
Volume 237, April 2014
ISSN 0379-0738
ELSEVIER
FSI
FORENSIC SCIENCE INTERNATIONAL
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Forensic Science International 237 (2014) 112–118

Contents lists available at ScienceDirect

Forensic Science International

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

Efficacy of drug detection by fully-trained police dogs varies by breed, training level, type of drug and search environment

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ARTICLE INFO

Article history:
Received 20 May 2013
Received in revised form 11 January 2014
Accepted 25 January 2014
Available online 7 February 2014

Keywords:
Drug detection
Dogs
Efficacy

ABSTRACT

Some recent publications claim that the effectiveness of police canine drug detection is uncertain and likely minimal, and that the deterrent effect of dogs on drug users is low. It is also claimed that more scientific evidence is needed to demonstrate to what extent dogs actually detect drugs. The aim of this research was to assess experimentally, but in actual training and testing environments used by the Polish police, how effective dogs trained by the police were at illicit substance detection depending on factors such as type of drug, dog breed, dog experience with the searching site, and drug odor residuals. 68 Labrador retrievers, 61 German shepherds, 25 Terriers and 10 English Cocker Spaniels, of both sexes in each breed, were used. Altogether 1219 experimental searching tests were conducted. On average, hidden drug samples were indicated by dogs after 64 s searching time, with 87.7% indications being correct and 5.3% being false. In 7.0% of trials dogs failed to find the drug sample within 10 min. The ranking of drugs from the easiest to the most difficult to detect was: marijuana, hashish, amphetamine, cocaine, heroin. German shepherds were superior to other breeds in giving correct indications while Terriers showed relatively poor detection performance. Dogs were equally efficient at searching in well-known vs. unknown rooms with strange (i.e., non-target novelty) odors (83.2% correct indications), but they were less accurate when searching outside or inside cars (63.5% and 57.9% correct indications respectively). During police examination trials the dogs made more false alerts, fewer correct indications and searching time was longer compared to the final stage of the training. The drug odor may persist at a site for at least 48 h. Our experiments do not confirm the recent reports, based on drug users' opinions, of low drug detection efficiency. Usefulness of drug detection dogs has been demonstrated here, even if their effectiveness may not be 100%, but different factors have to be taken into consideration to assure maximum effectiveness.

1. Introduction

Out of several kinds of biological organisms used as volatile compound detectors the most known and widely used are canines [1]. There are at least 30 different sets of detection tasks that trained dogs perform [2]. The most common use of detection dogs by law enforcement all over the world is for narcotics and explosives detection [3]. Although detector dogs still are the most recognized, fast, mobile, flexible and durable real-time detectors, there are a limited number of peer-reviewed scientific studies showing how reliable and efficient canine detection of illicit materials is [1,2,4–10]. There are different opinions as to the practical importance of drug detection by canines. Whereas some authors (e.g. Ensminger [11]) cite police accounts concerning the effectiveness of dogs in sniffing out narcotics, giving an example of 12 drug-sniffing dogs at the US Border Patrol Station in El Paso, Texas, that detected $100 million in narcotics in a nine-month period, some recent papers argue that detection and deterrence rates using canines may be lower than law enforcement authorities like to believe [10,12]. In an Australian study, two thirds of regular Ecstasy users interviewed said that they had drugs in their possession when in close proximity to drug detection dogs but only 7% of the time did the dogs positively indicate to them [10]. There are many uncontrolled variables in such a study, however, including whether the dogs were trained to recognize Ecstasy specifically or only trained on methamphetamines, how close the dogs got to the interviewees, whether the interviewees possessed or were under the influence of drugs when the dogs were near

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0379-0738/$ – see front matter © 2014 Elsevier Ireland Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.forsciint.2014.01.013

them, and whether it would have been legal to let a dog sniff a person under the specific circumstances. In another Australian study, interviews collected by Dunn & Degenhardt [12] suggest no significant impact either from police using drug detection dogs to identify and apprehend drug suppliers, or in addicts seeing detection dogs as an obstacle to using drugs.

Dray et al. [13], using agent-based simulation models, found that only very high detection rates by passive-alert detection dogs reduced the intensity of drug use, and noted that use of dogs may have also unintended health consequences for drug users who ingest their drugs upon seeing a police dog. Authors of some recent and earlier papers [2,10,13] note that up to now there has been limited evidence of the efficacy of drug detection by canines and many accounts of efficacy are only anecdotal [12]. It has also been argued that inaccuracies in the performance of detection dogs may be introduced because of expectations their handlers have that illicit substances will be found at a particular location [14]. Although dogs are regarded by some as the gold standard of detection technology [9], the question of dogs' exact detection performance is difficult to measure in spite of some studies on a diverse array of detection tasks. According to Helton [9], for instance, problems in assessing canine detection performance in the published research include lack of uniformity in how performance is measured and in testing conditions and a lack of information regarding canine training. Such concerns have, of course, encouraged some organizations to attempt to set national standards, such as the Scientific Working Group on Dog and Orthogonal Detector Guidelines (SWGDOG, http://swgdog.fiu.edu) in the U.S.

Performance of detection dogs can be assessed by two objective measures: detection speed and accuracy. Although detection speed may be considered a less important metric of performance compared to accuracy, it should be not underestimated [9]. In real scenarios detection dogs should be sufficiently quick, for example in sniffing cars at border checkpoints, to keep traffic flow at a reasonable level.

Also, too rapid a search may, in certain circumstances such as searching for explosives, contain risks such as pulling tripwires or triggering improvised explosive devices. Speed is usually quantified as search time, which entails speed of orientation, speed of movement and speed of appropriate response [9]. Of interest is also the time between initial scent detection and an overt signal to the handler. This interval may differ depending on the detection threshold of a substance that a dog is trained to recognize [15,16]. Detection accuracy involves measuring correct hits, false alerts, misses and correct rejections, from which two main parameters can be calculated: (1) sensitivity = proportion of hits to (hits + misses) and (2) specificity = proportion of correct rejections to (false alerts + correct rejections). Perfect detection sensitivity and specificity would guarantee that no target material remains undetected, and no other materials than the target are falsely indicated by dogs, the latter of which becomes a reason for complaints by people falsely suspected of possessing illicit material. It should be noted that false alerts and misses may not always be the dog's fault, but may instead be the result of human error. While false alerts can result from poor training of a dog, it has been argued that many false alerts result from actions of handlers [14,17].

Knowledge of how particular drugs differ in ease of detection by dogs and how some factors influence the detection parameters may be useful for training dogs and improving their skills such as determining amounts of target odor materials properly used in detection training, training for detection in unusual locations, and developing improved search tactics, all of which allow for evaluating proficiency and lead to increased reliability in the field. The aim of our research was to fill some gaps in the scientific literature on canine efficacy of drug detection by assessing performance of trained police dogs in tests conducted in different settings actually used by the police that are designed to closely model real world situations, taking into account different drugs and different breeds of dogs.

2. Materials and methods

Experimental drug detection tests were conducted using 68 purebred Labrador retrievers, 61 German shepherds, 25 Terriers (Fox, Welsh, Jagd- and Jack Russell Terriers) and 10 English Cocker Spaniels, all breeds of both sexes. The dogs were tested shortly before the first certification of their operational proficiency, during Polish police certification exams or during an annual recertification exam confirming proficiency. All dogs were considered to be fully trained drug detection dogs under Polish police training protocols [18], including those that were in the pre-certification stage but had not formally passed the examination of operational proficiency.

Drugs used for the training and testing were not of pharmaceutical grade but street materials. Although dogs detect substances by vapor concentrations, we chose to use samples based on weights of 10–15 g of hashish, marijuana, amphetamine ($C_9H_{13}N$ – a mixture of dextroamphetamine and L-amphetamine), cocaine and heroin, which were hidden approximately 1 h before searching rooms either known to the dogs (where training was usually conducted), or unknown rooms with odors new (and possibly distracting) to the dogs (stables for farm animals, storerooms), and inside and outside cars. The presence of such additional odors meant that tests were partially conducted in real-world sweep conditions.

During each test only one drug sample was used and each was placed in an unsealed plastic bag in the search area. In rooms known to the dogs tests were conducted at least a month apart to avoid confusing dogs by the presence of drug odor residuals from previous tests. Handlers were blind to the places where drug samples were hidden, while the experimenters present were not. The dogs moved independently (off leash) while searching, except for searching outside cars where they were on leashes. Handlers were allowed to encourage dogs to keep searching and to guide the dogs to search in specific locations.

All tests were recorded by a video camera. According to training protocols of the Polish police, a dog indicated a site where the drug odor was found primarily by scratching at the site (sometimes called an "active alert"). Another manner of indicating, sitting or lying down in front of the site (sometimes called a "passive alert"), was acceptable depending on individual training. If a dog's handler interpreted the dog's reaction as an indication, he/she signaled to the experimenter that a target material was found, and the experimenter confirmed the correctness of the dog's indication by saying "OK." The dog could not see the experimenter's face because the experimenter held a video camera. The experimenter did not interpret an alert as having been given until told by the handler that one had occurred. For a correct indication the dog was immediately rewarded by throwing the dog's favorite toy to retrieve and to play with. A false alert was not rewarded and the dog was mildly rebuked by saying "No".

As detection parameters the following were recorded: time from start to correct indication; number of false alerts (FA); number of passes of the dog closer than 1 m from the sample without indicating as recorded after the trial upon reviewing the video. The time limit for searching was 10 min. If a dog made a false alert, it was allowed to search further, so during a searching with a FA a dog had a chance to get reward if it eventually found the target odor. Such a trial, however, was not considered a correct indication. If a dog was not able to indicate a site where the drug sample was hidden within 10 min, the trial was considered a miss. On a single day, no more than two searching tests were conducted for any dog. If there were two searching tests on a day for a specific dog, the second test was conducted in another room. Several dogs (<10) tested on a day searched in the same room and the target was hidden in the same site for all dogs. Using the same room repetitively was necessitated by the limited training and testing spaces used by the Polish police. Dogs and their handlers waited in another building until they were asked to come for a trial. Altogether 1219 experimental searching tests were conducted, 440 with German shepherds, 517 with Labrador retrievers, 203 with Terriers, and 59 with English Cocker spaniels.

2.1. Statistical analyses

As the traits did not demonstrate normal distribution, the non-parametric *U*-Mann–Whitney test was used to assess significance of differences in detection time and in the number of passes <1 m from hidden material without indicating. The Chi-square test was used for correct indication, false alerts and misses.

2.2. Ethical approval

Ethical clearance to conduct this research project on dogs was obtained from The 3rd Local Ethical Commission for Animal Experimentation in Warsaw, Poland, in accordance with ED Directive 86/609/EEC for animal experiments.

3. Results and discussion

The shortest mean detection time (50 ± 55 s) was recorded for marijuana and the longest (81 ± 88 s) for heroin (Table 1), across all search environments. Also, marijuana was the easiest to detect in terms of the highest percentage of correct indications and the lowest percentages of false alerts and misses (Table 1). On average, for all kinds of drugs, dogs passed more than twice close to the hidden drug (<1 m) prior to indicating. When detecting heroin the dogs passed on average >3 times without indicating (Table 1).

Taking into account detection time and the percentage of correct indications, the ranking of drugs from easiest to most difficult to detect was determined to be as follows: marijuana, hashish, amphetamine, cocaine, heroin. German shepherds were superior to other breeds in the percentage of correct indications (Table 2); however, the difference was only significant in their performance over Labrador retrievers and Terriers. Terriers demonstrated longer detection times, a lower percentage of correct indications, and the highest percentage of false alerts (Table 2).

Detection time did not differ significantly during searching in known vs. unknown rooms or outside vs. inside cars. Significantly shorter detection times occurred in searches of lineups of luggage (Table 3). In the latter case the dogs had to compare 5 luggage pieces and indicate the one containing the target odor. On the basis of a lower percentage of correct indications, and a higher percentage of false alerts, detection outside and inside cars proved to be less accurate than in known or unknown rooms or outside rooms (Table 3). Searching outside cars more often ended with a miss and searching inside cars was characterized by the highest percentage of false alerts and thus lower percentage of correct indications (Table 3).

Detection times were longer during formal certification examinations, with more false alerts than was true of dogs before examinations and during annual recertification examinations (Table 4). This was probably caused by trainers being anxious because their dogs were taking their first certification examinations.

As to the persistence of residual drug odors, the odor of hashish lasted longest and was indicated by dogs in 100% of trials conducted 24 h after the hashish had been removed and in 80% of trials after 48 h (Table 5). The percentage of indications of residual hashish odor after 24 h was even higher than for fresh odor emitted by samples that were present at the searching site (Table 1). A significantly lower detection rate was found for residual odor of heroin, with almost no detection after 48 h (Table 5).

It is arguable that research on the forensic reliability of procedures based on canine scent capabilities has not adequately supported the widespread use of these capabilities in law enforcement. As for any type of scent detection with canines, the question often arises as to exactly which chemicals the dogs are being trained to recognize and alert to, and with what detection

Table 1
Detection parameters depending on drug kind in experimental search.

Drugs	Mean time ± s.d. to correct indication (sec) (1)	% correct indications (2)	% misses (3)	% false alerts (4)	How many times the dog passed <1 m to hidden material before indication (mean ± s.d.) (5)
Marijuana	50 ± 55^{BEFG}	91.8^{EFGH}	4.4^{AB}	3.8^{ABCD}	2.6 ± 2.2^{d}
Hashish	54 ± 53^{cDE}	82.4^{EjK}	5.7^{cD}	11.9^{B}	2.4 ± 2.3^{Aef}
Amphetamine	74 ± 89^{B}	78.3^{F}	5.0^{EF}	16.7^{A}	3.0 ± 3.8^{ABCd}
Cocaine	79 ± 82^{DG}	74.0^{Gj}	12.6^{BcE}	13.4^{C}	2.7 ± 2.0^{Bf}
Heroin	81 ± 88^{cF}	70.3^{K}	12.0^{ADF}	17.7^{D}	3.4 ± 3.0^{Ce}

Figures in columns denoted with the same letter differ significantly: superscript capitals = $P < 0.01$, superscript small letters = $P < 0.05$.
Mann–Whitney *U* test for columns (1) and (5), Chi-square test for columns (2)–(4).

Table 2
Detection parameters depending on dog breed.

Dog breed	Mean time ± s.d. to correct indication (sec) (1)	% correct indications (2)	% misses (3)	% false alerts (4)	How many times the dog passed <1 m to hidden material before indication (mean ± s.d.) (5)
German shepherds	61 ± 74^{a}	86.8^{aB}	5.0^{a}	8.2^{aB}	2.8 ± 3.3
English Cocker Spaniels	62 ± 56	82.0^{d}	12.0^{a}	6.0^{D}	2.5 ± 1.9
Labrador retrievers	66 ± 67	78.8^{aC}	8.2	13.0^{aC}	2.6 ± 2.2
Terriers	79 ± 90^{a}	67.0^{dBC}	8.4	24.6^{BCD}	3.0 ± 3.0

Figures in columns denoted with the same letter differ significantly: superscript capitals = $P < 0.01$, superscript small letters = $P < 0.05$.
Mann–Whitney *U* test for columns (1) and (5), Chi-square test for columns (2)–(4).

Table 3
Detection parameters depending on searching site (pooled for all drugs).

Searching site	Mean time ± s.d. to correct indication (sec) (1)	% correct indications (2)	% misses (3)	% false alerts (4)	How many times the dog passed <1 m to hidden material before indication (mean ± s.d.) (5)
Rooms known to dogs	70 ± 76^{A}	83.2^{AC}	7.3^{ade}	9.5^{AC}	2.7 ± 2.6^{A}
Rooms unknown to dogs	64 ± 80^{B}	83.2^{BD}	4.3^{BC}	12.5^{bD}	3.2 ± 3.8^{B}
Outdoors	61 ± 44^{C}	86.5^{EF}	7.7^{f}	5.8^{eF}	3.3 ± 3.8^{C}
Cars outside	64 ± 57^{D}	63.5^{ABEG}	14.6^{aBD}	21.9^{Abe}	2.7 ± 2.1^{d}
Cars inside	78 ± 84^{E}	57.9^{CDFH}	6.2^{C}	35.9^{CDFG}	3.0 ± 2.9^{E}
Lineup of luggage	23 ± 20^{ABCDE}	83.6^{GH}	1.6^{Def}	15.1^{G}	1.9 ± 1.6^{ABCdE}

Figures in columns denoted with the same letter differ significantly: superscript capitals = $P < 0.01$, superscript small letters = $P < 0.05$.
Mann–Whitney *U* test for columns (1) and (5), Chi-square test for columns (2)–(4).

Table 4
Detection parameters depending on dogs' experience.

Dogs' experience stage	Mean time ± s.d. to correct indication (sec) (1)	% correct indications (2)	% misses (3)	% false alerts (4)	How many times the dog passed <1 m to hidden material before indication (mean ± s.d.) (5)
Final training stage (before examination)	53 ± 71^{Ab}	86.6^{A}	3.8^{A}	9.6^{Ab}	2.7 ± 3.3^{a}
During examination	71 ± 87^{A}	74.7^{Ab}	2.9^{b}	22.3^{AC}	2.8 ± 3.4
During annual attestation	69 ± 71^{b}	84.6^{b}	9.2^{Ab}	6.1^{bC}	2.8 ± 2.4^{a}

Figures in columns denoted with the same letter differ significantly: superscript small letters = $P < 0.05$; superscript capitals = $P < 0.01$.
Mann–Whitney *U* test for columns (1) and (5), Chi-square test for columns (2)–(4).

sensitivity and specificity. Detection accuracy should ideally approach 100% sensitivity and specificity, with dogs alerting every time a target odor signature is sampled and never alerting to odors other than the trained target odors.

Canine detection sensitivity in different detection tasks reported by authors cited by Helton [9] ranged from 75 to 100% and specificity ranged from 82 to 100%. 100% detection accuracy must be regarded as exceptional and may be doubted since it may depend on methods of odor presentation, source of odor and the number of trials taken into consideration. Canine detection rates well over 80% were cited in a review published recently [1], involving accelerant detection, cadaver search, human scent trailing and explosives detection. Actually, the real detection performance, e.g. for illicit cocaine, was estimated at 80–90% [4], or at 70–100% with less than 10% false alerts depending on the individual dog and the number of arbitrarily selected odorous compounds [19]. The latter two studies, however, were conducted in experimental settings completely unlike actual drug search situations. In Waggoner et al. [4] a dog's response was to press the left or right lever in a small chamber the dog was placed in depending on the status of the odor (clean air – left lever, target odor – right lever), whereas in Williams et al. [19] the dogs had to sample odors placed in 20 marked positions in a circle. Thus, the dogs in both cited studies did not search for an odor source in an open environment but rather had to identify respective target odors at specific stations [19] or to master a left-right response depending on what odor was piped into a chamber [4].

Dogs' correct alerts to target odors, misses (non-alerts in the presence of a target odor), or false alerts (alerting where the presence of target odor is non-existent) may arise for different reasons. Dogs searching for drugs may alert rather to volatile odor chemicals associated with drugs than to the parent drug itself [2,7]. Therefore it has been claimed that the components of the substance on which the detection sensitivity depends must be determined [4] and there is a body of research attempting to specify the chemical components of such odor signatures. Substances targeted for detection usually involve multiple chemical components [4]. Some studies have demonstrated, for instance, that methyl benzoate, a common volatile cocaine byproduct, is the chemical to which dogs alert when detecting cocaine [4,7]. Lorenzo et al. [2], using headspace solid-phase microextraction (SPME) combined with gas chromatography,

Table 5
Detection parameters in experimental search for residual odor of drugs, depending on time elapsing from the last 3-h presence of a drug sample.

Drugs and time from the last presence before test		Mean time ± s.d. to indication of residual odor (sec) (1)	% indications of residual odor (2)	% no indication of residual odor (3)	% false alerts (4)	How many times the dog passed <1 m to hidden material before indication (mean ± s.d.) (5)
Marijuana	24 h	118 ± 99	69.6	13.0	17.4	3.8 ± 2.4^{bdh}
	48 h	81 ± 88^{e}	58.4^{F}	33.3	8.3	1.9 ± 1.9^{Fh}
Hashish	24 h	51 ± 25^{A}	100^{A}	0	0	2.7 ± 1.5^{c}
	48 h	59 ± 38^{C}	80.0^{C}	20.0^{BD}	0	4.2 ± 1.9
Amphetamine	24 h	89 ± 87^{b}	81.8^{b}	9.1	9.1	$2.1 \pm 1.0^{\underline{\mathbf{A}}b}$
	48 h	101 ± 67	57.1^{d}	42.9^{c}	0	1.7 ± 2.2^{e}
Cocaine	24 h	96 ± 122	66.7	0	33.3	6.0 ± 7.8
	48 h	49 ± 25^{d}	66.7^{E}	33.3^{e}	0	2.0 ± 1.0^{g}
Heroin	24 h	175 ± 84^{Ab}	33.4^{Ab}	$22.2^{\underline{\mathbf{A}}}$	44.4	$5.4 \pm 2.5^{\underline{\mathbf{A}}cd}$
	48 h	171 ± 77^{Cde}	8.4^{CdEF}	$83.3^{\underline{\mathbf{A}}BcDe}$	8.3	4.2 ± 1.2^{eFg}

Figures in columns denoted with the same letter differ significantly: superscript small letters = $P < 0.05$, superscript capitals = $P < 0.01$, superscript bold underlined capitals = $P < 0.001$.
Mann–Whitney *U* test for columns (1) and (5), Chi-square test for columns (2)–(4).

identified piperonal in an amount of 10–100 μg as a substance to which the canines alert when detecting MDMA (Ecstasy) tablets. Another study [20] showed a wide variance of MDMA with several compounds being common among MDMA samples regardless of starting compounds and synthesis procedure. These authors recommended training dogs using combinations of compounds, i.e., the primary odor piperonal in conjunction with secondary compounds, to maximize detection of different illicit MDMA samples. Piperonal is also found in flavoring and perfumes, meaning that dogs may sometimes alert to materials that are not illicit [21]. In studies on comparing canine detection performance for pharmaceutical and illicit cocaine hydrochloride [4], it was demonstrated that dogs are more sensitive to vapor from illicit than pharmaceutical cocaine. In another study Waggoner et al. [5], using substances that were not disclosed because of their relevance in practical detection tasks, found that detection performance could be disrupted if an extraneous odor was present, but concluded that only very large amounts of the extraneous odor in relation to the target odor disrupted canine detection ability.

Waggoner et al. [4] found that the average sensitivity threshold for methyl benzoate vapor and for illicit cocaine vapor was 16 ppb and 0.03 ppb respectively. Furton et al. [7] showed that the microgram levels of cocaine that have been reported to be present on circulated U.S. currency are not sufficient to evoke an alert from drug detector dogs.

Detection of trace amounts of drugs may be interesting but was not pursued in the present study since the practice of the Polish police in training dogs is not to use trace amounts of material. Also, there is a concern that alerting by dogs to trace amounts may create technical and legal problems with proving that finding a trace amount might have been the result of handler cues or was not otherwise accidental.

For practical reasons drug detector dogs are seldom specialized on a particular drug but are trained to detect several of the most commonly used and trafficked drugs. Generally there is little difficulty in training dogs to alert to multiple odors. Studies have demonstrated that dogs are able to detect untrained substances with a class depending on their similarity to substances used during training [19]. Moreover, the more target odors dogs have learned to discriminate from non-target odors, the fewer training trials are required for each new target [19,22].

In drug detector dog training, dogs are generally first trained to alert to odors considered "strong" or "easy" in terms of human olfaction. These are generally drugs of Cannabis origin (hashish and marijuana), which are for many law enforcement trainers also the most easily acquired drugs for canine training. The present results confirm that marijuana and hashish are the easiest to detect by dogs, at least dogs trained under Polish police regimens, in terms of detection time and accuracy.

In real-world scenarios it is impossible to estimate the true percentage of correct alerts and misses since it is not known whether the odorous material is or was actually present at the searching place. In our experimental setting the searching took place in situations with drugs hidden in all tests, i.e., there were no formal negative or "zero" trials. Some proofing trials were conducted in an attempt to assure that there were no residual odors, and such as were conducted produced no indications Unfortunately, because of the limited time frames of the certification exams and other testing procedures at the training center, it was generally not possible to allocate time for negative trials. This has some implications. First, the misses in our tests were true false negative reactions and not true correct negatives. Second, false positive alerts in our tests could have been caused by the dissemination of the odor plume around an odor source. Ideally, dogs should alert as close as possible to the site where the odorous material is hidden by comparing the differences in odor concentration inside the odor plume. We did not control the distribution of odor plumes across different drugs or searching sites. In practice, however, dogs may have difficulties in precisely indicating the place where the drug is hidden due to distribution of the odor plume. Comparing the concentration of an odor inside of the odor plume may correlate with the number of a dog's passes close to the odor source before indication. It is common for a dog to enter, then exit and reenter the scent cone during odor detection which may account for number of times a canine passed a hide as demonstrated in the data. The role of the distribution of the odor plume was evident in our experiment when comparing the percentage of false alerts in particular searching sites. When searching outdoors the distribution of the odor plume may often enable a more easily directional scenting and localization of odor source, which thus takes less time with more correct and fewer false alerts. On the other hand, inside the small space of a car cabin, the odor plume may be distributed throughout the space, which results in a higher percentage of alerts away from the odor source. When searching outside cars the changing air turbulence around the car may disrupt the odor plume, resulting in more misses and more false alerts.

The specific way the odor plume of a drug moves and disperses, depending on air currents, humidity, temperature, or features in the terrain, may also influence the detection performance [23]. There is little information available in the scientific literature on the influence of many common factors such as temperature, humidity or wind, on real-world detection by canines. The fluid dynamics of odorant transport during sniffing has generally been overlooked [24].

Combined detection using devices such as an ion scan or "electronic nose", aimed at reducing the number of sites within searching area where samples would be taken for analysis, has not been applied in practice to date. How such combined detection may improve detection efficacy in terms of sensitivity/specificity and speed or workload could not be determined in this study. Upon a dog's alert, a site will be thoroughly checked visually by the dog handler including disassembling items where illicit material is suspected of being hidden. Using an ion scan for examining difficult-to-access sites may reduce canine false alerts when the scan does not confirm dogs' indications, provided that the device is at least as sensitive as a dog's nose. If the device is not as sensitive as a dog's nose, ignoring the dog's alert may lead to failure to detect material that is actually present. Taking extra samples for ion scanning from sites where a dog shows more interest but does not alert may reduce dog's misses but may prolong searching time since dogs often show interest in sites where they do not eventually alert.

Using a control odor mimic permeation system (COMPS), Macias et al. [25] were able to demonstrate that the canine limit of detection of piperonal, which is a starting substance for the illicit drug MDMA, was 1 ng piperonal emanating from the 100 ng s^{-1} COMPS compared to 2 ng using the solid phase microextraction–ion mobility spectrometry (SPME–IMS) in a static closed system. It has been concluded [25] that detection capabilities for piperonal are similar in dogs and SPME–IMS, with generally a wider variation in the limit of detection for canines than for instruments. However, dogs were superior at the reaction time to odor approximately 1 s, compared to the SPME–IMS (37 s), which required 30 s for concentration of vapors onto SMPE fiber plus 7 s for detection itself [25]. Although IMS is widely used for security applications (contraband, explosives, drug detection – 15,000 instruments deployed, over 1 million analyses per year [25]) some authors [e.g. 26] point out the difficulties of developing chemical sensors vs canine biological sensors. For example, chemical reactions tend to change sensor composition, often in a nonreversible way, or the odor exposure quickly saturates the sensor which needs significant recovery time to be ready for the next measure.

Lit et al. [14] demonstrated that dog handler beliefs may affect outcomes of scent detection by dogs. The handler-dog interaction during searching is often evident when observing the dog's behavior, hesitations or more visible interest in particular sites of the searched area correlating with prompts and interest in such locations from the handler. On the other hand, Scheider et al. [27] conclude that dogs do not necessarily see human pointing as a command ordering them to a particular location. According to Marshall-Pescini et al. [28], however, the dog's human-directed communicative behavior is influenced by individual training experience. Lasseter et al. [29] found that during searching for cadavers, 10% of canine alerts went unrecognized by their handlers and 5% of positive detections were the results of the handlers themselves locating the target substances. Our results suggest that handlers' intrinsic state (stress) may influence dogs' performance: when the handlers knew that trials were certification trials, the dogs made more false alerts and thus fewer correct indications and searching time was longer (Table 4).

The suitability of particular breeds for detection tasks is of importance at procurement of dogs for the training and in operational work. The preference for a particular breed for detection may in different countries depend on a traditional choice of a breed, availability and current opinions. There is generally a lack of comparative scientific studies on suitability of particular breeds for detection tasks. In our study the German shepherds proved to be slightly superior to 3 other breeds and Terriers demonstrated on average relatively poorer detection performance. Terriers, on the other hand, have the advantage that they can fit into tight quarters and can be easily lifted to sniff areas difficult for other dogs to reach, such as narrow tunnels and inside cupboards.

The olfactory acuity of dogs' sense of smell toward various volatile chemical compounds may differ considerably, though results may also reflect different experimental designs of different laboratories [16]. Odors of different drugs may be differently sensed by dogs, and consequently ease of detection may differ. These differences may be related to polymorphic forms of olfactory receptor genes [30] or their breed specific allelic variants [31] or to the proportion of functional vs. non-functional genes [32], showing affinity to the volatile chemical compounds characteristic of a drug.

Opinions on suitability of particular dog breeds for detection tasks should be made with caution. Svartberg [33] found a decreasing relationship between breed-characteristic behavior and the original function of the breed at its origin. This suggests that current selection of breeding stock for appearance affects breed-typical behavior. Thus it could be expected that ranking of breeds used for detection would be different depending on the working quality of breeding stock in particular countries. Others studies, in contrast, have indicated that certain breed behaviors remain relatively stable despite decreasing use of original functions [34].

It is well known that scent detection dog performance depends not only on olfactory acuity but also on canine cognitive and learning abilities [35–38]. Out of several behavioral characteristics of candidate dogs for drug detection training, Maejima et al. [39], using principal component analysis, identified 2 components: Desire for Work and Distractibility. Desire for Work was significantly related to successful completion of training. Taking into account the high demands on trainee sniffer dogs to develop olfactory, cognitive and learning capacities as well as high motivation for work, Rooney et al. [40] point out that only a small minority of any given dog population possesses the traits necessary to complete specialist training. For example, in Japan, only approximately 30% of dogs that enter training programs for drug detection dogs successfully complete training [39].

The detection performance of sniffer dogs is context-dependent. Gazit et al. [41] have demonstrated that detection dogs will be differently motivated to search in locations where they have been trained and always have the possibility of finding a target scent (and being rewarded for this) vs. places that are always clean where the dogs never have a possibility of finding the target odor. In our study, however, no significant differences could be found in detection performance between rooms that were known to the dogs, due to training sessions having been conducted in them, and rooms that were entirely novel to the dogs and, moreover, contained odors that were completely strange to dogs. The short duration time of sniffs of lineups of luggage may reflect procedures in which dogs are trained on rows of boxes, bags, and other items in patterns that mimic baggage running on conveyor belts.

The persistence of odors of particular drugs coincides roughly with the ease of detection of drugs actually present in searching scenes. The odor residuals of hashish and marijuana were the most persistent and the odor residuals of heroin proved to be the least persistent and practically undetectable after 48 h from the last presence of heroin at the location.

Some independent research published by government agencies [10,42] reported low accuracy of drug detection by dogs in the field. Also, the deterrent effect of the presence of drug detection dogs was argued to be low [10,12]. However, the very low detection rate of 7% reported by Hickey et al. [10] was based not on experiments with dogs but on interviews of frequent Ecstasy users in Australia. This result cannot be directly compared with experimental results for several reasons. First, it was not known how thoroughly the dogs had sniffed or had the opportunity to sniff the interviewed Ecstasy users. The mere presence of dogs nearby or seen by a drug user cannot be regarded as a detection procedure. Depending on circumstances, a drug carried by a person can sometimes be undetected by dogs if, for example, the odor plume does not reach the dog's olfactory receptors. Hickey et al. [10] admit that they did not ask how far away participants were from dogs at the time of sighting, so it is possible that participants of this survey were simply out of range of the dogs' noses. Second, it is unknown how accurate drug users are in their opinions on dog efficiency. Third, deterrent effects of dogs' presence, or even reported harm due to hasty consumption of all drugs possessed upon sighting the dog, could reflect a drug user's psychology without saying anything about detection performance. Fourth, the random detection of illicit drugs carried by persons in a public place should be distinguished from active detection in rooms. Data suggesting that the use of detection dogs does not significantly assist police in identifying and apprehending drug suppliers [10,12] has to be interpreted by taking into consideration both the tactics used by police dog handlers, the nature (passive or active) of the dog's alert, the reliability of the dogs involved and the reason for the use of the dogs (deterrence vs. detection). An agent-based simulation model [13] revealed that only very high detection rates of passive-alert dogs may reduce the intensity of drug use. Even if a decrease of drug use due to using detection dogs is driven by a fourfold increase in negative health consequences to drug users [13], this may only suggest that using dogs to detect drugs on people is a questionable police policy, but this does not necessarily apply to the use of dogs to search for drugs in rooms or vehicles where the drug users have no immediate access to the drugs that they are not holding on their persons.

4. Conclusion

Our results do not confirm the information of low drug detection efficiency of trained dogs published recently on the basis of drug users' opinions. Rather, these results support the usefulness of drug detection dogs, even if their effectiveness may not be 100%. Also, we have shown how certain factors, such as breed of the detection dog, type of drug, and type of searching environment, may influence canine detection performance. Thus, dogs correctly indicated drugs in 70–91% of cases. German shepherds proved to be best detectors in terms of faultless indications. Marijuana was the easiest and heroin the most difficult to detect in terms of detection speed and accuracy. Rooms known vs unknown to dogs did not differ in detection parameters. Percent of correct alerts when searching outside or inside cars was lower than in rooms. During formal certification examinations detection success rates were worse than before examination and during annual recertification examinations. The odor of hashish lasted longer, at least for 48 h, whereas the residual odor of heroin was almost not detected by dogs after 48 h.

Acknowledgement

This study was financially supported by The National Centre for Research and Development (Poland), Department of Scientific Research and Studies for the Purposes of National Defense and Security, grant No. ON 311 0543 36.

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