENT OF USE OF MINE DETECTION AND EXPLOSIVE DETECTION DOGS (MDD/EDD) IN LAND RELEASE: FROM CLEARANCE TO TECHNICAL SURVEY

While REST for landmine detection was being explored, the use of dogs in the field of land release continued to develop. Initially the dogs were developed to be used as area reduction/clearance tools. Over the years, several organisations have used them successfully for this purpose in different ways. Their use has expanded from detecting buried mines only, to detecting all kinds of ERW and UXO, and they have developed from being used as an unrivalled clearance tool to a useful asset during TS.

In contrast to some other organisations, Global Training Centre (GTC) has always put a strong focus on developing a rigid search pattern for their mine detection dogs (MDD)/ EDD. The dogs are trained using either a short or a long leash search pattern.

The short leash search pattern involves the dog searching while walking parallel to the handler. It searches on the outside of a safe line while the handler walks in the safe area. If the dog does not find anything, the handler moves the safe line over the strip of land his dog has just cleared and continues on the next strip. In some countries, two dogs need to clear each strip before the safe line is moved. This method requires and inspires extreme confidence, because the handlers walk over the area their dogs have cleared.

The long leash search pattern is more difficult to train. Here, the dogs work perpendicular to the handler, searching in a straight line ten metres from the handler, turning left on command and searching back. In this way, strips of land are systematically cleared, while the handler remains inside the safe lanes. Dogs used in this way need to work more independently than short-leash dogs.

Separate from the training of the box-search pattern, GTC has always trained their dogs to search objects such as cars, piles of stones, walls, and rooms, allowing them to be used effectively for clearing houses or ruins from explosives.

Another training technique used by GTC is known as “hot lanes”. This enables the dogs to search straight out from any point in a given direction. It is primarily used to teach the dogs to work without guidelines, because in countries where the box-system is not used, dogs must work in a systematic manner without the aid of, for example, mine-tape along the sides of the boxes. This focus on search patterns and "hot lanes" as an integral part of the training, has allowed for the further development of the deployment of these dogs during clearance, as it permits a more flexible deployment of the dogs.

Manual deminers used to create safe lanes in areas that needed to be cleared, but now long leash MDD/EDD are used as they are faster and more effective. In countries such as Bosnia, CHAs are divided into boxes by safe lanes one to two metres wide, and then the dogs are used to further clear the area.

Another step in the development of creating safe lanes is the use of dogs in TS, wherein breaches are made into the SHA, either manually or with long leash MDD/EDD. Systematically breaching an area will clear a percentage of the land of mines. According to the national standards, a NMAA may determine a percentage of the land to be examined or verified in this manner, and if it doesn't contain any mines, this is sufficient evidence to release the land, following the evidence-based decision process. If evidence of mines or ERW is found, the area is upgraded to CHA and following IMAS or NMAA's guidelines, a polygon for clearing is established.

Dogs can also be used in other ways during a TS. When assessing land, specific hot spots needing further examination can be defined, eg, areas where an explosion has taken place in the past, or which are strategic strongholds. These areas may have been identified on a map prior to the survey, but may be obscured by bushes or the lay of the land, and long leash MDD/EDD can be used to clear a path to them. Here again, the use of MDD/EDD fits into the land release concept. Examining such spots is usually part of the "all reasonable effort" that has to be put into a survey leading to the release of the land.

THE ROLE OF REST IN LAND RELEASE: FROM ROAD CLEARANCE TO TECHNICAL SURVEY

REST has been developed with the idea of using it as a clearance tool, most importantly in road clearance. The basic idea was to take air or dust samples from defined stretches of roads, and analyse these samples elsewhere. The advantages of such a system have been discussed in this volume.

The sampling part of REST gradually evolved from air to dust sampling, in order to obtain samples that contain enough mine-related components for the animals to be able to detect the mines, as described elsewhere in this volume. The sampling has always been seen as a manual process, where technicians would follow in the tracks of a CASPIR, collecting samples of dust. Although the project did not get to a stage where predictions could be made about the size of area possible to sample each time, it became clear that the original concept based on air sampling of road stretches of 100 metres would not be achievable with dust sampling.

The animal detection part of REST has struggled with developing a training technique that would not generate false alarms while still being able to detect the presence of mines in samples. This has led to stringent requirements for the sampler and its use. In 2008, Joerik Machiels designed a fully automated sampler he called the WaziWazi that included a grass cutting device in the front and an air sampling method that barcoded the individual samples and linked the sampled area to specific map coordinates.

Although this was only a design exercise as a part of his study at the Hogeschool Antwerp, the results illustrated the complex logistics and practical challenges of the sampling process. In 2010, students from Sweden studied contamination issues concerning a prototype sampler and their results again gave reason for concern.

Taking the issues mentioned above into account, sampling for REST becomes more complex if it is to be used as a clearance tool. The stretches of road that could be covered with a dust sampler will be much smaller than originally anticipated with an air sampler. The field logistics of ensuring that the samples are not contaminated and are properly labelled are daunting. Transport to another area where the samples are to be analysed by dogs or rats could also provide unforeseen problems, as does taking possible indications of such analyses back to the field.

Using REST as a TS tool could be more fruitful, in that spot sampling areas of interest and having these samples analysed by animals located in the region appears feasible. To be an asset, this process should not take long. Because no animals have as yet been fully trained, it is not possible to predict if such a system could work. That would depend on the possibilities of setting up a REST animal facility in the proximity of areas under TS, and quickly training the animals under the local conditions.

NEW DEVELOPMENTS WITH MDD/EDD: ENHANCED SEARCH

Given the planned NPA mine action intervention in southern Iraq, where SHA could contain mixed cluster, UXO and possibly IEDs, GTC decided to develop a specific search pattern designed for route clearance with limited personnel risk. The foundation of this was the MDD long leash search pattern, utilising the "hot lane" part of the training described earlier. The search pattern was extended and the dogs were trained to search in much longer lines, either on or off leash, the most practical application seeming to be around 75 metres. The dogs could be called to return using a technical device if necessary. They searched a number of lanes on or beside a road depending on the width of the road, the quality of the soil and the wind. Two or three lanes on a narrow road are usually sufficient. Besides working the length of the road, they can also be directed at any angle to the road into the verges to examine objects that are suspicious or seem out of place. They are also trained on object search, so they can examine the sides of a bridge or a wall along the road.

In order for this to work well, experienced MDD/EDD proven to be environmentally stable were first chosen. For these dogs, the ten metre long leash search pattern had to be extended, but surface targets are relatively easy compared to the buried mines the dogs had been trained to detect. Surface targets are large odour sources compared to mines. Even when buried, they stick out more than mines that have been in the ground for years. After the system had been proven successful, new dogs were trained for this purpose. Besides being trained in the extended long leash system, the dogs were given much more environmental training, with a very wide range of surface and recently buried targets.

ALTERNATIVE TO REST: COMBINING ENHANCED SEARCH TECHNOLOGY WITH AN MDD/EDD FOR "ROAD RELEASE"

As a result of the land release concept, releasing a road for use has changed from clearing the full road to a more graded, evidence-based release approach. Surveying a suspected hazardous road with "all reasonable effort" will usually combine TS with clearance of identified hot spots. Of course, it would be possible to use REST technology at these hot spots in the manner that has been described before: technical samplers following in the tracks of a CASPIR, taking dust samples that are later analysed at an animal facility. However, an alternative could well be to use an MDD/EDD, especially one with some additional enhanced training along the lines described above. These dogs would be trained in long search lane patterns. Searching at angles to the road and searching specific objects/hot spots along the road is already part of their training and often part of their accreditation as a TS tool.

A TS of a road could mean a CASPIR driving down that road with, for example, a large loop in front of it. Experienced surveyors assess a road in this manner and identify areas that warrant further investigation. At the same time, the CASPIR could be transporting a few MDD/EDD and a handler trained for this purpose. These dogs could be deployed at the areas that need further investigation in much the same way as the REST samplers would have been deployed. The handler remains in the tracks of the CASPIR, directing his dog to search lanes to the left and right of the CASPIR tracks, and if necessary combining it with a lane in the middle of the tracks. The dogs could also be directed towards searching lanes at angles to the road, in the direction of suspected hotspots, and could be used to search strategic points such as bridges and tunnels.

The advantages of such a system over REST are abundantly clear. Instead of having to wait for samples to be analysed and perhaps having to return to areas that need clearance, the hot spots are investigated immediately, and if nothing is found, they are immediately cleared. This not only saves time, but also prevents logistical mistakes of incorrect labelling or registration of sample GPS coordinates.

The MDD/EDD used for road release need to be kept highly trained as they will be operating in very diverse environments. Alongside the CASPIR, a single handler can work with several dogs, however because of the high level of training required, and the skill needed to handle multiple dogs, a highly qualified handler/trainer, usually an experienced expat would be necessary. Because the handler will be working with several MDD/EDD, the additional expenses associated with an expat will be spread over several dogs.

An important part of the land release concept is that tools used in the process should have a confidence rating. Because land release is governed by an evidence-based decision process, the reliability of the tools that provide the evidence for the decisions should be known. This allows for the quantification of survey information to facilitate improved decision-making. In this respect, MDD/EDD already have a solid track record. Accreditation of MDD/EDD for road release needs to be arranged by some NMAAs, but in general, countries that already use MDD/EDD for TS can use them for "road release" too.

CONCLUSION

In my view, the REST system as a mine action road clearance tool is no longer necessary, because of a proven alternative tool available. Based on this conclusion, NPA has decided to no longer fund the development of REST. The use of the technology for other purposes, especially in those cases where the targets are bigger or more volatile, and/or where the sampling volume is smaller, is certainly promising, and much of what has been learned in the research and development of REST for landmine detection can be applied there.

CHAPTER 11

THE FUTURE OF REST | AN OPERATIONAL PERSPECTIVE

by Håvard Bach

CHAPTER 11

THE FUTURE OF REST | AN OPERATIONAL PERSPECTIVE

SUMMARY

Most elements of REST are now sufficiently researched and understood, a result of multiple scientists, institutions and demining organisations working in partnership to improve components contained in the generic term REST. Despite good progress there are still unresolved research questions that prevent a full conclusion on the real potential of REST in mine action. While much has been done to identify potential problem areas and systematically address them, these system enhancements have not yet been fully tested and validated by animals under real conditions with real scent from landmines. It is therefore dangerous to make conclusions on how well REST works in mine action, and more efforts are required to finalise the last stage of the research process.

If we assume that animals are able to detect minute traces from landmines not limited to explosive compounds it is worth discussing how REST can be used in mine action. Recent concept evolutions have recognised improved roles of various assets in technical survey. Some of these assets were historically considered for clearance but improved knowledge about how to make use of almost any asset and method in technical survey is changing the picture. REST may benefit from new concepts of land release and be considered in a role of technical survey. Understanding the concept of technical survey will inevitably resolve some problems, but new challenges will arise. Operational opportunities and constraints when considering using REST are further discussed in this chapter.

INTRODUCTION

There are two principle paths to using animals in mine action. The most common way is the direct detection of mines in the field. Less common is indirect detection; animals to detect traces from landmines in air/dust samples taken from suspected minefields or, more commonly, from roads, then presented to specially trained animals for analysis in a laboratory environment. This system is given the generic name Remote Explosive Scent Tracing (REST), but is also known under the brand name MEDDS (Mechem Explosive and Drug Detection System).

REST (MEDDS) used to detect traces from weapons in cargo in South Africa (mid-80s)

Casspir with suction tubes during sampling of power lines in Mozambique (Mechem, early 90s)

CHAPTER 11

THE FUTURE OF REST | AN OPERATIONAL PERSPECTIVE

REST is not a new technology. The Dutch police have used the principle of remotely analysing human scent for almost a century and still train dogs to remotely detect odour on metal sticks that have been in contact with humans. The South African company Mechem first developed modern REST in the 80s and has continued to use the system in several countries up until today. The Norwegian People's Aid (NPA) and APOPO have also invested heavily in developing REST, in close collaboration with the Geneva International Centre for Humanitarian Demining (GICHD).

Despite questions related to the quality of REST, it has been the preferred technology for approximately 90 per cent of all global road verification funded by the international community over the past 15 years. This underlines the importance and potential of REST. The UN has spent considerable amounts on REST for the verification of between 30 and 50 thousand kilometres of roads in countries like Mozambique, Angola, Afghanistan and Sudan, and there is still a high demand for it. If the quality of REST was proven and the system was commonly available, the cost of verifying roads would decrease and the ability to verify large road networks within comparatively short timeframes would increase. Yet few organisations have invested in REST, and only one company has used it consistently over long periods.

An obstacle to a more widespread use of REST is that the process is poorly understood, consequently casting doubt as to the validity of the system. Many of the critical aspects of REST have, however, been explored and appropriately addressed by the GICHD and partner organisations in recent years. Significant progress has been made towards understanding key factors that influence REST, positively and negatively, and there has been good progress in developing appropriate training methodologies, controlling the environment, and conditioning the animals on TNT. There has been less of a focus on scrutinising REST as a concept or looking for practical solutions to using it in the field, including assessing the operational requirements. It is not difficult to imagine that REST is well suited on linear targets, but it is more difficult to imagine how REST can be used on tracts of land. New ways of viewing REST as a technical survey may however change this picture in the future.

Land release is an evidence-based approach to determine which areas are mined and will need clearance, and which areas are mine-free and can be released by survey. REST has been viewed as a clearance methodology, but mine action has evolved to focusing more on finding appropriate technical survey solutions. There may have been missed opportunities, in that its potential in technical survey has not been fully explored. REST has been considered a full solution to resolving a mine problem, while it would have been more appropriate to integrate it into a technical survey approach.

This chapter explores REST as an evidence-based technical survey asset and discusses how REST can be integrated into a wider survey process for improved efficiency.

BROAD DESCRIPTION OF THE SYSTEM

The basic principle of REST is the ability to sample air or dust from mine-suspected ground, then seal and transport these samples for remote analysis by specially trained animals. If a sample is indicated to have traces of a landmine or unexploded ordnance (UXO), the ground where sampling has been undertaken will be considered potentially contaminated and requiring a degree of clearance. The broader process involves multiple separate or interlinked activities.

The three main components of REST are the:

- sampling process
- analysis process
- follow-on clearance process.

The sampling process

When conducting sampling, petrol or battery driven suction units are used to collect air or dust from the surface. After a certain period of time, the filter is released from the suction tube, marked and stored before a new filter is fitted. Repeating this process on multiple sectors will give quantities of filters where each sample represents a small sector of road or land. The size of the sector represented by one filter depends on multiple factors, including breakthrough in the filter, filter clogging, the need to collect sufficient amounts of dust, and practicalities in terms of the follow-on clearance process.

Sampling is normally undertaken by slow swinging of the suction tube from side to side while walking forwards at a moderate pace. The samples are typically changed every 100 m but there are examples where filters have only been changed for every 300 m.


Left Petrol driven suction units have been the preferred system, but battery or gas driven prototypes have shown promising results **Right** A sampling team walking in the tracks of a Casspir vehicle in Angola

The suction units are typically portable units, carried by people that follow in the tracks of mine protected vehicles. The ground pressure from the vehicle is higher than the pressure applied by the people following in the tracks. South African Casspirs have been the preferred vehicle but other vehicles may be used as long as they are able to withstand detonations from AT mines and provide the required ground pressure. Mechem has previously used Casspir vehicles as a sampling platform to eliminate the need for walking during sampling. Flexible suction tubes have then been lowered to the ground at the front of the vehicle through duct penetrations in the armoured vehicle body and the filters have been pulled into the cabin for exchange.

While it is ideal to use a sampling platform that would make manual sampling redundant, the downside is that the suction tube, when lowered to the front of the vehicle, only sucks in air or dust along a narrow and linear path. This could be addressed by facilitating the use of numerous filters to cover the full width of the road. There are, however, practical challenges and cost implications that speak in disfavour of such a system.

Various filter materials may be used in a filter sample. Mechem has developed a PVC filter that they have used for the past 15 years, while the GICHD and APOPO have conducted research on alternative filter materials and developed polyester filters that can be subjected to alternative Gas Chromatograph (GS) analysis. Recent research has, however, identified that a more feasible way to ensure that sufficient amounts of soil and dust are collected is to opt for pure dust/soil collection. A joint GICHD and APOPO effort resulted in the development of a prototype dust collector that will likely optimise the output from the sampling and allow a more controlled use of the collected dust during the analysis.

The analysis process

REST analysis has been considered the critical component of REST, where most things could go wrong. It should, however, be noted that a good REST system relies fully on quality sampling. If the sampling process is poor, a quality analysis facility will be of no use. Dogs and rats are typically used as detectors. Research on bees, moths and other insects has, however, demonstrated the ability of many insects to become credible REST detectors. The practicalities and logistic constraints of using insects for REST analysis has, however, not been explored.

An African giant-pouched rat and a Labrador Retriever analysing REST samples

Soil samples or filters can be presented to the animals in different ways. Mechem typically used a line setup with up to 12 filter holders, attached on a wall or on free-standing holders. Others, including Fjellanger Dog Training Academy and NPA have used rotating carousels with varying numbers of filter holders. APOPO uses several filter presentation systems, including line cages, wall mounted cages and carousels.

Multiple animals can be used to analyse the same samples successively, but the aim is to always use as few animals as possible. All animals will occasionally indicate negative filters as positive and this is called false alarm rate (FAR). Increasing the number of animals during analysis will increase the detection rate but also the cumulative FAR, which will reduce overall efficiency of the system. Six successive animals were typically used in the past. Today the aim is to limit the number of animals to two or three.

Critical elements of the analysis process include:

- Imprinting and training methodology in general
- Create target scents
- Develop practical methods of separating bouquet (target) scent from background scent
- Achieve stimulus control on target scents
- Prevent animals from responding to cues and background scent
- Reliable detection at varying concentration levels
- Prevent animals from indicating falsely

The greatest weakness today is that the collaborative effort managed by the GICHD failed to achieve stimulus control on target scents (bouquet scent from landmines). We may have achieved this in the past but there were other system weaknesses at the time that contributed to poor analysis results and prompted intermediate conditioning of animal detectors on TNT. It could be purified, controlled and added to various background environments, in contrast to bouquet scents from landmines, which is difficult to obtain without additional, undesired background scents.

The conditioning of the animals on TNT therefore offered more controlled resolving of other training and conditioning aspects. Many of the weaknesses in the past have since been addressed using TNT, but the last stage of re-establishing stimulus control on the bouquet scent was not achieved. This was in part due to time constraints, but also to a failed approach to develop artificial bouquet scents from landmines.

A credible final conclusion on how credible REST is in mine action stands or falls on accomplishing stimulus control on landmines, as opposed to TNT. The ability of animals to detect small traces of TNT has been the pet subject among many scientists and some have even drawn conclusions that REST will never work because, under some conditions, traces of TNT are almost absent above landmines.

There are, however, far superior concentrations of the bouquet scent from landmines but we haven't been able to test whether they are sufficiently high for reliable detection. When the sensitivity of REST is in question, however, it makes no sense to limit the system to detecting isolated and well-sealed explosive compounds that will further reduce the sensitivity.

The complexity of REST analysis and the many potential pitfalls is one reason why most organisations have hesitated to get involved in REST. It is, however, possible to facilitate a more widespread use of REST by allowing the broader mine action community to develop and conduct sampling, which is far easier, and then ship the samples to a few organisations that have specialised in developing and managing the more complex analysis component.

The follow-on requirement

There will always be a follow-on requirement after a REST analysis. Positive sectors will be a mix of real and false positive sectors. Regardless, these sectors will require some degree of investigation to confirm that there were mines or UXO and remove them, and in some cases confirm false positives.

The follow-on requirement is the costly part of the REST process. If, for example ten per cent of a 100 kilometre long and eight metre wide road is indicated as positive, between 80,000 and 120,000 square metres will need some form of technical survey or clearance.

Many assets can be used, but some are more efficient than others. A manual demining team may, for example, take a year or more to clear 100,000 square metres of road, while dogs and rats may complete the task much faster, especially where there is not much vegetation; usually the case on roads.

Depending on the perceived threat, large loops or other scrap metal/target discriminating detector systems may be used successfully. Flails, tillers and road graders may also have a certain application.

BASICS OF TECHNICAL SURVEY

Like non-technical survey, the technical survey is evidence-based. Its role is to confirm or contradict information from the non-technical survey that may have identified certain areas as mine-free, but with less than the required confidence to fully release the land. The non-technical survey may have identified a minimum requirement for technical survey that, if confirming the results from the non-technical survey, will lead to land release. The requirements for technical survey may therefore vary, depending on the non-technical survey. There is therefore a potential relationship between a prior non-technical survey and the follow-on technical survey.

The requirement for technical survey can be broken into a qualitative and quantitative requirement. The first is the probability of an asset or system to detect a mine or UXO. The second is the size of the area where the asset/system will need to be applied. A high qualitative performance of an asset implies a lower quantitative requirement of the same asset. Likewise, a low qualitative performance of another asset implies a higher quantitative requirement, ie a bigger area to be searched with the same asset, to provide the same level of confidence that an area is mine-free (confirming the non-technical survey).

Manual mine clearance is often referred to as the technical survey benchmark. Mines are occasionally missed, but the method is considered full clearance by IMAS. We expect 100 per cent of the mines to be found during manual mine clearance. It has a higher probability of detecting landmines than any other asset or methodology.

There is a difference between the clearance performance of an asset and the technical survey performance of the same asset. During technical survey, some areas will show no evidence of mines and will be released, while other parts will show evidence of mines and will need clearance. The implication is that it may be sufficient to use a less reliable asset in technical survey if no evidence of mines shows up. If there is evidence of mines, a clearance requirement has been identified and this asset may no longer be used. The main gain from technical survey is the ability to use rapid and cost-effective methods to investigate wider areas and release the parts that show no evidence of mines. This process will also define the real clearance requirement in areas where there is evidence of mines.

The requirement for technical survey may be determined by the non-technical survey. It is often referred to as a percentage of land that will need to be searched by manual mine clearance. A methodology with a lower probability of detecting a mine will provide a lower qualitative assessment and there is therefore a higher quantitative assessment requirement. In other words, the lower the qualitative performance of an asset, the greater the size of an area that needs to be searched will be, to provide the same level of confidence that an area or stretch of road is mine-free.

TABLE 1 | illustrates the relationship between qualitative performance, or value, of an asset and the percentage requirement for ground search during technical survey. Manual mine clearance has been benchmarked as the default technical survey methodology and given a qualitative value of 100 per cent. If a default technical survey requirement has been identified as 25 per cent search of the area before releasing it (provided that nothing is found) manual mine clearance will have to be applied on 25 per cent of the area, while an area multiplying factor will need to be applied for less reliable assets. An asset that only has a 20 per cent probability of detecting a mine will need to search the entire area. It is in theory not possible to search more than 100 per cent of an area but a concept of searching an area several times with an asset is feasible.

Qualitative value of asset	Area multiplying factor	Example 1 20 % default TS requirement	Example 2 30 % default TS requirement	Example 3 50 % default TS requirement
100 %	1.00	20 %	30 %	50 %
90 %	1.11	22.2 %	33.3 %	55.5 %
80 %	1.25	25 %	37.5 %	62.5 %
70 %	1.43	28.6 %	42.9 %	71.5 %
60 %	1.67	33.4 %	50.1 %	83.5 %
50 %	2.00	40 %	60 %	100 %
40 %	2.50	50 %	75.0 %	-
30 %	3.33	66.6 %	100 %	-
20 %	5.00	100 %	-	-
10 %	10.00	-	-	-

TECHNICAL SURVEY ASSETS

A range of different assets can be used for technical survey. In addition to manual mine clearance, the most common assets or methods are:

- flails
- tillers
- rollers
- direct search with animals
- large loops

Other potential assets include ground penetrating radars (GPR) and REST.

The performance of these assets and methods will vary, depending on the type of hazard, the ground, the amount and type of vegetation, and other factors. There is a further range of other types of machine that all perform slightly differently.

Studies of test data combined with empirical experience suggest that flail machines have an average qualitative performance of 85 - 95 per cent, while tillers score slightly less. With these machines it is possible to collect information from audible detonations, visible debris from crushed mines and visible mines that have been thrown out.

From rolling, it is possible to collect information from audible detonations only. Crushed mines during rolling, although perhaps considered cleared, will add no value when the roller is used in technical survey, since it is not normally possible to trace any evidence of crushed hazards. Rollers typically detonate between ten and 40 per cent of mines, but there may be local variations to take into account.

Large loops will have a high detection probability (close to 100 per cent) on all high metal mines and UXO, and a low detection probability on low metal mines.

Dogs and rats used in direct search, if well-trained, have demonstrated a near 100 per cent detection rate, but there is evidence of animals with a much lower probability of detection. Some animals struggle to detect well-sealed metal cased mines (when they have been trained mainly to detect TNT) while they will easily find mines with plastic cases. Animals are typically used in a dual search role during clearance, and a single search role during technical survey.

REST as a technical survey tool

A precondition for the successful use of REST has been that the animals do not indicate false positives (mine-free sectors indicated as potentially mined sectors). A second precondition for success has been reliable detection of positive sectors.

The latter has been the most important, and the most difficult, to achieve. Most roads have no or few mines; regular false positive filters will result in all roads becoming suspect, while many of them contain no mines. Moreover, in survey it may be more important to identify whether or not a road is mined than reliably detecting all sectors that are mined. Even if the system fails to identify a positive sector, it is sufficient to identify some positive sectors to conclude that more mine action is required. The same logic applies for REST used to verify segments of land. Land release methodology may therefore change the requirements for REST; it becomes more important to avoid false positives than to detect all real positives. Accepting this will likely make it easier to develop a functional REST system within short time frames.

It is slightly complex to determine the detection probability of REST. Because of a degree of uncertainty with regard to how well dogs and rats detect minute traces from landmines in filters or samples, multiple animals are typically used during the analysis. Moreover, animals have on many occasions proven themselves smarter than their human "counterparts", which has led humans to believe that REST works well, while the animals are in fact detecting cues that have been artificially added to the search process.

TABLE 2 | illustrates an increased detection probability as a factor of number of animals used during the search. A certain degree of random detection and false alarms is assumed. The green columns are three examples of how a false alarm rate (FAR) of one, two, and five per cent will cumulate with an increased number of animals. It is possible to achieve high clearance rates with a cumulative increase of animals during analysis. The trade-off is that the FAR will also increase. The challenge is therefore to find a balance between the number of animals required and the FAR. Table II shows that if animals only have a 60 per cent detection probability, the use of two animals will in fact increase the detection to 84 per cent, comparable with flails and tillers, while maintaining a FAR that is fairly low.

1 x animal		2 x animal		3 x animal		4 x animal		5 x animal		6 x animal	
100 %		100 %		100 %		100 %		100 %		100 %	
90 %		99 %		99.9 %		100 %		100 %		100 %	
80 %	1 %	96 %	1.99 %	99.2 %	2.97 %	99.8 %	3.94 %	100 %	4.9 %	100 %	5.85 %
70 %		91 %		97.3 %		99.2 %		99.8 %		99.9 %	
60 %	2 %	84 %	3.96 %	93.6 %	5.88 %	97.4 %	7.76 %	99.2 %	9.6 %	99.8 %	11.41 %
50 %		75 %		87.5 %		93.8 %		96.4 %		98.2 %	
40 %	5 %	64 %	9.75 %	78.4 %	14.26 %	87 %	18.55 %	92.2 %	22.62 %	95.3 %	26.49 %
30 %		51 %		65.7 %		76 %		83.2 %		88.2 %	
20 %		36 %		48.8 %		59 %		67.2 %		73.8 %	

Consequence of high false alarm rates (FAR)

If REST is to be used on 100 km of road, which has been classified as probably mine-free by the non-technical survey, the technical survey will hopefully be able to confirm that the road is mine-free and it may be put forward for release.

The problem is that false alarms will draw suspicion towards certain parts of the road. If we assume that filters have been sampled in intervals of 100 metres, and that the road width has been sampled twice (towards each side of the road), there will be a total of 2000 samples. If we also assume that one positive indication on one side of the road will require both sides of the road to be checked, as well as the area before and after the sector that was indicated as positive, a considerable follow-on clearance will be required.

In the worst case, all the false alarms are in different sectors, with at least one sector between them. In this case, there will be 40 false alarms with a one per cent FAR per animal, which will generate a follow-on clearance requirement on 120 sectors of 100 metres each. Twelve per cent of the road would then need follow-on clearance.

If the FAR is four per cent, the worst possible scenario is a need to clear 24 per cent of the road. A five per cent FAR will, in the worse case, require that 60 per cent of the road needs clearance after the REST analysis. In real life, some of the false alarms will overlap, and the clearance requirement will be less. However it is still true that even a low FAR will have a major impact on efficiency. If it is too high, the value of the system is questionable.

How to address false alarm rates (FAR)

In the past, if a filter is indicated as positive, it has been considered so, regardless of whether all or only a few of the animals indicated them as positive in a successive search. Looking beyond the maths in the paragraph above, however, there may be a potential to avoid applying costly amounts of technical survey and clearance by developing an analytical approach where each filter is viewed carefully and differently.

A positive filter may be a real or a false positive. If multiple animals analyse a filter and a majority indicate it as a negative while one animal indicates it as a positive, this particular filter is more likely a false negative than a real positive. The filter may under some conditions be considered a negative, and under other conditions may be put forward for re-analysis, still considerably cheaper than to just treat it as a positive by default and clear the appurtenant sector of land/road. An analytical approach to carefully re-assessing samples that have been classified as partially positive may considerably reduce the number of false positive filters, thereby reducing the costly and time-consuming follow-on requirement on positive sectors. Changes to the way sampling is undertaken may further reduce the follow-on requirement. Some methods of addressing FARs include:

> Reanalysing filters that have been indicated as positive before assuming that they are positive. If, for example, three animals are used during the analysis and two of them indicate a filter as negative while the third indicates it is positive, it may be reanalysed by two more animals. If indicated as negative by both these animals, the filter may be considered a negative.

> Chemically analysing filters that have been indicated as positive by only one animal and concluding that the filter was negative if chemical analysis is unable to detect traces from a landmine.

> Disregarding filters that are indicated as positive if one of several animals indicated it as positive and none of the bordering sectors have been indicated as positive. The theoretical reduction of detection probability could, however, be negligible and may oust the negative consequences of high FARs.

> Keeping the FAR down during training, likely more important than ensuring high probabilities of detection. Equal attention should be given to minimising the FAR when training animals for REST.

> Modifying the sampling approach to include searching the full width of a road in one sample, and reduce the sampling length from, for example, 100 metres to 50 metres. This will give a near 25 per cent reduction in follow-on clearance requirements, but will also pose some deployment challenges.

FUTURE OF REST

Many countries with past major mine-suspected road networks have partially resolved these problems. There will always be new areas of conflict, but the demand for REST appears to have diminished. Mines are used to a lesser extent in new conflicts, but this does not necessarily reduce the need for large-scale road survey and clearance. Large sections of road may become mine-suspected, despite very few mines used during the conflict, and there will likely be a demand for rapid road survey and clearance for many more years.

REST, if appropriately developed, recognised and used in a wider technical survey context, may still offer higher efficiency than any other approach. REST will, however, only become a viable alternative if the responsibility for developing, maintaining and offering REST analysis is shifted from field operators to a few organisations that have specialised in REST analysis. If there is a need for REST in a country, mine action organisations could train and develop small sampling teams, which would require minimal investment and preparation, and conduct sampling in accordance with agreed standards. The filters could be shipped abroad for remote analysis and the results could be returned by e-mail a week or two later.

The idea of separating the sampling and analysis components of REST institutionally was widely supported by the members of the GICHD advisory board some years back, but it was never fully explored. This was mainly because of a desire to first address the many challenges of first proving the concept of REST; that it actually works as intended. Sadly, despite considerable effort over the past years and significant improvements, the system has not been fully proved, nor disproved.

THE FUTURE OF REST | AN OPERATIONAL PERSPECTIVE

Provided that REST is recognised as a viable technical survey solution and the concept is proven, the concept of introducing free, partially sponsored or fully charged analysis to the wider mine action community should be further explored. Concepts of Quality Assurance and Control will need to be developed, as well as practical logistical solutions and training packages.

There is still scope to improve the concept of sampling, for example the ability to collect dust without using filters would enhance the quality of sampling. Dust or soil offers a more versatile use than filters with dust during analysis. Recent efforts to develop portable sampling units for more effective dust and soil collection have been promising and could lead to considerable sampling improvements.

The wide acceptance of principles of land release by the non-technical and technical survey processes may pave the way for new and improved roles of REST. If the system is viewed as part of a wider survey effort, it may offer high credibility even if the qualitative performance of each animal is fairly low. The mental focus needs to be shifted from assessing what REST may miss to what it may find.

A REST system, where the probability of detection by each animal is as low as 50 - 60 per cent will easily compete with any other technical survey asset. The real question is whether REST will offer higher efficiency than other approaches. Here, the critical factor is the FAR. If it is higher than two to three per cent per animal, REST is likely to lose out when compared to other available solutions.

The REST technology is not limited to mine action. Spin-offs from the work of the GICHD, APOPO, NPA and others within the mine action sector could lead to the development of successful REST applications within a variety of sectors, including security, drug detection, food control and the detection of disease, viruses, bacteria etc. While animals are still considered the most sensitive detectors, Gas Chromatographs (GC) and other chemical systems are gradually closing the gap.

Unlike animals, however, chemical systems have limited ability to detect multiple compounds, a considerable drawback in most REST applications. That said, chemical systems could provide a more consistent detection of specific substances than animals. The combination of highly sensitive animals and less sensitive but more consistent chemical detection systems may enhance REST, and offer more credible future solutions in any application.

GLOSSARY

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Note: This glossary defines the terms used in research and operational activity involving animal detectors of mines and UXO that are mentioned in the publication.

Accreditation
In mine action, the procedure by which a demining organisation is formally recognised as competent and able to plan, manage and operationally conduct mine action activities safely, effectively and efficiently (IMAS, 2005).

Analysis
In REST, the inspection of samples or filters by specially-trained animal detectors. In research, any manipulation of data.

Analysis room
In REST, the room used for presenting samples/filters to animal detectors and which houses the apparatus containing samples (eg, carousel).

Animal detector
In REST and MDD, an animal that has been trained by way of instrumental and/or classical conditioning to emit a specific indication response upon detection of odours emanating from mines and/or UXO. Dogs, rats, goats, pigs, bees, and wasps have been used as animal detectors in research and/or operational activity. Also known as sniffer animals.

Anti-Personnel Mine Ban Convention (APMBC)
Provides for a complete ban on the use, stockpiling, production and transfer of anti-personnel mines (APMs), and on their destruction. For the purposes of IMAS documents, Article 5 of the APMBC lays down requirements for the destruction of APMs in mined areas. Article 6 details transparency measures required under the Treaty including information on the location of mined or suspected mined areas and measures taken to warn the local population. Also called the Ottawa Convention and the Mine Ban Treaty (IMAS, 2005).

Anti-Personnel Mine (APM)
A mine designed to be exploded by the presence, proximity or contact of a person and which can incapacitate, injure or kill (IMAS, 2005).

Applied Behaviour Analysis (ABA)
A branch of psychology that is concerned with applied research into methods of changing behaviour and the development of technologies based on the principles of learning and behaviour that have been unveiled in the Experimental Analysis of Behaviour. Professionals in ABA apply principles of learning, including instrumental and classical conditioning, in order to address behavioural needs of widely varying people and animals in diverse settings. Previously called Behaviour Modification.

Applied research
Research focused at clearly defined problems and market opportunities.

Background
In REST and MDD, all detectable stimuli in a sample (or on a filter) that are irrelevant for the discrimination between known-positive and known-negative samples and so should be ignored by the animal detector. Background has often referred to odours associated with the location from which a sample was taken (eg, diesel, animal faeces, etc). Training ignorance of the background is sometimes attempted by using additives in samples or filters. Background is also called noise.

Baseline
In research, the phase of an experiment where a stable and replicable performance of some behaviour is established and against which the effects of some independent variable can be assessed. In MDD, the line demarcating cleared from uncleared land and from which animal detectors move into uncleared land.

Behaviour
In psychology, anything that an animal does and that it can be observed to be doing. Drives are not behaviour but rather states inferred from behaviour but chasing a thrown kong is behaviour. Similarly, jealousy is not behaviour but fighting with a peer who is receiving attention from some other person is behaviour.

Behaviourism
A philosophical approach to psychology and the study of learning that emphasises the investigation of relations between observable and measurable aspects of the environment and observable and measurable aspects of behaviour. Behaviourism does not state that all behaviour is learned. Rather, it states that behaviour is a function of inheritance, current environment and learning history. Behaviour does not originate from within the animal (eg, a result of free will).

Blocking
In psychology, a controlled stimulus (CS) is less likely to control (or elicit) responses if another CS has already acquired some ability to elicit responses. Control by the second stimulus has been blocked by the first stimulus. For example, if TNT is first paired with food, later pairings of TNT and diesel with food will result in animals learning very little about diesel. Blocking is a phenomenon of selective stimulus control. See also overshadowing.

Bouquet
In MDD and REST, the set of odours that theoretically emanates from a mine/UXO. Each odour in the set is presumed to be discriminable from every other odour, and so has the potential to serve as the discriminative stimulus for the indication response. A bouquet is a compound stimulus where all the elements of the compound are odours.

Box
In MDD, a squared area that is developed for the purpose of being searched by MDDs. A box normally measures 10 m x 10 m, but other sizes may be preferred. Also called search box (IMAS, 2005).

Breaching
In demining, the production of a safe access lane into a minefield or hazardous area. Breaching is usually conducted by using machines able to detonate mines but it may also be carried manually or by MDDs.

Carousel
In REST, a piece of apparatus that is used to present samples (or filters) to an animal detector – usually a dog. A carousel presents samples in a circle rather than in a line as is usually the case when stands are employed. The carousel is usually constructed so that it can rotate on a central axis and so allow a trainer to vary the position of any known-positive sample. Also called an ADSM.

Casspir
In demining, a mine-protected vehicle developed by Mechem and used for carrying personnel or REST sampling equipment. It has a unique V-shaped undercarriage and can be fitted with steel wheels and rollers when used for breaching.

Cleared area
In demining, an area of land that has been physically and systematically processed by a demining organisation to ensure the removal and/or destruction of all mine and UXO hazards to a specified depth. Also called cleared land (IMAS, 2005).

Clicker
In animal training, a small hand-held plastic device that produces two clicks in close succession when a spring-steel plate is pressed and then released by one's thumb. The clicking sound is established as a conditioned reinforcer by classical conditioning. The clicking sound is ideal for this use because it can be sensed by an animal without it needing to orient to the handler.

Clicker training
In animal training, a term coined by Karen Pryor and defined by her as a subset of instrumental conditioning using positive reinforcement, extinction, negative punishment, and an event marker to modify behaviour. The behaviour modification techniques employed are not new; they are common applications of principles of learning and behaviour in animals (particularly shaping) as they have been discovered in laboratory research since the 1930s. In the 1980s, Gary Wilkes collaborated with Karen Pryor (a dolphin trainer) to introduce this method of training to dog trainers (see www.clickertraining.com).

Compound stimulus
In psychology, a stimulus that is made up of a number of smaller (elementary) stimuli, any number of which might acquire stimulus control over some instrumental behaviour or come to be a conditioned stimulus for some conditioned response. (That is, an element of a compound stimulus generally acquire selective stimulus control). Most naturally-occurring are compound stimuli and it is often difficult to predict exactly which elementary stimulus (or stimuli) will acquire stimulus control or become a conditioned stimulus. For example, the odour of a mine is probably a compound stimulus in so far as its constituent parts (mine casing, rubber seals, primary explosive, detonator) probably each emanate distinct odours and so produce a bouquet for the animal detector.

Concept
In psychology, a set (or class) of stimuli which serve the same behavioural function. That is, an animal generalises among all stimuli within the class (and so responds similarly to all stimuli) but discriminates them from stimuli in other classes. A goal of MDD and REST is to establish stimulus control over the indication response by the stimulus class 'mine odour' (ie, the bouquet of odours emanating from a mine).

Conditioning
Any manner of training that produces learning in an animal. Types of conditioning include habituation, classical conditioning and instrumental conditioning.

Conditioned stimulus (CS)
In classical conditioning, an initially-neutral stimulus (eg, clicker) that develops the capacity to elicit a conditioned response (eg, salivating) after it has been paired with an unconditioned stimulus (eg, food) in a classical conditioning procedure.

Correct rejection
In REST and signal-detection theory, an animal does not emit the indication response (eg, sitting in dogs) in the presence of a sample that does not contain the target stimulus or signal (eg, odour of TNT). Correct rejections are desirable. The correct-rejection rate is the inverse of the false alarm rate (ie, correct-rejection rate = 1 – false alarm rate).

Correction
In animal training, the definition of this term varies between trainers:

1. A stimulus consequence that is sometimes arranged for inappropriate behaviour and signals that that behaviour will not be reinforced. A verbal reprimand - "no" – as long as it is never followed by aversive stimuli, can be used as a correction, and should develop as a discriminative stimulus for behaving in a very different way.
2. The application of an aversive stimulus when arranging positive punishment. Also called correction command.

Data; datum
In science, recorded information or measurements (usually in numerical form) which can be analysed and assessed. Data is plural and datum is singular. Scientific discoveries are based on data. Opinions or beliefs are usually arguments without data to support them.

Deminer
A person qualified and employed to undertake demining activities on a demining worksite (IMAS, 2005).

Demining
Activities which lead to the removal of mine and UXO hazards, including technical survey, mapping, clearance, marking, post-clearance documentation, community mine action liaison and the handover of cleared land. Demining may be carried out by different types of organisations, such as NGOs, commercial companies, national mine action teams or military units. Demining may be emergency-based or developmental. Also called humanitarian demining and mine action (IMAS, 2005).

Detection
In MDD and REST, an animal emits the indication response in the presence of the target stimulus. Also called a hit in REST. Detection involves discriminating the presence of the target odour from its absence. In the context of humanitarian demining, the term refers to the discovery by any means of the presence of mines or UXO.

Discrimination
In either classical or instrumental conditioning, responding to one stimulus but not to another, or more generally, responding differently in the presence of different stimuli. Animal detectors have learned to discriminate the presence versus absence of mine-related odours if they emit the desired indication response in the presence of those odours but not in their absence.

Discrimination training
In psychology and animal training, reinforcing responses in the presence of one stimulus or one set of stimuli (eg, rewarding sitting in the presence of mine-related odours) but not in the presence of another stimulus or another set of stimuli (eg, ignoring sitting in the presence of odours unrelated to mines). That is, arranging differential reinforcement of responses to two stimuli. Discrimination training aims to establish stimulus control over some instrumental response. Discrimination training is the technical term for imprinting as that term is used in REST and MDD.

DNB (1, 3 Dinitrobenzene)
A residual product of TNT manufacture. DNB can normally be smelled by humans when a block of TNT is freshly cut. The vapour pressure of DNB is much higher than that of DNT and TNT.

DNT (2, 4 Dinitrotolulene)
A residual product of TNT manufacture, and a breakdown product of TNT decay. Is normally present in varying amounts in any explosive device containing TNT. The vapour pressure of DNT is much higher than that of TNT, and under some conditions it may be easier to detect DNT than TNT.

Emit
In instrumental conditioning, the instrumental response is said to be emitted by the animal in the absence of any eliciting stimulus. That is, although there may be stimulus control over some instrumental response, the discriminative stimulus does not exert the same control as unconditioned and conditioned stimuli. Instead, the response occurs because of its history of reinforcement, albeit in the presence of a discriminative stimulus. Consequently, the response appears more voluntary than involuntary, and this is captured by the term emit.

Empirical research
In science, research that involves collecting and analysing data that are obtained by way of observation or experiment.

Environmental factors
In MDD and REST, factors relating to the environment and that influence the transportation of odour from the mine, the detection of the target odour or the ability of people and dogs to work safety and effectively. (For example, wind, rain, temperature, humidity, altitude, sun and vegetation).

Environmental sample
In REST, a sample (or filter) that has been collected by way of the Standard Operating Procedures (SOPs), for collecting operational samples. Environmental samples can be either known-positive samples, known-negative samples, or operational (ie, unknown) samples.

Environmental training
In MDD, that phase of training where animal detectors are presented with opportunities to habituate to stimuli which may be encountered when they are later deployed in operations. Environmental training also often includes socialisation.

EOD
An acronym for Explosive Ordnance Disposal. The detection, identification, evaluation, rendering safe, recovery and disposal of UXO (IMAS, 2005).

ERW
An acronym for explosive remnants of war. All munitions containing explosives, nuclear fission or fusion materials, or biological and chemical agents. This includes mines, bombs, warheads, guided and ballistic missiles, artillery, mortars, rockets, small-arms ammunition, torpedos, pyrotechnics, IED, etc (IMAS, 2005).

Experimental Analysis of Behaviour
A branch of psychology that is concerned with empirical research into principles of learning and behaviour. This field involves pure research and is based on behaviourism.

Explosive
A substance or mixture of substances which, under external influences, is capable of rapidly releasing energy in the form of gas and heat (IMAS, 2005).

Explosive ordnance (EO)
All munitions containing explosives, nuclear fission or fusion materials and biological and chemical agents. This includes bombs and warheads; guided and ballistic missiles; artillery, mortar, rocket and small arms ammunition; all mines, torpedoes and depth charges; pyrotechnics; clusters and dispensers; cartridge and propellant actuated devices; electro-explosive devices; clandestine and improvised explosive devices; and all similar or related items or components explosive in nature.

Extinction
In psychology and animal training, the gradual decline, and ultimate disappearance of some response. In classical conditioning, presenting the conditioned stimulus (CS) without the unconditioned stimulus will result in extinction of conditioned responses to the CS. In instrumental (operant) conditioning, no longer presenting the reinforcer when the response is made will result in extinction of the response. The time course of extinction depends on the schedule of reinforcement that was originally maintaining it.

Fading
In psychology and animal training, a procedure for transferring stimulus control from one discriminative stimulus to another, by pairing that which already has control with that with which control is intended, and gradually removing the first stimulus while the second is gradually emphasised. Fading is sometimes used to transfer stimulus control over sitting (indicating) from a toy (eg, kong) to TNT.

False alarm (FA)
In MDD, REST and signal-detection theory, an animal detector emits the indication response (eg, sitting in dogs) in the presence of a sample that does not contain the target stimulus (eg, odour of TNT). They can occur for a variety of reasons but generally reflect a bias to indicating because of limited history of reinforcement for not indicating. Also called false positive.

False alarm (FA) rate
In MDD, REST and signal-detection theory, the number of known-negative samples divided by the number of false alarms times 100 (ie, FA rate = no. FAs / no. known-negative sample * 100). The false alarm rate is the inverse of the correct-rejection rate (ie, false alarm rate = 1 – correct-rejection rate).

Filter
In REST and MEDDS, a permeable material designed to trap odour molecules from mines and UXO and later presented to animal detectors for analysis. The filter material is enclosed in a less permeable cover (a cartridge) and placed at the end of a suction pump. The filter material is generally designed to retain airborne explosive vapours although significant amounts of dust are also often trapped.

Free-running MDD
Any mine-detection dog (MDD) that has been trained to indicate mines or UXO in the actual areas suspected of containing mines or UXO (animal detectors used in REST). The term free-running does not imply that the dog is being used without a leash, or has been trained to adopt a less systematic search pattern.

Gas chromatography (GC)
A method of analytic chemistry whereby the sample, dissolved in a solvent, is vapourised and carried by an inert gas through a column packed with a sorbent to any of several types of detector. Each component of the sample, separated from the others by passage through the column, produces a separate peak in the detector output, which is graphed by a chart recorder. This technique is often used to detect the presence of various types of explosives.

GIS
An acronym for Geographical (or Geospatial) Information System. An organised collection of computer hardware, software, geographic data, and personnel designed to efficiently capture, store, update, manipulate, analyse, and display all forms of geographically referenced information (IMAS, 2005).

GPS
An acronym for Global Positioning System.

Gramme
A unit of mass/weight. Originally defined as the mass of one cubic centimetre of water at 4°C but now taken as the one one-thousandth of the base unit kilogramme, or 1×10^{-3} kg, a mass preserved by the International Bureau of Weights and Measures.

Headspace
In chemistry, the vapour mixture trapped above a solid or liquid in a sealed container.

Hit
In REST, MDD and signal-detection theory, an animal detector (or observer) makes the indication response (eg, sitting in dogs) in the presence of a sample (or filter) that contains the target stimulus (eg, odour of TNT).

Hit rate
In REST, MDD and signal-detection theory, the number of known-positive samples divided by the number of hits times 100 (ie, hit rate = no. hits / no. known-positive samples * 100). A high hit rate is indicative of an accurate discrimination if, and only if, the false alarm rate is simultaneously low.

IED
An acronym for Improvised Explosive Device. A 'homemade' munition (IMAS, 2005).

IMAS
An acronym for International Mine Action Standards, which is a set of documents prepared by GICHD for the United Nations Mine Action Service (UNMAS). IMAS describe guidelines for the safe, effective and efficient detection and subsequent disposal of ERW (landmines & UXO) that should be adapted by a National Mine Action Authority to suit a country's circumstance.

Impact
In mine action, the level of social and economic suffering experienced by the community resulting from the harm or risk of harm caused by mine and UXO hazards and hazardous areas (IMAS, 2005).

IMSMA
In mine action, an acronym for the Information Management System for Mine Action. This is the United Nation's preferred information system for the management of critical data in UN-supported field programmes. The Field Module (FM) provides for data collection, information analysis and project management. It is computer software used by the staff of MACs at national and regional level, and by the implementers of mine action projects - such as demining organisations (IMAS, 2005).

Indication response
In REST and MDD, an easily-detected response (by an animal detector) that is trained to occur in the presence of specific target stimuli (eg, mine-related odours) but not in their absence. In dogs, the indication response is usually sitting while remaining still and oriented to the source of the target stimuli until the trainer issues a release command. In rats, the indication response has been scratching or biting at the ground immediately above the source of the target stimulus. In bees, the indication response has been the proboscis extension reflex.

Kong
In animal training, a toy specifically designed for dogs. It is made of durable rubber to withstand chewing, and is used in chasing and play-fighting games that are arranged as rewards for hits or successive approximations to hits. Note that it is unlikely that the kong per se is the reinforcer, but rather, the opportunity to engage in play.

Learning
In psychology and animal training, relatively long-lasting and observable changes in an animal's (human and non-human) behaviour that result from its interactions with its environment. Excluded are behaviour changes that result from changes in the physiological or physical state of the animal (eg, fatigue, maturation, losing limbs, etc). Learning is not simply the domain of young animals, and often involves the loss of behaviour as much as the acquisition of new behaviour.

LIS
In mine action, an acronym for Landmine Impact Survey. An assessment of the socio-economic impact caused by the actual or perceived presence of mines and UXO, in order to assist the planning and prioritisation of mine action programmes and projects. Also called impact survey and Level 1 survey (IMAS, 2005).

Litre
A unit of volume equal to that within a cube with sides of 10 cm. A litre was originally defined as the volume 1 kg of water would occupy at standard pressure and temperature. The original metric system used litres as a base unit.

Long-leash MDD
One of the operational systems for mine-detection dogs (MDDs) where dogs are tethered on a long (generally 8 m to 11 m) leash and search inside a box. Dog handlers generally avoid entering the box until the entire box has been searched and any indications have been investigated by manual demining methods such as prodding.

Maintenance training
In REST and MDD, a phase of training animal detectors that follows successful initial training and is conducted intermittently and while the animals are engaged in operational activity. Maintenance training aims to keep the intensity of the searching behaviour high, keep the stimulus control by mine-related odours strong, and keep the form of the indication response tidy and easily detected. Also known as refresher training.

Mass spectrometry (MS)
A method of analytic chemistry whereby information about a solid, liquid or gaseous sample is obtained by analysing the dispersion of ions (charged molecules) generated by the mass spectrometre when those ions interact with the sample, generally using the mass-to-charge ratio.

MDD
An acronym for Mine Detection Dog, which is a dog trained and employed to detect mines, UXO and other explosive devices. Such dogs are taken to areas suspected of containing mines and are either untethered, or on a long or a short leash.

MEDDS
An acronym for the Mechem Explosive and Drug Detection System. Mechem is a commercial demining organisation based in South Africa. MEDDS was developed to serve a security function at airports and international borders before it was applied to mine action. It was the first attempt to develop REST.

Microgramme
A unit of mass/weight equal to one millionth (0.000001) of a gram or 10^{-6} of a gramme. Often written "mcg" or "µg". There are 1,000,000 mcg in one gramme.

Microlitre
A unit of volume equal to one millionth (0.000001) of a litre or 10^{-6} of a litre. Often written "µl" or "µL". There are 1,000,000 µl in one litre.

Milligramme
A unit of mass/weight equal to one thousandth (0.001) of a gramme or 10^{-3} of a gramme. Often written "mg". There are 1,000 mg in one gramme.

Millilitre
A unit of volume equal to one thousandth (0.001) of a litre or 10^{-3} of a litre. Often written "ml" or "mL". There are 1,000 ml in one litre.

Military grade TNT
The most common primary explosive used in munitions worldwide. The three most important vapour constituents include 2,4,6-TNT, 2,4-DNT and 1,3-DNB, but other additives such as plasticizers and stabilisers usually emit odours also. The manufacturing processes of military grade TNT vary within and between factories, which produce a variety of impurities at different concentrations and usually results in batches having different odours for animal detectors.

Mine
Munition designed to be placed under, on or near the ground or other surface area and to be exploded by the presence, proximity or contact of a person or a vehicle (IMAS, 2005).

Mine action
Activities which aim to reduce the social, economic and environmental impact of mines and UXO. Also called demining (IMAS, 2005).

Mine Action Centre (MAC)
Also called Mine Action Coordination Centre (MACC). An organisation that carries out mine-risk education (MRE) training, conducts reconnaissance of mined areas, collection and centralisation of mine data and coordinates local mine action plans with the activities of external agencies, of (mine action) NGOs and of local deminers. For national mine action programmes, the MAC/MACC usually acts as the operational office of the NMAA (IMAS, 2005).

Mine casing/Mine housing
The external housing of an anti-personnel or anti-tank mine. Materials used for mine casings vary but plastics, woods and metals are most common.

Minefield
An area of ground containing mines laid with or without a pattern (IMAS, 2005).

Miss
In REST, MDD and signal-detection theory, an animal detector does not emit the indication response (eg, sitting in dogs) in the presence of a sample that contains the target stimulus (eg, odour of TNT). Misses are undesirable. Miss rate is the number of known-positive samples divided by the number of misses times 100 (ie, miss rate = no. misses / no. known-positive samples * 100). The miss rate is the inverse of the hit rate (ie, miss rate = 1 – hit rate). A low miss rate is indicative of an accurate discrimination if, and only if, the false alarm rate is simultaneously low.

Motivation
In psychology and animal training, the extent to which an animal works (or strives) for a particular consequence. (For example, a dog shows high motivation for the kong if it searches thoroughly, and for a long time, for a kong that was visibly thrown). In so far as that consequence reinforces the working, motivation describes the reinforcing effectiveness of a particular consequence. Alternatively, motivation describes the resistance to extinction of some behaviour. Motivation is often used synonymously with drive.

Nanogramme
A unit of mass/weight equal to one billionth (0.000000001) of a gramme or 10^{-9} of a gramme. There are 1,000,000,000 nanogrammes in one gramme.

NMAA
In mine action, an acronym for National Mine Action Authority. The government department(s), organisation(s) or institution(s) in each mine affected country charged with the regulation, management and co-ordination of mine action. In some cases, the national Mine Action Centre (MAC) or its equivalent will act as, or on behalf of, the NMAA (IMAS, 2005).

Noise
In signal-detection theory, those features (or elements) of a compound stimulus that are irrelevant for the detection task arranged. Detection tasks are often assumed to involve a discrimination between two sets of stimuli; one set contains the signal amidst noise, and the other set contains noise alone. For example, the odour of tyre rubber in a REST sample can be considered noise because it is an irrelevant stimulus that can appear with and without the odour of mines or UXO. Also called background.

Olfaction

The sense of smell or the ability to perceive odours that animals possess. The importance and sensitivity of smell varies among different organisms: most mammals have a good sense of smell, whereas most birds don't. Among mammals it is well developed in the carnivores and ungulates, who must always be aware of each other, and in those, such as moles, who smell for their food. It is less well developed in the catarrhine primates and nonexistent in cetaceans, who in compensation have a sensitive and well-developed sense of taste. Insects sense smell with their antennae. In many insect species, olfaction is highly tuned to pheromones; a male silkworm moth, for example, can smell a single molecule of bombykol.

Operant conditioning/Instrumental conditioning

In psychology and animal training, the training procedure whereby behaviours are established in an animal's repertoire (ie, reinforced) by following that behaviour closely in time with either a reward or the removal of unpleasant stimuli. Instrumental conditioning is involved in REST and MDD to the extent that the indication response occurs because of its history of reinforcement. Instrumental conditioning is also called operant conditioning.

Operational sample

In REST, a sample that has been collected via Standard Operating Procedures (SOPs) and whose assignment as positive or negative is unknown to all parties.

Overshadowing

In psychology, an element of a compound stimulus will acquire less stimulus control (or elicit less conditioned responding as a CS) than the control acquired by that stimulus when it appears alone (ie, not within a compound stimulus). That is, elements in compound stimuli compete for stimulus control with the result that the most salient one overshadows all others. For example, if the odours of TNT and PVC are paired with food, the odour of TNT will elicit less conditioned responding than it would if it was presented alone with food. Overshadowing is a phenomenon of selective stimulus control. See also blocking.

Picogramme

A unit of mass/weight equal to one trillionth (0.000000000001) of a gramme or 10^{-12} of a gramme. There are 1,000,000,000,000 picogrammes in one gramme.

Positive reinforcement

In instrumental conditioning and animal training, a response is rendered more likely to occur in the future because it has been followed by an appetitive (desirable) event. Positive reinforcers are rewards. Positive reinforcement establishes instrumental behaviour in an animal's repertoire. See note regarding reinforcement.

Positive sample/Known-positive sample

In REST, a sample that has been shown to contain the target stimulus (eg, mine-related odours) by methods other than an animal detector's indication response (eg, gas chromatography, mass spectrometry). Known-positive samples are used in either training or testing, and are in contrast to operational samples (whose assignment as positive or negative is unknown).

Psychology
The scientific study of behaviour in animals (human and non-human). Experimental psychologists seek to explain why particular behaviour occurs. Applied psychologists apply principles from Experimental Psychology to real-life problems.

Psychophysics
A branch of Experimental Psychology that is concerned with quantitative relations between measures of physical stimuli and measures of sensory or perceptual experience. Establishing the sensory thresholds for vision, hearing and olfaction in a range of animal species, and the most appropriate methods for doing so, has a long history in psychophysics.

Punishment
In instrumental conditioning and animal training, any procedure that involves arranging a consequence for some behaviour and that results in that behaviour being less likely to occur in the future. Punishment can be said to have occurred only once some decrease in the behaviour has been observed. Thus, punishment is an operation, punishers are stimuli, and responses (rather than animals) are said to be punished.

Polypropylene (PP)
A type of plastic used in some mine casings.

RDX (1, 3, 5-triazacyclohexane)
A military explosive which is used extensively as an explosive in many munitions formulations. RDX is relatively insensitive; it has a high chemical stability, although lower than that of TNT. RDX is never handled pure and dry because of the danger of accidental explosion. It is used as a component in explosive mixtures, especially plastic explosives.

Reinforcement
In instrumental conditioning and animal training, any procedure that involves arranging a consequence for some behaviour and that results in that behaviour being more likely to occur in the future. Reinforcement can be said to have occurred only once some increase in the behaviour has been observed. Thus, reinforcement is an operation, reinforcers are stimuli, and responses (rather than animals) are said to be reinforced. Reinforcement establishes instrumental behaviours in an animal's repertoire.

Research
The systematic inquiry, examination and experimentation to establish facts and principles.

Respondent conditioning
Another term for classical conditioning.

Response
In psychology, an instance (or unit) of behaviour; a discrete and usually recurring segment of behaviour. Responses can be measured by a number of dimensions including amplitude, latency, duration, and quality (eg, accuracy).

REST
In mine action, an acronym for Remote Explosive Scent Tracing. REST involves the collection of air samples (on filters) or dust/soil samples from the ground surface in suspected hazardous areas using vehicle-mounted or portable collection devices. Samples/ filters are coded to represent the locations from which they were taken and then analysed in a remote laboratory. This analysis might involve animal detectors or analytic chemistry techniques such as GC or MS. REST should be considered a survey tool that can distinguish between suspect positive sectors and suspect negative sectors.

REST system
In mine action, a defined method of conducting REST including how samples (or filters) are collected, stored, transported, analysed by animal detectors, and how the results of the analysis are fed back to field operators. A REST system generally undergoes QA.

Reward
In instrumental conditioning and animal training, a stimulus that a trainer has judged will be valued by his/her trainee animal. On most occasions, rewards will serve as positive reinforcers, but the category of reinforcers is larger than the category of rewards.

Risk
In mine action, the combination of the probability of occurrence of harm and the severity of that harm (IMAS, 2005).

Risk analysis
In mine action, the systematic use of available information to identify hazards and to estimate the risk. (IMAS, 2005).

Run
In REST, a set of samples/filters made available for the animal detector to inspect. The number of samples/filters defining a run is determined by the apparatus containing those samples (eg, carousel) and, therefore, the maximum number that can be inspected on one visit to the analysis room - this number is usually 12.

Sample
In REST, a quantity of dust or soil that is assumed to be representative of the dust/soil found in a specific area of land. Samples are taken from field sites to a remote laboratory where they are inspected by animal detectors.

Search pattern
In REST and MDD, the pattern of whole-body movements that an animal detector has been trained to perform while searching for mines or UXO. Search patterns vary considerably across organisations. Some MDDs have been trained to search in straight and narrow lanes (approximately 30 cm wide), while others have been trained to move around a box in a less structured fashion.

Selective stimulus control
In psychology, the phenomenon that stimulus control will usually be acquired by only some features (or elementary stimuli) of a compound stimulus and NOT by all features equally. For example, if every mine that was used in training for a MDD emanated the same five distinct odours, selective stimulus control would probably be seen in do far as only one or two of those odours acquired stimulus control over the indication response (ie, was attended to by the MDD). Blocking and overshadowing are two examples of how selective stimulus control can occur.

Session
In REST and MDD, that period of time in which an animal detector receives training or performs operational activity.

Short-leash MDD
One of the operational systems for mine-detection dogs (MDDs) where dogs are tethered on a short (generally 1 m) leash and search inside a box. Dog-handlers walk alongside their dogs while the dog searches back and forth in parallel lines. Thus, this method requires the dog handler to walk inside the box over land that his/her dog has searched without indications.

Signal
In Psychophysics, the stimulus whose presence should be reported by a subject. In MDD and REST, the signal is mine-related odour.

Signal-detection task
In psychology, a procedure in which animals or humans are trained to report the presence of a specific stimulus, namely the signal. The procedures arranged for animal detectors in REST can be conceptualised as signal-detection tasks.

SOPs
In mine action, an acronym for Standard Operating Procedures. Document(s) which define the preferred or currently established method of conducting an operational (or research) task or activity. Their purpose is to promote recognisable and measurable degrees of discipline, uniformity, consistency and commonality within an organisation, with the aim of improving operational effectiveness and safety. SOPs, and the degree to which actual methods concord with those SOPs, are usually examined in quality assurance (IMAS, 2005).

Spiked samples
In REST, samples that have been artificially constructed by way of the procedure known as spiking.

Spiking
In REST, any procedure that involves artificially adding mine-related odours (eg, TNT dissolved in water) to a sample or filter. Spiked samples are in contrast to environmental samples.

Stand
In REST or MEDDS, a piece of equipment designed to hold filters (or samples) during inspection by animal detectors. A single stand normally holds one or two filters.

Statistically significant
A research finding that scientists accept as being accurate because a statistical test shows that the results were unlikely to have occurred by chance and must, therefore, be meaningful. By convention, a result is usually considered statistically significant if that result can be expected by chance less than one time in 20 (.05). More conservative scientists might adopt a cut off of .01 (ie, less that one time in 100).

Stimulus
In psychology and animal training, any change in, or feature of, the physical environment that can be sensed by an animal and, therefore, has the propensity to influence an animal's behaviour.

Stimulus control
In instrumental conditioning, the extent to which stimuli which precede or accompany some instrumental response control the rate or probability of that response. Therefore, although instrumental behaviours are emitted because they have a history of producing reinforcing consequences, these behaviours are usually emitted in specific situations; namely, those that resemble situations where they have been previously reinforced. (For example, TNT may come to exert stimulus control over sitting in a dog.) The stimulus that has acquired stimulus control is called discriminative stimulus or SD. Strong stimulus control implies that the response occurs reliably in the presence of the SD, that it seldom occurs in the absence of the SD, and that little other behaviour occurs in the presence of the SD. Stimulus control is established by reinforcing the response in the presence of an intended SD (single-stimulus training), by reinforcing it in the presence of the SD and extinguishing it in the absence of the SD (presence-absence training), or by reinforcing it in the presence of one value of the SD and extinguishing it in the presence of another value of the SD (intra-dimensional discrimination training).

Subject
In psychological or ethological research, the organism (usually an animal) whose behaviour (or physiology) is under investigation.

Target stimulus
In REST and MDD, that stimulus which is intended to be the discriminative stimulus (or the conditioned stimulus) for the indication response. The target stimulus will generally be some mine-related odour such as the odour of TNT.

Technical survey
In mine action, the detailed topographical and technical investigation of known or suspected mined areas identified during the planning phase. Such areas would have been identified during any information gathering activities or surveys which form part of the general mine-action assessment process or have been otherwise reported. Also called Level 2 survey (IMAS, 2005).

Test site
In mine action, the site at which a series of test boxes or lanes containing mines (or UXO) of known types and in known locations are prepared for the purpose of operational accreditation testing of MDD or a REST system. Also called test field (IMAS, 2005).

Threshold
In psychophysics, the minimum amount of a defined stimulus (measured in physical units such as luminance or decibels) necessary for a detectable sensation. See absolute threshold and difference threshold.

Time-out
In psychology and animal training, a punishment procedure in which the opportunity to earn reinforcers is temporarily removed if the subject performs the undesirable behaviour. Time-out usually involves removing the animal from its immediate environment to a time-out area in order that a discrimination might be learned between time-in and time-out environments. Time-out can only be effective if the time-in environment offers a higher rate of reinforcement than the time-out environment. Therefore, this method is contraindicated for behaviour maintained by negative reinforcement.

TNT (2, 4, 6 Trinitrotoluene)
One of the most widely used primary ingredients in military high explosives. TNT is very stable, non-hygroscopic and relatively insensitive to impact, friction, shock and electrostatic energy. Also called pure TNT.

Training
In REST and MDD, the process of deliberately arranging specific experiences for an animal in order that some manner of learning (ie, behaviour change) might occur.

Training mines
In mine action, landmines (APMs and AT mines) that have been sourced, and perhaps buried in known locations, for the purpose of training animal detectors. When training mines have been buried, the detonator will have been either removed or disabled. When the detonator has been removed, it is sometimes buried next to the mine, and any hole left in the mine where the detonator once was is sometimes filled. Also called school mines.

Transfer
In psychology, shifting stimulus control from one SD (or class of SD s - concept) to another SD (or concept) by some specific method. This strategy can be a useful way of establishing TNT as an SD if an animal is already indicating the presence of some other stimulus (eg, the kong). See fading as an example of one method of transfer.

Transfer test
In psychology, a method for assessing which elementary stimulus of a compound stimulus had acquired stimulus control over the defined response. There are several kinds of transfer tests, but the most common involves presenting the elementary stimuli separately and measuring the rate (or probability) of the response in the presence of each stimulus to see which were controlling the response (being attended to) in the original compound stimulus. Such tests can be useful to establish which features of a mine's odour (eg, the primary explosive, the rubber components, the casing, etc) were being detected by an MDD.

UNMACA
An acronym for United Nations Mine Action Centre for Afghanistan - the UN organisation charged with the responsibility of overseeing UN sponsored mine action in Afghanistan.

UNMAS
In mine action, an acronym for United Nations Mine Action Service. UNMAS is the focal point within the UN system for all mine-related activities. UNMAS is the office within the UN Secretariat responsible to the international community for the development and maintenance of IMAS (IMAS, 2005).

UXO
In mine action, an acronym for Unexploded Ordnance. Explosive ordnance that has been primed, fused, armed or otherwise prepared for use or used. It may have been fired, dropped, launched or projected, yet remains unexploded either through malfunction or design or for any other reason (IMAS, 2005).

Vapour pressure
In chemistry, a measure of the tendency of a solid material to form a vapour. The higher the vapour pressure, the more easily the material turns to vapour and the higher the potential vapour concentration. In general, a material with a high vapour pressure is more likely to be an inhalation or fire hazard than a similar material with a lower vapour pressure.

Visit
In REST, the time between an animal detector being taken into the analysis room and it being removed. If the animal 'indicates' a sample and is subsequently removed from the analysis room, it may need to make several visits to the analysis room before it examines every sample presented in the set and so completes the run.