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Use of dogs as odour detectors

- A review of the scientific literature

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Outline

Abstract
A lot of various substances can be detected by dogs, as oestrous in cows, endangered species or non-biological substances like accelerants, narcotics, explosives, mines and pollutions and biological substances like identity (suspects), cancer (breast, lung, colorectal and bladder cancer), human remains (cadaver), bacteria and mould in buildings. The dogs are trained using non-scientific methods and not much research in detection training exists. This is a review of different types of dog detection, with focus on new research.

Sammanfattning

Hundar används till detektion av många olika substanser till exempel brunst hos kor och leta utrotningshotade arter och icke-biologiska substanser, såsom tändvätska, narkotika, explosionsämnen och föroreningar. De används även till att detektera biologiska ämnen såsom identitetssök, cancer (bröst-, lung-, tjocktarms- och blåscancer), kadaver, bakterier och mögel. Hundarna tränas med icke-vetenskapliga metoder och det finns inte mycket forskning om lukt-detektion med hund. Den här litteraturstudien belyser befintlig litteratur om lukt-detektion med hund och har fokus på ny forskning.

Introduction

Dogs have a superior olfactory sense to humans and can detect small amounts of odour. For this reason, detection dogs are used to detect a lot of different odours both non-biological like accelerants, narcotics, explosives, mines and pollution and biological like cancer, criminals, various species, cows in oestrus or bacteria. Detection in different applications has often been portrayed in the media (newspapers, TV and internet) but not much has been tested using scientific methods. Therefore, the aim of this literature study is to investigate what dogs can detect, with a focus on examples reported in the peer-reviewed scientific literature, and to assess both the difficulties and possibilities with canine odour detection.

In the nasal cavities all species have a sensory epithelium, folded like a labyrinth (*ethmoidal turbinate bones*). Species with a good olfactory sense have a larger surface on the sensory epithelium because of increased folding and more bones. In humans the area of the epithelium is 5 cm^2 whereas the dog has a surface of 150 cm^2 and 250 million olfactory cells (Sjaastad et al., 2010).

Humans probably began to take advantage of dogs' superior olfactory sense relatively early in canine domestication, using dogs in hunting to track prey. Mine detection using dogs started during World War II to clear land so military could pass. There are 700 mine detector dogs in the world, spread in 23 countries (Fjellanger et al., 2002). At the beginning of the 1900s, dogs began to be used by the police and military in special dog units. Accelerant detection was first trained and used in the field in 1987 (Gialamas, 1996). Since the World Trade Centre bombing in 1993, it has been routine to use dogs in search and rescue. Other applications where dogs are considered to be superior to other methods include screening for narcotics in employees and looking for termites in buildings (Furton & Myers, 2001).

In the future more research about the dog's olfactory ability can lead to the development of advanced electronic noses that can detect all that the dog can today but more reliably than detection dogs.

Literature research

To find literature for this review, searches in Google Scholar and Web of Knowledge were made. Search terms used were: "canine or dog", "detection or discrimination", "odour or scent" to find more general articles. To find more specialist articles: "arson dogs", "canine/dog detection accelerants", "mold dogs", "drug dogs", "mine detecting dogs", "cancer dogs", "dogs/canine detecting oestrus". Some of the articles had interesting references, which I then used as primary sources. In this literature review the focus is on new research, so when new literature was available and superseded knowledge from older sources, the newer literature was used.

Detection methods

Choosing a suitable dog for detection is not an easy task. In one study by Fjellanger et al. (2002) the dogs were chosen because of their breed, all Springer Spaniels or Springer spaniels x Labradors, chosen because of their good olfactory sense. Some dogs were rejected from the experiments for not fulfilling the training criteria like missing an extended search pattern or being too dependent on the handler (Fjellanger et al., 2002). In accelerant detection, the Labrador retriever is the most common breed, because of its strong motivation to search (Gialamas, 1996). In a scat detection study, only dogs with an obsession with food or objects were selected for the project. The object or food was used to create an interest for the target odour (Smith et al., 2003).

Target scent is the odour that the dog should identify, for example narcotics, cancer etc. Non target scent includes all other odours that the dog should ignore. Dogs' ability to learn multiple target scents has been tested (Williams & Johnston, 2002). The study found that the dog has the ability to learn at least 10 different target scents without decreased accuracy of detection. There were also 13 non target scents that the detection dogs learned to ignore. During training, the dog had to do five consecutive trials with one target scent without errors before starting training for another target scent. For every scent the dog learned, its ability to learn another scent increased. By the end of training, the dogs could learn a new target scent in only two days.

When first starting to train a naïve dog in detection, the dog may be more likely to choose a target scent more often than expected by chance because of an inherent interest in the scent. If a food treat is presented together with the target scent, the dog will take more time to learn the scent than if the dog receives the treat after. This might be because the dog focuses on the smell of food and not the target scent. It has been shown that odour discrimination takes less time for dogs to learn than visual discrimination (Hall et al., 2013).

Scent lineup is often used to train detection dogs. A scent lineup is when samples with different odours are placed next to each other and the dog is asked to identify the target scent and ignore the non-target scents (Schoon, 1996). Often the scent is on cotton pads that have been in contact with the target, and these may, for example, be presented inside glass jars placed in heavy pots. The dog shows which sample is correct (target sample) either by sitting, standing still with the nose at the jar or lying down (Jezierski et al., 2008).

Detection of non-biological target scents

Detecting accelerants (Arson dogs)

An accelerant detection dog (or arson dog) detects small amounts of accelerants used to start a fire. A study comparing an accelerant detection dog with different detection dyes was conducted by Nowlan et al. 2007. In this study three different accelerants (odourless paint thinner, gasoline and campfire-fuel) were dispersed at three different volumes (50, 100, 250 ml) in three different furnished rooms of a house; bedroom, kitchen and bathroom. The accelerants were poured on two different sorts of materials, Oriented Strand Board (OSB, a wooden board made of compacted wood flakes) and carpeted OSB. During the burn out, the temperature was monitored, and the fire was allowed to spread freely within the rooms. The dog used in this test was a female Labrador retriever, certified by the Maine Criminal Justice Academy and trained in the State Farm Hydrocarbon Detection Canine Program (http://arsondog.org/). Prior to adding the accelerant and burning the room, the dog examined the room and didn't mark on anything within the room. After burning the room the panels with OSB and carpeted OSB were removed and examined by the dog outside of the room.

Table 1, Canine results in Nowlan et al. 2007

Volume and Panel	Room 1 – Bedroom Odourless Paint Thinner	Room2 – Kitchen Gasoline	Room3- Bathroom Campfuel
50 mL – OSB	-	-	+
50 mL – OSB+carpet	+	+	+
100 mL – OSB	+	+	+
100 mL – OSB+carpet	+	+	+
250 mL – OSB	+	+	+
250 mL – OSB + carpet	+	+	+

The dog succeeded in finding all accelerant volumes on both panels except the lowest volumes of paint and gasoline on OSB (see table 1). It is difficult to say why the dog was able to find the lowest volume of camping fuel; it may have been because the fire was less severe or because it might be easier to detect the fuel. There is a lack of information about how the dog was trained, on which accelerants the dog was trained and which volumes were used. Moving the panels might also have affected the dog's results. Today the easiest non-biological way to detect accelerants is with an indicator dye, which is hard to use on large surfaces. The most accurate way to detect accelerants is by taking samples for analysis at a laboratory, which is expensive. Therefore the extent of the areas to be tested can be minimised by using dogs to detect points of interest and sampling only these for laboratory analysis. To have reliable results in this application however, more dogs need to be tested.

Detection of explosives and mines

One field where detection dogs have been used for a long time is mine detection. Even though the technique is old, there are some problems that can occur. A study by Gazit et al. (2005) with seven detection dogs showed that re-searching an area where the dogs had previously searched without finding explosives resulted in a reduction in motivation for the dog. This meant that subsequent searches in the same area resulted in fewer detections. On a path with five buried explosives, the detection rate was 86.3 % ± 2 %. When the dogs had searched a path without any explosives and re-searched the same path after one explosive had been hidden, the detection rate was only 52.46 % ± 6.1 %. This can be compared to a path with one explosive that was unfamiliar to the dogs, where the detection rate was 95.83 % ± 2.6 %.

Another problem with mine detection is that the mines have often been buried in the ground for a long time, resulting in an odour signature characteristic of ageing. Therefore, it is difficult to rapidly train dogs by simply planting new mines. If the dog is rewarded for finding recently buried mines, there is a risk the dog will miss mines that have been buried for a long time. Therefore, all mines used in training need to be in the ground for at least several months.

An experiment in explosive detection with six detection dogs (Gazit & Terkel, 2003a) tested if the olfactory sense was influenced by vision. The explosives were in containers known to the dog, with same shape that was used in detection training. Indoor and outdoor searches were made, in both dark and in light. The results showed a detection rate of 87.78 % in the dark and 93.83 % in the light, but this difference was not statistically significant. Thus, vision did not influence olfactory searching in this study.

Another study (Gazit & Terkel, 2003b) tested whether hot weather and associated stress would influence the accuracy in detecting explosives. Dogs that ran on a treadmill and were panting heavily showed longer search time. However, although the detection rate decreased, the difference before (91.46 % ± 2.56 %) and after (80.94 % ± 3.78 %) exercise was not statistically significantly different.

Mine detection is dangerous, with a risk of death or injury for both dog and handler. Therefore different techniques have been tested to limit the risk with mine detection. Remote Explosives Scent Tracing (REST) has been developed to detect mines without risking either the dog's or the handler's life. Mine field soil samples are processed through a filter and transported to dogs positioned away from the mined area. A study (Fjellanger et al., 2002) with four Springer spaniels has tested the REST training method. The target scent was Trinitrotoluene (TNT) and the test apparatus was in the shape of a circle with 12 steel arms each with a filter. For the trial, the dog entered the room, walked around the apparatus sniffing all the filters and alerted the handler by sitting or lying down. If the dog was correct, a whistle was blown and the dog was rewarded with food. At the beginning of the training process, a lower number of steel arms were used. The first step was then to increase the number of arms until all 12 were included. If there was no target odour, the dogs were rewarded after leaving the room.

Two problems common to dog scent training are if the dog alerts to a non-target or if the dog fails to alert to a target scent. Alerting to a non-target is considered a training problem; the connection between the target odour and the alert is not clear to the dog, it alerts only to get the reward. If a dog fails to alert a target odour, this is a discrimination problem and the dog needs to train further to identify lower concentrations of the target odour. This can be done in two ways, either by rewarding for just sniffing at the target odour, as in early training sessions, or by adding more of the target odour to the positive sample, and then slowly decreasing the amount. In the TNT study, the way that took less time was to reward the dog when sniffing the target odour with a reduced amount. All dogs made more mistakes when the amount of TNT was decreased. This seemed to be difficult for all four dogs.

The dogs' ability to focus was measured by the rate of mistakes, ability to work independently from the handler and endurance to repeat a large number of trials in succession. The dogs in the TNT study (Fjellanger et al., 2002) had a detection rate of 95 % after 4 months of training (range: 93 % to 96 %). From the study, it was unclear how dogs were rewarded when alerting in the field tests, where the presence or absence of mines was unknown to the handler. This is important since rewarding a false alert could encourage dogs to continue to alert to non-targets, whereas failing to reward a correct alert may cause dogs to lose motivation.

Another way to reduce the risk for the handler is to use an electronic tool that enables a handler to see if the dog is working without being close. It consists of a specially designed muzzle with a microphone placed by the nostrils to allow the handler to hear if the dog is sniffing or panting, and a transmitter is attached to the collar. The handler will be able to know if certain areas need to be re-searched. For research purposes, the recordings can be analysed by computer software and the frequency of panting and sniffing can be counted (Gazit et al., 2003).

As mine detection is dangerous for both handler and dog, researchers are trying to design an electronic nose. These devices mimic the canine nose, and react to small concentrations of volatile chemicals. There are different electronic noses based on fibre optics, use of fluorescent polymers and others. New techniques have made it possible to make them smaller and portable. Buying an electronic nose is more expensive than training a dog to detect. The electronic nose can detect explosives because they consist of known volatile chemicals, but other biological target scents, like humans, cancer or diabetes, are not yet possible to detect. As understanding of the canine nose increases, it might be possible in the future to detect everything a dog can detect (Yinon, 2003).

Detecting pollutants

Detecting pollutants with dogs is an area that needs more research, there is only one study by Arner et al., (1986) where two experienced detecting dogs were trained to detect toluene. Toluene is a common component of gasoline and therefore can be used to find hidden or buried gasoline storage tanks. The training began with 0.5 g toluene and decreased to 0.1 g toluene. The pollutant was placed on a cotton ball on a wooden dowel and the dogs were trained to locate it further and further away. A second target scent was introduced, 2, 4, 6-trichlorophenol, which represented compounds of the dioxin class. The dogs could successfully detect 2, 3, 7, 8-TCDD which is a common dioxin isomer, but as this is a solid compound it was dissolved with 10 % methanol. The dogs were tested outdoors and one of them found toluene 50 ft (15m) away. Only one object with 2, 4, 6-trichlorophenol was not found, but the amount was only 0.05 g which was half of the lowest amount used at training. None of the pollutants were dangerous to the dogs at the low concentrations used (Arner et al., 1986).

Mercury detection has not been tested in any scientific studies. Information available on internet suggests that three dogs have been trained to detect mercury, contrary to the general opinion in the past that dogs could not detect metal because its lack of odour. In projects in Minnesota and in Sweden where the ambition was to clean mercury from schools, detecting dogs have helped to locate more than one metric ton of mercury (Mercury Free Zone, 2013; Kretslopp, 2013). Unfortunately, there have been no scientific experiments investigating dogs' ability to detect mercury or other metals.

Water leaking from pipes in the ground is a big economic problem for the energy companies. Borlänge Energy in Sweden added pyranine to the water to be able to trace the leaking water. Pyranine is not toxic and has no taste. Humans cannot smell it but dogs can. Borlänge Energy has started to use dogs to detect the leakage of water by training them to detect pyranine (Lundén, 2013). However, so far no scientific experiment has investigated this ability.

Detecting narcotics (Drug dogs)

Drug detection is one of the most common canine detection applications. Police and customs use them but they are also used within psychiatry.

In psychiatry the aim is to have a drug-free environment. Urine sampling of all patients is expensive and time consuming, so it would be useful with a drug dog to detect narcotics. There are good arguments for using drug dogs to check psychiatric wards on a daily basis, though there is a risk that false alerts from the dog may lead to incorrect accusations against patients, which would be very undesirable (Gordon & Haider, 2004).

Training a dog to detect narcotics is often done by connecting a favourite toy with the drug scent; after some repetitions the toy is hidden and the dog will search for the toy. The next step is hiding the narcotics for the dog to find in hope it will find the toy. Directly after finding the narcotics, the dog is rewarded with the toy. Training a dog to detect narcotics generally takes 2-6 weeks. The scents the dog needs to ignore are legal drugs and food. The dogs need to be used to all sorts of environments (Bird, 1996). As it is illegal to own drugs, it is difficult to routinely train drug dogs using real narcotics. Therefore it is possible to buy pseudo scents of marijuana, heroin, LSD and cocaine (Sigma Aldrich, 2013).

Surprisingly, despite their prominent profile in the media and popular culture, very little published scientific research has been conducted on the training of drug detection dogs.

Detection of biological scents

Human detection

Identity detection (detection of human scent)

Detection of different human scents is an ability that most dogs use in everyday life to recognise their owners and families, and it is commonly trained in obedience and in tracking (the dog follows footsteps of a human). Previously it was thought that every human has a specific scent present throughout the body. In a study in which dumbbells were touched by different body parts of both handler and a stranger, the three dogs tested could distinguish the handler's smell from a stranger in 93.1 % of trials (Brisbin & Austadi, 1991). The dog with lowest detection rate had 87.5 % correct results. However, when the dumbbell was touched by the elbow of its handler and the hand of the stranger, it was harder for the dogs to distinguish the handlers' dumbbell; the detection rate was then only 84.2 %. The conclusion was that different body parts may have different scents, although the amounts of odour may also be involved.

Evidence containing scent from a crime scene can be collected and presented in an identification scent lineup, where the dog is asked to smell a suspect and then identify which object belongs to the suspect. A study has tested the temporal aspect of this ability (Schoon, 1996). A person touched an object varying amounts of time passed until it was presented to the dog for detection. The time spans were 0, 2, 4, 8, 12, 16, 20 and 24 weeks. Ten detecting dogs participated, and in the tests the dog smelled the target person and then sniffed at the scents placed in a circle. The different objects used were steel tubes, hard and soft plastic and clothes. The study showed that dogs could more easily detect odours on steel than plastic and that clothing was most difficult. A 100 % detection rate was recorded for fresh scent (0 weeks) and this declined rapidly when the odour was older than one week. Dogs that were trained on material as old as 4-6 days could detect much older scent. The object with scents was stored in glass jars and most of the scent could be expected to evaporate during the first week. At 24 weeks, only three trials of nine had correct recognition and six had no recognition.

Well trained police dogs can distinguish the scents of different members of the same family, but with identical twins, a particular protocol is needed. If the dog is trained to odour from twin A, it will subsequently alert to odour from twin B if presented alone. However, if presented simultaneously with odour from twins A and B, the dog is able to pick out twin A. This shows that it is possible to detect and distinguish scents from people as close as brother/sister/mother/father but it is harder to discriminate between twins (Kalmus, 1955).

Detecting cancer in humans

Detection of cancer in humans is an emerging dog detection field. Bladder, lung, breast and colorectal cancer have been detected by dogs, from different types of samples such as breath, urine or stool samples.

Detection of bladder cancer with urine samples has been investigated in an experiment with six dogs (Willis et al., 2004). Prior to the test, all dogs were novices in scent training. The dogs, of various breeds and ages, were trained for seven months by handlers experienced in scent training. The samples used were urine from 36 patients with bladder cancer before surgical intervention. The control samples were from 108 people that had recently undergone a cystoscopy that ruled out visible bladder cancer. Pure urine, diluted urine and urine with blood from menstruating women were used as control samples. For every test, new samples were used and there was always one correct positive with bladder cancer and six controls. The person handling the samples changed their gloves between every sample. Samples were presented in a scent lineup, and the clicker method with positive reinforcement was used when the dog identified the right sample. The alert the dogs were taught was to lie down at the right sample. Four dogs were tested with wet urine and two dogs were tested with urine that was dried overnight.

The four dogs trained on wet urine had 50 % correct results and the two with dried urine had 22 % correct results, suggesting that the scent diminishes in the drying process. The mean detection rate was 41 %, with a range of 26 % to 52 %. It is hard for the dogs to distinguish the smell of bladder cancer from the other odours present in urine, and it is hard to know if the dogs smell the scent of tumours or the secondary symptoms such as blood, infection, dead cells etc. It is good that similar controls were used, like urine with menstrual blood, to teach the dogs to not react to the scent of blood. In the trial there was one control sample from a patient that all dogs reacted to. After further investigation, doctors found a tumour in the right kidney of that patient, providing a dramatic validation of the method.

In another study by Sonoda et al. (2011), a Labrador retriever was trained to detect colorectal cancer, both with stool samples taken at a colonoscopy and with breath samples stored in a breath sampling bag. The dog used was an experienced 8 year old Labrador retriever, from St Sugar Cancer Sniffing Dog Training Center, Japan. In the trials, the dog smelled a positive sample before smelling five samples in a lineup where one was correct. The results for detecting cancer in breath samples had a sensitivity (cancer correctly identified by the dog) of 0.91 and specificity (control samples discriminated by the dog) of 0.99. For stool samples the sensitivity was 0.97 and specificity was 0.99. One explanation for the high accuracy might be due to preparing the dog by sniffing a cancer sample before starting the lineup, so the dog was reminded of what scent it was supposed to identify in the lineup. In the beginning of training, the dog sniffed colorectal cancer before the lineup, but later in training different types of cancers were used. This could help the dog to discriminate and alert on different kinds of cancers. It was easier for the dog to identify the target scent from the stool sample than with the breath sample, which is understandable as colorectal cancer is in the colon and more odours is likely to be present in a stool sample than a breath sample (Sonoda et al., 2011).

A study on detection of lung and breast cancer used five dogs, 7-18 months old without prior training (McCulloch et al., 2006). The dogs were trained in a lineup with five breath samples. The samples used were from 55 lung cancer patients, 31 breast cancer patients and 83 controls (biopsy had not shown any signs of cancer). In the beginning of training a dog treat was placed together with the cancer sample to help them learn to distinguish it. In a first phase, the paired sample was presented together with four blank samples. In the second phase the paired sample was presented with four control samples from people without cancer. In the final phase, the positive sample was presented without the treat, together with one cancer sample and four control samples. After completing their training, the dogs were first tested with a single blind test (the positive sample's position unknown to the handler) and then with a double blind test (the test leader and the handler didn´t know the positive sample's position). After the dog sniffed at the five samples and marked one, no reward was given, the dog and the handler exited the room and the dog was rewarded with "good dog!".

In a real situation where a handler does not know if the dog is correct in alerting or not, the risk is that the handler rewards the absence of target scent or fails to reward even on a positive sample. McCulloch et al. (2006), compared the ability to detect lung cancer was compared to the ability to detect breast cancer from a breath sample. The results suggested that lung cancer was easier to detect. The sensitivity of detecting lung cancer was 0.99 and specificity 0.99, while the sensitivity of detecting breast cancer was 0.88 and the specificity was 0.98. This might be simply because lung cancer is more directly connected to breathe than breast cancer is. One of the control samples was marked in 24 of 25 trials. At that stage the patient was "healthy" but 18 months later was diagnosed with breast cancer. This suggests that the scent of cancer was detectable even though the tumour could not been seen (McCulloch et al., 2006), illustrating the diagnostic potential of trained dogs.

To have a dog to detect cancer on live humans in a hospital environment would not be effective due to the limited number of patients that could be processed per day. However, if samples taken by endoscopy or urine were sent for dog detection at another location, this could give valuable clues about where to look further. As the accuracy is not 100 % this could not be used as the sole diagnostic method. Since there are cases where dogs have detected cancer before symptoms are visible, to investigate the cancer odour further might lead to much faster diagnostic methods that could detect cancer in an earlier stage.

It would be interesting to see if it is possible for cancer detection dogs to detect on live humans, and if it is possible for the dog to detect the location of the cancer on that person's body. This could save a lot of valuable time in deciding where to take further samples from.

Detecting human remains (cadaver dogs)

Cadaver dogs detect the scent of dead bodies. This is done both at crime scenes, from boats or when searching for dead bodies. To train cadaver dogs, the handler needs the scent of human remains, which can be collected on a swab from a dead human or from soil from a crime scene. Because the samples are so inaccessible, pseudo scents can be bought. How the pseudo scents are created is unknown but they are sold commercially by Sigma Aldrich (Sigma Aldrich, 2013). Pseudo scents were analysed and found to lack the scent of decomposition, which contains characteristic degrading amino acids like lysine and ornithine (Stadler et al. 2012).

A study examined whether a recently deceased human could be detected by dogs (DeGreeff et al. 2012). Five handlers and 26 dogs of various breeds participated in the study. The target scent was a recently deceased human and decomposition fluid from two dead persons. Cotton pads that had been in contact with the bodies or the fluid were placed in a jar and the headspace was collected and stored either in glass jars or aluminised bags. The samples stored in glass jars gave significantly more correct results in the trials, possibly due to the glass being a less reactive surface than aluminium. The odour from chicken remains and from live humans was used as controls. Eighty six percent of the dogs detected at least one correct sample. However, since dogs were used only in one trial, this does not represent a true detection rate. The detection rates for individual dogs were at best 100 % and worst 0 %. The average for samples stored in jars was 33 % and for plastic bags was 13 %. Several of the dogs did not alert on either of the controls or the remains. The dogs' experience varied greatly, from 0.25 years to 8 years, but this did not have a statistically significant effect on the results. This suggests that it is not the amount of training that matters most. One handler in this trial used scent lineup in his regular training, and his dogs had the highest rate of correct results. Dogs trained with a small quantity of scent had significant better results.

In a study by Oesterhelweg et al. (2008) the ability of cadaver dogs to detect a carpet that had been in contact with a recently deceased human (less than three hours) was tested. One hundred and ten minutes after death, 24 pieces of carpet were placed under the cadaver for 10 minutes, with a cotton blanket in between. Eight pieces of carpet were placed under a second cadaver 120 min after death for two minutes with a cotton blanket in between. False samples from carpets that been in contact with live humans were used as controls. Three dogs trained at the Police Dog Training Center, Hamburg State Police Department, Germany, were used for detection. These dogs were trained to search for wet material such as blood and other body fluids or muscle tissue. The dogs were tested with a scent lineup with six samples in each trial. The alert signal when the dog found a cadaver scent was barking or scratching. Samples that were contaminated during two minutes were used for 35 days and the carpet that was contaminated for 10 minutes was used for 65 days. The dogs' accuracy of detecting the two minute carpets was 86 % and for 10 minutes it was 98 % across all 354 trials. The results are encouraging, but as the scents were from only two individuals it is possible the dogs learned to recognise the individual subjects (like in an identity search), rather than the generic odour of a cadaver. If samples could be taken from a live subject, and then again after death, this problem would be avoided. Nevertheless, it is encouraging that dogs could detect the scent on a carpet, and that the samples were taken from a cadaver that only been dead for a few hours.

Detecting Clostiridium difficile (C. difficile) in humans

C. difficile is a bacteria causing diarrhoea in hospitals. To detect whether patients are infected with *C. difficile,* a sample is sent to the laboratory where it needs to be cultivated on a plate. A beagle, eight years old without any detecting training, was trained to detect *C. difficile* (Bomers et al., 2012). Wooden sticks were placed together with plates with *C. difficile* overnight with a gradually reduced exposure time that eventually reached only 5 minutes. The dog was trained with search and find games with these wooden sticks. After this, the dog was trained with stool samples that were tested by a laboratory. Stool samples confirmed by laboratory as *C. Difficile* free were used as controls. For every lineup, control and target samples from patients in the same hospital ward were chosen. After the dog completed the training with samples, it was tested with real patients in a hospital ward. For the test, the dog walked past the patients' beds and if it detected *C. difficile* the dog alerted by sitting down. The test showed a high accuracy; of 30 cases of *C. difficile* the dog marked correctly 25 cases (83 % accuracy), and of the 270 controls the dog did not mark 265 of them. The dog was tested if it could detect *C. difficile* in live patients in a living room rather than in beds, but this was much harder for the dog. It may be that beds contain more odour as patients spend more time there.

Detecting fungus (Mould dogs)

Dogs that detect fungus in buildings are called mould dogs. In a study, two dogs were trained to detect the most common molds in buildings (Kauhanen et al., 2002). The training started with detecting *Serpula lacrymans*, *Coniophora puteana* and *Antrodia sinuosa* that were cultivated on pine wood and *Cladosporium herbarum*, *Trichoderma viride*, *Botrytis cinerea*, *Penicillium verrucosum*, *Aspergillus niger*, and *Streptomyces sp.* (five strains) that were cultivated on agar. The dogs were trained during 3 months, searching for target samples hidden in buildings under pine timber. The alert was scratching at where the sample was hidden. Two tests were conducted in a class room and in a library; the tests were one month apart with no training during that month. One test dog alerted to 79 % of decayed wood (correct samples), 60 % to samples with bacteria and 13 % healthy wood (false positive). The other dog found 72 % of the decayed wood, 56 % of the bacteria and 12 % of the healthy wood. The second test one month later was less accurate which suggests that the dogs need to maintain their training without interruptions. To get a more realistic test, the mould should have been directly on the walls. This may also have reduced false positives since no pieces of wood would have been there.

Animal detection

Detecting oestrus in cows

To detect the right time for artificial insemination (AI) is of vital importance to a dairy farm. As early as 1978, experiment in dogs' ability to detect cows in oestrus was performed with samples collected from 160 dairy cows (Kiddy et al., 1978). The target samples were from cows that showed visible signs of oestrus such as standing still when mounted by another cow or mounting of other cows. Dioestrous (control) samples were taken from the same cows 6-12 days later. Both vaginal fluid and urine were taken. Four dogs were used in the study. "Within cow comparison" was tested i.e. all the samples on the board were from the same cow, taken from different times in the cows oestrous cycle (dioestrous and oestrus). The opposite, a "between cow comparison", was a dioestrous and anoestrous sample from the same cow and four dioestrous samples from different cows. This is most similar to real life tests with cows on a farm and was more difficult than the within cow comparison.

A real life test was conducted in which three cows were tied up next to each other, and one of the cows showed visible signs of oestrus. The cows were not moved between trials and were not replaced with other individuals, so it is possible the dogs learned which individual cow they should identify. Dogs detected 87.3% of the cows in oestrus, which means they were able to generalise from a sample to the real cows. To maintain the accuracy of oestrus detection, the dogs must be continuously tested with a lineup. As the target samples were taken from cows with only visible signs of oestrus, some of them were possibly in dioestrus. A big advantage of the study was the large number of samples, three samples from 160 cows, though using only visible signs as a measure of oestrus is too unreliable. On average the dogs could detect 81.6 % of the samples from cows in oestrus (Kiddy et al., 1978).

In 2011 Fischer-Tenhagen et al. performed a trial to test if dogs can learn to detect oestrus in cows from vaginal fluid, and if they then can also generalise to detect oestrus in urine and milk. Samples were taken from 23 cows that showed visible signs of oestrus and the cows were inseminated within two hours. After 35-42 days a rectal palpation showed if the cow was pregnant, and only those samples were used for training (12 of the cows were pregnant). Twenty five cows in dioestrus were used as controls, dioestrus was confirmed with ultrasound (had prominent *corpus luteum*). The dogs used for detection had no prior training, but underwent early training in which they learned to detect chamomile tea and to alert by standing still with their nose pressed to a jar. Samples were tested in a scent platform with four dioestrus and one oestrus sample from four different cows. Accuracy in detecting oestrus in vaginal fluid was at best 100 % and at worst 58.3 %. The average for all dogs was 80.3 % and of the controls 3 % were falsely identified. After completing training with vaginal fluid, the dogs were tested for detection of oestrus from milk and urine samples. Milk proved most difficult, and some of the dogs stopped sniffing and started licking the jar instead. As the controls and the positive samples were from separate cows, it is possible that the dogs learned which cows they were supposed to detect and therefore performed an identity search instead of oestrus detection, especially as the cows in oestrus numbered only 12. This could be avoided if the dogs had been trained with "within cow comparison", with samples from different times in the oestrus cycle taken from each cow and trained with a lineup. No test in the farm yard or on real cows was performed (Fischer-Tenhagen et al., 2011).

On a farm it would be more practical if the dog could detect cows in oestrus just by sniffing at the cows head. Therefore dogs have been tested for the ability to learn to detect oestrus in bovine saliva (Fischer-Tenhagen et al., 2013). The same cows were used as in Fischer-Tenhagen et al. (2011) and 12 dogs were tested. Six of the dogs had no previous training and six were already trained as detection dogs. Three of the professional dogs had the greatest detection rates, 75 %, whereas the best detection rate of the dogs without prior training was 65.6 %. It can be concluded that that it is harder for dogs to detect oestrus in saliva compared to vaginal fluid (Fischer-Tenhagen et al., 2013).

Detection dogs used for wildlife conservation

Dogs can be trained to locate wildlife droppings, or scats, over a large area. The scats can then be analysed, and tracking of wildlife species is possible.

Two combined experiments (Wasser et al., 2004) were completed in 1999 and 2001 where teams of four to five dogs looked for scats from grizzly and black bears. The dogs were trained with a scent box (2 m x 30 cm x 30 cm), with holes 5 cm in diameter. The dogs alerted at the target scent by sitting and were then rewarded with a tennis ball. After completing the training, only the dog team that had found 90 % of the target species and 0 % of the non-target species (controls) was included in the test. In 1999 the study area was 5200 km^2 divided into forty 25 km^2 cells, and in 2001 an area of 1500 km^2 divided into thirty 25 km^2 cells. Some of the bears in the area were tracked by radio collar. The scats found were analysed by DNA. In 1999 the team found 0.34 – 1.12 scats per hour and in 2001 0.45-1.11 scats per hour. Looking at the frequency of location during the day, it was clear that the dogs found more scats later in the afternoon. This could be an influence of temperature since the scats' scent increases at a higher temperature.

In the above study, if a long time passed without finding a scat, a scat was placed without the dog´s knowledge, to keep the dogs motivation. Of the scats found, 78 % were less than two weeks old and 94 % were less than one month old. This shows that the scent may decrease with time. The accuracy of scat detection in the field is impossible to calculate, because of not knowing how many scats there are. Every scat gives valuable knowledge about individuals, moving patterns, species, feeding and so on, and to ensure that the dogs find as many scats as possible tests with placed scats must be done on a regular basis.

In another study, dogs were taught to find scats from San Joaquin Kit foxes (Smith et al., 2003). The dogs were chosen because they were obsessed with a toy or foods, and when this object was present the dogs would focus completely on the object despite other distractions. A scent lineup was used where the scent of scats from kit foxes was in one hole. When the dog sniffed at that hole it was immediately rewarded with the object. When the dog understood the connection between the target scent and the reward object, the dog had to sit to get the reward object. The dogs also learned to discard scent from other species; if the dog sniffed too long at a non-target scent it was corrected by leash and voice. Immediately after this, it was led to the target scent and rewarded. In training the dogs managed to identify Kit fox scats even if red fox scats were also present. If only red foxes scats were present the dogs marked that scat as well. This suggests that the dogs should be introduced early in training to a scenario with no correct alternative in the scent lineup. During the trial the dogs found from 0.43 scats to 5.37 scats per km searched. At high temperatures, panting elevated and detection rates decreased. All scats found were from kit foxes, and the dogs ignored scats from coyote, striped skunk and American badger.

Vynne et al. (2010) taught detection dogs to detect multiple endangered species including maned wolf, puma, jaguar, giant armadillo and giant anteater. The test was conducted at two national parks in Brazil, using the same training methods as the study with grizzly and black bears. The giant armadillo and giant anteater were introduced to the dogs two years after the other target species and adding more target species did not reduce the detection rate. The dogs detected 0.09 jaguar scats per km and 0.3 scats from maned wolf per km. The overall average was 0.86 scats of all species per km. It is difficult to compare these figures with other area since population density of these animals varies greatly. In scat detection, the species can only be determined subsequently by DNA test, so when the dog is rewarded it is always a risk that it is a non-target species.

Detecting scats from north Atlantic right whales has only before been done by human olfactory sense. In a scientific study, humans could smell the scats at 56 to 359 meters distance but a dog could detect whale scats at a distance of 22 m to 1.93 km (Rolland et al., 2006). In the study, humans managed to detect on average 0.25 scats per hour whereas dogs detected 1.10 scats per hour. This detection is done on a boat and needs a good sailor who can read the wind and follow the dogs' signals. The study shows great possibilities to use dog detection to learn more about free swimming species. Using DNA analyses of the scats, a lot of information can be gained, including species, sex, and identity and population density, but also hormone levels and feeding patterns.

In another study (Reindl-Thompson et al., 2006) two dogs detected black footed ferrets, finding multiple signs of presence such as scats, hair, bedding or live animals. The dogs had prior training in finding scats, so they were rewarded when they sniffed at live ferrets and other material to learn the smell of ferrets and not just their scat. The test was performed in an area of 2100 ha, in a colony with prairie dogs in South Dakota. On average the dogs searched 26 ha per hour. One of the dogs found 100 % of the signs and the other dog only 57 % of the signs, but neither dog falsely indicated ferrets presence. However it was not clear how they determined the number of signs, and how one could determine how many the dogs missed.

Detection of live animals, in this case Mojave Desert Tortoise, was conducted in 2004 at a conservative centre for Desert Tortoise in Las Vegas, USA (Cablk et al., 2008). Gauze that had been in contact with tortoise skin was used as target scent in training. In the test, the two detection dogs found 184 and missed eight tethered tortoises. The dogs were tracked with GPS, and if the dog suddenly turned against the wind and found a tortoise it was assumed that the dog used its olfactory sense. Dogs found 163 of the tortoises using olfaction and 21 visually. The maximum distance to turn and locate the tortoises was 62.82 meter and the distance was significantly longer when the wind speed was higher. The distance was not affected by temperature or if the tortoise been handled by humans. The dogs didn't detect scats or dead tortoises.

Discussion

From the scientifically performed studies reviewed, it is possible to identify the most common problems encountered when training dogs for detection:

- Too few samples to train and test with. Not only is the number of samples important, but they had to come from a wider variety of sources, for example individual cows, patients etc. It is important that training testing is not done with the same samples.
- Low confirmed accuracy in samples. It is important to know that the target scent is from samples that actually are positive for the scent. This can be achieved with certain forms of cancer detection where the cancer can be confirmed by biopsy or cystoscopy.
- Too few dogs are tested, and the dogs that are tested are trained with unknown or incompletely reported methods.

For many of the targets that can be detected, it is impossible for the handler to know if the detection is correct. This true for *C. difficile*, body fluid or blood from deceased humans, cancer, identity search at crimes scenes, pollution, mine detection, accelerant detection and mould detection. In these cases it is important to maintain accuracy by testing the dog with a scent lineup, where it is known which samples are correct.

Not all scent lineup are with known samples, as is the case with REST in mine searching. Samples from different potentially dangerous areas are presented for the dog to show which area the mines are buried. As the lineup is with samples where it is not known where the mines are, it is also important to alternate with known samples. The positive aspect of remote searching for mines is the dogs´ safety. This search method should also be adapted for detecting dangerous pollutants since even if the dog is taught to mark at a distance, if facing downwind the dog will be very close before discovering the potentially dangerous chemical.

It is simpler in cases where the dog finds an object or an animal, a dead person, scats (might not be the right species) or narcotics. Here the handler can instantly reward the dog. In some detection searches like scat detection, or narcotics, if the dog doesn't find anything for a long time the handler can place a scat or narcotic so the dog can be rewarded and remain motivated to work.

Table 2 - Detection rate, from the literature where it can be calculated

Target scent	**References**	**No. of dogs**	**Worst**	**Average**	**Best**
Accelerants	Nowlan et al., 2007	1		89 %	
Mines	Fjellanger et al., 2002	4	93 %	95 %	96 %
Explosives	Gazit et al., 2005	7	85 %	87 %	89 %
Explosives (after not finding any)	Gazit et al., 2005	7	46 %	52 %	58 %
Explosives – dark	Gazit & Terkel, 2003a	6		88 %	
Explosives – light	Gazit & Terkel, 2003a	6		94 %	
Explosive – before activity	Gazit & Terkel, 2003b	6	88 %	91 %	94 %
Explosives – after activity	Gazit & Terkel, 2003b	6	78 %	81 %	85 %
Humans (handler)	Brisbin & Austadi, 1991	3	87 %	93 %	
Human elbows	Brisbin & Austadi, 1991	3		84 %	
Bladder cancer	Willis et al., 2004	6	26 %	41 %	52 %
Colorectal cancer	Sonoda et al., 2011	1		91 %	
Lung & breast cancer	McCulloch et al., 2006	5	16 %	42 %	85 %
Cadaver, 10 min contamination	Oesterhelweg et al., 2008	3	95 %	98 %	100 %
Cadaver, 2 min contamination	Oesterhelweg et al., 2008	3	75 %	86 %	96 %
C. difficile	Bomers et al., 2012	1		83 %	
Mold, decayed wood	Kauhanen et al., 2002	2	72 %	76 %	79 %
Mold, bacteria	Kauhanen et al., 2002	2	56 %	58 %	60 %
Oestrus cows, vaginal fluid	Kiddy et al., 1978	6	74 %	82 %	91 %
Oestrus cows, vaginal fluid	Fischer-Tenhagen et al., 2011	7	58 %	80 %	100 %
Oestrus cows, saliva	Fischer- Tenhagen et al., 2013	13	40 %	58 %	75 %

Table 2 presents numbers of dogs trained and their detection rates, from studies where these can be calculated. This shows only the detection rate of the target scent, some cases may have a high detection rate but also a high false detection rate (detecting non targets) which is not evident from the publication. When only one or a few dogs are used, the detection rates have limited scientific value. The number of samples is also important; if only a few samples are used or the dogs practice with the same samples, they may learn the samples themselves rather than the generic target odour.

Comparing the detection rate in the different studies, many of them are around 80 % to 90 % of the target scents. Least detection rate was of bladder cancer using wet urine, average detection rate was less than 50 % (Table 2).

The choice of target odour makes a huge difference in training time and amount of samples needed. It takes less time and needs fewer samples for pure substances that cannot be confused with other odours, such as TNT, narcotics or accelerants. For cancer in humans or oestrus in cows, it is always the person or the cow the dog needs to discriminate in the search for the oestrus or cancer odour. There is always a risk that dogs will perform an identity search rather than a target search. In oestrus detection and detection of human remains, the best method to rule out identity search is to take control samples from the same individual. For example, if one sample was taken before the moment of death and one sample after death. In accelerant detection it is important which materials the accelerant is on before the fire because both the temperature of the fire and absorption are different depending on material. This way of testing could also be useful for mould detection, as mould odour might differ depending on material and humidity.

Most of the studies use already trained dogs, and not much research has been published about training methods in detection. There seems to be two types of training; (a) with scent lineup using reinforcement on detecting the right scent with either food, a toy or connecting a toy to a scent (b) direct training with searching in the relevant environment. Although the latter alternative is more realistic, it has a disadvantage as the dog is not presented with similar smells as distractions and is not as easily trained since the amounts of odour are lower. The trained dogs are often trained by companies and it is not clear to what extent the methods used have been scientifically tested.

There are not many studies on how the handler affects the dogs' performance. In many of the studies the tests are double blinded, so neither the handler nor the test leader is aware of which sample is correct. Another aspect is that often the handler is also the trainer, and it takes a lot of experience to train detection dogs where there is much to keep in mind, such as the samples, which samples the person has touched, in which can is the correct sample and so on. It is also hard to compare handlers or trainers because they have different dogs, with different breeds, age and experience and different training methods.

An interesting future development may come from further understanding of the dog´s olfactory sense to develop electronic noses. These could be able to detect more than just volatile chemicals. If the chemical odour composition of, for example, cancer could be understood more reliably, faster diagnostic methods could be developed.

Conclusion

There are a lot of differences both in samples, odour and training methods between the different fields that dog detection is used in. Most of the studies showed that a detection dog finds about 80 % to 90 % of correct samples. It would be interesting to conduct a study with a lot of dogs and multiple target scents, with lots of samples for training and, where possible, a real test in the end, with real cows, people, mould etc. Surprisingly, there are relatively few peer-reviewed scientific studies on the training and use of detection dogs. Clearly, dogs are used very successfully in several fields without the performance (or publication) of scientific studies. However, it would be desirable for more rigorous studies to be carried out, particularly on training methods. In the future, fuller understanding of the canine olfactory sense may mean electronic noses can be created to detect the identity of humans or detect cancer as sensitively as dogs, but even more reliably.

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