Accelerant detection canines' ability to detect ignitable liquids

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CONTENTS

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ABSTRACT

The efficacy of accelerant detection canines has never been investigated before using burned ignitable liquids (ILR). However, burning alters the liquid's chemical consistency, and the liquid may thus have a different smell after burning. We were also interested to find out, does the delay from the burning event affect the dog's ability to detect ILR. In this study, we investigated the efficacy of trained accelerant detection dogs (N = 5) to detect ILR (gasoline, charcoal lighter fluid, isopropanol) after one or three days of burning event. Each dog sniffed six tracks, where each track included three control samples and one ILR sample in a randomized position. All ILR samples, and also all the control samples that the dogs marked, were analysed with gas chromatography-mass spectrometry (GC-MSD) to determine the exact amount of ILR. Samples detected by GC-MSD having traces of ILR were found by dogs with 0,89 likelihood, however, dogs also found those ILR samples, that GC-MSD did not detect (with likelihood 0,59). Isopropanol was the most difficult ILR for the canines to detect. The delay (in days) from the fire event did not have effect on the likelihood of detecting ILR. To summarize, acceleration canines found burnt ILR very reliably, without false alerts, when the concentration of the substance was above reporting limit. Dogs found substances relatively well also in cases when the residue of the substance could not be reliably verified (below the reporting limit), and even in cases when the substance was not detected in laboratory analysis at all.

1. INTRODUCTION

The two most important objectives of fire investigation are determining the origin and the cause of the fire. If there is reason to suspect that the fire was started deliberately using ignitable liquids such as gasoline or lighter fluid, either technical devices or accelerant detection canines (ADC) are used in the investigation. Dog has an excellent sense of smell, and humans are using it to a greater extent in, for example, searching for drugs, explosives, human remains, cancer, mold, and predicting sudden attacks of disease. Dog's ability to distinguish smells is 10 000–100 000 times more acute than that of a human, and dogs can detect much smaller concentrations of various substances compared to humans[1]. ADCs are dogs used in arson investigation and they search for potential ignitable liquid residues. Accelerant detection canine training started in the United States in 1980s, and the first European ADC was trained in England in 1996. An ADC will usually be brought to the fire scene as soon as it is possible and safe, usually within 1–3 days following the extinguishing of the fire. If the handler sees that the dog has alerted at a potential ignitable liquid residue, a sample is collected and later analyzed at a forensic laboratory, and the compounds in the sample are identified. Occasionally, the laboratory analysis is unable to present evidence of ignitable liquid residue in a commercial product even if a dog has alerted in the area at the scene. In Finland, usually only ignitable liquid residues that meet sufficient quality criteria in forensic laboratory testing are admissible as evidence in court, as many objects and substances release similar compounds when burning as ignitable liquid residues contain. On the other hand, in the U.S. and England, for example, convictions have been reached based solely on ADC detection[2]. How efficient is an accelerant detection canine in finding ignitable liquid residue? Although ADCs are commonly used all over the world, only a few studies have been conducted on their reliability in detecting ignitable fuel residues. In earlier studies, ADCs' ability to reliably detect ignitable liquid residues has varied considerably between dogs and, at its best, a dog has been able to detect very small concentrations of unburnt ignitable liquid[3] that older forensic analyzers (1990's) where unable to detect[2]. On the other hand, there have been a lot of differences between ADC teams in both finds and false alerts; some dogs have been considerably more reliable than others[3].

In prior studies, ADCs have searched for liquids that have been added into either burned or unburned material afterwards, meaning that the ignitable liquid has not been burned at all[3]. However, the reality at a fire scene is different: the dog must be able to detect the ignitable liquid after burning. Burning is known to alter the composition of ignitable liquids in a way in which light components burn or evaporate entirely or in part. The liquid is likely to smell very different to the dog after burning. Also, the ADC cannot necessarily access the fire scene immediately due to safety reasons and other factors. In 2016 and 2017 in Finland, ADCs visited the fire scene on average 48–72 hours after the fire.

The effect of several days of evaporation on ADC's ability to detect various substances has not been studied at all in earlier research.

An ADC can be trained to detect several odors, and in Finland the most typical substances that ADCs search for are gasoline, lighter fluid and isopropyl alcohol, which are often used in arsons. We do not know, if all substances are equally easy for an ADC to detect after burning. In this study, we look into ADCs' ability to detect various ignitable liquids, such as gasoline, lighter fluid and isopropyl alcohol, after burning and determine how evaporation over several days affects the ADC's ability to detect the substance. The actual amount of ignitable liquid is analyzed in the forensic laboratory in order to compare the effect of the amount of substance on the probability of an ADC detecting it.

2. METHODS

2.1. Research population

The study was conducted using five trained Finnish accelerant detection canines. The dogs were all male, and the breeds were Belgium Shepherd Malinois (3 dogs) and German Shepherd (2 dogs). The average age of the dogs at the time of study was 5 years 8 months (varying between 2 years 10 months and 9 years 10 months). Four out of five of the dogs were what are known as combination dogs, whose training consists of protection, search, tracking, obedience and special training, in this case, accelerant detection training. One of the dogs was a special search dog serving only as an accelerant detection canine.

2.2. Study protocol

The study was conducted on November 15th, 2017 at the Police Dog Training Centre in Hämeenlinna. Three substances often used in arsons (gasoline, lighter fluid and isopropyl alcohol) were used in the study. The effect of evaporation was studied by comparing the ADCs' ability to detect ignitable liquid residue (gasoline, lighter fluid and isopropyl alcohol) 24 and 72 hours after the fire was extinguished (Table 1). Each dog went through six can tracks in one day, three in the morning and three in the afternoon. The handlers did not know the location of the ignitable liquid on the track.

One can track consisted of four cans, one of which, in a randomly selected location, had the substance to be searched (Figure 1). The cans were placed 1.4 meters apart. Three cans contained material burned using the same method and without ignitable liquid (control sample of charcoal). Each of the three cans of control samples on one track were from different burnings resulting in three independent references. The control samples on each track had evaporated as long as the target substance on that track: if the target substance was gasoline that had been burned 72 hours prior, the other three cans on the track contained control samples from three separate burns also done 72 hours prior. Each dog searched for the substances in the same order (Table 1) but the location of the can containing the target substance was random and therefore varied between dogs.

***Figure 1.* Test track with three concrete blocks containing control samples and one containing the target substance, located at a random spot.**

Table 1.

Name	**order on the can track**	**explanation**
GAS3	morning 1	gasoline, evaporated 72 hours
ISO3	morning 2	isopropyl alcohol, evaporated 72 hours
LF1	morning 3	lighter fluid, evaporated 24 hours
LF3	afternoon 1	lighter fluid, evaporated 72 hours
ISO1	afternoon 2	isopropyl alcohol, evaporated 24 hours
GAS1	afternoon 3	gasoline, evaporated 24 hours
R1A	AM 3, PM 2 and 3	control sample, burn A, evaporated 24 hours
R1B	AM 3, PM 2 and 3	control sample, burn B, evaporated 24 hours
R1C	AM 3, PM 2 and 3	control sample, burn C, evaporated 24 hours
R3A	AM 1 and 2, PM 1	control sample, burn A, evaporated 72 hours
R3B	AM 1 and 2, PM 1	control sample, burn B, evaporated 72 hours
R3C	AM 1 and 2, PM 1	control sample, burn C, evaporated 72 hours

After each track, both cans (control samples and target sample) and the concrete blocks used as casing were replaced with new, unused ones, to avoid odor contamination. If a can tipped over, the area was carefully cleaned. Only one person handled the can containing the ignitable liquid (wearing gloves) and placed it in its casing. The person handling the control samples, (who was a different person), touched all casings when all four samples were on the track before the ADC's arrival. After the study, samples from all cans containing ignitable liquid were collected in nylon bags and delivered to the forensic laboratory in order to determine concentration. Samples were also collected from all control samples the ADC marked as we wanted to ensure that false markings were not due to potential contamination.

On the day preceding the study (November 14th, 2017) all ADCs took an official Finnish police ADC certification test where they had to find three hidden samples of unburnt ignitable liquid. Each ADC undergoes certification annually and we wanted to compare potential differences in the probability of detecting burnt and unburnt substances.

2.3. Burning events

The control and the target samples containing ignitable liquid were burned at the Police Dog Training Centre on either November 12th, 2017 or November 14th, 2017 between 9 a.m. and 1.30 p.m. The burnt material in all samples was dry birch which was lit with a match. Birch bark was used as tinder in the control burns. There were six control burns and two ignitable liquid burns per liquid. The detailed burn schedule is in Appendix 1. A total of 50 ml of ignitable liquid was used in each burn and it was applied evenly on wood with a dedicated brush. A total of 100 ml of each liquid was used (e.g. GAS1 50 ml and GAS3 50 ml). The burn was done on a metal plate and extinguished with a sheet metal lid *(Figure 2)* with a dedicated lid for each liquid (four lids in total: three plus control). Burnt material was collected from each ignitable liquid burn and put in five cans (30 cans in total), and material from each control burn was collected and put in three cans (90 cans in total). The cans were covered with lids during transport.

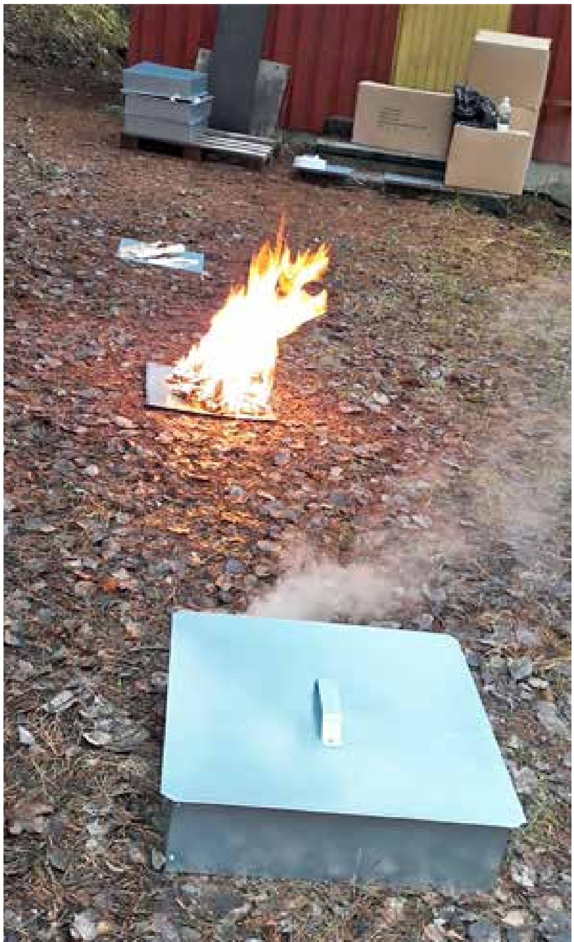

Figure 2. **The burns were done on a metal surface using a small amount of wood and extinguished using a lid.**

2.4. Evaporation

The cans were transported to an unheated building made of wooden boards (indoor temperature varied between +2.1°C and +4.4°C) and stored there for either 24 or 72 hours. We decided to evaporate the containers indoors rather than outdoors where rain and snow might have had an effect and created more variation. During evaporation, the cans were stored without lids but shielded from rain and snow. On the morning of the study, lids were put on the cans for transport and only taken off at the scene of the study when the samples were placed in the concrete block containers. The cans including different target substances and control samples were all kept apart *(Figure 3)* in the storage to avoid contamination.

***Figure 3*. Storage of the cans in the outdoor storage. The cans were stored for either 72 or 24 hours without lids.**

2.5. Correct and false marking

A change in behavior approved by the handler at the correct can was recorded as a correct marking, and a change in behavior approved by the handler at an incorrect can was recorded as a *false marking*.

2.6. Laboratory analyses

After the study, the cans containing the samples (all target samples and false markings) were put in nylon bags and transported to the forensic laboratory for an analysis. The bags were heated in 100°C for 45 minutes, the lid was then taken off while the can was still in the bag and a 1 ml HS sample was taken with a hot syringe. The sample was injected into a gas chromatograph (GC-FID) with an analysis time of 30 minutes. If a finding was detected with this method, a further analysis was conducted with a gas chromatograph-mass spectrometer (GC-MSD). The analysis results are divided into three categories: 1) above reporting limit (arl), 2) below reporting limit (brl) and 3) no findings. The sample is interpreted to be above reporting limit if it exceeds the instrument detection limit. Gas chromatography method detection limit is approximately 0.5 µl/l and gas chromatography-mass spectrometry (MSD) detection limit is approximately 0.1 µl/l. In a sample which is below the reporting limit, the ignitable liquid can be traced but it does not meet the quality criteria for a positive report. If a sample is categorized as “no finding”, there are no ignitable liquids to be detected.

2.7. Certification test

The day before the study, all accelerant detection canines that took part in the study underwent a certification test using small amounts of unburnt substance (ISO, LF, GAS). In the certification test, there were three hidden samples of ignitable liquid (ISO, LF, GAS) in a 70 m² unfurnished apartment (five rooms). Each hidden sample contained several drops (4–6 drops, an estimated amount of approximately 3–5 µl) of unburnt ignitable liquid. The samples were evaporated between approximately 10 minutes and approximately an hour. The ADCs searched for the same hidden samples in a randomly selected order. The test was prepared and supervised by a person who was not involved in the study the following day (sergeant Timo Nikkinen).

2.8. Statistical analysis

The special characteristics of the data were taken into account in the statistical analysis: there was a relatively small amount of data compared to variables and each ADC went through several tracks. Due to the latter, the random effect introduced by the ADCs was taken into consideration in modeling. Due to the former, the analysis was divided in parts according to fixed effects and the definition of successful result. Substance, amount of substance and evaporation were considered fixed effects. Success was defined as either finding target substances without false markings or finding the right target despite false markings. As the effect of each three variables on the probability of success was observed separately in relation to two definitions of success, six separate models were applied to the data. This method makes analysis easier but ignores potential dependencies between effects. Therefore the statistical results are approximate and entail considerable uncertainty in this regard.

The analyses themselves were carried out by applying logistic regression using a mixed model in which the dependent variable was one of the two variables depicting success in turn and the independent variables were the dog as the random effect and either substance, amount of substance or evaporation as the fixed effect. As the calculation of classic confidence interval frequencies using probabilities produced by these kinds of models is complicated, and because the data was scarce, Bayesian modeling was used in the analysis. This enabled the estimation of Bayesian credible intervals of the posterior distribution of success probability using the Markov chain Monte Carlo (MCMC) simulations.

The statistical analysis was conducted using R software *(R Core Team (2018). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.)* using the stan_glmer function of the *rstanarm* package (Stan Development Team (2016). *rstanarm: Bayesian applied regression modeling via Stan. R package version 2.13.1. http://mc-stan.org/.)*. The function in question produces MCMC-simulated samples of the posterior distribution of the defined model. The prior distributions used were the defaults offered by the function which are scaled based on the data and should be weakly informative.

3. RESULTS

3.1. ADCs' correct and false markings in the study and the certification test

There were clear differences between the ADCs in how well they found the substance and how many false alerts they gave *(Table 2)*. The number of correct findings varied among teams between four and six (max. six substances), as did the number of false markings between zero and four. The number of clean tracks (only correct markings from the dog, no false markings) varied between three and five (max. six). The substance that was found the least was ISO1, the isopropyl alcohol that had evaporated for 24 hours, and the ones found the most easily were the gasoline that had evaporated for 72 hours and the lighter fluid that had evaporated for 24 hours. In the certification test (conducted a day before the study), where the ADCs searched only for unburnt substances, the success rate was 100 % with no false markings. One of the ADCs (K3) in the study was diagnosed with advanced cancer after the study and was euthanized. This dog gave the most false alarms in the study but also found the most samples.

***Table 2.* The table shows each ADC's performance during the study as well as the number of finds and false alarms per dog in the previous day's certification test for comparison. In the study, the substance was burned, whereas in the certification test, the substance was unburned (clean track = only correct alerts, no false alerts).**

ADC	FALSE MARKING	CORRECT FINDING	CLEAN TRACK	GAS3	GAS1	ISO3	ISO1	LF3	LF1	*certification test: finds*	*certification test: false alert*
K1	2	4	4	1	1	1	0	0	1	*3*	*0*
K2	1	4	4	0	1	1	0	1	1	*3*	*0*
K3	4	6	3	1	1	1	1	1	1	*3*	*0*
K4	0	5	5	1	1	1	0	1	1	*3*	*0*
K5	2	4	4	4	1	0	1	1	1	*3*	*0*
total	**9**	**23**	**20**	**3**	**5**	**4**	**2**	**4**	**5**		

3.2. Ignitable liquid residue concentration in samples

In the laboratory analysis, findings exceeding reporting limit were found only in four of the 30 samples taken from burns ignited using an ignitable liquid *(Table 2, Figure 4)*. ADCs performed flawlessly in all of them, meaning that the dog marked the correct sample and did not give any false markings (success rate 100 %). There were a total of 17 samples below the reporting limit and the ADCs gave a correct alert in 14 cases (82.4 %). The laboratory analysis did not detect substance in nine samples, however, the dog correctly marked five of these samples (all LF3). The samples that elicited false markings were also analyzed to ensure they did not contain traces of ignitable liquids. No traces of ignitable liquids were found in samples falsely marked.

Table 3. ***Ignitable liquid residue concentrations in study. Brl = concentration below reporting limit, arl = concentration above reporting limit.***

SUBSTANCE								
		ISO1	ISO3	GAS1	GAS3	LF1	LF3	Total
Concentration	no finding	3	0	0	1	0	5	9
	brl	2	5	4	3	3	0	17
	arl	0	0	1	1	2	0	4
Total		5	5	5	5	5	5	30

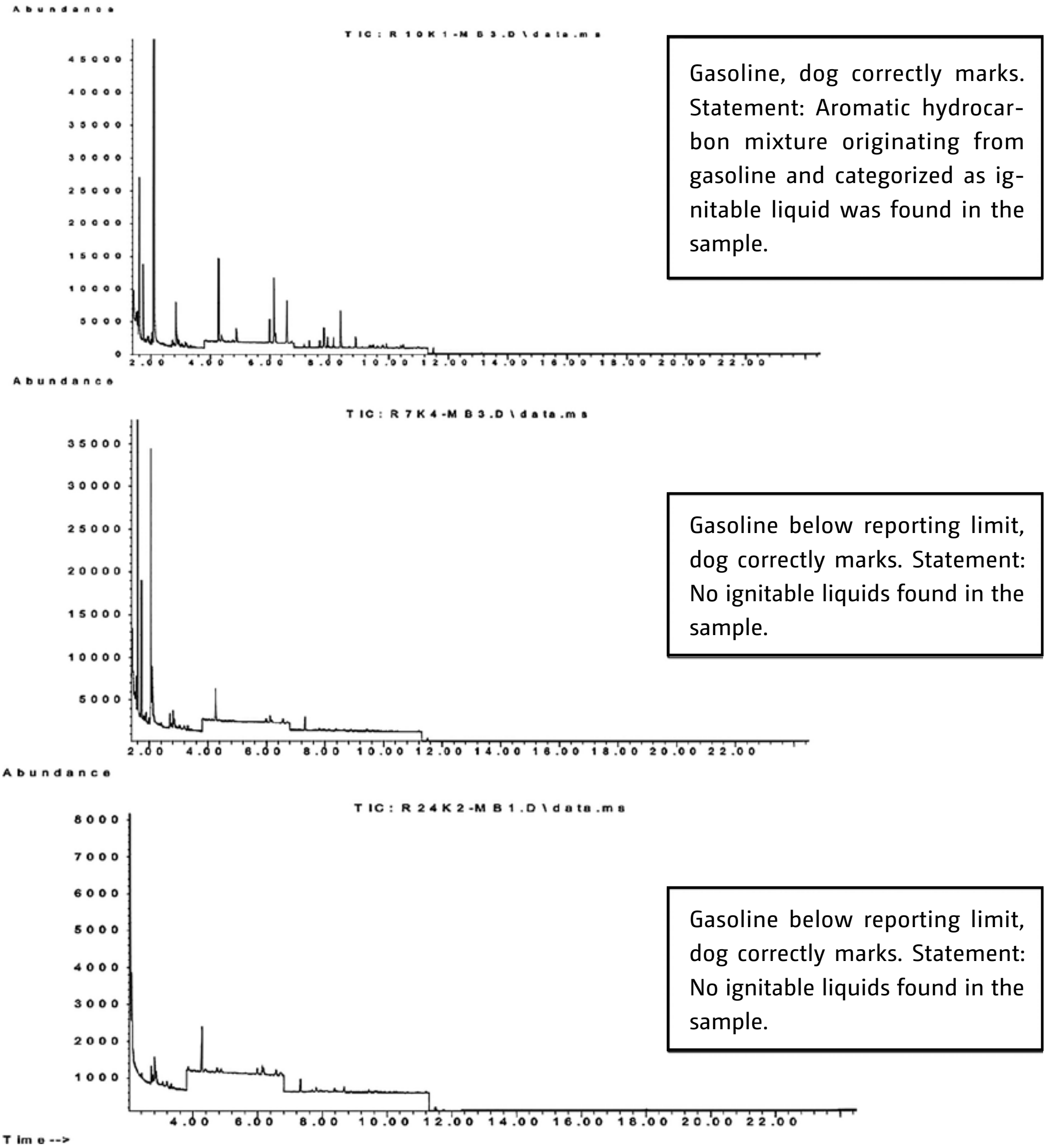

***Figure 4.* An example of the different findings (and statements) of gasoline in the study. The finding of ignitable liquid residue exceeds reporting limit only in the top sample. There are no reliable findings of ignitable liquid residue in the bottom two samples. ADC found all the samples above.**

3.3. The effect of concentration in the sample, substance and evaporation on ADC's success

We were interested in the effect of the concentration of the substance, the substance itself and evaporation on whether the ADC finds the correct sample and whether it finds it without false markings. In investigating only whether the ADC found the target sample or not (i. e. no attention was payd to false markings), we discovered that the concentration and the substance itself were the most significant factors in the probability of finding the target sample. Evaporation did not seem to have an effect. (Table 3). If the concentration of the target sample was below or above reporting limit, the probability of the ADCs to find the target sample was, on average, 0.89. However, if the substance was not detected in analysis, the probability of the ADCs finding the target sample dropped to 0.59 (probability 1 = all found). Of the different substances searched, ISO was more difficult to find than GAS or LF.

The probability a dog to perform a clean success (meaning tracks with only correct marking, without any false markings) is 0.61, if the target substance can be found in laboratory analysis (above or below reporting limit). The probability of clean success when the substance is not detected in the sample is significantly lower, 0.46. In this case too, there are differences between substances: ISO was the least found (0.34) and LF the most found (0.77). There is also a slight trend in evaporation time: the probability of finding a sample that had evaporated for 72 hours was slightly lower (0.54) than that of a sample that had evaporated for 24 hours (0.60).

***Table 4.* The probability of a) ADC finding the correct substance on the track (false markings allowed) and b) ADC finding the correct substance without false markings. The effect of concentration, evaporation (24 or 72 hours) and the searched substance on success probability are recorded in the table. Substance detected in analysis (= brl and arl), substance not detected in analysis (= no findings).**

a) Probability of ADC finding the substance, false alerts allowed					95 % Bayesian credible interval	
		Average	Standard deviation	Median	Lower control limit	Upper control limit
Amount of substance	Substance not detected in analysis	0,59	0,17	0,60	0,25	0,89
	Substance detected in analysis	0,89	0,07	0,91	0,72	0,99
Evaporation	24 hours	0,81	0,11	0,82	0,55	0,96
	72 hours	0,81	0,11	0,82	0,55	0,96
Substance	ISO	0,66	0,15	0,67	0,33	0,91
	GAS	0,88	0,10	0,91	0,62	0,99
	LF	0,88	0,10	0,91	0,62	0,99
b) Probability of ADC finding the substance without false alerts (clean track)						
Amount of substance	Substance not detected in analysis	0,46	0,16	0,46	0,16	0,78
	Substance detected in analysis	0,61	0,12	0,62	0,37	0,83
Evaporation	24 hours	0,60	0,13	0,61	0,33	0,83
	72 hours	0,54	0,14	0,53	0,27	0,79
Substance	ISO	0,35	0,15	0,33	0,10	0,66
	GAS	0,58	0,16	0,59	0,26	0,86
	LF	0,77	0,13	0,79	0,46	0,96

4. DISCUSSION

Burning is known to alter the composition of ignitable liquids in a way in which light components burn or evaporate entirely or in part. The liquid is likely to smell very different to a dog after burning. Nevertheless, in our study, the ADCs picked up the odor of the burnt substance with a probability of 100 % and without false markings when the concentration of the substance exceeded reporting limit in laboratory analysis. Therefore, one of the main conclusions in this study is that ADC finds very reliable those samples in which a laboratory can also detect ignitable liquid residue. However, burning cannot be controlled, and only four (out of 30) target samples exceeded reporting limit in our study. The probability of a detecting target sample decreased and the number of false markings increased when samples with concentration below reporting limit were included in the analysis. When samples with concentration either above or below reporting limit where included in the analysis, probability of finding a target sample was 0.89. The probability of a clean track (no false markings) was 0.61 when at least some substance was detected in the samples (above or below reporting limit). The other main conclusion in our study is that ADCs can also find relatively well very small amounts of ignitable liquid residue, that cannot be reliable traced in laboratory analysis. However, the number of false markings clearly increases in these cases.

Earlier studies on the reliability of an ADC finding ignitable liquids have been conducted using unburnt substance. In one study, for example, 42 ADC teams found gasoline (50 %, 3 µl, unburnt) with 96.7 % probability[3], and with 96.9 % probability in another study (50 % gasoline, 5 µl)[4]. In the certification test (preceding the actual study), in which the target was unburnt substance (ISO, LF, GAS), the success rate was 100 % without false alerts. However, the amount of substance used in our certification test was considerably higher than in previous studies in which the target was unburnt substance, and cannot be directly compared. In our study, the ADC's success rate was 100 % also in these four cases in which the concentration of the substance after burning exceeded reporting limit (>0.1 µl/l). Overall, Finnish ADCs' probability of finding ignitable liquid residue is very good based on this study, particularly when the substance's concentration exceeds reporting limit after burning (>0.1 µl/l), or its is unburnt.

The most interesting find in our study was that the ADCs alerted at ignitable liquid residue traces that a mass spectrometer was unable to detect. We were able to verify that these were correct findings as the samples had indeed been burned using ignitable liquid. This suggests that a dog's sense of smell is considerably more sensitive than a laboratory analysis in detecting small amounts of ignitable liquids. In earlier studies an ADC had also found ignitable liquid residue that laboratory analysis was unable to support. Some of the earlier studies can, however be explained by the fact that at the time (in the 1990s) laboratory equipment was unable to detect very small amounts[5]. As many other substances may result in small amounts of similar compounds as ignitable liquids when burned, many ACD alerts that were unverified by laboratory analyses have been interpreted false. The effect of the amount of substance on the probability of finding the ignitable liquid residue has been studied in two earlier studies. In those studies, the unburnt substance was added into cotton wool with a pipette and therefore the exact amount was known. Overall, it would seem that 3–5 μl is easily found5, as is 0.1 μl; in one study, four ADC teams out of five even found 0.005 μl (50 % gasoline) of substance[3].

In those trials, where the laboratory could not detect any trace of the target substance, the number of false alerts increased considerably. Similarly, with only a small amount of substance (samples below reporting limit) the probability of a clean track, i.e. alerting only at correct containers, decreased and the number of false alerts increased. False alerts have been reported also in earlier studies with small amounts of substance. In one study, a large portion of the ADCs gave false markings at burnt samples of other materials (carpets, etc.), which may contain compounds similar to ignitable liquid residues4, when the amount of substance searched was small. In this study, as all falsely marked target samples were analysed in the laboratory, we were able to exclude the possibility of false alert due to contamination. The samples in all cans that dog marked were analyzed and there were no findings. There were differences between ADCs in the number of false alerts and clean tracks, some of which can be explained by chance; some ADCs happened to have several samples on their track in which there were no trace of target substance detected or it was below reporting limit. Considerable differences in the detecting ignitable liquid residue has been reported in ADCs before but some are explained by handler behavior and the relationship between the dog and its handler3. Dog's olfactory system is affected by several factors, and their sense of smell is weakened, for example, by illnesses, certain pharmaceuticals (such as anesthetics, antihistamine, metronidazole) as well as excessive panting (due to hot weather or poor physical condition)1. In our study, the ADC that gave the most false alerts was K3, which died shortly after the study and was ill during it (unknown to the handler and the people conducting the study at the time). The illness is likely to have had an effect on the dog's performance. In addition to illnesses and pain, gastrointestinal microbiota and diet affect animals' olfactory system and are likely to also have an effect on dog's sense of smell[1]. High arousal and impulsiveness also weakened the probability of finding explosives on Finnish explosive detection canines (Tiira, et al., submitted manuscript).

In the study, the ADCs found gasoline and lighter fluid the best whereas isopropyl alcohol proved the most difficult to find. This concurs with experiences from fire scenes (Tapani Turunen, personal comment). The effect of substance on a success find was studied in one earlier study with 17 ADC teams. It compared the dog's probability to succeed with different petroleum-based products (Light: Ronsonol Lighter Fluid; Medium: Royal Oak Charcoal; Heavy: diesel), gasoline and lighter fluid (Gulf-Lite Charcoal Lighter Fluid). Gasoline was the most easily found in this study as well (100 %), and 88.2 % of the ADCs succeeded in finding lighter fluid[3].

Evaporation (as long as 72 hours) did not seem to have a significant impact on the probability of a find, although there was a small difference between 72 and 24 hours, when looking at clean tracks only; the sample that had evaporated for 24 hours was found slightly better than the sample that had evaporated for 72 hours.

In conclusion, it can be stated that the ADCs in the study found burnt ignitable liquid residues without false alerts when the concentration of the substance was above reporting limit. The ADCs found substances relatively well also in cases when the residue of the substance could not be reliably verified (brl) or detected in laboratory analysis at all. Dog's sense of smell is clearly more sensitive than laboratory analysis, however, when the concentrations of residues are very low, also number of false alerts increases.

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