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Experimental evaluation of the impact of reduced anticontamination measures on the integrity of items sampled within mock crime scenes

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ABSTRACT

Crime Scene Investigators (CSIs) in the UK conduct extensive anticontamination measures to mitigate the risk of introducing extraneous DNA into forensic evidence. This study empirically evaluated the effectiveness and proportionality of such measures, focusing on equipment cleaning and glove-changing practices during evidence recovery in mock crime scenes. The experimental design deliberately introduced contamination risks, such as the use of contaminated equipment, transport containers, and gloves and included both standard and streamlined (reduced glove changes/cleaning) procedures. Six CSIs from two police forces recovered 24 biological samples (semen, blood, saliva, and touch DNA) from two mock scenes. Critically, no extraneous DNA profiles were detected in any evidential samples, even under deliberately compromised conditions or when streamlined practices halved the time required for recovery.

These findings indicate that many current anticontamination measures exceed what is necessary to protect evidential integrity. The results support a more proportionate, risk-based approach, suggesting that UK police forces could safely reduce certain anticontamination practices without compromising the quality of forensic evidence. Further research in real-world settings is recommended to confirm these conclusions and guide policy.

1. Introduction

The risk of contamination to the biological/DNA evidence recovered from a crime scene through inadvertent DNA transfer must be considered throughout the end-to-end crime scene investigation process. DNA transfer is either active (movement of DNA from perpetrator to scene during an incident) or passive (not related to the incident). [1] This study focuses on passive transfer caused by actions of a Crime Scene Investigator (CSI) throughout a crime scene investigation, aiming of understanding the risks posed to the integrity of forensic evidence recovered at crime scenes via different sources.

If DNA contamination occurs, it can impact a criminal investigation by potentially masking the DNA profile of a true evidential sample or, if not identified to be contamination, can mislead an investigation. In the most extreme circumstances, this could ultimately result in a miscarriage of justice. It has been long understood that DNA contamination can be introduced at any stage before or during the forensic investigative process, from the production of DNA-critical consumables, the examination and recovery of evidential material at the crime scene, subsequent storage and transfer of this material to and during its laboratory analysis by a Forensic Service Provider (FSP).

The risk of DNA contamination to forensic evidence is considered significant due to the sensitivity of DNA analysis technology. However, these risks are mitigated by UK police forces through strict anticontamination management. [2] For more than 20 years wearing personal protective equipment (PPE) has been identified as a means of reducing contamination during crime scene examinations. [3] Additional adopted anticontamination measures include frequent changes [4–6] and/or cleaning of gloves, especially prior to recovery of each evidential item, plus cleaning of both equipment and the containers used for transferring forensic DNA grade consumables into the crime scene.

Much consideration has been paid to scene investigation, forensic medical and DNA analysis processes, and strategies have been developed to manage the associated risks. For example, the guidelines published by

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the UK Forensic Science Regulator (FSR), (FSR-GUI-0016 *Guidance: Contamination controls – Scene of crime*, [7] FSR-GUI-0017 *Guidance: DNA contamination controls – Forensic Medical Examinations*, [8] FSR-GUI-0018 *Guidance: DNA contamination controls – laboratory)* [9] provide comprehensive guidance on what these risks are and how they can be mitigated, although it should be noted that many of these risks have not been evaluated empirically.

The means of contamination can be categorised according to the number of transfer steps or degrees of separation between the contamination source and the evidential sample. Direct contamination by, for example, a CSI inadvertently coughing directly onto an item or touching it with an ungloved hand, entails one transfer step. Secondary transfer has two transfer steps, for example contamination of a critical consumable during manufacture which is then used in collection/processing of an evidential sample. Tertiary and more complex transfers have three or more steps, for example a piece of equipment is contaminated by an operator with their own DNA, then the equipment is taken into a scene where it is transferred onto the gloves of a CSI and from their gloves onto an evidential sample during recovery (person-to-equipment-to-gloves-to-evidential item).

A recent study of potential sample-to-sample contamination within simulated crime scene recoveries, demonstrated that the risk of contamination being detected, is amongst other factors, inversely related to the number of transfer steps occurring at a crime scene investigation. [10] Interestingly, another study demonstrated that although secondary transfer may be a possible reason for DNA to be found at a crime scene through wearing contaminated gloves previously worn outside the scene, the authors concluded that detection of secondary transfer is a very rare event under realistic conditions. [11] These and many other studies in the field of DNA transfer have contributed to the understanding of the wider field of transfer and persistence of DNA to forensic evidence. [12–14].

End-to-end validations of the CSI evidential recovery process have been successfully conducted by many UK police forces which have demonstrated the anticontamination measures unilaterally adopted are fit for purpose. Similarly, many forces have also conducted cleaning validations for the effective reduction of biological material from various surfaces and crime scene investigation-related items using a variety of cleaning reagents applied either as a pre-impregnated wipe or applied as a spray and then wiped. [15] All the validated methods demonstrated a reduction in contamination levels, however, scoring/acceptance criteria chosen to demonstrate whether or not the cleaning processes met defined performance levels were not consistent between all police forces. Most utilised one of the three different environmental monitoring (EM) scoring systems provided by their chosen FSP, the criteria of which are based on scoring EM results from highly controlled DNA laboratories and therefore were not developed specifically for uncontrolled, challenging crime scene environments. This discrepancy is nationally recognised and has been highlighted in other areas of forensics such as forensic medical examination facilities, where a new specific criteria has been developed to address this challenge. [16] A key limitation to all the forensic cleaning validations is that they only assess performance against these arbitrarily defined acceptance criteria, there is no alignment or level of cleanliness of a surface or item comparable to the actual risk posed to contaminating evidential samples in a 'live' crime scene.

2. Experimental aims and outline

Concerns about the impact of statutory regulation on the delivery of effective and efficient crime scene examination were raised with the FSR and through Home Office ministers in the UK. Following an investigation which included a national survey and engagement with police forces, the FSR published a report which highlighted that most police organisations disagreed (75%) or strongly disagreed (17%) with the statement: *the volume of work and impact of the accreditation process is proportionate to the risk of error or quality failure*. [17]

In response the Forensic Capability Network (FCN) coordinated an investigation into the proportionality of anticontamination measures conducted by forces in relation to the risk of contamination to the forensic evidence recovered in crime scene investigations. This study is a component of this national initiative.

The aim of this study was to assess the practical value of current anticontamination measures for reducing the risk of evidential samples becoming compromised during scene investigation. This was approached by both reducing the anticontamination measures taken, and by deliberately introducing contamination of items and surfaces encountered during evidence recovery from mock crime scenes. The recovered samples were then assessed for any impact of contamination from the scene or the practitioner during the recovery process.

Two experimental approaches were undertaken: 1) Impact of relocating photographic scales during an investigation and 2) Impact of taking reduced anticontamination measures and exposure to increased contamination levels within the evidential recovery process.

A national survey was also sent out to CSIs across the UK to gather data on their individual experiences to support understanding of the likelihood of certain scenarios occurring during a crime scene examination that may be considered a risk of contamination to forensic evidence.

2.1. Experiment 1: Impact of relocating photographic scales during an investigation

Experiment 1 was undertaken by Lancashire Constabulary and assessed the direct contamination risk from relocating equipment within a crime scene. Photographic scales were chosen for this assessment as these come into direct contact with surfaces which could potentially require sampling at the same point of contact, and therefore could be a risk through;

a) a change in crime scene sampling strategy during an investigation,
b) accidental misplacement of the scales or
c) inadvertent contact.

The aim was to measure the level of DNA transfer where contamination mitigation was carried out and where it was not, by introducing contamination that is above what would be expected to occur at a crime scene. In phase 1, photographic scales were placed on a surface area (area A) contaminated with either dried blood or saliva, then cleaned and placed in contact with a new area on the same surface (area B) with the latter subsequently sampled to determine the level of DNA transfer from the scales from surface area A to surface area B. Different cleaning reagents (Chemgene HLD_4L Laboratory- Byotrol, Grimex −Assist Hygiene Products Ltd., and distilled water) were used to clean the scales, following contact with area A, and prior to transfer onto area B. These cleaning reagents represented some of the more common products used by CSIs. This experiment was also repeated without cleaning the scale between contact with the seeded DNA on surface area A prior to transfer onto surface area B.

Phase 2 was an extension of phase 1 to determine whether contact of the scale with DNA would subsequently contaminate evidential DNA evidence if it were to come into direct contact with DNA evidence on a second surface (surface area C or a carpet).

2.2. Experiment 2: Impact of taking reduced anticontamination measures and exposure to increased contamination levels within the evidential recovery process

Experiment 2 was undertaken by both Lancashire Constabulary (LC) and East Midlands Special Operations Unit's (EMSOU's) Derbyshire Police (DP) and supported by the FCN, with the aim of assessing the impact and therefore risk of the following:

- Potential contamination of recovered samples by transfer of background DNA present within the scene during the investigation process.
- Potential item to item cross-contamination during collection and transport.
- Potential contamination of consumables by either the outside of the consumable packaging, the outside or inside of the critical DNA consumables box used to transport consumables to the scene, and from the outside of the disposable bag used to transport consumables from the CSI vehicle into the crime scene.
- Potential impact on evidential samples from using tamper evident bags (TEBs) contaminated on the outside.
- Potential impact on evidential samples from using contaminated equipment.
- Potential impact of reducing anticontamination measures.
- Potential contamination of samples by CSIs.

A mock scene was set up at each force, each with four separate areas containing seeded semen, blood, saliva or touch DNA (on a screwdriver handle), the term touch DNA is used to describe sources of DNA transferred by contact with uncovered skin. All body fluids were allowed to dry before recovery. Three CSIs from each force undertook an end-to-end scene recovery exercise: two of the three CSIs used their own force standard operating procedures (SOPs), and one CSI used a streamlined version of their current practice, still employing good scene practice and professional judgment but with reduced anticontamination measures, details of the differences in procedures has been provided in Appendix B: Table 5. Each CSI took swabs from the evidential samples in a specific sequence, and these were analysed to identify whether sample integrity was impacted by the specific anticontamination measures taken. Biological material from a known donor was used to provide background DNA seeded onto critical surfaces within the experimental area to facilitate identification of the potential source of contamination if any was detected in the recovered samples. This experimental assessment included deliberately contaminating the inside of boxes used to store and transport the DNA consumables within the CSI vehicles, outside of bags for transferring consumables from the vehicle into the crime scene, and the outside of TEBs into which the recovered samples were placed. Other surfaces including work tops, door handles and light switches were also contaminated with another donor's DNA. The potential for indirect contamination from equipment taken into the scene was also assessed by pre-contaminating equipment surfaces by vigorous handling of the equipment prior to its' deployment into the crime scene.

2.3. National CSI survey

It was not known what risk is posed to DNA evidence at a crime scene if a CSI uses equipment that is not free from detectable levels of DNA during their crime scene examination. It is standard practice in the UK for CSIs to clean or change their gloves immediately prior to the recovery of DNA evidence therefore gloves as the vector for contamination to the evidence from equipment is unlikely. The most likely route of contamination is by direct contact of the equipment with the evidential sample. To support an understanding of this risk a survey was conducted to identify the likelihood of CSI equipment coming into direct contact with DNA subsequently recovered as potential evidence.

3. Materials and detailed methods

3.1. Participants and DNA donors

A list of all participants in this study and their roles have been summarised in Table 1.

Table 1
List of all participants in the experimentation, their unique identifier and their role. The provision of all DNA donors has also been described here and the location in which they underwent their role. (FCN denotes Forensic Capability Network individual; LC denotes Lancashire Constabulary; DP denotes Derbyshire Police).

Identifier	Role	Experiment	Location	DNA Provision
FCN 1	Experiment co-ordination, body fluid donor	Experiment 1 Experiment 2	LC LC & DC	Blood & saliva Saliva
FCN 2	Body fluid donor	Experiments 1&2	LC & DC	Semen
FCN 3	Experiment co-ordination, body fluid donor	Experiments 1&2	LC & DC	Blood
FCN 4	Body fluid donor	Experiment 2	LC	Saliva
FCN 5	Experimental set-up, touch DNA donor	Experiment 2	LC & DC	Touch
LC CSI 1	Contamination of consumable box and scene case	Experiment 2	LC	Touch & saliva
LC CSI 2	Scene examination / evidential recovery	Experiment 2	LC	N/A
LC CSI 3	Scene examination / evidential recovery	Experiment 2	LC	N/A
LC CSI 4	Scene examination / evidential recovery	Experiment 2	LC	N/A
LC CSI 5	Deliberate contamination of outside of TEBs	Experiment 2	LC	Touch DNA
LC CSI 6	Deliberate contamination of tripod legs	Experiment 2	LC	Touch DNA /saliva
LC CSI 7	Sample/Control collection Experiments 1 & 2	Experiments 1&2	LC	N/A
DP CSI 1	Contamination of consumable box and scene case	Experiment 2	DP	Touch & saliva
DP CSI 2	Scene examination / evidential recovery	Experiment 2	DP	N/A
DP CSI 3	Scene examination / evidential recovery	Experiment 2	DP	N/A
DP CSI 4	Scene examination / evidential recovery	Experiment 2	DP	N/A
DP CSI 5	Deliberate contamination of outside of TEBs	Experiment 2	DP	Touch
DP CSI 6	Deliberate contamination of tripod legs	Experiment 2	DP	Touch & saliva
DP CSI 7	Sample/Control collection	Experiment 2	DP	N/A
DP CSI 8	Body fluid donor	Experiment 2	DP	Saliva

3.2. Materials/Equipment

All consumables used during the experimentation, detailed in Appendix A: Table 4, were supplied by the participating forces or the FCN, having been procured via the UK framework for the provision of national crime scene consumables and stored as per local protocols. All equipment used throughout the mock crime scene examinations were force issued assets in current operational use within their respective force CSI units.

The national survey for CSIs was developed on Microsoft Forms and emailed out to all CSI leads across all police forces in England and Wales for distribution to their practitioners.

3.3. Analysis

DNA extraction, analysis and interpretation of all samples recovered throughout all experimentation in this study was conducted by Cellmark

Forensic Services at their facilities in Abingdon, UK. A list of consumables and instruments used throughout are provided in Appendix A: Table 4. DNA recovery, extraction, quantification and analysis was conducted using ISO/IEC 17,025 *Testing and Calibration Laboratories* [18] standard accredited processes, UKAS accredited testing laboratory No.2045. The swabs from each of the experiments were extracted and purified using the EZ1® and EZ2® Investigator kit (Qiagen) and the BioRobot® EZ1 workstation (Qiagen), using the 200 μl lysis procedure. Each extract was eluted into a 50 μl volume of Tris-EDTA buffer. An extraction negative control sample was included to monitor any contamination events.

Quantification was performed using a 7500 Real-time PCR system with Qiagen's Quantiplex PRO RT PCR kit. The DNA quantification results were used to determine the volume of DNA placed in the PCR reaction. The samples were amplified using Thermo Fisher's AmpFLSTR™ NGM Select™ PCR Amplification kit.

Following amplification, all samples were run on a 3500 Genetic Analyser. After electrophoresis, the samples were interpreted using Genemapper® IDX v1.5 software.

Quantification data generated using the Quantiplex PRO qPCR system were evaluated using standard curve statistics, including the coefficient of determination (R^2), slope, and PCR efficiency, to ensure assay performance remained within validated limits ($R^2 \geq 0.98$; efficiency 90–110%). For each sample, mean DNA concentration, standard deviation, and coefficient of variation (CV%) were calculated from replicate measurements to assess precision and reliability.

The DNA analysis technique used is fully validated, with an analytical threshold of 60 Relative Fluorescence Units (RFU). The results have been interpreted by DNA analysts who have applied established interpretation guidelines, any profile that meets the search criteria will have been searched on the force staff elimination database.

3.4. Experimental details

3.4.1. Experiment 1. Impact of relocating photographic scales during an investigation: Experimental detail

A schematic of the experimental set up, process and samples recovered in Experiment 1 is shown in Fig. 3, and experimentation set up and results provided in Appendix C: Table 6.

Prior to experimentation the L-shaped plastic photographic scales were cleaned using duplicate spray/wipe cycles with 1250 ppm Presept and a final spray/wipe with water.

3.4.1.1. Phase 1: Transfer of DNA from a seeded surface to a clean surface. The set up and experimentation carried out on Formica surface areas A and B has been described in steps 1–6 (shown in Fig. 1a-1f). Each of these stages were repeated four times using 10 μl of blood as the contaminant and four times using 10 μl of saliva as the contaminant. Each scale was decontaminated following contact with the seeded surface area A either using a duplicate water wash, a duplicate Grimex wipe, duplicate Chemgene wipe or not washed at all.

The contact time of a scale with a surface in a crime scene is usually $<$ 1 min, therefore the contact time of approximately 30 min used throughout these experiments provides disproportionately longer contact time to ensure a DNA transfer is detected if it were to occur.

3.4.1.2. Experiment 1- Phase 2: Interference of DNA- transfer of DNA from a seeded surface to evidential DNA on a second surface. Additional steps (shown in steps 7–11 in Fig. 2a-2e) were conducted to simulate a crime scene scenario where a scale, following contact with body fluid in one area of a scene (step 3: Fig. 1c), may subsequently come into contact with another source of body fluid (step 10: Fig. 2d) within the same scene where that direct contact point subsequently becomes a source of potential 'evidential' material. To test this, following stages 1–3 (shown in Fig. 1a-1c), scales were cleaned with water and placed onto a Formica surface area C or a carpet which had been seeded using an electronic pipette, with triplicate 10 μl dried blood spots (from a second donor). Following approximately 30 min contact time the scale was removed and the 'subsequent potential evidential' samples were recovered from the blood stains on surface area C or the carpet.

This part of the experiment showed previous direct contact with DNA, followed by normal anticontamination mitigations of the scale (between scene area cleans) and then direct contact with a new DNA source subsequently recovered as evidential interest to assess the risk of within scene transference and the impact to the DNA sources of interest.

3.4.1.3. Control samples. Triplicate negative control samples were recovered from the Formica surface following step 1 (Fig. 1a), where this surface was cleaned with Presept. This same surface, split into to two discrete areas, was used as surface area A and surface area B.

Positive control samples were taken of the body fluids, where 10 μl of saliva and 10 μl of blood was pipetted directly onto a swab and then analysed, to demonstrate the seeding load used throughout Experiment 1.

All samples were taken using moist and then dry swabbing by LC CSI 7 (wearing PPE). The swabs were stored frozen by LC until transported to the FSP for analysis. Samples were extracted, quantified, DNA profiled and where appropriate, compared against their corresponding control samples and relevant body fluid donor profiles, as detailed in Appendix C: Table 6. with all donors'/participants' profiles already held on the staff elimination database (SED).

3.4.2. Experiment 2 assessment of contamination risk from End-to-End crime scene investigation process: Detailed experimental set-up

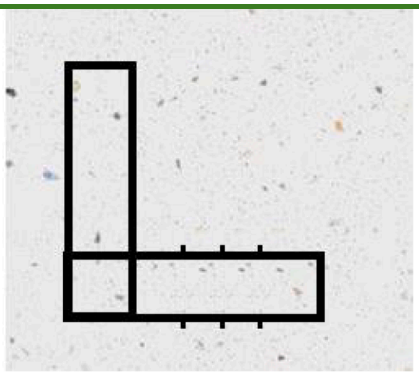
Details of the roles conducted by each CSI and which body fluid donors were used has been provided in Table 1. Each force provided trained personnel, equipment and consumables to conduct a scene examination by three CSIs, two of which (CSI 2 & CSI 3) followed their force SOPs and the third (CSI 4) used less PPE and reduced within-scene anticontamination measures based on their professional judgement, details of these procedural differences are provided in Appendix B: Table 5.

3.4.2.1. Pre- examination (Day 1). Prior to scene attendance, some surfaces including equipment and TEBs were deliberately contaminated by staff members who were not conducting the mock scene examination, as shown in Fig. 4.

CSI 1 deliberately contaminated, by handling and coughing over first the inside, and then the outside of the boxes used to transport the critical DNA consumables within the CSI van, and the outside of three bags used by the CSIs for moving consumables into the crime scene. Contamination was with touch DNA by prolonged (approximately 1 min) handling by CSI 1 with ungloved hands after having rubbed their face and not washing their hands for approximately an hour prior. The insides of the CSI cases were also contaminated with saliva from the same individual by coughing multiple times into the case and then distributing any droplets by wiping with their ungloved hands. The same donor put the packaged consumables required for the scene recovery exercise in the transport container using ungloved hands and placed the container in the CSI van.

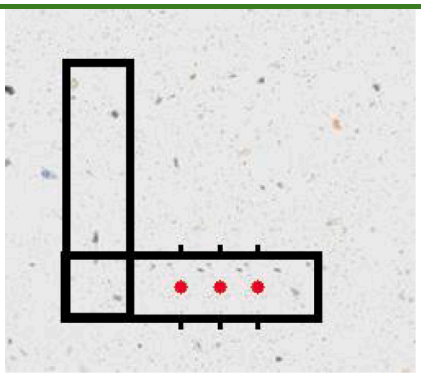
CSI 5 deliberately contaminated the outside of the TEBs to be used in the exercise with touch DNA by prolonged (approximately 1 min) handling with ungloved hands which had not been washed for at least an hour prior to them rubbing their face then the TEB. The TEBs were placed into a separate bag by CSI 5 to ensure these did not contaminate other items.

CSI 6 cleaned three tripod stands at the CSI hub and then covered the tripod legs with their own touch DNA and saliva by coughing repeatedly on the legs and smearing the droplets over the surface with bare hands. Tripods were then transported in the CSI van as per standard practice.



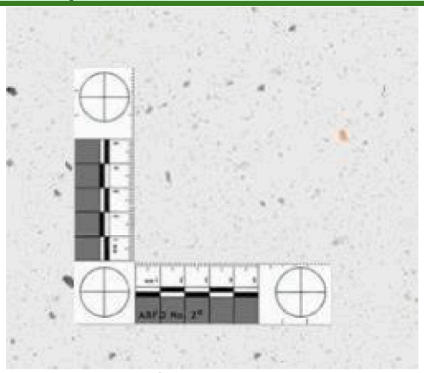
1a: Image of scale outline drawn onto Formica surface areas A and B, using a sharpie® pen, with markers for the three body fluid deposition sites, prior to the cleaning of the Formica surface with 2x Presept and 1x water wash.

Step 1: Surface areas A and B



1b: Image of scale outline drawn onto the Formica surface seeded with three 10 µl spots of body fluid (blood or saliva using an electronic pipette), shown in red. These spots were left to air-dry for approximately 30 minutes.

Step 2: Surface area A

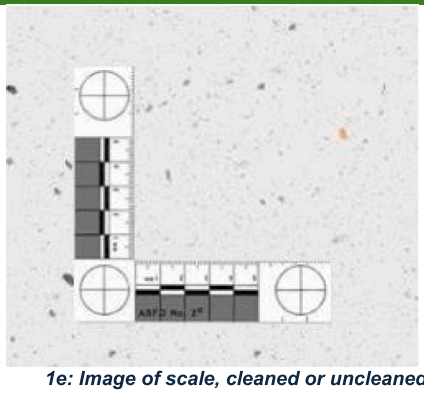


1c: Image of cleaned scale placed over the marked-out scale on top of the triplicate set of dried spots of body fluid (saliva or blood). The scale was left in this position for approximately 30 minutes.

Step 3: Surface area A

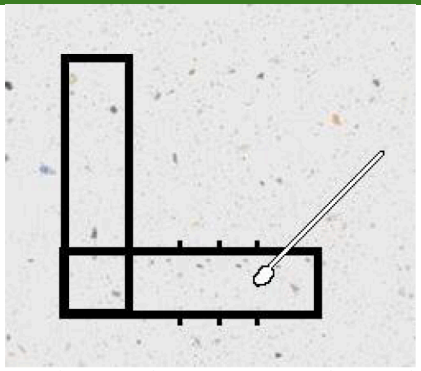
1d: Image of scale, following removal from surface area A then cleaned using one of three commonly employed crime scene cleaning methods, i.e. double wipe with Grimex wipes, double wipe with water using a cloth, or double wipe with Chemgene wipes, or they were not cleaned at all.

Step 4



1e: Image of scale, cleaned or uncleaned then placed onto the decontaminated hard Formica surface area B and left in situ for 30 minutes, before being removed.

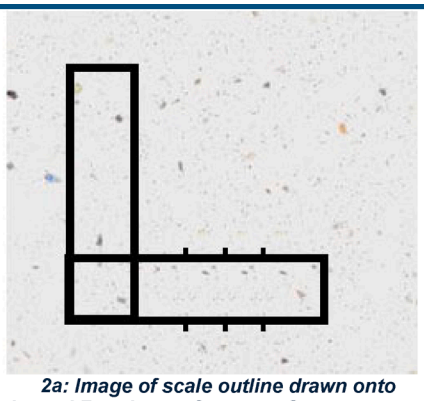
Step 5: Surface area B



1f: Image of swabs recovered from surface area B following contact with the scale that had previously been in contact with body fluids on surface area A.

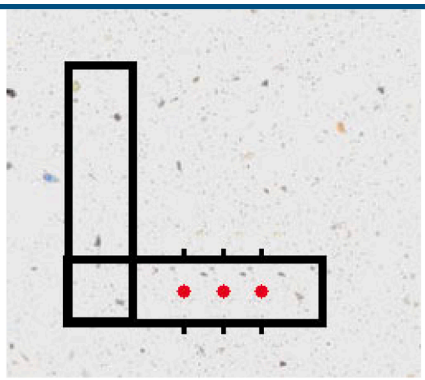
Step 6: Surface area B

Fig. 1. The step-by-step process followed in Experiment 1 Phase 1.



2a: Image of scale outline drawn onto uncleaned Formica surface area C or onto carpet.

Step 7: Surface areas C or Carpet

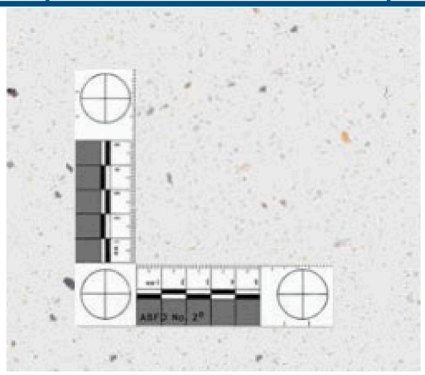


2b: Image of scale outline drawn onto the uncleaned Formica surface area C or onto carpet seeded with three 10 µl spots of blood (from a second donor) using an electronic pipette, shown in red. These spots were left to air-dry for approximately 30 minutes.

Step 8: Surface areas C or Carpet

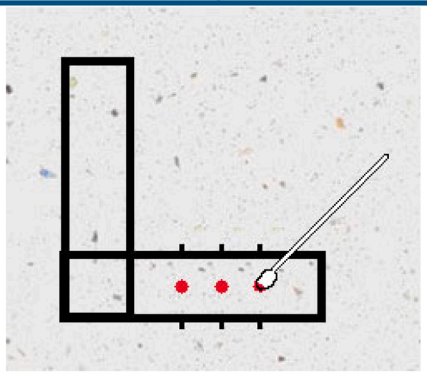
2c: Image of scale, following step 3, removed from surface area A then cleaned with water.

Step 9



2d: Image of scale, placed onto either surface area C or carpet placed over the marked-out scale on top of the triplicate set of dried blood spots. The scale was left in this position for approximately 30 minutes, then removed.

Step 10: Surface areas C or Carpet



2e: Image of swabs recovered from surface area C or carpet from seeded blood (from a second donor) following contact with the scale that had previously been in contact with body fluids (from the first donor) on surface area A.

Step 11: Surface areas C or Carpet

Fig. 2. The step-by-step process followed in Experiment 1 Phase 2.

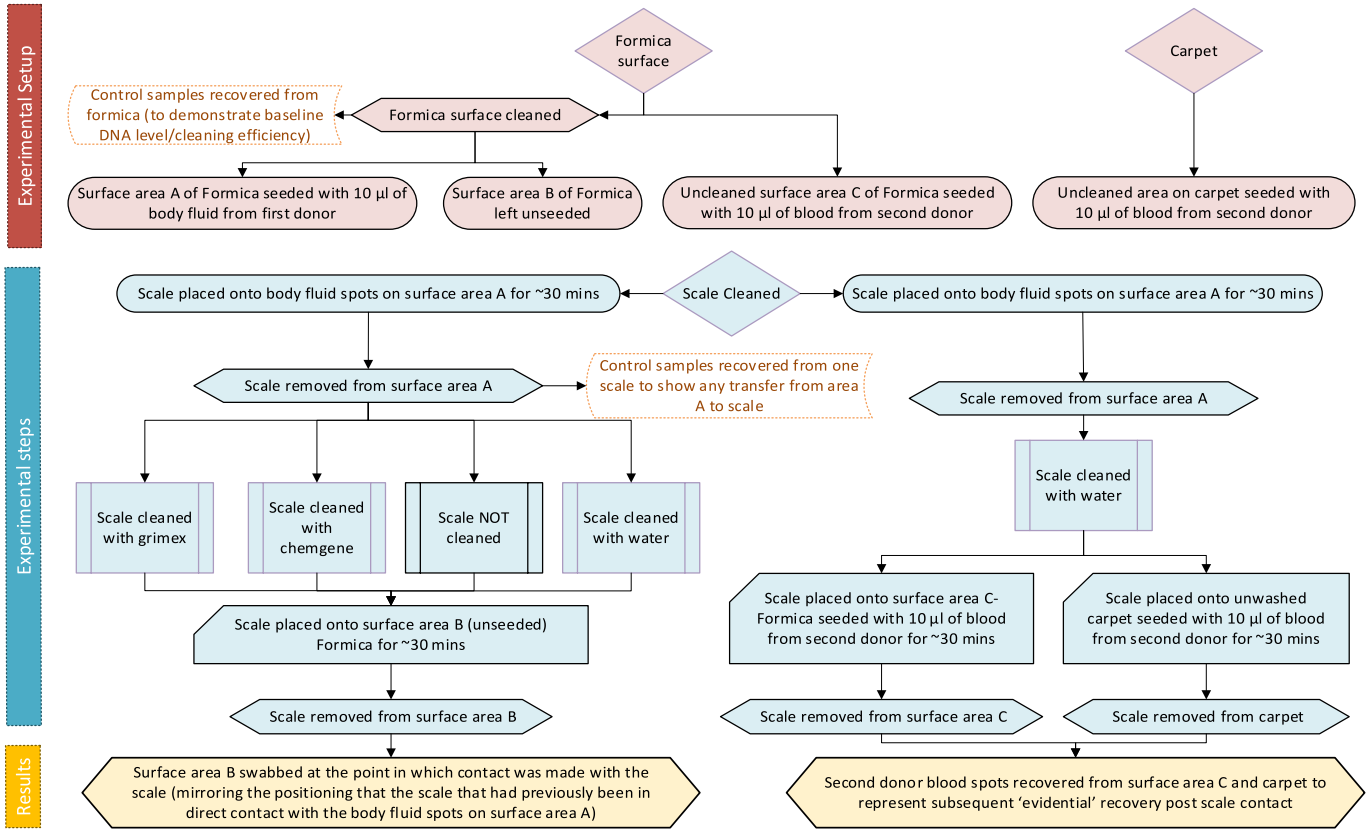


Fig. 3. Schematic of the Experiment 1 process.

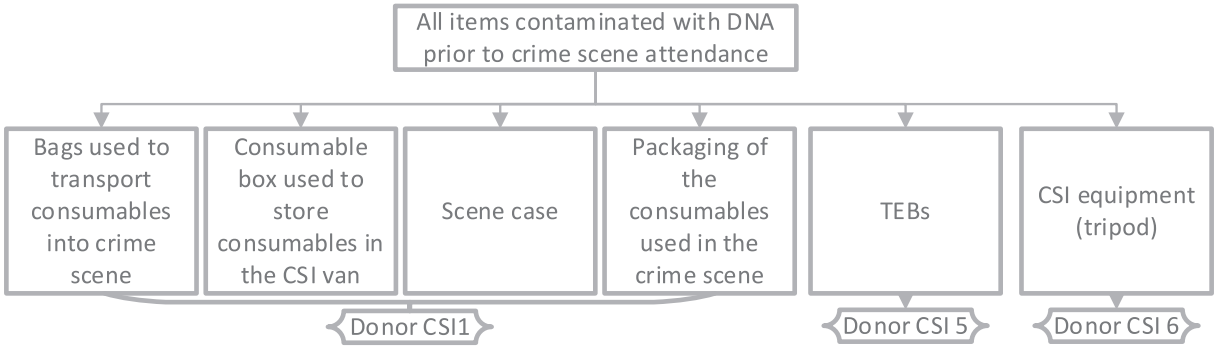


Fig. 4. Schematic to show the items that were seeded with DNA prior to attendance to the mock crime scene in Experiment 2.

Within the crime scene houses/rooms, four horizontal surface areas, A-D, were cleaned by duplicate Presept wash/wipes and then cleaned thoroughly with repeated water wash/wipes. Four 20 cm x 20 cm plastic boxes were also cleaned with Presept in the same manner. The surfaces were allowed to dry for approximately 1 h. The cleaned, open plastic box was placed faced down in the middle of each of the surfaces and taped down, covering the area that will later be seeded with spots of body fluid, or screwdrivers.

The set up of the mock crime scene has been shown in Fig. 5. Each surface was then coated uniformly, with saliva (FCN 1) using a 1/10 homogeneous dilution in 100 ml phosphate buffered saline (PBS) solution applied with a roller brush, avoiding the area on each surface covered by the plastic box taped to the surface. High contact touch points throughout the scene such as door handles, stair banister and light switches were also coated in the diluted saliva from the same donor, which the CSIs were not aware of.

The saliva was allowed to dry for approximately 2 h, then the plastic boxes were removed. The following was then applied to the exposed surfaces previously covered by the box: 3 x 10 µl semen (FCN 2), 3 x 10 µl blood (FCN 3) and 3 x 10 µl saliva (FCN 4 at LC and CSI 8 at DP) on surfaces A-C, respectively.

Three screwdrivers were cleaned with duplicate Presept washes followed by a water wash and allowed to dry for approximately 2 h. These were then handled with ungloved hands (by FCN 5) which had not been washed for at least an hour prior to them rubbing their face then handling the screwdrivers for approximately 1 min before placing them onto the designated area on surface D, as shown in Fig. 6.

3.4.2.2. Scene examination. (Day 2). PPE was donned by CSI 7 prior to the collection of all control samples, all control samples were taken from areas away from where the CSI is likely to make most contact, where practically possible. On arrival of the CSI van at the scene, CSI 7 took control wet and dry swabs from the inside and the outside of the DNA consumables transport box.

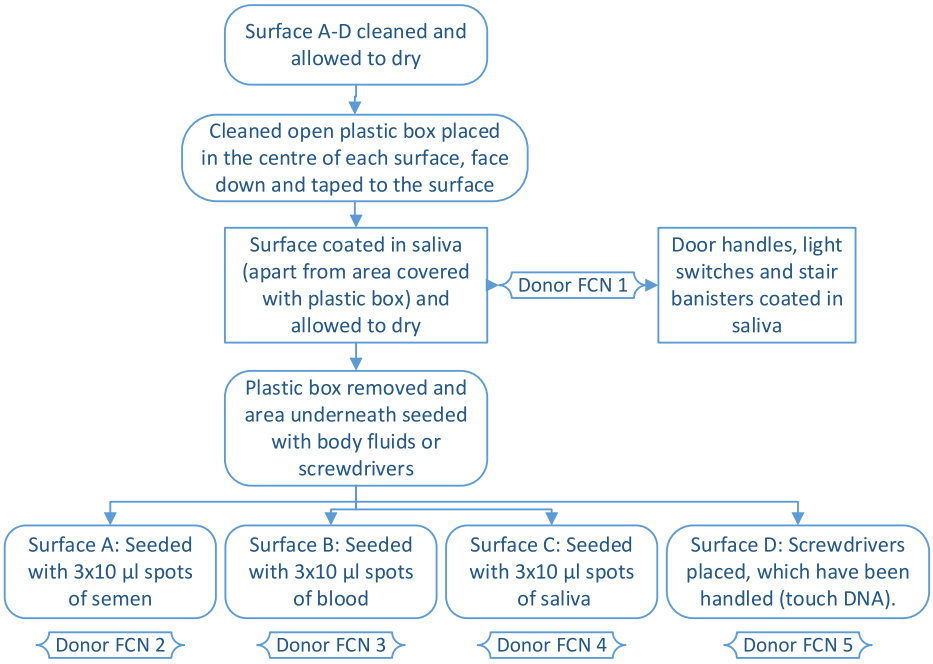


Fig. 5. Schematic of the experimental set up within the mock crime scenes in Experiment 2.

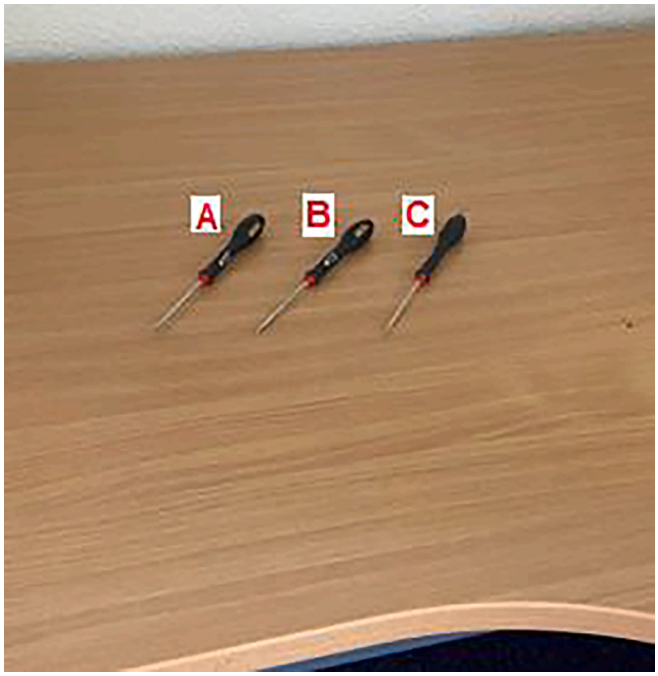


Fig. 6. Image of surface D where three screwdrivers were placed which have been previously handled (by FCN 5). The surface area of D shown in this image was seeded with saliva, from donor FCN 1.

Following their individual force protocol for crime scene attendance, the first of the three CSIs, CSI 2, donned PPE and transferred consumables from the critical DNA consumables transport box into the externally pre-contaminated bag for transferring the DNA consumables, then entered the crime scene. The contaminated tripod was also brought into the scene and set up. CSI 7 took control wet and dry swabs of the outside of the transfer plastic bag, the tripod and from the horizontal surfaces on which the evidential items were placed.

CSI 2 then worked through the mock crime scene as if it were a genuine crime scene examination recovering a single spot of body fluid from each of the designated areas in each of the separate rooms, starting with semen from surface A, blood from surface B followed by saliva from surface C. Presumptive tests for body fluids were conducted, as appropriate, according to the protocols of each police force. Studies have shown that semen stains can be remarkably resilient, and DNA can be recovered from them even after being washed and aged for decades. [19] Semen samples can have higher overall human DNA concentrations than blood samples, notably a 2024 study [20] found significantly higher DNA concentrations in semen compared to blood when assessing detection and collection on various fabrics. Due to the resilience of semen, these samples were recovered first by each CSI as the most likely body fluid to cross contaminate the subsequent samples recovered.

After the saliva sample had been recovered, and immediately prior to recovering touch DNA from the screwdriver, CSI 2 firmly placed their gloved hands onto the table, surface D, which had been contaminated with saliva, on which the screwdrivers were placed. Different areas of surface D were touched by each CSI, which again was separate to the area the control samples were recovered. CSI 7 then took control wet and dry swabs from the glove of CSI 2′s dominant hand and then CSI 2 proceeded with touch DNA recovery from the screwdriver handle whilst wearing the contaminated gloves.

The purpose of deliberately contaminating the CSIs gloves prior to recovery of touch DNA was to understand the risk of contamination to the evidential DNA if the CSI had inadvertently contaminated their gloves with significant quantities of DNA prior to recovery. To test a worst-case scenario, the most challenging DNA to recover (touch DNA) was used and surface D, used to contaminate the CSIs gloves, was seeded with a high quantity of DNA rich saliva. A control sample was taken from the passive gloved hand (holding the tip of the screwdriver at the opposite end of the handle that was to be swabbed), ensuring the gloved hand directly carrying out the swabbing of the handle has the full quantity of contaminant DNA available for potential transfer during the activity.

CSI 2 then exited the mock scene with the collected samples and equipment.

The above exercise was repeated with CSI 3 with controls and evidential samples taken as before, using a fresh (externally contaminated) plastic bag to transport the consumables from the CSI van into the crime scene.

The third and final CSI, CSI 4, entered and recovered the same samples in the same order, utilising reduced anticontamination measures, including wearing the same pair of gloves throughout. All CSIs were witnessed by CSI 7 throughout their scene examination with observations recorded to assist in result understanding (if required).

3.4.2.3. Post-examination. All recovered material was packaged as per standard crime scene practice and the items transported back to the CSI hubs.

In experiment 2, for each participating force, 12 "evidential" swabs were taken (4 per investigating CSI). These were extracted, quantified, profiled and checked against their relevant control profiles (FCN 2–5 and CSI 8). Where additional alleles were detected which were deemed sufficient for comparison (i.e. enough allele information to facilitate a DNA profile comparison to a known profile), the FSP was instructed to attempt to identify the source of the contaminant against the other controls and reference DNA profiles, including the background DNA source in the crime scene (FCN 1) and other deliberate sources of contamination.

4. Results

4.1. Experiment 1

All DNA results from Experiment 1 are provided in Appendix C: Table 6 and summarised in Table 2.

4.1.1. Phase 1 results: Transfer of DNA from a seeded surface to a clean surface

No detectable levels of DNA suitable for comparison were found on the 24 samples taken from surface area B following contact with the scales that had been placed onto saliva or blood on surface area A prior to contact. These results demonstrate that DNA from the dried body fluid that came into direct contact with the scale on surface area A was not transferred onto the second surface area B after contact with the scale.

No detectable levels of DNA suitable for comparison were identified on the samples recovered from the scales post contact with blood or saliva on surface area A. Demonstrating that DNA was not transferred onto the scales from the direct contact with dried body fluid on surface area A.

4.1.2. Phase 2 results: Interference of DNA- transfer of DNA from a seeded surface to evidential DNA on a second surface

The full DNA profile of the second blood donor (FCN 3) was recovered from the samples taken from the duplicate seeded blood spot on surface area C and the carpet, there was no remaining DNA sufficient for comparison. These results demonstrated that there was no contamination of the evidential DNA sample (which was blood from FCN 3) from the scale following contact with surface area A (seeded with blood from FCN 1). Therefore, despite the scale being placed directly onto a source of DNA then wiped with water before being placed directly onto an evidential DNA spot, there was no transfer or interference to the evidential sample.

4.1.3. Control samples

Positive control samples; a swab directly pipetted with 10 μl of saliva and a second with 10 μl of blood both provided the full DNA profile of the donors, evidencing sufficient load throughout the experimentation.

No detectable levels of DNA were found on any on the three negative control samples recovered from the Formica surface post clean, prior to seeding with body fluids, demonstrating that the surfaces within the crime scenes, prior to seeding with evidential samples were sufficiently free from detectable levels of DNA.

4.2. Experiment 2

The DNA results from Experiment 2 are provided in Appendix D: Table 7 and summarised in Fig. 7.

4.2.1. Equipment & consumable controls

The consumable boxes stored in the CSI van that were used to store the consumables and the bag used to transfer these consumables into the mock crime scenes were seeded with touch DNA and saliva by CSI 1. In total 5/6 of these control samples taken from the inside and 6/6 control samples from the outside of the consumable box identified a full DNA profile match to CSI 1 and additional DNA from at least 1 further contributor (that was unsuitable for comparison). From the six control samples taken from outside of these consumable bags, five recovered DNA matching CSI 1. The control samples taken from the one bag and inside of one of the consumables boxes where a DNA match could not be determined still identified low level DNA profiles matching the donors. These results demonstrated that consumables used in the mock scene examination were stored and transported into the scene in contaminated containers and bags.

The general surface area of the areas A, B, C and D were heavily seeded with saliva, and all eight control samples taken from these surfaces recovered DNA matching the donors' (FCN 1) profile, demonstrating the mock crime scene was suitably contaminated with the donors' DNA.

For the TEBs used to store the evidential samples recovered from the mock scenes which were seeded with touch DNA and saliva, 5/6 control samples taken from these TEBs identified a match to the donor's DNA (CSI 5). The single sample that did not return a match was a low-level partial profile matching the donor. This demonstrated that the

Table 2
Summary of Experiment 1 results as average DNA quantification (ng/μl).

Sample reference		Sample type	Average DNA quantification (ng/μl)
Negative control samples			
1.1		Control of Formica surface post clean	0
Positive control samples			
1.18		10 μl blood (FCN 1) pipetted directly onto swab	0.7231
1.19		10 μl saliva (FCN 1) pipetted directly onto swab	0.1391
Contaminant		**Phase 1**	
Saliva	**Blood**		
1.2	1.7	Swab of surface area B post scale contact	0
1.3	1.8	Swab of surface area B post scale contact	0
1.4	1.9	Swab of surface area B post scale contact	0
1.5	1.10	Swab of surface area B post scale contact	0
1.6	1.11	Swab of **scale** after initial contact with area A	0
Phase 2			
1.12		Swab of deposit of blood from second donor (surface C) post scale contact	1.36975
1.13		Swab of deposit of blood from second donor (carpet) post scale contact	0.1534

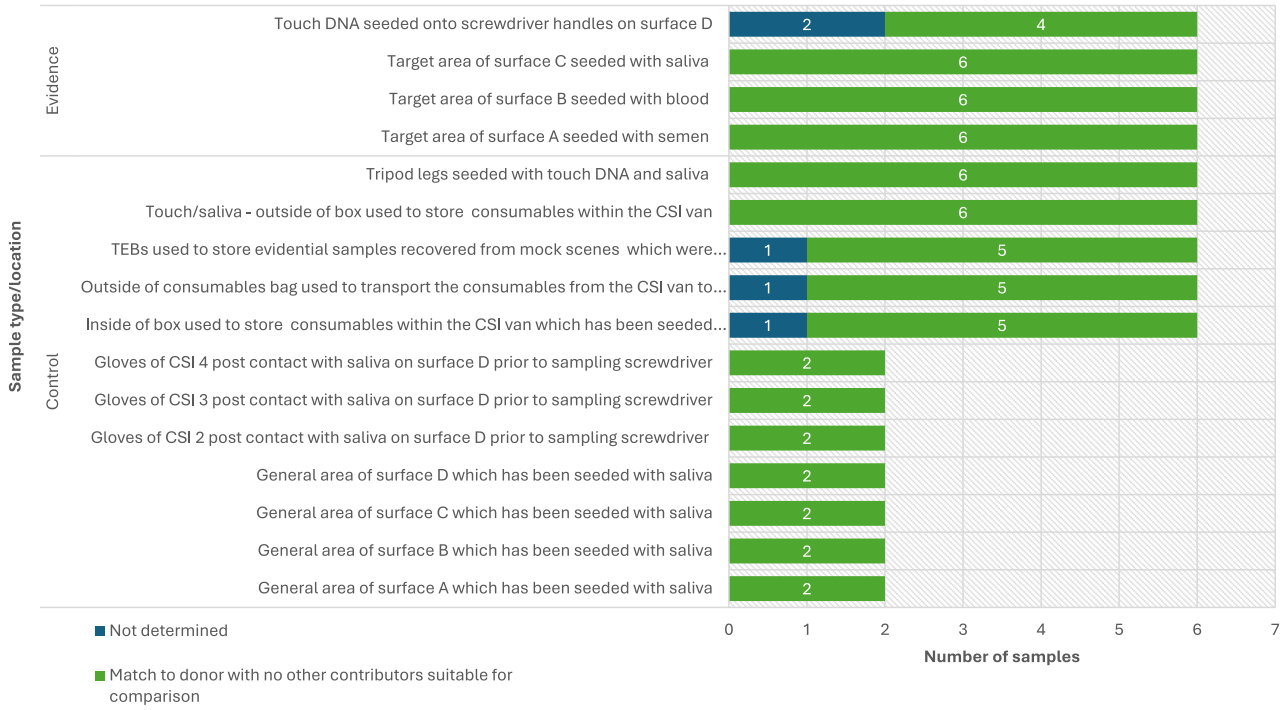


Fig. 7. Graph showing overall results from Experiment 2 for both the evidence recovered, the controls taken at contamination points throughout the process and the result of whether the recovered DNA matched the expected donor (in green) or unable to be determined (blue). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

evidential samples recovered were stored in TEBs that were contaminated on the outside.

All six control samples recovered from the tripod legs, which were seeded with touch DNA and saliva, recovered DNA matching the donor (CSI 6), demonstrating this equipment used in the mock crime scene examinations were suitably contaminated with donor DNA.

CSIs conducting the mock examination made direct contact, as instructed, with the area, wiping their gloved hands across the surface, applying pressure on surface D which had been seeded with saliva (FCN 1) prior to handling the screwdriver to recover touch DNA. All six control samples recovered from their gloves immediately after contact with surface D resulted in a detectable DNA profile that matched the donor's DNA (FCN 1). This demonstrated that the CSIs' gloves where suitably contaminated prior to the evidential sample recovery of touch DNA from the screwdrivers.

4.2.2. *Evidential samples*

Evidential samples recovered by the six CSIs from the following target areas yielded the expected profiles of the donors DNA with no further DNA suitable for comparison:

- Semen: 6/6 samples from surface A identified a full profile match to the semen donor,
- Blood: 6/6 samples from surface B identified a full profile match to the blood donor
- Saliva: 4/6 samples from surface C identified a full profile match to the saliva donor and 2/6 yielded partial profiles which could still be matched to the donor
- Touch DNA from screwdriver handles on surface D: 1/6 gave a full profile, 3/6 yielded partial profiles and 2/6 yielded insufficient DNA for comparison

These results demonstrate that despite the box and bag used to store and transport the consumables, the equipment, evidence bags and CSI gloves being grossly contaminated, none of this contamination was found on the evidential samples recovered.

4.3. *National CSI survey results*

In total 501 CSIs from 41 police forces completed the survey, representing approximately a third of CSIs across England and Wales. CSIs were asked; to the best of their knowledge, how many times in their working experience have items of equipment, or their gloves come into direct contact with a surface at a crime scene that was subsequently sampled for DNA analysis at exactly the same contact point, responses are summarised in Table 3.

The likelihood of occurrence has been calculated using Equation 1.

Equation 1: Likelihood calculation

Combined years of CSIs working experience.

(11721 years) ÷ Total number of occurrences by all CSIs = Likelihood of occurrence.

Table 3
Summary of survey results from CSIs on whether items of equipment may have come into contact with a surface that was subsequently sampled for DNA analysis, to the best of their knowledge. Including how many times this event may have occurred during their career as a CSI.

Equipment	No. of CSIs stated this contact may have occurred. % out of the total number of CSIs respondents.	Total no. of occurrences by all CSIs	Likelihood of occurrence:
Tripod Foot	6 (1.2%)	26	Once every 451 years
Measuring scale	14 (2.8%)	172	Once every 68 years
Stepping Plate	17 (3.4%)	158	Once every 74 years
Other CSI Equipment	14 (2.8%)	25	Once every 469 years
Gloves	58 (11.6)	353	Once every 33 years

5. Discussion

5.1. Experiment 1

The amount of biological material transferred from the seeded Formica surface onto the scales was orders of magnitude lower than the starting source material: transfer was not quantifiable in all the samples recovered from the scales following contact with the seeded surface. This finding is consistent with previous literature, but the present study also provides new empirical data under deliberately challenging conditions.

Controls of the blood and saliva starting material spotted onto the Formica surface yielded 0.7321 and 0.1391 ng/μl DNA, respectively. Given that no measurable levels of DNA were transferred onto the scales, and assuming a limit of quantitation of 0.0005 ng/μl, this represents at least 3 orders of magnitude reduction in the transfer from one hard surface to another. Therefore, even without any intervening cleaning of the scales following removal from the body fluid-seeded surface area A, there was insufficient contamination on the scales available to be detectably transferred onto any new surface. This suggests that the risk of DNA transfer via equipment is extremely low in realistic operational scenarios. Indeed if the efficiency of transfer from the scales to a new hard surface is in the same ballpark as was observed from a surface to the scales there would be a further 2–3 orders of magnitude reduction in the total amount transferred. This would require a much larger amount of initial seeding body fluid than was used in this experiment for any contamination to be detectable on the second contact surface. Aside from the levels of contamination present, the transferability of the body fluid/DNA is a key consideration, which in turn is likely to be impacted by many factors including the type of biological material being transferred, whether it is wet or dry, the type of surfaces in contact, the contact area, mechanical shearing and pressure during contact, plus duration of the contact. [11]

A limitation of this study is that only dried body fluids were examined. This reflects the conditions most commonly encountered in forensic casework, where biological materials are typically recovered as dried stains. Body fluids dry rapidly after deposition and remain on surfaces long enough to be examined, and forensic literature consistently describes dried stains as the usual form recovered at crime scenes.

Once fluids such as blood, semen, and saliva have dried, they become more biologically stable and degrade more slowly, allowing them to persist in a condition suitable for analysis. [21,22] In contrast, wet fluids deteriorate quickly due to microbial activity, environmental exposure, and dilution, meaning that scenes are rarely encountered with fluids still in a liquid state. Most UK crime scenes attended by CSIs are volume crimes; burglary, vehicle crime, and criminal damage, where significant bleeding is uncommon and large quantities of wet blood are rarely present. [23] Scene processing also typically occurs after delays caused by securing the scene and initial investigative activity, by which time any biological material has usually dried. [24,25] For these reasons, dried stains represent the most realistic and forensically relevant sample type for experimental work. Future studies could usefully examine wet biological materials and a broader range of environmental conditions.

Studies have demonstrated that the transfer of DNA upon contact depends significantly on the dryness of the biological material being transferred [26] and the transfer of blood and saliva is significantly influenced by moisture content. [27] Therefore, a wet body fluid may be more readily transferred from a surface onto a scale, however this would likely be more visible than dried on transfer and should be cleaned immediately as per standard CSI SOPs. These SOPs also dictate that a CSI must not place a scale onto a stained area where this is practically possible, therefore this would only occur in extremely rare circumstances.

It is recognised that a limitation to this study is that the sample size is very small, and further work is recommended to draw definitive conclusions on how much transfer can reasonably be expected in reality, including how this low-level transfer could affect a lower concentration DNA source such as cellular. Additionally, the experiments were conducted in mock crime scenes rather than live operational environments, which may not capture all possible contamination dynamics.

Nevertheless, the indication here is that there is such little DNA transfer that it cannot be detected, and the risk is correspondingly very low given that similar orders of magnitude reduction in transfer might reasonably be expected from the now contaminated scales placed on another surface that is subsequently sampled. In addition, the overall risk factor also depends on the frequency which such an event may occur. The national CSI survey identified that evidential recovery acquired from a surface on which scales have previously been placed occurs on average once every 68 working years for an active CSI practitioner. Similar responses from CSI practitioners were found for other equipment types where the potential direct contact of a tripod foot with a surface of subsequent evidential DNA interest has occurred for 6/501 CSIs, taking place on average once every 451 years and once every 158 years with a stepping plate. Good crime scene practice recommends that direct contact of equipment with material identified for potential DNA recovery within the scene is avoided where possible and recorded if it were to occur. With this in mind, excepting the limitation that the data from the survey is anecdotal and could be influenced by bias, reviewing this survey data in combination with the data from the transfer experimentation indicates how unlikely an event of measurable contamination through direct contact of equipment with an evidential sample area is to occur. Therefore, putting in place onerous anticontamination measures (additional cleaning and routine EM) is not proportionate to the risk posed during scene examination.

5.2. Experiment 2

The CSIs that conducted the crime scene examination were informed prior to sample recovery where the evidential body fluids had been deposited for them to recover, which may be a limiting factor of this study. However, the high contact areas within the scene (e.g. door handles, light switches, banister) were contaminated with donor DNA, which the CSIs were not made aware of.

The recovery of control samples from equipment and items used throughout the experiment was essential to show the level of contamination but conversely also presents a limitation of potentially reducing the overall DNA on these seeded surfaces. Taking this into consideration, in order to provide an accurate representation of the contamination levels during the recovery process, control samples were taken immediately prior to the CSIs' contact with the item/area, avoiding the most likely area the CSI has direct contact (where the impact of this limitation would have the greatest influence). With this approach, overall substantive decrease in available DNA in some instances caused by the control swabbing cannot be eliminated, but given the extreme quantities of DNA seeded it seems unlikely that this will have had a significant overall impact.

In total, 24 mock evidential samples of semen, blood, saliva and touch DNA were recovered by the six CSIs, and all gave full expected DNA profiles apart from 4/6 of the touch DNA profiles recovered from the screwdrivers which were partial profiles, 2 of which were matches to the expected donor, 2 where insufficient for a DNA comparison. These 24 DNA results were either single profiles, or where additional DNA components were detected, it was insufficient for comparison purposes.

No sample-to-sample contamination nor DNA from the CSIs undertaking the exercise was detected. Likewise, no traceable levels of contamination from the scene, consumable transport boxes, TEBs, and equipment were detectable in any of the recovered samples despite contamination from control DNA being deliberately deposited on all these surfaces. Contamination on the inside and outside surfaces of the consumables box and on the outer surface of TEBs were relatively low despite sustained efforts to deposit touch DNA and saliva on these, resulting in low partial profiles detected from most of the control swabs

of these surfaces. The majority of the contamination on the tripod legs were detected as low mixtures, comprising the donor DNA profile, plus 2 other profiles suitable for comparison purposes but not attributed to any of the individuals involved in the experiments. Conversely, the contamination on seeded surfaces within the crime scene was of higher concentration and the majority yielded a full profile matching the control donor.

Interestingly, despite the CSIs deliberately contaminating their gloves by touching a DNA-seeded surface prior to undertaking the recovery of touch DNA from the screwdriver, recovery was achieved without evidence of contaminant transfer from the gloves holding the item, to the swabs taken from the screwdriver handle. This was despite contaminant levels of between 0.0026 and 0.0493 ng/μl DNA present on their gloves, which comprised of mixtures of the known control DNA on the touched surface plus other components. The lack of any of this contamination on the recovered mock evidential samples is attributable to the good technique of the CSIs which included ensuring that their gloves did not come into direct contact with the swabbed part of the screwdriver.

Also of interest is that the results achieved by CSI 4 at both LC and DP were comparable to those of CSI 2 and 3 despite the reduced precautions taken, which enabled the scene examination to be completed in 30 min versus approximately 60–75 min where the police forces SOPs were followed in their entirety. The gloves of LC CSI 4 had higher accumulated contamination levels than CSI 2 and 3, with the deliberate contaminant from touching the saliva-seeded surface being a minor component in the contamination mixture. DP CSI 4 although had a lower quantification score than CSI 3, the allele count was significantly greater with at least three further contributors to the DNA present on the glove. Despite this, there was, if anything, less indication of contamination from DP CSI 4s recovered samples.

These findings demonstrate that even when anticontamination measures were substantially reduced, there was no increased likelihood of detectable transfer, indicating that the use of streamlined anti-contamination practices, applied through professional judgement under realistic operational conditions, does not elevate the risk to evidential integrity.

5.3. Discussion Summary

More experiments of this nature are needed to generate empirical data on the realistic risk to casework within live scenes. However, this initial study indicates that existing anticontamination measures are effectively mitigating risk and adopting a more time–efficient approach to crime scene investigation did not compromise the DNA results obtained from evidential material.

Other countries have highlighted risks arising from inadequate training, improper PPE use, poor scene preservation, and errors in evidence collection, packaging, and transportation, all of which can undermine the reliability of DNA evidence. [5,28,29] This has not been observed in the UK, where strict regulation requires compliance with the FSR Code of Practice [30] for organisations conducting crime scene examination. The FSR Code of Practice [30] and associated guidance [7,31] outline detailed contamination–prevention measures, many of which were not derived from empirical data and may have unintentionally led police forces to adopt anticontamination practices that exceed the proportionality of the actual risk. [17]

Current anticontamination measures in the UK appear to have been shaped largely by organisations and individuals with laboratory–based backgrounds focused on eliminating all inferred or implied risk, rather than managing empirically evidenced risks in the inherently variable environment of crime scenes. Within the CSI community, there is a widely held view that the imposed levels of anticontamination control exceed what is operationally necessary. [17]

A key safeguard in the UK is the use of DNA elimination databases, which all CSIs must be included on. Crime–related profiles are routinely checked against these databases, enabling the identification and removal of any contamination originating from CSIs. As a result, instances of CSI–derived contamination are closely monitored and investigated. There are no reported UK cases of DNA contamination being transferred from one crime scene to another, although the mechanisms for detecting such an event may not be standardised and warrants further examination. Research evaluating DNA transfer via laboratory equipment has shown that, in casework where suspect profiles are unknown, contaminating alleles can complicate interpretation and reduce the probative value of the evidence. [32] This reinforces the need for robust practice to protect evidential integrity.

Although this study focuses on CSI practice, the findings have broader implications for all professionals handling evidential material across the forensic pathway. One notable gap in current statutory oversight concerns forensic pathologists. Unlike CSIs, their attendance at crime scenes and involvement in postmortem evidence collection are not currently subject to the FSR's statutory code of practice. This discrepancy is difficult to justify given that pathologists routinely enter scenes, handle bodies and clothing, and collect samples such as fingernail scrapings or swabs that may be critical to an investigation.

Research from postmortem environments consistently demonstrates that mortuaries can act as reservoirs of persistent human DNA and that transfer during autopsy is a documented phenomenon. Studies have reported contamination of surfaces and instruments despite routine cleaning, [33] the presence of "phantom DNA" introduced during autopsies [34], and the impact of procedural changes, such as enhanced COVID–19 cleaning regimes, on background DNA levels. [35] These findings show that contamination risks extend beyond the crime scene and that inadvertent transfer by forensic pathologists is plausible, even if the evidential impact is often low.

The present study suggests that some anticontamination measures applied to CSIs may be more stringent than necessary under realistic operational conditions. However, proportionality has not been similarly evaluated for postmortem practice, where contamination risks may be comparable or, in some cases, greater. Aligning expectations for CSIs and forensic pathologists would improve coherence across the forensic process and ensure that statutory requirements reflect actual risk rather than historical assumptions.

The results of the experiments conducted in this study reinforce these conclusions. Even when anticontamination measures were deliberately reduced and equipment, consumables, and gloves were heavily contaminated, no detectable contamination was found on evidential samples. This demonstrates the effectiveness of good scene practice and the importance of practitioner competence in mitigating contamination risk. It also suggests that a more proportionate, risk–based approach to contamination control could be safely adopted, improving efficiency without compromising evidential quality.

6. Conclusion

On face value the results from this pilot study appear to contradict accepted wisdom regarding the necessity for particular levels of contamination risk mitigation in crime scene examination including glove changes/EM/cleaning. But it should be noted that previous studies have focussed primarily on physical contact of the gloves with items, whilst the scenario tested here is the swabbing of evidence rather than directly handling the target area. As such, an additional transfer step is required from the glove onto the swab and is at least one transfer step removed, thereby reducing the risk compared with direct transfer. [10] As a caveat to the results, material additional to the expected body fluid or touch DNA was detected in some samples albeit at too low a level to facilitate any form of comparison or search. This may be reflective of the dirty environments in which the recovery scenes were set up and conducted but certainly more experimental data is needed to corroborate the findings.

The results from this study demonstrate that there was no

contamination, sufficient for DNA comparison, found on the evidential samples recovered despite the box and bag used to store and transport the consumables, the equipment, evidence bags and CSI gloves used all being deliberately contaminated. This is because none of these items came into direct contact with the evidential sample and the risk of contamination from any of these items was mitigated at the point of recovery. The CSI survey results demonstrated the rarity of an item of equipment making contact with an evidential sample, this in combination with the data from the transfer experimentation calls into question the necessity of EM and excessive cleaning, when these measures do not bring any value to reducing the risk of contamination to the forensic evidence.

This study demonstrates that even when anticontamination measures are deliberately reduced, the likelihood of compromising evidential samples during scene examination appears low. These findings support a more proportionate, risk–based approach to contamination control for CSIs. However, the implications extend beyond policing.

Given the documented presence of background DNA in postmortem facilities [33,35] and the potential for transfer during autopsy, [34,36] it is neither proportionate nor scientifically coherent for statutory compliance to apply to CSIs but not to pathologists who enter the same scenes or handle the same evidential material. A unified, end–to–end contamination–control strategy that includes forensic pathology is therefore essential. Ensuring that all practitioners involved in the recovery and handling of biological evidence are subject to consistent, evidence–based standards will strengthen the integrity of the forensic process as a whole.

In summary, the data from this study infers CSI competence and adoption of good scene practices is likely to have a greater impact on the risk to evidential material than background or scene to scene contamination. Adopting an approach to crime scene investigation that is more focused on the proportionality of the risk of contamination to the forensic evidence should be considered by UK police forces. Allowing CSIs to take a pragmatic approach and manage the risks dynamically within scenes, based on a) the risks identified, b) scene environment and c) seriousness of the offence with the overriding focus to preserve the integrity of the specific evidence being recovered. This approach could allow for reduced anticontamination measures that would significantly increase efficiency without adversely affecting the quality of the evidential output.

Ethics statement

This study was reviewed and approved by the Science Ethics Review Board of the University of Central Lancashire (Ethics approval number: SCIENCE 01143). All body fluid donors provided informed written consent before providing DNA and all CSI participants provided informed consent before participation, the research has adhered to the principles outlined in the Declaration of Helsinki and its subsequent amendment.

CRediT authorship contribution statement

Michelle Gaskell: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Richard Sherlock:** Writing – review & editing, Resources, Methodology, Investigation. **Sarah Allen:** Resources, Investigation, Funding acquisition. **Guylaine Hanford:** Writing – review & editing, Resources, Project administration, Methodology, Investigation. **William Goodwin:** Writing – review & editing. **Kevin Sullivan:** Writing – review & editing, Writing – original draft, Validation, Supervision, Resources, Methodology, Investigation, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A

Equipment & Consumables.

Table 4
A list of the consumables and equipment used throughout the experimentation, including the supplier of the item and the experiments they have been used in.

	Item	Source
Experiment 1	Chemgene wipes (HLD_4L)	SceneSafe (Manufacturer: Byotrol)
	Grimex wipes Key ingredients include: 2-butoxyethanol: $C_6H_{14}O_2C$ Tetrapotassium pyrophosphate: $K_4P_2O_7$ Ammonia solution: NH_3 Alcohols, C9-11 ethoxylated	SceneSafe (Manufacturer: Assist Hygiene Products Ltd.)
	L-shaped photograph scales	SceneSafe
	DNA free scissors	SceneSafe (Provided by the FCN)
	DNA Grade MW104 Medical Wire swabs	

(*continued on next page*)

Table 4 (*continued*)

	Item	Source
	DNA free water vials 10 ml	
	Large evidence bag to submit swabs	
	Buccal swab kits	
	P1000 pipette	Gilson
	P200 pipette	
	P200 Filtered pipette tips	
	P1000 Filtered pipette tips	
Experiment 2	20 ml v-bottom pots	SceneSafe
	200 ml Sterile container	SceneSafe (Provided by the FCN)
	Phosphate buffered saline (PBS)	
	Tamper evident bags	SceneSafe (Provided by police force)
	DNA Grade MW104/MWSCS Medical Wire swabs, water vials for 3x scene exams	
	PPE for scene exam	
	Transfer bags from van to scene	
	Critical consumables box for van (plastic)	Supplied by police force
	Tripod stand	
	Foam decorating roller/tray	Screwfix
	Sandwich boxes (20 cm)	Amazon
	Roll Gaffer tape	
	Screwdrivers (rubber handles)	
Experiments 1 & 2	Presept tablets (sodium dichloroisocyanurate is $C_3Cl_2N_3O_3Na$)	SceneSafe (Manufacturer: Advanced Sterilization Products)
	Paper roll	SceneSafe
	Spray bottles (1 L)	
	Distilled water	
	Disposable nitrile gloves (large & medium)	
	Disposable lab coats (large & medium)	
	Disposable Masks	
	Anticoagulant blood tubes	
	50 ml Sample pot for saliva/semen	
	Sharpie pens thick and fine points	Amazon
	EZ1 & EZ2 DNA Investigator kit	Qiagen
	MDithiothreitol	Sigma Aldrich
	Proteinase K	
	Investigator Quantiplex Pro kit	Qiagen
	AmpFLSTR™ NGM™PCR Amplification kit	Themo Fisher Scientific
	Tris-EDTA Buffer	Sigma Aldrich
	007 Human Control DNA	Themo Fisher Scientific
	GS600 Liz v2.0 Size Std	Themo Fisher Scientific
	Hi-Di Formamide	Themo Fisher Scientific
	BioRobot® EZ1 workstation	BioRobot® EZ1 workstation
	7500 Real-time PCR system	7500 Real-time PCR system
	Quantiplex PRO RT PCR kit	Quantiplex PRO RT PCR kit
	3500 Genetic Analyser	3500 Genetic Analyser
	Genemapper® IDX v1.5 software	Genemapper® IDX v1.5 software

Appendix B

Experiment 2- Procedures

Table 5
Experiment 2: The police force-specific commonality and differences between standard operating procedures followed by CSI 2 and CSI 3, versus the streamlined procedure followed by CSI 4.

Scene examination process	CSI 2 and CS1 3		CSI 4	
	Lancashire Constabulary	Derbyshire Police	Lancashire Constabulary	Derbyshire Police
First entry	Full PPE following major crime SOP, including scene suit, booties, mask, double pair of gloves	Full PPE following volume crime SOP including mask, double pair of gloves	No PPE on entry. Mask and single pair of gloves donned prior to sample recovery	No PPE on entry. Single pair of gloves donned prior to sample recovery
Glove cleaning	Use of hypo protect gel for glove cleaning in between activities during DNA recovery process	Use of Grimex wipes for glove cleaning in between activities and during DNA recovery process	No glove cleaning or changing between activities or recoveries	
Cleaning of photographic scales	Scale cleaned before and after use, for each exhibit		Scale not cleaned, just ensured it is placed away from the site to be sampled	

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Table 5 (*continued*)

Scene examination process	CSI 2 and CS1 3		CSI 4	
	Lancashire Constabulary	Derbyshire Police	Lancashire Constabulary	Derbyshire Police
Clean working area	Clean working area set up using a non-forensic DNA grade brown sheet for DNA recovery. Consumables only placed on brown sheet	Clean working area set up using brown sheet for DNA recovery. Consumables only placed on brown sheet	Used the top of their uncleaned fingerprint case to place their consumables – not using a designated clean working area	Worked on uncleaned bench
DNA pen	'DNA pen' (designated as clean) used to markup exhibit bags.	Pen cleaned before and after use to markup exhibit bags.	Pen from pocket used	
Cleaning of equipment	No cleaning of any of the other equipment prior/post scene			
Consumables transfer van to scene	Consumables placed in TEB bag for transfer into the scene			
TEB handling	Exhibit TEBs marked up and sealed at scene			
Presumptive testing	Haemastix test for blood following procedures			

Appendix C

Experiment 1- Experimental design and results

Table 6
The sampling plan and results for Experiment 1, the assessment of risk from equipment in direct contact with evidential material.

Sample reference	Cleaning regime for scale after first placement	Cleaning reagent	Sample type	Result	DNA quantification (ng/μl)	DNA result interpretation
Negative Control Samples						
1.1a	N/A	Presept on Formica	Control of Formica surface post clean	Insufficient for DNA comparison	0	No background – Presept was effective
1.1b				No profile	0	
1.1c				No profile	0	
Positive Control Samples						
1.18	10 μl blood (FCN 1) pipetted directly onto swab		Control to demonstrate seeding load	Full profile	0.7231	Corresponds to the donor and amount of contaminant pipetted onto the surface
1.19	10 μl saliva (FCN 1) pipetted directly onto swab		Control to demonstrate seeding load	Full profile	0.1391	Corresponds to the donor and amount of contaminant pipetted onto the surface
Phase 1: Scales placed on surface area A seeded with 10 μl of saliva from donor FCN 1 for approx. 30-minute contact time						
1.2a	Duplicate wash/ wipe	Water	Swab of Area B post scale contact	Insufficient for DNA comparison	0	Realistic contact with a contaminant followed by a clean with 2 x wash/wipe with water prevented contamination of the second surface
1.2b				No profile	0	
1.2c				No profile	0	
1.3a	Duplicate wipe	Grimex	Swab of Area B post scale contact	Insufficient for DNA comparison	0	Realistic contact with a contaminant followed by a clean with Grimex wipe prevented contamination of the second surface
1.3b				Insufficient for DNA comparison	0	
1.3c				Insufficient for DNA comparison	0	
1.4a	Duplicate wipe	Chemgene	Swab of Area B post scale contact	Insufficient for DNA comparison	0	Realistic contact with a contaminant followed by a clean with Chemgene prevented contamination of the second surface
1.4b				Insufficient for DNA comparison	0	
1.4c				Insufficient for DNA comparison	0	
1.5a	Unwashed	N/A	Swab of Area B post scale contact	Insufficient for DNA comparison	0	Realistic contact with a contaminant followed by no cleaning still caused no contamination of the second surface
1.5b				Low partial profile	0.0001	
1.5c				No profile	0.0001	
1.6a	Unwashed	N/A	Swab of **scale** after initial contact with area A	Insufficient for DNA comparison	0	Realistic contact with a contaminant followed by no cleaning didn't contaminate the actual surface of the scale in the first place
1.6b				Low partial profile – insufficient for DNA comparison	0	
1.6c				No profile	0	
Phase 1: Scales placed on surface area A seeded with 10 μl of blood from donor FCN 1 for approx. 30-minute contact time						
1.7a	Duplicate wash/ wipe	Water	Swab of Area B post scale contact	Insufficient for DNA comparison	0	Realistic contact with a contaminant followed by a clean with water prevented contamination of the second surface
1.7b				No profile	0	

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Table 6 (*continued*)

Sample reference	Cleaning regime for scale after first placement	Cleaning reagent	Sample type	Result	DNA quantification (ng/μl)	DNA result interpretation
1.7c				No profile	0	
1.8a	Duplicate wipe	Grimex	Swab of Area B post scale contact	Insufficient for DNA comparison	0	Realistic contact with a contaminant followed by a clean with grimex prevented contamination of the second surface
1.8b				Insufficient for DNA comparison	0	
1.8c				Insufficient for DNA comparison	0	
1.9a	Duplicate wipe	Chemgene	Swab of area B post scale contact	Insufficient for DNA comparison	0	Realistic contact with a contaminant followed by a clean with Chemgene prevented contamination of the second surface
1.9b				Insufficient for DNA comparison	0	
1.9c				Insufficient for DNA comparison	0	
1.10a	Unwashed	N/A	Swab of area B post scale contact	Insufficient for DNA comparison	0	Realistic contact with a contaminant followed by no cleaning still caused no contamination of the second surface
1.10b				No profile	0	
1.10c				No profile	0	
1.11a	Unwashed	N/A	Swab of scale after initial contact with area A	Insufficient for DNA comparison	0	Realistic contact with a contaminant followed by no cleaning didn't contaminate the actual surface of the scale in the first place
1.11b				No profile	0	
1.11c				Low partial profile – insufficient for DNA comparison	0.0001	
Phase 2: Surface area A seeded with 10 μl of blood from donor FCN 1 and surface areas C and the carpet seeded with 10 μl of blood from donor FCN 3						
1.12a	2x wash/wipe	Water	Swab of deposit of blood from second donor (surface area C) post scale contact	Full profile and match to second donor (FCN 3) No match to donor FCN 1. 1 further contributor, insufficient for comparison	0.9918	Full profile of donors DNA from the blood sample recovered from the area C which had been seeded with second donor blood
1.12b				Full profile and match to second donor (FCN3). No match to donor FCN1.	1.7477	
1.13a	2 x wash/wipe	Water	Swab of deposit of blood from second donor (carpet) post scale contact	Full profile and match to second donor (FCN3). No match to donor FCN1. >1 further contributor, insufficient for comparison	0.0769	Full profile of donors DNA from the blood sample recovered from the area C which had been seeded with second donor blood
1.13b				Full profile and match to second donor (FCN3). No match to donor FCN1.	0.2299	
Reference Samples						
1.14	Reference buccal swab for FCN 1 donor – not required as DNA profile already available					
1.15	Reference buccal swab for FCN 3 donor – not required as DNA profile already available					
1.16	Reference buccal swab for FCN 5 Experimental set up – not required as DNA profile already available					
1.17	Reference buccal swab for LC CSI 7 conducting recovery swabbing – not required as DNA profile already available					

Appendix D

Experiment 2- Experimental design and results

Table 7
Experiment 2 set up and results for the assessment of the potential contamination of evidence in crime scene investigations. FCN denotes Forensic Capability Network individual; LC denotes Lancashire Constabulary individual; DP denotes Derbyshire Police individual.

Sample Reference	Experiment Set up				Experiment results				
	CSI Operator	Donor	Sample type	Item Description	Quantification ng/μl	Allele count	Profile Type	Expected SED Match	Comments
2.1a	**LC CSI 7**	**LC CSI 1**	**Control**	Inside of box used to store consumables within the CSI van which has been seeded with touch and saliva	0.0004	N/A	Low level partial profile	Not determined	Could not determine if LC CSI 1 is present, due to low-level nature of result. Result remains suitable for further comparisons.
3.1a	DP CSI 7	DP CSI 1			0.2554	39	Clear and complete major profile	Yes	Remaining DNA components from at least one further contributor that are unsuitable for database searches or further comparisons

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Table 7 (*continued*)

Sample Reference	Experiment Set up				Experiment results				
	CSI Operator	Donor	Sample type	Item Description	Quantification ng/μl	Allele count	Profile Type	Expected SED Match	Comments
2.1b	**LC CSI 7**	**LC CSI 1**			0.0018	N/A	Low level partial profile		
3.1b	DP CSI 7	DP CSI 1			0.0382	48	Mixed profile		
2.1c	**LC CSI 7**	**LC CSI 1**			0.0024	N/A	Low level mixed profile		
3.1c	DP CSI 7	DP CSI 1			0.325	52	Clear and complete major profile		
2.2a	**LC CSI 7**	**LC CSI 1**	**Control**	Touch/saliva – outside of box used to store consumables within the CSI van	0.0017	N/A	Low level partial profile	Yes	Remaining DNA components from at least one further contributor that are unsuitable for database searches or further comparisons
3.2a	DP CSI 7	DP CSI 1			0.2527	35	Clear and complete major profile		
2.2b	**LC CSI 7**	**LC CSI 1**			0.0019	N/A	Low level mixed profile		
3.2b	DP CSI 7	DP CSI 1			0.0548	46	Mixed profile		
2.2c	**LC CSI 7**	**LC CSI 1**			0.0035	N/A	Low level mixed profile		
3.2c	DP CSI 7	DP CSI 1			0.0529	N/A	Clear and complete major profile		
2.3a	**LC CSI 7**	**LC CSI 1**	**Control**	Outside of consumables bag used to transport the consumables from the CSI van to the scene	0.0005	N/A	Low level partial profile	Not determined	Could not determine if CSI 1 is present, due to low-level nature of result. Result remains suitable for further comparisons.
3.3a	DP CSI 7	DP CSI 1			0.1003	33	Partial profile	Yes	Partial match to DP CSI 1 (due to peak imbalance) and 1 further DNA contributor identified but not sufficient for further comparisons.
2.3b	**LC CSI 7**	**LC CSI 1**			0.0005	N/A	Low level partial profile		Remaining DNA components from at least one further contributor that are unsuitable for database searches or further comparisons.
3.3b	DP CSI 7	DP CSI 1			0.1575	32	Full profile		None
2.3c	**LC CSI 7**	**LC CSI 1**			0.0037	N/A	Low level partial profile		Remaining DNA components from at least one further contributor that are currently unsuitable for database searches but remain further comparisons.
3.3c	DP CSI 7	DP CSI 1			0.0497	N/A	Complete Profile		None
2.4	**LC CSI 7**	FCN 1	**Control**	General area of surface A which has been seeded with saliva	0.1249	N/A	Partial profile	Yes	Partial DNA result due to peak imbalances.
3.4	DP CSI 7				0.372	39	Clear and complete major profile		1 further DNA contributor identified but not sufficient for further comparisons.
2.5	**LC CSI 7**	FCN 1		General area of surface B which has been seeded with saliva	0.0301	N/A	Complete Profile		None
3.5	DP CSI 7				1.1145	33	Complete Profile		1 further DNA contributor identified but not sufficient for further comparisons.
2.6	**LC CSI 7**	FCN 1		General area of surface C which has been seeded with saliva	0.2887	N/A	Complete Profile		None
3.6	DP CSI 7				0.3959	32	Complete Profile		No other contributors.

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Table 7 (*continued*)

Sample Reference	Experiment Set up				Experiment results				
	CSI Operator	Donor	Sample type	Item Description	Quantification ng/μl	Allele count	Profile Type	Expected SED Match	Comments
2.7	**LC CSI 7**	FCN 1		General area of surface D which has been seeded with saliva	0.0641	N/A	Complete Profile		Remaining DNA component indicates the presence of at least one further contributor and is unsuitable for database searches and comparisons.
3.7	DP CSI 7				0.2143	37	Mixed profile		Remaining DNA component indicates the presence of at least one further contributor and is unsuitable for database searches and comparisons.
2.8	**LC CSI 2**	FCN 2	**Evidence**	Target area of surface A seeded with semen	10.078	N/A	Complete Profile	Yes	Remaining DNA component indicates the presence of at least one further contributor and is unsuitable for database searches and comparisons.
3.8	DP CSI 2				12.7785	32	Complete Profile		No other contributors.
2.12	**LC CSI 3**				8.9243	N/A	Complete Profile		Remaining DNA component indicates the presence of at least one further contributor and is unsuitable for database searches and comparisons.
3.12	DP CSI 3				11.0785	34	Complete Profile		Remaining DNA component indicates the presence of at least one further contributor and is unsuitable for database searches and comparisons.
2.16	**LC CSI 4**				10.766	N/A	Complete Profile		None
3.16	DP CSI 4				13.0941	32	Complete Profile		No other contributors.
2.9	**LC CSI 2**	FCN 3	**Evidence**	Target area of surface B seeded with blood	0.1343	N/A	Complete Profile	Yes	Remaining DNA component indicates the presence of at least one further contributor and is unsuitable for database searches and comparisons.
3.9	DP CSI 2				1.8911	33	Complete Profile		Remaining DNA component indicates the presence of at least one further contributor and is unsuitable for database searches and comparisons.
2.13	**LC CSI 3**				0.2553	N/A	Complete Profile		None
3.13	DP CSI 3				1.0356	32	Partial profile		Partial DNA result due to peak imbalances.
2.17	**LC CSI 4**				0.2597	N/A	Complete Profile		None
3.17	DP CSI 4				1.1268	33	Complete Profile		Remaining DNA component indicates the presence of at least one further contributor and is unsuitable for database searches and comparisons.
2.10	**LC CSI 2**	FCN 4	**Evidence**	Target area of surface C seeded with saliva	0.3764	N/A	Complete Profile	Yes	None
3.10	DP CSI 2				2.0452	32	Complete Profile		No other contributors.
2.14	**LC CSI 3**				0.4635	N/A	Complete Profile		Remaining DNA component indicates the presence of at least one further contributor and is unsuitable for database searches and comparisons.
3.14	DP CSI 3				6.7816	33	Partial profile		Partial DNA result due to peak imbalances. Remaining DNA component indicates the presence of at least one further contributor and is unsuitable for database searches and comparisons.
2.18	**LC CSI 4**				0.4319	N/A	Complete Profile		Remaining DNA component indicates the presence of at least

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Table 7 (*continued*)

Sample Reference	Experiment Set up				Experiment results				
	CSI Operator	Donor	Sample type	Item Description	Quantification ng/μl	Allele count	Profile Type	Expected SED Match	Comments
									one further contributor and is unsuitable for database searches and comparisons.
3.18	DP CSI 4				4.9269	34	Partial profile		Partial DNA result due to peak imbalances. Remaining DNA component indicates the presence of at least one further contributor and is unsuitable for database searches and comparisons.
2.11	**LC CSI 2**	FCN 5	**Evidence**	Touch DNA seeded onto screwdriver handles on surface D	0.0062	N/A	Partial profile	Yes	Partial DNA result due to peak imbalances. Remaining DNA component indicates the presence of at least one further contributor and is unsuitable for database searches and comparisons.
3.11	DP CSI 2				0.0003	5	Low level partial profile	Not determined	DNA insufficient for comparison.
2.15	**LC CSI 3**				0.0208	N/A	Complete Profile	Yes	Remaining DNA component indicates the presence of at least one further contributor and is unsuitable for database searches and comparisons.
3.15	DP CSI 3				0.0008	15	Low level partial profile	Yes	No other contributors.
2.19	**LC CSI 4**				0.0096	N/A	Partial profile	Yes	Partial DNA result due to peak imbalances and low-level peaks.
3.19	DP CSI 4				0.0001	4	Low level partial profile	Not determined	DNA insufficient for comparison.
2.20	**LC CSI 7**	LC CSI 5	**Control**	TEBs used to store evidential samples recovered from mock scenes which were seeded with touch DNA and saliva	0.0008	N/A	Low level partial profile	Not determined	Result insufficient for comparisons and database searches.
3.20	DP CSI 7	DP CSI 5			0.0258	50	Mixed profile	Yes	Remaining DNA component indicates the presence of at least two further contributor and is unsuitable for database searches and comparisons.
2.21	**LC CSI 7**	LC CSI 5			0.0097	N/A	Partial profile		Partial DNA result due to peak imbalances
3.21	DP CSI 7	DP CSI 5			0.0056	51	Mixed profile		Remaining DNA components suitable for comparisons, unsuitable for database searches.
2.22	**LC CSI 7**	LC CSI 5			0.0012	N/A	Low level mixed profile		Remaining DNA components from at least one further contributor that are unsuitable for database searches but remain suitable for further comparisons.
3.22	DP CSI 7	DP CSI 5			0.0036	65	Mixed profile		Remaining DNA components suitable for comparisons, unsuitable for database searches
2.23	**LC CSI 7**	LC CSI 6	**Control**	Tripod legs seeded with touch DNA and saliva	0.0111	N/A	Low level mixed profile	Yes	Remaining DNA components indicates the presence of at least two further contributors and are suitable for comparisons but unsuitable for database searches.
3.23	DP CSI 7	DP CSI 6			0.158	33	Partial profile		Partial DNA result due to peak imbalances. Remaining DNA component indicates the presence of at least one further contributor and is unsuitable for database searches and comparisons.
2.24	**LC CSI 7**	LC CSI 6			0.0139	N/A	Mixed profile		Remaining DNA components from at least two further contributor that are unsuitable for database searches but remain suitable for further comparisons.
3.24	DP CSI 7	DP CSI 7			0.1585	34	Full profile		Additional trace level DNA components, insufficient for comparisons and database searches.

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Table 7 (*continued*)

Sample Reference	Experiment Set up				Experiment results				
	CSI Operator	Donor	Sample type	Item Description	Quantification ng/µl	Allele count	Profile Type	Expected SED Match	Comments
2.25	**LC CSI 7**	LC CSI 6			0.0091	N/A	Mixed profile		Remaining minor DNA components from at least two further contributor that are unsuitable for database searches but remain suitable for further comparisons.
3.25	DP CSI 7	DP CSI 6			0.0695	33	Full profile		Additional trace level DNA component, insufficient for comparisons and database searches.
2.26	N/A	LC CSI 1	**Reference**		N/A				
				Buccal Swab					
2.27		LC CSI 2							
				Buccal Swab					
2.28		LC CSI 3							
				Buccal Swab					
2.29		LC CSI 4							
				Buccal Swab					
2.30		LC CSI 5							
				Buccal Swab					
2.31		LC CSI 6							
				Buccal Swab					
2.32		FCN 3							
				Buccal Swab					
2.33		FCN 4							
				Buccal Swab					
2.34		FCN 2							
				Buccal Swab					
2.35	LC CSI 7	FCN 1	**Control**	Gloves of CSI 2 post contact with saliva on surface D prior to sampling screwdriver	0.0026	N/A	Low level mixed profile	Yes	Remaining DNA component indicates the presence of at least one further contributor and is unsuitable for database searches and comparisons.
3.26	DP CSI 7				0.0072	36	Mixed profile		
2.36	LC CSI 7			Gloves of CSI 3 post contact with saliva on surface D prior to sampling screwdriver	0.0029	N/A	Low level mixed profile		
3.27	DP CSI 7				0.0493	39	Clear and complete major profile		
2.37	LC CSI 7			Gloves of CSI 4 post contact with saliva on surface D prior to sampling screwdriver	0.013	N/A	Mixed profile		The prominent components present do not match FCN 1. However, FCN 1 present in the low-level portion of the result. The prominent components are suitable for comparisons and database searches. The remaining minor components are unsuitable for comparisons and database searches.
3.28	DP CSI 7				0.0323	86	Mixed profile		Remaining DNA component indicates the presence of at least three further contributor and is unsuitable for database searches and comparisons.

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