




Investigation of explosives traces in pre-blast contamination scenarios using optimised wet swab sampling

Christopher W. Becher^{1,a} , Sarah Milne², Peter M. Kaul^{1,b}

¹ Institute of Safety and Security Research, Von-Liebig-Straße 20, 53359 Rheinbach, Germany

² Robert Gordon University, Garthdee Road, Aberdeen AB10/QB, UK

Received: 25 March 2024 / Accepted: 3 January 2025

© The Author(s) 2025

Abstract Explosives trace residues on surfaces are utilized for forensic investigations and to check suspicious objects using technical and non-technical detection procedures. Data about expected trace contaminations after the handling of explosives and how they relate to a potential chemical background help to determine requirements and limitations of detection procedures. Often swab sampling is used for the analysis of surface contaminations. A wet swab sampling procedure was optimized for PETN, TNT and ammonium nitrate. Good results were achieved using PU-foam swabs wetted with a mixture of acetonitrile/water (90/10). The swabs were subsequently solvent extracted and analysed using LC-triple-quad-MS and ion-chromatography. The swabs were applied for the determination of explosives residues in a mock-up car scenario simulating one person loading the car with explosives followed by a short car travel by the same person. As test substances an ANFO, TNT and plasticized PETN were used. Additional samples were taken from indoor installations regularly used for the training of explosive detection dogs as well as other objects and buildings close by. The surface contaminations found in the investigated scenario ranged from the ng to the µg scale. The results indicate that simple cleaning procedures might not sufficient to remove explosives contaminations in training settings for explosive detection dogs. A significant spreading of explosive traces beyond direct contact with the person handling the explosive or with the explosive itself was not observed.

1 Introduction

Explosives traces provide important cues for forensic [1–3], environmental monitoring [4, 5] and for security applications [6–9]. Established explosives trace detectors (ETD) usually do not detect bulk explosives or the explosive payload of an improvised explosive device (IED) directly. With few exceptions like explosives detection dogs (EDD) these systems are dependent on surface contamination caused by the explosive object directly or indirectly by the persons preparing and handling it [10]. These contaminations are often collected via swab sampling before being introduced into the ETD [6, 7]. The quality of IED related explosives traces in comparison to background contaminations from benign sources or military activities influence detection rates, limits, thresholds and have therefore a major influence on the operation of the ETDs in civil or military scenarios [11]. Some investigations about the background of explosives traces have been published. Results from these works indicate, that in public places seldom trace contamination from organic explosives can be found, while nitrate appears to be rather common [12–14]. However, in a military environment a significant background of organic explosives can be expected [11].

Swab and wipe sampling methods are widely used for many different purposes ranging for instance from collection of forensic evidence (explosives, drugs, DNA, biological agents), [15–20] sampling of surfaces and persons for environmental and occupational health investigations [21–24] in order to control decontamination success [25]. The success of the swab sampling depends on the sampled surface, sampling technique, swab type, wetting solvent and efficiency of the following extraction. The simultaneous forensic swab sampling of organic and inorganic explosives, follow up extraction of several swab-types, solvents for swab wetting and solvent extraction methods have been investigated in earlier works. Song-im et al. achieved good results using skin cleansing alcohol wipes, solvent wetted cotton or polyester swabs and considered acetonitrile (ACN) as favourable wetting solvent. Test surfaces were contaminated by dripping dissolved explosives on the surface and subsequent drying [26]. For the follow up sample preparation of swabs and wipes the same authors suggest a ultrasonic extraction with Methanol/water (Me/W) 60/40, solid phase extraction (SPE) of the extract and a five-step washing/elution process using water, (Me/W) 60/40 and ACN [27]. DeTata et al. [15] report better results with ACN compared to (Me/W) 60/40 when extracting organic explosives from spiked swabs. Inorganic explosives were equally good extracted using either water or (Me/W) 60/40.

^a e-mail: christopher.becher@h-brs.de

^b e-mail: peter.kaul@h-brs.de (corresponding author)

Fig. 1 PU-foam (PU), cotton (CS) and makeshift microfiber swabs (MF) with original container and centrifuge tubes used for extraction and storage



In IED events cars can play an important role: Either as means to transport explosives to the bomb maker, the prepared IED to the final attacker or as car bomb. The main goal of this work was to investigate the contamination to be expected in a scenario where an explosive or IED has been transported in a car. For this a car mock-up scenario with TNT, PETN based plastic explosive and a commercial ANFO was carried out and thereby created explosives traces contaminations determined using an optimized swabbing procedure. Additional swabs were taken from an EDD training facility providing real-life contaminations for comparison.

2 Methods

2.1 Swab spiking and extraction

Three different swabs (See Fig. 1: cotton swab (wood shaft, cotton tip, Sterilin) PU-Foam Swab (CF1050, Chemtronics), microfiber wipe (TX 1009 AlphaWipe, folded around and attached to CF1050 handle with a melting point via soldering iron) were spiked with 150 μL spiking solution acetonitrile/Water (ACN/W (70/30)). Spiking solution 1, representing a high contamination, contained TNT (135 $\mu\text{g}/\text{mL}$), PETN (1,4 mg/mL) and 320 $\mu\text{g}/\text{mL}$ NH_4NO_3 . Solution 2, simulating a low contamination, contained TNT and PETN 1,4 $\mu\text{g}/\text{mL}$ each. Spiked swabs contained 20,25 μg TNT, 210 μg PETN 37,2 μg NO_3^- (high contamination, solution 1) and 210 ng for TNT and PETN (low contamination, solution 2). After spiking the swabs were dried for 10 min at room temperature. For the extraction a swab was placed in a centrifuge tube. After adding 3 ml solvent the closed tube was sonicated for 10 min, the swab squeezed out at the tube walls and discarded. The extract was subsequently filtered with a 0,45 μm nylon membrane syringe filter. For the analysis of the organic explosives by HPLC–UV/VIS (high contamination) or LC-Triple Quad MS (low contamination) an aliquot of 500 μL were taken from the filtrate and diluted 1/1 with ultrapure water in a 1,5 ml analytical glass vial. The content of NO_3^- was determined by ion-chromatography (IC) using a second aliquot of 500 μL diluted with 2500 μL ultrapure water. Additional blank swabs were extracted as control and in case of nitrate used for background correction.

As extraction solvents 2-propanol/Water (2-prop/W), Methanol/Water (Me/W) and ACN/Water in ratios 90/10, 70/30, 50/50 were chosen. Experiments were done with $n = 4$. Initial experiments using acetone as organic solvent produced cloudy extracts and were therefore not continued.

2.2 Test surfaces and swab sampling

Swabbing efficiencies of the swabs were tested with mechanically contaminated slides ($90 \times 10 \times 1$ mm (l/w/h); each 20 cm^2) of PMMA, glass and aluminium. 2.2 mg finely powdered TNT and 80 g corundum balls (Alodur 0.5–1 mm) were placed in a 100 mL round bottomed flask and thoroughly mixed on a vibrating platform for 30 min at maximum amplitude. 10 g of the contaminated balls were diluted with 90 g fresh corundum in a clean 100 mL round bottomed flask. The diluted balls were shaken for an additional 30 min on the vibrating platform, at maximum amplitude.

Contaminated slides were produced in batches. Ten slides were placed into a steel box ($103 \times 71 \times 22$ mm). Two aluminium plates with an attached rubber seal were placed at either end of the box in order to secure the test bodies and prevent them from moving. The box was then filled with 90 g diluted TNT-coated corundum balls. The box lid was closed, and sealed with tape. The sealed container was then shaken for 30 min contaminating and abrading the slides. From each batch four contaminated slides were randomly chosen as control and placed individually in centrifuge tubes. 10 mL ACN/W was added and the closed tube shaken for 15 min in an overhead shaker. The extract was subsequently filtered with a 0.45 μm nylon membrane syringe filter. From the filtrate

an aliquot of 500 μL was added into a 1.5 mL analytical glass vial and diluted with 500 μL of ultrapure water. The samples were afterwards analysed by LC-triple quad MS.

The remaining slides were swabbed twice from all sides including the edges using only one side of the swab for the first round and the opposite site for the second. For the swabbing PU-foam or cotton swabs were used which were either dry or solvent wetted. The swabs were wetted with 150 μL (cotton) or 400 μL (PU-foam) with acetone, isopropanol or methanol. Swabbing were done in triplicate, meaning that out of one batch 6 slides were used for two swabbing experiments and the swabs subsequently extracted as described in chapter II A. The sampling efficiencies were calculated using the average TNT content of the extracted control slides.

2.3 Analytical methods

2.3.1 HPLC–UV/VIS (high concentrations of organic explosives)

System: Agilent 1100 series with quaternary pump and UV/VIS DAD;

column: LiChroCART[®] 125–4 Purospher[®] RP-18e (5 μm) with 5 mm C18 guard column; mobile phase: ACN/W 50/50 (isokratisch) @ 1 mL/min; column oven: 25 °C; injection volume 20 μL ; DAD Signals: 200 nm (PETN, RT: 8.2 min) and 235 nm (TNT, RT 4.5 min).

2.3.2 Ion chromatography (IC) (NO_3)

System: Metrohm IC 861 Advanced Compact 2 with 863 Compact Autosampler;

column: Metrohm Metrosep A Supp 5–250/4.0; mobile phase: ultrapure water (18.2 m Ω) with 3.2 mM Na_2CO_3 , 1 mM NaHCO_3 and 5% (V/V) acetone; regeneration: ultrapure water (18.2 m Ω) with 50 mM H_2SO_4 ; RT NO_3^- : 15,5 Min.

2.3.3 LC-triple quad MS (low concentrations of organic explosives)

System: Agilent 1200 System with AB Sciex QTrap 5500;

LC-Method: Column: Phenomenex Luna 3 μm C18(2), 150 \times 2 mm; mobile phase: 200 $\mu\text{L}/\text{min}$ 60% ACN with 10 mMol ammonia acetate and 40% water with 10 mMol ammonia acetate (isocratic); column-oven: 25 °C; Injection 20 μL ;

Method MS: scan type MRM; polarity negative; ion source: ESI; CAD: Medium; TEM: 450,00; GS1 and GS2: 60.00; IS: –4500,00; Ions: TNT (226/46), PETN (315/62), HMX + acetate (355/46), 2,6-DNT (181/46), 2,4-DNT (181/46); RDX + acetate (281/46), Tetryl (286/46).

2.4 Mock-up car contamination scenario and swabbing

The contamination procedure started with the subject thoroughly contaminating his hands with either Semtex 1A (piece of 20 g), 20 g Rioxam HD (ANFO, Ammonia Nitrate Fuel Oil Explosive, as prills) or TNT (one solid 20 g piece). In case of Semtex 1A the explosive was kneaded intensively for one minute in each hand and another minute between both hands. The Rioxam HD prills were rubbed 10 times over both hands. The ANFO partially dissolved in the natural moisture of the hands generating an oily coating. Due to its toxicity TNT contamination was done with gloved instead of bare hands using nitrile gloves. The TNT was repeatedly rubbed over both palms while occasionally rubbing both hands together. The following mock car contamination scenario was then followed, with each step being performed sequentially using a inoperative scrap car:

- The car boot was unlocked using the key, then opened using the boot button and handle. The trunk lid was opened and closed again.
- The driver's door was unlocked and opened, and the subject sat into the driver's seat. The driver's door was closed from the inside using the appropriate handle.
- The key was placed in the ignition and the seat belt was put on.
- The car was put into first gear and the car engine 'started' by turning the key in the ignition.
- The hand break was taken off, both hands were placed on the steering wheel and the gear was changed.
- The indicator was put on, and then the gear was changed. The indicator was then put off.
- The air control was turned on and off again.
- The windscreen wipers and the back window de-frost were switched on and off again. The air vent was manoeuvred.
- The indicator was put on and then the wheel was turned to the left—the wheel was then corrected. The indicator was put on and then the wheel was turned to the right—the wheel was then corrected. These steps were repeated once.
- The hand break was put on and the ignition was turned off by turning the key to the off position.
- The seat belt was removed and then the door was opened from the inside using the door release
- The door was closed using the outside handle. The key was placed on a fresh piece of aluminium foil.

Fig. 2 Volkswagen Polo used for mock car scenario. Above: Side, and rear view of car; small pictures: specific car parts swabbed: 1—Boot button, 2—Boot handle, 3—Tray from boot, 4—Door handle outside, 5—Door handle inside, 6—Key, 7—Top of gear, 8—Bottom of gear, 9—Hand break, 10—Steering wheel left side, 11—Steering wheel right side, 12—Indicator, 13—Windscreen wipers, 14—Air speed control, 15—Back window de-frost, 16—Air vent, 17—Seat belt holder, 18—Seat belt, 19—Door release, 20—Front glass window (control for contamination)



Once the above procedure had been performed the car and the key was swabbed within 30 min at specific areas (see Fig. 2) using the optimised swabs described in the results section. Each predefined area was swabbed in triplicate using a fresh swab each time. The car was subsequently cleaned using an undisclosed method and the cleaning success monitored by follow-up swab sampling.

2.5 Real-life scenarios

Additional swabs were taken in a military facility used for the training of explosives detection dogs (EDD). This included two EDD indoor set-ups (canine test area and canine training area). The canine test area contained a metal box line-up where the EDD were tested with TNT odour sources placed inside the depicted metal boxes (Fig. 3). During one session dogs consistently alerted at box B although it was not equipped with TNT. This and some other boxes were subsequently swabbed inside as well as at the opening used by the dogs for sniffing. The canine training area consisted of shelves which could be equipped with rows of plastic boxes in different heights. Here an odour source (e.g. a military demolition charge) is placed in one box while other boxes remain empty or are equipped with non-explosive materials as distractors. After training the odour sources are removed and the boxes cleaned with water. For this study three cleaned and uncleaned boxes each were sampled and the swabs analysed. Additionally, the hands of the explosives handler as well as the steering wheel of the car used to transport explosives and 15 objects (door handles, keyboards) in nearby buildings used as office or cafeteria were sampled. The hand swabs were exceptionally wetted with 2-propanol/W (90/10).

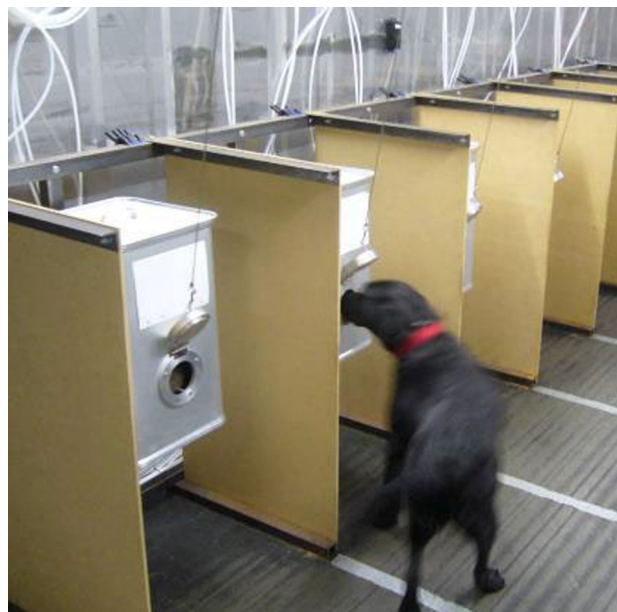
3 Results and discussion

3.1 Results of swab extraction

Good extraction efficiencies >85% at high (μg -range) and low (ng-range) contaminations were achieved with PU- and MF-swabs using solvents with high content of organic solvent. As shown in Table 1, especially the PU-swabs but also the others showed elevated levels for nitrate out of unknown reasons. 2-propanol/w-extracts caused problems in analysis due to an elevated chemical background, likely caused by the lower quality of the solvent (pro analysis) compared to methanol and acetonitrile which were both LC-MS grade. Extracts of the MF-swabs accelerated the incremental pressure increase of the column in the liquid chromatographic

Table 1 Table with the highest extraction efficiencies achieved for each swab type and spiked substance

Concentration	Substance	PU	CS	MF
μg -range	PETN	95% ($\pm 3\%$) ACN/W (90/10)	84% ($\pm 5\%$) ACN/W (70/30)	93% ($\pm 3\%$) ACN/W (90/10)
	TNT	87% ($\pm 3\%$) ACN/W (90/10)	87% ($\pm 4\%$) ACN/W (90/10)	95% ($\pm 1\%$) ACN/W (90/10)
	Nitrate	126% ($\pm 2\%$) ACN/W (90/10)	113% ($\pm 12\%$) 2-prop/W (70/30)	105% ($\pm 5\%$) ACN/W (90/10)
ng -range	PETN	92% ($\pm 5\%$) ACN/W (90/10)	75% ($\pm 1\%$) ACN/W (70/30)	90% ($\pm 2\%$) ACN/W (90/10)
	TNT	91% ($\pm 6\%$) ACN/W (90/10)	69% ($\pm 8\%$) ACN/W (90/10)	90% ($\pm 2\%$) ACN/W (90/10)

Fig. 3 Canine test area with metal sniffing boxes. In one box a TNT containing odour source is placed and the dog tries to detect the hidden TNT by sniffing at the opening

systems and were therefore excluded as swab-sampling material. The elevated nitrate levels might be batch dependent since it wasn't observed in later experiments and could be countered in future by pre-washing of the swabs. Overall best results were achieved with PU-swabs and ACN/W (90/10) as extraction solvent (Table 1).

3.2 Results of swab sampling of test surfaces

As can be seen in Fig. 4 best sampling efficiencies ($>85\%$) were achieved with wetted PU-swabs. No significant difference was found within one swab type (PU, CS) between the solvents used for wetting. Dry swabbing resulted as expected in clearly lower efficiencies. The lower sampling efficiencies of the cotton swabs is likely generated by a combination of lower extraction and sampling efficiencies. The latter might be caused by a lower content of wetting solvent ($150\ \mu\text{L}$ vs. $400\ \mu\text{L}$) and the smaller size of the sampling head of the CS compared to the PU-swab.

Based on the results of chapters 3.1 and 3.2 III A and B an optimised swab sampling and extraction procedure was specified which was later used as tool for mock-up car and real-life scenarios. Since it was observed that the wetting solvent did not have significant influence on the sampling efficiencies ACN/W (90/10) was chosen as wetting agent in order to increase the compatibility with the mobile phase used in the LC-triplequad MS method.

3.2.1 Optimised swab sampling and extraction procedure

A number of PU swab were wetted with $400\ \mu\text{L}$ ACN/W (90/10) and individually stored in closed centrifuge tubes. The tubes were placed for up to one week in a fridge at $5\text{--}7\ ^\circ\text{C}$ until being used. For sampling a swab was taken out of its tube and the area thoroughly swabbed twice using both sides of the swab. The contaminated swab was then put back in the centrifuge tube which was subsequently extracted with $3\ \text{mL}$ ACN/W (90/10) for 10 min in an ultrasonic bath. For the analysis of the organic explosives by LC-Triple Quad MS an aliquot of $500\ \mu\text{L}$ were taken from the filtrate and diluted 1/1 with ultrapure water in a $1.5\ \text{ml}$ analytical glass

Fig. 4 Sampling efficiencies of PU and CS, dry or wetted with different solvents

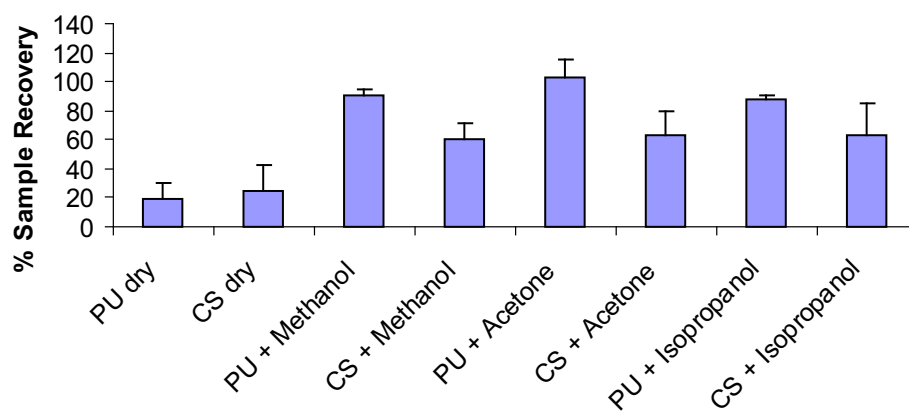
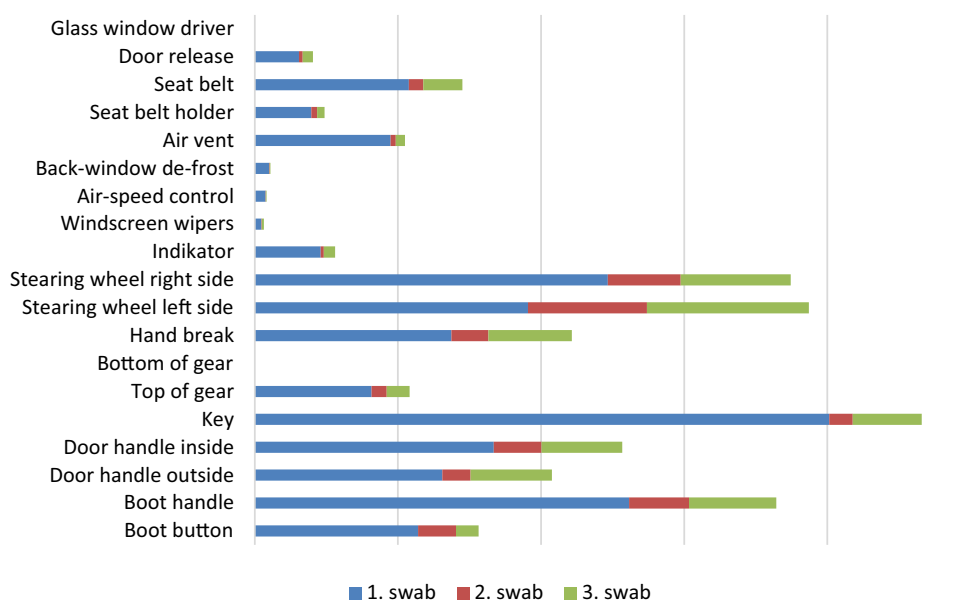


Fig. 5 Results of triplicate swabbing of car after contamination with Semtex 1A. Amounts are not given in detail but are well located in the ng-range



vial. For analysing nitrate by IC an aliquot of 500 μL was diluted with 2500 μL ultrapure water in an IC sample vial. Additional blank swabs were extracted as control.

3.3 Results of mock-up car scenario

In Figs. 5, 6 and 7 the measured contaminations of PETN, Nitrate and TNT are displayed as concentration range. For Semtex 1A, Rioxam HD and TNT contaminations in the ng-, μg - and ng up to lower μg range were found.

Usually higher contaminations were found on objects which were touched intensively with the whole hand (steering wheel, handbrake) or—although less consistent—touched early during the contamination procedure (Key, boot handle, door handle outside). Contaminations appeared to be sedentary and did not spread much inside the car (glass window driver, bottom of gear). Relating to the sum of contamination found in three successive swabs, about 60% of the total contamination was found in the first swab. The sampling efficiencies in the mock-up scenario are lower compared to the efficiencies represented in chapter 3.2, but can be explained by the more demanding materials, geometries as well as the often bigger areas sampled. In Figs. 6, 7 the second swab of the left side of steering wheel exhibited a very high TNT contamination. Obviously, a spot with a high contamination, perhaps a particle, was overlooked at the first swabbing attempt. Without this outlier the contamination with TNT would be well within the ng-range, comparable with the contaminations found in experiment with Semtex 1A (Fig. 5).

Fig. 6 Results of triplicate swabbing of car after contamination with Rioxam HD (ANFO). Amounts are in the μg -range

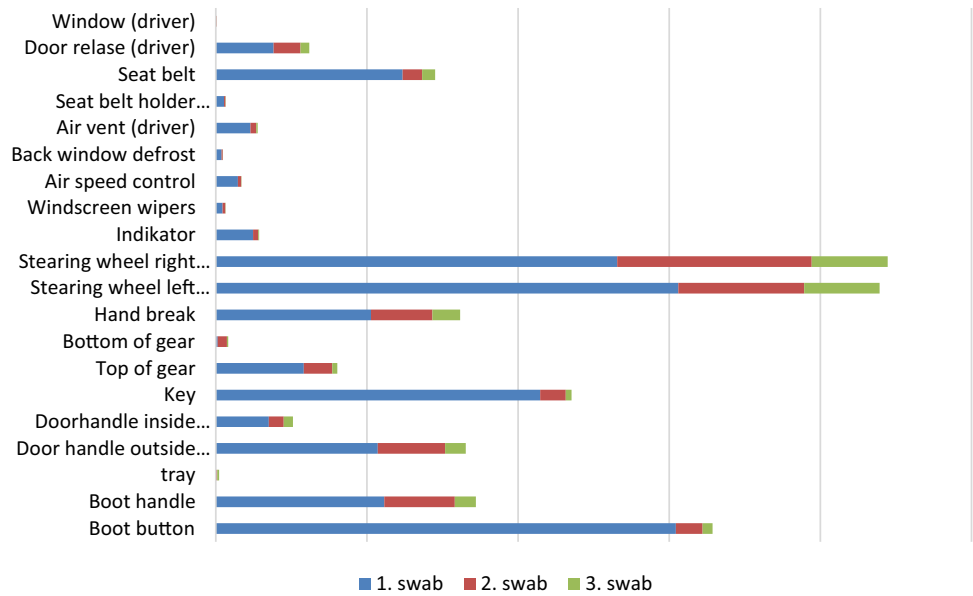


Fig. 7 Results of triplicate swabbing of car after contamination with TNT. Amounts are in the μg -range up to low μg -range

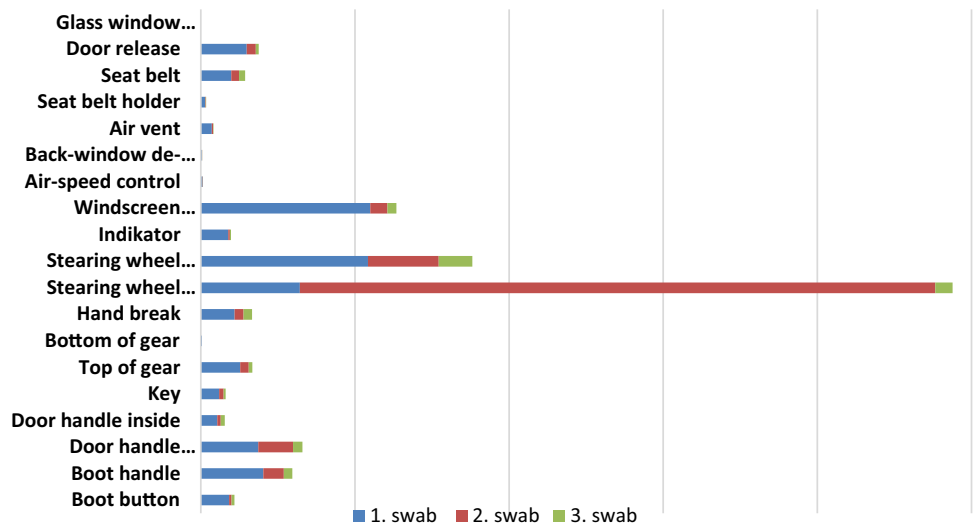


Table 2 Results of sampled boxes used in canine test area. The single digit nanogram contaminations are close to LOQ

Description	TNT/Swab [ng]
Box B, front	2
Box D, front	1
Box F, front	2
Box B, inside	1302
Box D, inside	1
Box F, inside	1

3.4 Sampling results in real-live scenarios

3.4.1 Canine test area (metal box line up)

The results in Table 2 show, that all boxes were contaminated. However, the contamination found in box B exceeded the otherwise observed low background contamination in the other boxes massively, thus explaining the dog’s behaviour.

Table 3 Results of sampled cleaned and uncleaned plastic boxes used in a canine training area

Description	TNT [ng]	PETN [ng]	HMX [ng]	RDX [ng]	Tetryl [ng]
Box 1, uncleaned	73	734	–	–	580
Box 2, uncleaned	44	101	754	–	20
Box 3, uncleaned	1586	17	4	18	–
Box 4, cleaned	–	32	12	–	–
Box 5, cleaned	–	5	98	–	–
Box 6, cleaned	7774	8	6	–	–
Hand (right)	120	68	–	1	–
Hand (left)	84	112	–	1	–
Steering wheel	874	2523	–	6	–

3.4.2 Canine training area (plastic boxes in rack), explosives handler with car, buildings nearby

The results displayed in Table 3, illustrating a mix of different explosives traces likely originating from different explosives containing objects used for canine training. It also demonstrates, that the cleaning of the boxes was not completely successful.

As expected considerable amounts of explosives traces were found on the hands of the explosives handler as well as the steering wheel of the car. However, no quantifiable explosives residues were found on the 15 sampled objects in the nearby benign buildings although these buildings were also frequented by persons with direct contact with explosives.

4 Conclusions

Overall the optimized swab sampling and extraction procedure worked well in- and outside the laboratory when used on smooth surfaces. Rough surfaces on the other hand will quickly destroy the soft PU-foam. Materials like microfiber wipes are more robust, but should be tested on extractable substances which might interfere with the analysis or increase the wear of LC-columns. The method developed is suitable for checking non-rough surfaces for explosive trace residues. Repeated sampling of the same surface presumably allows rough quantitative statements to be made about the amount of substance present, but should be further qualified for this purpose.

In the mock-up car scenario, the highest contaminations were observed after handling of Rioxam HD. However, there is also a significant background of nitrates from benign sources [14]. This decreases the value of nitrate traces as evidence for the handling of explosives if used as only parameter. The contaminations found in the mock-up car scenario match roughly with the contaminations found in the real-life scenarios. Both can be considered as very optimistic, since only limited if all contamination prevention procedures were applied. The values found for pre-blast explosive traces could, for example, be used as an initial indication of the required performance of such systems when developing spectroscopic explosive trace detectors capable of detecting distances.

Acknowledgements This study was in parts funded by the German Ministry of Defense (Project: Fast identification of explosives and strategies for the detection of IED typical signatures"; GRANT_NUMBER: E/E210/7(D005/7F206)).

Funding Open Access funding enabled and organized by Projekt DEAL.

Data availability The research was conducted on behalf of the German Armed Forces. Data beyond the analysed form presented in the paper are classified as confidential. The raw data may only be passed on and viewed with the permission of the client.

Declarations

Conflict of interest All authors declare that they have no conflicts of interest.

Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by/4.0/>.

References

1. D.J. Klavec, G. Czarnopys, J. Pannuto, Interpol review of the analysis and detection of explosives and explosives residues. *Forensic Sci. Int. Synergy* 6(2023), 100298 (2023). <https://doi.org/10.1016/j.fsisyn.2022.100298>

2. B. Sharma, R. Gadi, Analytical tools and methods for explosive analysis in forensics: a critical review. *Critical Rev. Anal. Chem.* **7**(2023), 1–27 (2023). <https://doi.org/10.1080/10408347.2023.2274927>
3. F.G.M. Mauricio, V.R.M. Abritta, R. de Lacerda Aquino, J.C.L. Ambrósio, L.P.L. Logrado, I.T. Weber, Evaluation of interferers in sampling materials used in explosive residue analysis by ion chromatography. *Forensic Sci. Int.* **307**(2020), 109908 (2019). <https://doi.org/10.1016/j.forsciint.2019.109908>
4. T. F. Jenkins, J. C. Pennington, T. A. Ranney, T. E. Berry, P. H. Miyares, M. E. Walsh, A. D. Hewitt, N. M. Perron, L. V. Parker, C. A. Hayes, E. G. Wahlgren, Characterization of explosives contamination at military firing ranges, Cold Regions Research and Engineering Laboratory (U.S.); Engineer Research and Development Center (U.S.), <https://erdc-library.erd.c.dren.mil/jspui/handle/11681/8471>.
5. J. Pichtel, Distribution and fate of military explosives and propellants in soil: a review. *Appl. Environ. Soil Sci.* **2012**, 1–33 (2012). <https://doi.org/10.1155/2012/617236>
6. I.V. Novosselov, C.A. Coultas-McKenney, L. Miroshnik, K. Kottapalli, B. Ockerman, T.E. Manley, M.W. Gardner, R. Lareau, J. Brady, M. Sweat, A.R. Smith, M.J. Hargather, S. Beaudoin, Trace explosives sampling for security applications (TESSA) study: evaluation of procedures and methodology for contact sampling efficiency. *Talanta* **234**(2021), 122633 (2021). <https://doi.org/10.1016/j.talanta.2021.122633>
7. D. Fisher, R. Zach, Y. Matana, P. Elia, S. Shustack, Y. Sharon, Y. Zeiri, Bomb swab: can trace explosive particle sampling and detection be improved? *Talanta* **174**, 92–99 (2017)
8. J.M.E. Glackin, R.N. Gillanders, F. Eriksson, M. Fjällgren, J. Engblom, S. Mohammed, I.D.W. Samuel, G.A. Turnbull, Explosives detection by swabbing for improvised explosive devices. *The Analyst* **145**(24), 7956–7963 (2021). <https://doi.org/10.1039/d0an01312a>
9. C.J. Miller, D.F. Glenn, S.D. Hartenstein, S.F. Hollowell, Mapping of explosive contamination using GC/chemiluminescence and ion mobility spectrometry techniques. *SPIE* **3575**, 335–341 (1998)
10. Guide for the selection of commercial explosives detection systems for law enforcement applications, U.S. Department of Justice, Office of Justice Programs, National Institute of Justice, 1999.
11. R.R. Kunz, K.C. Gregory, D. Hardy, J. Oyler, S.A. Ostazeski, A.W. Fountain, Measurement of trace explosive residues in a surrogate operational environment: implications for tactical use of chemical sensing in C-IED operations. *Anal. Bioanal. Chem.* **395**(2), 357–369 (2009). <https://doi.org/10.1007/s00216-009-2748-2>
12. H.E. Cullum, C. McGavigan, C.Z. Uttley, M.A.M. Stroud, D.C. Warren, A second survey of high explosives traces in public places. *J. Forensic Sci.* **49**(4), 1–7 (2004). <https://doi.org/10.1520/JFS2003237>
13. C.A. Crowson, H.E. Cullum, R.W. Hiley, am Lowe, A survey of high explosives traces in public places. *J. Forensic Sci.* **41**(6), 14035J (1996). <https://doi.org/10.1520/JFS14035J>
14. K.G. Lahoda, O.L. Collin, J.A. Mathis, H.E. LeClair, S.H. Wise, B.R. McCord, A survey of background levels of explosives and related compounds in the environment. *J. Forensic Sci.* **53**(4), 802–806 (2008). <https://doi.org/10.1111/j.1556-4029.2008.00743.x>
15. D.A. DeTata, P.A. Collins, A.J. McKinley, A comparison of common swabbing materials for the recovery of organic and inorganic explosive residues. *J. Forensic Sci.* **58**(3), 757–763 (2013). <https://doi.org/10.1111/1556-4029.12078>
16. A.L. Ciesielski, J.R. Wagner, M. Alexander-Scott, J. Snawder, An optimized method for sample collection, extraction, and analysis of fentanyl and fentanyl analogs from a non-porous surface. *Talanta* **228**, 122210 (2021)
17. J. Hedman, Y. Akel, L. Jansson, R. Hedell, N. Wallmark, C. Forsberg, R. Ansell, Enhanced forensic DNA recovery with appropriate swabs and optimized swabbing technique. *Forensic Sci. Int. Genet.* **53**, 102491 (2021)
18. S. Baechler, Study of criteria influencing the success rate of DNA swabs in operational conditions: a contribution to an evidence-based approach to crime scene investigation and triage. *Forensic Sci. Int. Genet.* **20**, 130–139 (2016)
19. P. Tozzo, E. Mazzobel, B. Marcante, A. Delicati, L. Caenazzo, Touch DNA sampling methods: efficacy evaluation and systematic review. *Int. J. Mol. Sci.* **23**(24), 15541 (2022)
20. J. Crowder, R. Adams-Brown, S. Geisler, E. Southworth, M. Zuniga, I. R. Fruchey Literature review of surface sample collection methods, Dec (2021) <https://apps.dtic.mil/sti/citations/ad1154428>.
21. E. Verscheure, M. Creta, J. Vanoirbeek, M. Zakia, T. Abdesselam, R. Lebegge, K. Poels, R.-C. Duca, L. Godderis, Environmental contamination and occupational exposure of Algerian hospital workers. *Front. Public Health* **8**, 374 (2020). <https://doi.org/10.3389/fpubh.2020.00374/full>
22. T. Verdier, M. Coutand, A. Bertron, C. Roques, A review of indoor microbial growth across building materials and sampling and analysis methods. *Build. Environ.* **80**, 136–149 (2014)
23. G.W. Park, P. Chhabra, J. Vinjé, Swab sampling method for the detection of human norovirus on surfaces. *J. Visualized Exp. JoVE* **120**, 2017 (2017). <https://doi.org/10.3791/55205>
24. T.M. Muggli, S. Schürch, Analysis of pesticide residues on fruit using swab spray ionization mass spectrometry. *Molecules (Basel, Switzerland)* **28**(18), 2023 (2023). <https://doi.org/10.3390/molecules28186611>
25. P. Yang, K. Burson, D. Feder, F. Macdonald, Method development of Swab sampling for cleaning validation of a residual active pharmaceutical ingredient, Pharmaceutical technology, (2005) <https://www.semanticscholar.org/paper/Method-development-of-Swab-sampling-for-cleaning-of-Yang-Burson/eee9664cfc95b342f3142dc6a6a52619ea3603d5>.
26. N. Song-im, S. Benson, C. Lennard, Evaluation of different sampling media for their potential use as a combined swab for the collection of both organic and inorganic explosive residues. *Forensic Sci. Int.* **222**(1–3), 102–110 (2012). <https://doi.org/10.1016/j.forsciint.2012.05.006>
27. N. Song-im, S. Benson, C. Lennard, Establishing a universal swabbing and clean-up protocol for the combined recovery of organic and inorganic explosive residues. *Forensic Sci. Int.* **223**(1–3), 136–147 (2012). <https://doi.org/10.1016/j.forsciint.2012.08.017>