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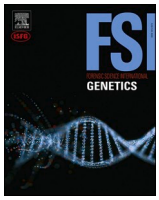

DNA transfer when using gloves in burglary simulations

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ABSTRACT

Several studies have demonstrated that DNA can be indirectly transferred from an individual onto a surface. Therefore, the presence of DNA that is compatible with a given person does not necessarily mean that this person has touched the surface on which the DNA was recovered. The present work simulates cases, where DNA is recovered on a door handle and compared to several reference DNA profiles. The DNA profile of the trace shares DNA components with a person of interest (POI). When asked about the DNA results, the POI says he has nothing to do with the incident and has never been at the scene. However, a possibility would be that the DNA came from his recently stolen gloves. Someone else, the alternative offender (AO), could have opened the door wearing his gloves (POI's gloves), and transferred his DNA (POI's DNA). Based on the above-mentioned scenario, 60 burglary simulations experiments were carried out to generate data to assess DNA results given these allegations. The quantity and quality of DNA profiles (NGM SElect) recovered when the POI opened/closed the door bare-handed or when someone else performed the same activity but using POI's gloves, were compared. The gloves were regularly worn during at least three months by their owner during the winter. On the contrary, the AO wore them only for two minutes. Among the traces collected on the door handles, less than 50% of the traces led to interpretable DNA profiles. In 30% of the cases (3/10), when the door was opened/closed with bare hands, the DNA found on the door handle led to a mixed DNA profile with the POI's DNA aligning with the major contributor. For the experiments where the AO opened/closed the door with the POI's gloves, the POI's DNA was compatible with 22% (11/50) of the mixed DNA profile, aligning with the major in 8% of the cases (4/50). The DNA profiles of the offices' occupants were observed on the door handles, but not the AO's. In addition to the results of the experiments, we show two examples of how one can assess results observed in casework. Given the possibility of indirect transfer of minute DNA quantities, this research emphasizes the need to evaluate DNA results given the activities when the POI has a legitimate reason that can explain the presence of their DNA.

1. Introduction

Technical improvements and optimization in sensitivity have increased the proportion of reportable DNA traces. From an investigating point of view, this is desirable. It allows the police to develop new leads. From an evaluative point of view, working with very small quantities has raised new challenges, shifting the issue from "Is it the DNA of the person of interest (POI)?" to "How did the POI's DNA get there ?" [1–5]. The issue for the court is then not so much the source of the DNA, but the activities from which it resulted. It has been argued [6] that forensic scientists can add value to the process by making their specialized knowledge on factors such as transfer available to the court.

To account for transfer, persistence, recovery and prevalence of DNA, scientists need to consider their biological results given so-called "activity level" propositions [7,8]. According to ISFG and ENFSI guidelines for evaluative reporting, DNA traces when present in small quantities should be evaluated considering propositions at that level [9, 10]. This is crucial when there are legitimate reasons that could lead to the presence of the DNA of a given person of interest on an object or a person. This situation can be encountered with DNA collected on burglary scenes, as the quantity of DNA transferred and recovered because of these activities will generally be low [11].

In this article, we discuss a case where DNA is recovered from a door handle of a burgled house. The DNA profile derived from the trace shares

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components with the DNA profile of the POI. The prosecuting party alleges that the DNA recovered from the door handle has been left by the POI when opening/closing the door handle with his bare hands. According to the defense, the POI has never touched this door. However, someone stole his gloves just a day before. It follows that it must have been an unknown person, who opened the door, robbed the place and closed the door wearing his stolen gloves. Hence, it would be indirect transfer and not direct transfer.

In such cases, DNA scientists have two options: the first is to indicate that indirect transfer through the gloves is possible. However, as it has been discussed in ISFG [10], and Evett et al. [12], answering that indirect transfer is a possible explanation, is not the most helpful. The second option is to assign the value of the results in the context of the alleged activities (i.e., opening/closing the door with bare hands or with stolen gloves). This involves specific training of the forensic scientists [13] and access to data regarding transfer, persistence [14–16], recovery [13,17,18], background, substrate [19,20] and possibly shedder status of the individual [21–24], as well as environmental conditions such as humidity and temperature [20]. The lack of experimental data is often cited as one of the hurdles preventing the evaluation of biological results given activity level propositions. We provide below a review of the literature and perform new experiments for our case situation, where we consider the case information and following propositions: "The POI opened/closed bare-handed the door of the burgled house" as alleged by prosecution versus "An unknown person (alternative offender: AO) opened/closed the door of the burgled house with POI's stolen gloves" as alleged by defense. We consider the situation, where the gloves would have been recently stolen and barely worn by the AO.

Direct and indirect transfer of DNA to a surface with bare hands has been widely studied [14, 25–29]. However, as in our case, the activity alleged by the defense implies that DNA could be first transferred to the gloves and then to the surface of interest, it is also important to assess the DNA transfer from the person to the gloves. According to [30], DNA is easily transferred onto clothing following regular daily activity. Moreover, the wearing time of a garment and the probability of obtaining an exploitable profile seem to be positively correlated [31]. This opens the possibility for gloves to act as an intermediate vector, provided that DNA persists.

Several studies on gloves have shown that surgical gloves can transfer DNA of innocent persons to a crime scene [13,32,33]. This phenomenon has also been observed during laboratory examinations, with DNA being transferred from exhibits to gloves and from gloves to other exhibits [34–36]. Otten et al. [37] and Tanzhaus et al. [38] performed burglary simulations and observed indirect DNA transfer on items of interest through different types of gloves. In their study, Otten et al. [37] observed that the shedder status of the person wearing the gloves had an impact on the results.

The vector by which DNA is transferred onto a surface of interest is not the only factor that forensic practitioners consider when evaluating results. It is also important to assess the influence of the prevalent and background DNA on the surface on which traces are collected [39,40], in our case, the door handles. A study published by [17] shows that the regular user of an office is often found as a major contributor to the mixed DNA profiles recovered from objects present in that office. This is the case even when another person occupies the office for a short period of time (between 2.5 h and 7 h). According to results reported by [41], the individuals living in a home are very likely to contribute the most to the DNA profiles recovered from common entry points. They also show that the DNA profile of the last person who touched the surface may not always be compatible with the DNA profiles recovered. Lehmann et al. [40] suggest that the detection capacity of DNA of interest will decrease after multiple contacts because of an increasing complexity in the detected mixture and of a diminution in the proportion of DNA of interest contributing to the mixed DNA profile.

In this study, we first describe the experimental design and methodology chosen. We then present the results from the experiments and show how the data can be used to assign the probability of DNA being transferred (persisted and recovered), as well as the probability of recovering DNA as background (i.e., DNA present from unknown persons for unknown reasons). We also present what would be -in our case scenario- the added value of considering the office occupants' DNA profiles when interpreting the DNA profile. Indeed, it is known that the occupants' DNA can be found on objects present in their surroundings. Does the fact that their DNA is rarely collected in casework cause a major drawback? We then illustrate how this approach can be implemented and present two examples where we assess the value of the DNA results given activity level propositions in accordance with professional guidelines [9,10]. Results are finally discussed and compared with published studies. Our aim is to determine whether the results (i.e., quantity of DNA and the quality of the DNA profiles recovered from the door handles) allow to discriminate between the activities alleged by the parties.

2. Material and methods

2.1. Experimental design

Two different runs of simulations were carried out with volunteers pretending to burglar one of the 10 offices considered in our facility. Oral informed consent was obtained from all the participants.

The volunteers did not work on the premises so that it was reasonable to assume that the only possibility for their DNA to be introduced within the offices was through the burglary simulations. The same offices were used for several experiments. One week before each simulation, the external door handles, drawers and shelves of the offices were washed with soap and 70% ethanol in order to remove the DNA deposited during the previous simulations. To ensure that the DNA from the POI or AO could not be due to the previous experiment, a control swab was collected on the cleaned door handles. The doors were then used normally by the occupants of the office (between 1 and 4 persons). In order to mimic reality, no other restriction was applied and no instructions were given to the volunteers regarding hand washing.

In the first set of experiments (Fig. 1I), we studied the transfer of DNA when opening doors with bare hands. Each of the 10 volunteers (taking the role of the POI in this set of experiments) was asked to open the door, to simulate a burglary by opening drawers and searching shelves for about 60 s and to leave the office closing the door using the same door handle and the same hand. Experiments were performed using different offices (one office per volunteer) on different days to reduce the risk of DNA transfer among volunteers.

In the second set of experiments (Fig. 1 II), we simulated opening the door with gloves. These were provided by 50 participants (acting as the POI in this set of experiments) who had regularly worn them for at least 3 months (December to February). The gloves - made of wool (9), silk (1), leather (13), acrylic (8), polyester (7) and/or other synthetic fibers (12) - were stored in sealed paper bags for approximately 1 month, until the simulations. The types of gloves have been chosen according to information given by the police forces on the population of burglars in the French speaking part of Switzerland. Three new volunteers (acting as the AO in this set of experiments) simulated a burglary as described above but wearing each time a different pair of gloves. Before entering the office, the volunteers were asked to put on the gloves for 60 s, to remove them and to put them back on twice before the 'burglary'. Therefore, the burglars wore the gloves during approximately 120 s for their fitting and the burglary. After simulations, the surfaces contacted by the burglar were cleaned with soap and 70% ethanol. Before performing the next round of experiments, the doors were normally used during at least one week: this allowed to acquire background DNA. In all, 50 simulations were performed wearing each time a different pair of gloves.

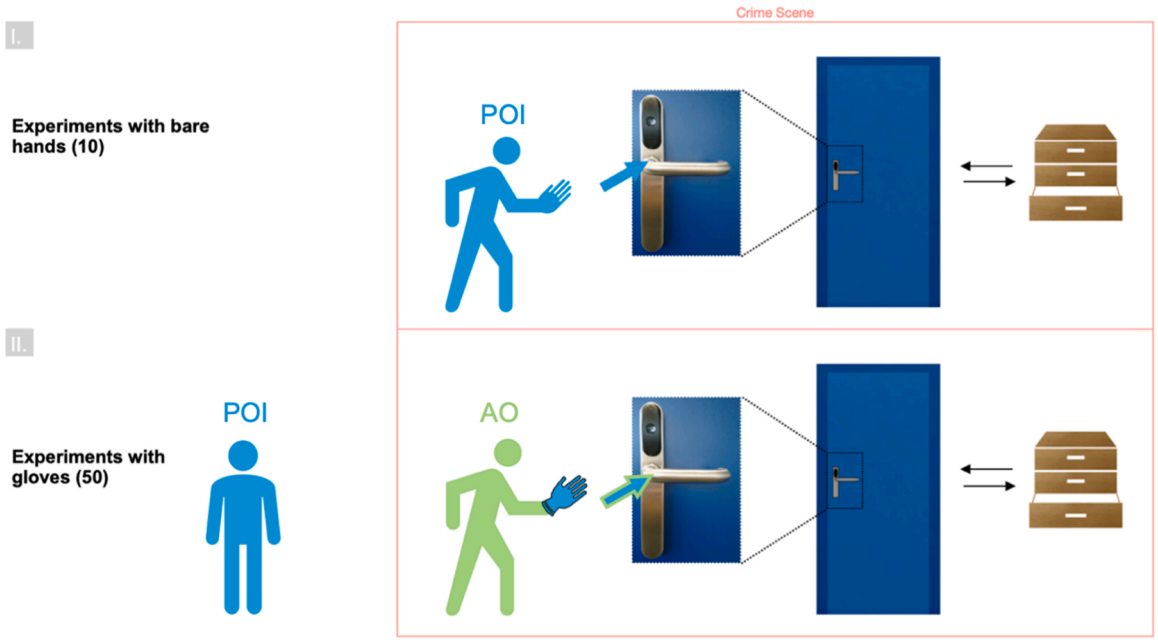

Fig. 1. set-up of the experiments. (I.) The POI opens the door of an office bare-handed, enters, opens drawers and searches shelves for 60 s. The person then leaves the office and closes the door using the same hand. The blue arrow indicates a direct transfer of the POI's DNA to the door. (II.) Same design as in (I.), but the alternative offender (AO), uses the POI's gloves who never visited the office. The blue arrow with a green border represents the indirect transfer of the POI's and AO's DNA through the gloves.

2.2. DNA recovery and analysis

The door handles were swabbed using cotton swabs (Prionics, Evidence Collection Kit, ref. 9021030). A first swab - moistened with sterile water - was used on the metallic door handle. Immediately after, a dry swab was applied on the same surface. Buccal swabs were obtained from the volunteers (simulated burglars, office occupants and the gloves 'owners') to establish their DNA profiles. DNA was extracted from the two swabs used to collect each specimen following the QIAshredder/QIAamp (Qiagen AG, Hombrechtikon, Switzerland) procedure [42]. A Microcon-30 (Millipore AG, Zug, Switzerland) was then used to concentrate the DNA in a 25 µl elution volume. DNA was quantified with the Investigator Quantiplex HYres Kit (Qiagen) using an ABI 7500 Real Time PCR system instrument (Thermo Fisher Life Technologies, Zug, Switzerland) following the manufacturer's instructions, but with half reaction volume. The AmpFLSTR NGM SElect PCR amplification kit (Life Technologies) was used for the DNA amplification with a PCR 9700 system (Life Technologies), using 5ul of the DNA extract in a 12.5 µl total PCR volume when its concentration was less than 0.1 ng/ul and running the PCR with 30 cycles. When the concentration was higher than this value, the volume of DNA extract added to the PCR volume was reduced, targeting 0.5–1.0 ng DNA. In these cases the amplifications were performed at 29 PCR cycles. The amplified DNA was separated and analyzed with an Applied Biosystems 3500 Genetic Analyzer (Life Technologies) following standard procedures. The GeneMapper ID-X software (v1.4, Life Technologies) was used to process the data with an analytical threshold set at 175 RFUs. The DNA from each specimen was amplified and processed twice using the same conditions (two replicates per specimen).

2.3. DNA profile interpretation

The DNA profiles derived from the door handles were first observed to determine their quality. The number of contributors was assigned based on the two replicates, considering the number of peaks and their height. The DNA profiles presenting a majority of not-reproducible peaks between replicates, or that had less than 5 reproducible alleles, or mixed DNA profiles from more than 4 contributors were considered as not interpretable. The interpretable DNA profiles were then compared to the reference DNA profiles of the POI, AO and office occupants to decide whether or not they could be considered as possible contributors. When clearly excluded, that is when the alleles of the person DNA profile were not observed within the DNA profile of the trace at 4 loci or more, the DNA profile of the person was considered as not compatible. When the reference DNA profiles were retained as potential contributors, STRmix™ [43] was used to quantify the value of the comparison.

2.3.1. Evaluation of the DNA results given sub-source level propositions

The likelihood ratios given sub-source level propositions were assigned using STRmix™ v2.5 and considering the following propositions:

- The POI and *n*-1 unknown persons are the source of the DNA recovered on the door handle.
- *n* unknown persons are the source of the DNA recovered on the door handle.

The letter *n* denotes the number of contributors to the mixed DNA profile and can take a value between 1 and 4. The POI can be replaced by the AO or the office occupant depending on whose profile is compared.

To assign the LRs given sub-source level propositions, allelic proportions from the Swiss population [44] and an Fst value of 0.01 were used. The diagnostics of the STRmix runs using both replicates were examined according to the user manual [45]. When the LR for the reference DNA profile analyzed was greater than 10, we considered that the DNA of this person was present, as this would not have been contested in our scenario. Conversely, when the LR was smaller the person was considered as excluded for the purpose of this study.

For mixed DNA profiles, the presence of a major contributor was considered when its contribution, determined with STRmix™, was greater than 70%, 60% and 50% in mixed DNA profiles of 2, 3 and 4 contributors, respectively. In such cases, the other contributors were considered as minor contributors and the mixed DNA profiles were described as "Maj/Min". When it was not possible to distinguish

between a major and a/some minor contributor/s in the mixture, the DNA profile was described as unresolved and classified as "Other".

In case of compatibility between the DNA profiles of the person of interest, the office occupant(s) and the trace, the DNA profile of the occupant was considered as known under the following alternative propositions:

- The POI, the office occupant(s) and *n*-1 unknown persons are the source of the DNA recovered on the door handle.
- The office occupant(s) and *n* unknown persons are the source of the DNA recovered on the door handle.

2.3.2. Evaluation of the DNA results given activity level propositions

In order to assign the probability of the DNA results given activity level propositions the results of the experiments were classified as follows:

- No (interpretable) DNA profile
- Single source DNA profile
  - which does not align with the POI's DNA profile
  - which aligns with the POI's DNA profile
- Mixed DNA profile (with no major)
  - which does not align with the POI's DNA profile
  - which aligns with the POI's DNA profile
- Mixed DNA profile (Maj/Min)
  - which does not align with the POI's DNA profile
  - with a major profile aligning with the POI's DNA profile
  - with a minor profile aligning with the POI's DNA profile

The probabilities of the observations were assigned adding uniform prior counts with empirical observations and dividing them by the total number of posterior counts as in [46].Considering the alleged activities, we described the possible events explaining our observations in terms of transfer, persistence and recovery. Note that we used the expression " The DNA profile of the POI aligns with the DNA profile of the (mixed) trace" to mean that the reference listed as from POI and the trace yield profiles with (partly) similar allelic designations. We avoided the word "match" on purpose, as it is sometimes misunderstood [47].

For the person opening/closing the door with bare hands (POI) we defined the following events as in [28]:

1.1 « T_0^{POI}» which means that the DNA of the POI either did not transfer, or did not persist, or was not recovered following the activities.
1.2 « T_{Single}^{POI}» when the DNA of the POI is recovered and that the POI's DNA profile aligns with the single source DNA profile.
1.3 « T_{Major}^{POI}» when the DNA of the POI is recovered and that the POI's DNA profile aligns with the major contributor of a mixed DNA profile.
1.4 «T_{Minor}^{POI}» when the DNA of the POI is recovered and that the POI's DNA profile aligns with one of the minor contributor(s) of a mixed DNA profile.
1.5 «T_{Other}^{POI}» when the DNA of the POI is recovered and that the POI's DNA profile aligns with one of the contributors, but that there is no major contributor in the mixed DNA profile.

Similarly, we have considered the same categories for events "transfer, persistence and recovery" of the DNA of alternative offender given AO opened/closed the door handle with POI's stolen gloves ("T'^{AO}_X") and "transfer, persistence, and recovery" of the glove owner's DNA, the POI ("T'^{POI}_X"), where "*X*" indicates the type of aligning profile observed. Note that no "T^{AO}" category was defined, as the AO has not touched the door handle with bare hands.

For the DNA present as background on the door handles, we defined the following events:

2.1 « B_0 » which means that no (interpretable) DNA profile is recovered as background on the door handle.
2.2 «B_{Single} » which means that a single source DNA profile is recovered as background on the door handle and it aligns neither with the POI's, nor with the AO's DNA profile.
2.3 « B_{Major} » which means that a mixed DNA profile is recovered as background on the door handle and the major contributor aligns neither with the POI's nor with the AO's DNA profile.
2.4 « B_{Minor} » which means that a mixed DNA profile is recovered as background on the door handle and the minor contributor(s) aligns neither with the POI's nor with the AO's DNA profile.
2.5 « $B_{Maj/Min}$ » which means that a mixed DNA profile (Maj/Min) is recovered as background on the door handle and neither the major nor the minor/s contributor/s align with the POI's nor with the AO's DNA profile.
2.6 « B_{Other} » which means that an unresolved mixed DNA profile is recovered as background on the door handle and that no contributor (s) aligns with the POI's, or with the AO's DNA profile.

When presenting the two case examples, we have complied with the existing notation and formulae in the field [48], but have considered transfer and background as possibly dependent: if there is little DNA, the presence of background DNA could affect the type of profile obtained. The probabilities associated to each type of event were named using the same notation but using lowercase instead of the capital letters, therefore "*t*" for transfer (persistence and recovery), and "*b*" for background probabilities.

3. Results

3.1. Control samples

The DNA concentration was zero or less than 5 pg/uL for 55 control samples. For the 5 other control samples, the DNA profiles obtained from the traces collected one week after the cleaning were either not interpretable (only few peaks were observed) or did not align with the POI or the AO. Therefore, we considered the results as valid.

3.2. Quantification

The total DNA quantity detected in the traces collected after the POI opened/closed the door handle bare-handed varied between 55 and 1350 pg, with a median value of 155 pg. For the traces obtained after the AO opened/closed the door handle with the POI's gloves, the total DNA quantity varied between 30 pg and an extreme value of 30 ng. The median value was of 250 pg.

Considering the first series of experiments, for the traces where one of the contributors aligned with the reference profile of the POI, a median value of 365 pg of DNA was attributed to this latter. These results were obtained by multiplying the mixture proportion by the total DNA quantity. For the mixed DNA profile that aligned with the reference profile of an office occupant, a median value of 135 pg of DNA was attributed to this contributor.

Concerning the experiments where the AO opened the door with the POI's gloves, the median value for the DNA quantity that aligned with the POI's DNA, was 153 pg. The median amount of DNA that aligned with the reference DNA profile of one office occupants was 903 pg and no DNA was attributed to the AO.

3.3. Classification of the DNA traces

The DNA profiles obtained for the experiments aiming to study DNA transfer mechanisms when the POI acted (as described in the methodology) bare-handed were judged overall of low quality. The reproducibility of the replicates was poor because of the low quantity of DNA recovered. Based on the genetic information present on the

electropherograms (EPG) only 50% of the 10 DNA profiles were deemed interpretable. About 20% of the traces were classified as a 2 person, 10% as a 3 person and 20% as a 4 person mixed DNA profiles respectively. All these profiles presented a major contributor. The remaining DNA profiles (50%) were not considered interpretable, either because of the lack of the genetic information present on the EPG or because of the complexity of the mixed DNA profile (more than 4 contributors).

The quality of the DNA profiles obtained for the traces collected when the AO opened/closed the door handle with the POI's gloves was judged of limited quality. 54% of the 50 traces were not interpretable because of the same two main reasons previously mentioned. 44% of the traces were deemed interpretable and were mixed DNA profiles: 4% of the traces were a 2 person mixture, 24% a 3 person and 16% of the traces were classified as a 4 person mixture. Only one interpretable trace gave a single DNA profile: this represents 2% of the totality of the DNA traces obtained for these experiments. For all the mixed DNA profiles obtained in this series of experiments the mixture proportions allowed to infer the DNA profile of the major contributor.

3.4. Description of the DNA traces and comparison with the reference profiles

The DNA profiles that were considered interpretable were compared to the references profiles of the POI, the AO and of the office occupants.

When the POI opened/closed the door bare-handed, 50% of the 10 traces were interpretable mixtures with a major component:

- For 20% of the traces, the major profile aligned with the DNA profile of one of the office occupants.
- For 30% of the traces, the major profile aligned with the profile of the POI.

The minor contributor(s) did not align with any of the known persons.

Considering the experiments where the AO opened/closed the door using the POI's gloves, 46% of the 50 traces were interpretable:

- The single source DNA profile (2% of traces) obtained in this series of 50 experiments, aligned with the DNA profile of one of the office occupants.
- 10% were mixed DNA profiles where one of the office occupants aligned with the major contributor; the other persons were excluded as contributors based on the LR.
- 8% were mixed DNA profiles where the POI aligned with the major contributor; the other persons were excluded as contributors based on the LR.
- 8% were mixed DNA profiles, where the office occupant aligned with the major contributor and the POI with the second contributor. The other known persons were excluded as possible sources based on the LR.
- 6% were mixed DNA profiles, where the major contributor was unknown while the POI aligned with the second contributor.
- 12% were mixed DNA profiles of unknown sources.

None of the DNA profiles matched the profile of the AO, wearing gloves.

Table 1 summarises the results of the first set of experiments and indicates the number of observations obtained for each event associated to the burglar (POI) opening/closing the door with bare hands.

In Table 2, we report the results of the second set of experiments and indicate the number of observations obtained for each event associated to the alternative burglar (AO), opening/closing the door using the recently stolen gloves.

3.5. Taking into account the office occupants reference profile

In the experiments where the door was opened/closed by the AO wearing gloves, four mixed DNA profiles presented a major contributor aligning with the reference profile of one of the office occupants; the minor contributor or one of the minor contributors aligned with the glove owner reference profile (POI). To study the impact of considering or not the DNA profile of office occupant in our case scenario, we proceeded as if the DNA profiles of the office occupants were not available and assigned a LR for the POI's without considering the office occupants' DNA profile. Then, we assigned our LR for the POI by conditioning the DNA mixture with the DNA profiles of the occupants (i.e., "The POI, the occupant(s) and n-1 unknown persons are the source of the DNA recovered on the door handle" or "The occupant(s) and n unknown persons are the source of the DNA recovered on the door handle). The impact on our likelihood ratios is shown in Table 3.

The results shown in Table 3 indicate that when the DNA profile of the office occupant was considered as known under both propositions: this adds no discrimination for traces *a)* and *b)*, higher discrimination

Table 1
Results of the experiments [10] when the burglar (POI) opens/closes the door with bare hands.

DNA results	Transfer/ background events	Number of observations
No (interpretable) DNA profile	$T_0^{POI}B_0$	5
Mixed DNA profile (Maj/Min) that does not align with the DNA of the POI	$T_0^{POI}B_{Maj/Min}$	2
Mixed DNA profile (Maj/Min) with a major DNA profile aligning with the DNA of the POI	$T_{Major}^{POI}B_{Minor}$	3
Total		10

Table 2
Results of the experiments [50] when the alternative burglar (AO) opens/closes the door wearing the POI's gloves.

DNA results	Transfer/background events given the activity	Number of observations
No (interpretable) DNA profile	$T_0^{,AO}T_0^{,POI}B_0$	27
Single DNA profile that does not align with the DNA of the AO nor with the POI's	$T_0^{,AO}T_0^{,POI}B_{Single}$	1
Mixed DNA profile (Maj/Min) that does not align with the DNA of the AO nor with the POI's	$T_0^{,AO}T_0^{,POI}B_{Maj/Min}$	11
Mixed DNA profile (Maj/Min) with a major contributor aligning with the DNA of the POI and minor contributor(s) that does not align with the DNA of the AO	$T_0^{,AO}T_{Major}^{,POI}B_{Minor}$	4
Mixed DNA profile (Maj/Min) with a major contributor that does not align with AO and one of minor contributors aligning with the DNA of the POI	$T_0^{,AO}T_{Minor}^{,POI}B_{Major}$	7
Mixed DNA profile (Other) that does not align with the DNA of the AO nor with the POI's	$T_0^{,AO}T_0^{,POI}B_{Other}$	0
Total		50

Table 3
Table 3 shows the likelihood ratios (LR) calculated with and without conditioning the mixed DNA profiles with the DNA profiles of the office occupants.

Trace	Number of contributors	Log (LR) for the POI: DNA profile from office occupant is unknown	Log (LR) for the POI: DNA profile from office occupant is known and considered under Hp and Hd
a)	3	3	3
b)	3	3	3
c)	3	10	16
d)	2	4	5

for trace *c)* and limited further discrimination for trace *d)*.

3.6. Evaluation of the DNA traces given activity level propositions

The design of the two types of experiments allowed to assign the probability of the observations given the following alleged activities:

- H_p: The POI opened/closed bare-handed the door of the burgled house.
- H_d: An AO opened/closed the door of the burgled house with the POI's gloves.

As we use formulae, we denote the first proposition as "H_p" for prosecutor proposition and the alternative as "H_d" for defence proposition.

3.6.1. Probability of the observations given the alleged activities

There are two ways of assessing the value of the DNA findings given activity level propositions: scientists may directly assign the probability of the observations assuming the events transfer/persistence/recovery and background are dependent (A), or may assume that transfer/persistence/recovery and background are independent events (B).

If we take as an example the situation in which we observe "no interpretable DNA profile" and we note this outcome as *E,* we can use either "Equation 1" or "Equation 2" displayed in Table 6, in order to assign the probability of the observations together or as separate events. Table 4.

Depending on the approach chosen by the expert, the probabilities of the outcomes will be assigned slightly differently. In Tables 5 and 6, we provide the probability of the observations given H_p and H_d and we describe the transfer and background events associated to these observations assuming that they are dependent (A). In the Appendix A.1 we modelled the corresponding Bayesian Network and provide the associated conditional probabilities.

When approaching the inference problem following situation B, we can assign the probabilities using the data reported in Tables 7–9. The probabilities of the transfer/persistence/recovery events in Table 7 are assigned based on the experiments performed by the POI acting bare-handed and given uniform prior counts. For Tables 8 and 9, we proceed in a similar manner given that the AO acted with the POI's stolen gloves.

Table 10 illustrates the probability of recovering DNA as background (i.e., from an unknown source for unknown reasons) in such a quantity/quality as to produce a DNA profile of given type (none, single, major, minor, other). If we consider that the background does not depend on the activities, we can assign the probabilities of the events based on the data obtained from all the experiments performed (when opening the door with or without gloves).

In the supplementary material, we further provided the Bayesian Network modelling situation B and the associated conditional probabilities (Appendix A.2).

Table 4
Analytical formulae (taking the example where the observations E are: no interpretable DNA profile is observed) in a case where the propositions are: the POI opened/closed bare-handed the door or an alternative offender performed the same activity but with the POI's gloves.

LR formula assuming that transfer/persistence/recovery and background are dependent (A)		LR formula assuming that transfer/persistence/recovery and background are independent (B)[a]	
$LR = \frac{\Pr(E\|H_p, I)}{\Pr(E\|H_d, I)}$	Equation 1 (A)	$LR = \frac{t_0^{POI} b_0}{t'^{AO}_0 t'^{POI}_0 b_0}$	Equation 2 (B)

[a] This corresponds to a situation where no DNA was recovered because of the activities and no background was present.

3.7. Examples of evaluation of cases given alleged activities

Once we have the data from the experiments, we can use them for the evaluation of the DNA findings. Below we present two examples of evaluation assuming that transfer/persistence/recovery and background are dependent (A). As recommended by the forensic community (e.g., ENFSI, ISFG), we have assessed the value of these findings considering the probability of the results given two alternative propositions and the case information. That is, the DNA results have been evaluated through the assignment of a likelihood ratio (LR). The LR measures the strength of support that the results give for one proposition compared to the other proposition. For the evaluation of our case scenario, we consider the alternative propositions Hp and Hd.

Example 1. : single source DNA profile of the trace that aligns with the DNA profile of the POI.

In this example, we consider that there is a single DNA profile aligning with the DNA profile of the POI. In general, if the source of the DNA is not contested, then we do not need to consider the source of the DNA. Here, we would like to tackle a more general situation where we should also consider that there is a possibility that the DNA came from an unknown person. In such as case, we need intermediate association propositions (i.e., sub-source level propositions). These intermediate association propositions are here: the DNA came from the POI or an unknown unrelated person. The likelihood ratio calculated for the comparison with STRmix™ is in the order of a million. All task relevant information available (e.g., unknown person is from the Swiss population, gloves were stolen given defense view) is taken into account in the evaluation and indicated in the formula by letter *I*.

Considering *E* as the presence of a single DNA profile aligning with the reference profile of the POI, the likelihood ratio given activity level propositions can be developed as follows [48]:

$$LR = \frac{\Pr(E|H_p, I)}{\Pr(E|H_d, I)}$$

The upper part of the formula (i.e., the numerator) is developed considering prosecution proposition. It is the probability of obtaining a single source DNA profile aligning with the reference profile of the POI if s/he acted bare-handed. If this is true, then there are two possibilities: either DNA from POI was transferred/persisted/recovered or it did not. If there was DNA recovered from the POI given that activity, then as we have recovered no other DNA, it means that there was also no background. The first possibility can be expressed by the term $t^{POI}_{Single} b_0$.

Now, if we consider the second possibility and that there was no DNA recovered because of the POI opening/closing the door (this is indicated in our formula by t_0^{POI}) there could still be DNA because of background, that is for unknown reasons. This single profile present as background (b_{Single}) would have to align with the DNA profile observed. To account for this we consider the LR calculated in STRmix™ with our intermediate association propositions. Combining the probabilities of our observations with the rarity of the profile, we obtain $t_0^{POI} b_{Single} \gamma$, where γ is the 1/LR calculated with the associated sub-source propositions.

The lower part of the formula is developed in a similar fashion, but we now consider the transfer of DNA through the gloves. In this case, one will assign the probability of no DNA transfer from the AO and DNA transfer from the POI detected as a single source profile ($t'^{AO}_0 t'^{POI}_{Single} b_0$) based on our observations. We then add a second term, as there is the possibility that no DNA was recovered from either of AO or the POI given the activities and it is present as background ($t'^{AO}_0 t'^{POI}_0 b_{Single}$).It would have to align with the DNA profile observed. As before to account for this we consider the LR calculated in STRmix™ with our intermediate association propositions. Combining the probabilities of our observations with the rarity of the profile, we obtain $t'^{AO}_0 t'^{POI}_0 b_{Single} \gamma$. The third possibility we consider is that the AO transferred DNA because of

Table 5
Probability of the observations and transfer/background probabilities, given the proposition that the POI opened/closed bare-handed the door.

Possible observations in a case (noted E) and results expected for the first set of experiments	Transfer/background event given the activity	Prior counts	Number of Observations	Posterior counts	Probability
No (interpretable) DNA profile	$T_0^{POI}B_0$	1	5	6	0.32
Single DNA profile that does not align with the DNA of the POI	$T_0^{POI}B_{Single}$	1	0	1	0.06
Single DNA profile that aligns with the DNA of the POI	$T_{Single}^{POI}B_0$	1	0	1	0.06
Mixed DNA profile (Maj/Min) that does not align with the DNA of the POI	$T_0^{POI}B_{Maj/Min}$	1	2	3	0.16
Mixed DNA profile (Maj/Min) with a major profile aligning with the DNA of the POI	$T_{Major}^{POI}B_{Minor}$	1	3	4	0.22
Mixed DNA profile (Maj/Min) with a minor profile aligning with the DNA of the POI	$T_{Minor}^{POI}B_{Major}$	1	0	1	0.06
Mixed DNA profile (Other) that does not align with the DNA of the POI	$T_0^{POI}B_{Other}$	1	0	1	0.06
Mixed DNA profile (Other) aligning with the DNA of the POI	$T_{Other}^{POI}B_{Other}$	1	0	1	0.06
Total		8	10	18	1

Table 6
Probability of the observations and transfer/background probabilities, given the proposition that AO opened/closed the door, wearing the POI's gloves.

Possible observations in a case (noted *E*)	Results expected for the second set of experiments (where the DNA of the AO is available)	Transfer/background event given the activity	Prior counts	Observations	Posterior counts	Probability
No (interpretable) DNA profile	No (interpretable) DNA profile	$T'^{AO}_0T'^{POI}_0B_0$	1	27	28	0.48
Single DNA profile that does not align with the DNA of the POI	Single DNA profile that does not align neither with the POI's nor with the AO's DNASingle DNA profile aligning with the DNA of the AO	$T'^{AO}_0T'^{POI}_0B_{Single}T'^{AO}_{Single}T'^{POI}_0B_0$	1	1	2	0.03
Single DNA profile that aligns with the DNA of the POI	Single DNA profile aligning with the DNA of the POI	$T'^{AO}_0T'^{POI}_{Single}B_0$	1	0	1	0.02
Mixed DNA profile (Maj/Min) that does not align with the DNA of the POI	Mixed DNA profile (Maj/Min) that does not align neither with the POI's nor with the AO's DNAMixed DNA profile (Maj/Min) with a major contributor aligning with the AO's DNA and (a) minor contributor(s) that does not align with the POI's DNAMixed DNA profile (Maj/Min) with a major contributor that does not align with the POI's DNA and one of minor contributors aligning with the DNA of the AO	$T'^{AO}_0T'^{POI}_0B_{Maj/Min}T'^{AO}_{Major}T'^{POI}_0B_{Minor}T'^{AO}_{Minor}T'^{POI}_0B_{Major}$	1	11	12	0.20
Mixed DNA profile (Maj/Min) with a major profile aligning with the DNA of the POI	Mixed DNA profile (Maj/Min) with a major contributor aligning with the POI's DNA of and (a) minor contributor (s) that does not align with the DNA of the AOMixed DNA profile (Maj/Min) with a major contributor aligning with the POI's DNA and one of minor contributors aligning with the DNA of the AO	$T'^{AO}_0T'^{POI}_{Major}B_{Minor}T'^{AO}_{Minor}T'^{POI}_{Major}B_0$	1	4	5	0.09
Mixed DNA profile (Maj/Min) with a minor profile aligning with the DNA of the POI	Mixed DNA profile (Maj/Min) with a major contributor aligning with the AO's DNA and a minor contributor aligning with the DNA of the POIMixed DNA profile (Maj/Min) with a major contributor that does not align with the AO's DNA and one of minor contributors aligning with the DNA of the POI	$T'^{AO}_{Major}T'^{POI}_{Minor}B_0T'^{AO}_0T'^{POI}_{Minor}B_{Major}$	1	7	8	0.14
Mixed DNA profile (Other) does not align with the DNA of the POI	Mixed DNA profile (Other) that aligns neither with POI's or AO's DNAMixed DNA profile (Other) that aligns with the POI's DNA but not AO's	$T'^{AO}_0T'^{POI}_0B_{Other}T'^{AO}_0T'^{POI}_{Other}B_{Other}$	1	0	1	0.02
Mixed DNA profile (Other) aligning with the DNA of the POI	Mixed DNA profile (Other) that does not align with the DNA of the AO but with the POI'sMixed DNA profile (Other) aligning with both POI's and AO's DNA	$T'^{AO}_0T'^{POI}_{Other}B_{Other}T'^{AO}_{Other}T'^{POI}_{Other}B_{Other}T'^{AO}_{Other}T'^{POI}_{Other}B_0$	1	0	1	0.02
Total			8	50	58	1

the activity and has a profile compatible with the trace; that the POI's DNA has not been recovered because of the activities and there is no background ($t'^{AO}_{Single}\gamma t_0^{POI}b_0$)..

The LR formula is as follows:

$$LR = \frac{t_{Single}^{POI}b_0 + t_0^{POI}b_{Single}\gamma}{t'^{AO}_0 t'^{POI}_{Single}b_0 + t'^{AO}_0 t'^{POI}_0 b_{Single}\gamma + t'^{AO}_{Single}\gamma t'^{POI}_0 b_0}$$

Table 7
Probabilities of the POI's DNA being transferred and recovered in a quantity/quality such as to produce a profile of given type (none, single, major, minor, other) when the POI opens/closes the door without gloves.

Transfer event	Prior counts	Number of Observations	Posteriorcounts	Probability
T_0^{POI}	1	7	8	0.53
T_{Single}^{POI}	1	0	1	0.07
T_{Major}^{POI}	1	3	4	0.26
T_{Minor}^{POI}	1	0	1	0.07
T_{Other}^{POI}	1	0	1	0.07
All	5	10	15	1

Table 8
Probabilities of the POI's DNA being transferred and recovered in a quantity/quality such as to produce a DNA profile of given type (none, single, major, minor, other) when an AO opens/closes the door wearing the POI's stolen gloves.

Transfer event	Prior counts	Number of Observations	Posteriorcounts	Probability
T'^{POI}_0	1	39	40	0.73
T'^{POI}_{Single}	1	0	1	0.02
T'^{POI}_{Major}	1	4	5	0.09
T'^{POI}_{Minor}	1	7	8	0.14
T'^{POI}_{Other}	1	0	1	0.02
All	5	50	55	1

Table 9
Probabilities of the AO's DNA being transferred and recovered in a quantity/quality such as to produce a profile of given type (none, single, major, minor, other) when opening/closing the door wearing the POI's recently stolen gloves.

Transfer event	Prior counts	Number of Observations	Posteriorcounts	Probability
T'^{AO}_0	1	50	51	0.92
T'^{AO}_{Single}	1	0	1	0.02
T'^{AO}_{Major}	1	0	1	0.02
T'^{AO}_{Minor}	1	0	1	0.02
T'^{AO}_{Other}	1	0	1	0.02
All	5	50	55	1

γ, which expresses in part the rarity of the profile obtained from the trace, is usually very small. Here it is neglected and we simplify the formula as follows:

$$LR = \frac{t^{POI}_{Single} b_0}{t'^{AO}_0 t'^{POI}_{Single} b_0}$$

This shows that when there are legitimate reasons for the POI's DNA to be present, even if there is no agreement on the source of the DNA recovered, we can consider activity level propositions [47]. The terms of the likelihood ratio formula can be replaced by the numerical values summarized in Tables 5 and 6. The likelihood ratio obtained given activity level propositions is the following:

$$LR = \frac{0.06}{0.02} \cong 3$$

The numerical value obtained indicates that it is 3 times more likely to observe a single source profile matching the reference profile of the POI if she/he opened/closed bare-handed the door rather than if an AO opened/closed it wearing the POI's worn gloves. In other words, if we refer to the verbal scale used by Marquis et al. [49], these results provide limited support for the first proposition compared to the alternative.

Example 2. : DNA trace presenting a mixed DNA profile with a minor profile aligning with the DNA profile of the POI and major profile from an unknown source.

In this second example, we consider that we observe a mixed DNA profile with a minor contributor aligning with the reference profile of the POI. Like in the previous example, the trace is evaluated considering the two intermediate association propositions, namely: the DNA came from the POI and an unknown unrelated person or two unknown unrelated persons. These are the propositions used for the comparison of the DNA profiles with STRmix™. We take into account the same available information (e.g., the unknown persons are from the Swiss population, the gloves were stolen given defense view). The likelihood ratio calculated for the comparison with STRmix™ is of the order of a million.

Considering E as the presence of a minor DNA profile aligning with the reference profile of the POI and of a major profile from an unknown source, the likelihood ratio general formula is as follows [48]:

$$LR = \frac{\Pr(E|H_p, I)}{\Pr(E|H_d, I)}$$

Similarly to the previous example, the upper part of the formula is developed considering prosecution proposition. It is given by the probability of obtaining a mixed DNA profile with a minor contributor aligning with the reference profile of the POI when s/he acted bare-handed. If this is true, then there are two possibilities: either DNA from POI was transferred/persisted/recovered or it did not. If it has been recovered because of her/his activity, as we have observed a mixed DNA profile, then it means that there was DNA of an unknown unrelated person as background. One must also consider the DNA profile characteristics: if the DNA has been transferred by the POI and that there is DNA as background, it means that the DNA comes from the POI and an unknown unrelated person. The probability of the DNA profiles given this proposition is equal to the numerator of the LR computed by STRmix™. We denote the numerator by the letter ϑ.. The first possibility can be expressed by the term $t^{POI}_{Minor} b_{Major} \vartheta$.

Now, if there was no DNA recovered because of the POI opening/closing the door (this is indicated in our formula by t_0^{POI}) there could still be DNA because of background, that is for unknown reasons. This mixed DNA profile present as background ($b_{Maj/Min}$) would have to align with the DNA profile observed. To account for this, we consider this time the denominator of LR calculated in STRmix™ with our intermediate association propositions. Indeed, if the DNA has not been transferred by the POI and that there is DNA as background, it means that the DNA

Table 10
Probabilities of DNA being recovered as background in such a quantity/quality as to produce a profile of given type (none, single, major, minor, other) when opening/closing the door with or without gloves.

Background event	Prior counts	Number of Observations given			Posterior counts			Probability of background given		
		H_p	H_d	all	H_p	H_d	all	H_p	H_d	all
B_0	1	5	27	32	6	28	34	0.38	0.50	0.48
B_{Single}	1	0	1	1	1	2	3	0.06	0.04	0.04
$B_{Maj/Min}$	1	2	11	13	3	12	15	0.19	0.21	0.21
B_{Major}	1	0	7	7	1	8	9	0.06	0.14	0.12
B_{Minor}	1	3	4	7	4	5	9	0.25	0.09	0.12
B_{Other}	1	0	0	0	1	1	2	0.06	0.02	0.03
All	6	10	50	60	16	56	72	1	1	1

comes from two unknown unrelated persons. The probability of the DNA profiles given this proposition is equal to the denominator of the LR computed by STRmix™. We denote the denominator by the letter δ. We thus obtain for this term $t_0^{POI} b_{Mixture} \delta$.

The lower part of the formula (i.e., denominator), is developed in a similar fashion, but we now consider the transfer of DNA through the gloves. In this case, one will assign the probability of no DNA transfer from the AO (our alternative offender) and DNA transfer from the POI detected as a minor contributor of a mixed DNA profile ($t'^{AO}_0 t'^{POI}_{Minor} b_{Major} \vartheta$) based on our observations. We then add a second term, as there is the possibility that no DNA was transferred from either the POI or the AO and it is present as background ($t'^{AO}_0 t'^{POI}_0 b_{Maj/Min} \delta$).It would have to align with the DNA profile observed with a probability δ. The third possibility we consider is that the AO DNA has been recovered as a major, that DNA transfer from the POI was detected as a minor contributor and there was no background ($t'^{AO}_{Major} \vartheta t'^{POI}_{Minor} b_o$).

The LR formula is as follows:

$$LR = \frac{t^{POI}_{Minor} b_{Major} \vartheta + t^{POI}_0 b_{Maj/Min} \delta}{t'^{AO}_0 t'^{POI}_{Minor} b_{Major} \vartheta + t'^{AO}_0 t'^{POI}_0 b_{Maj/Min} \delta + t'^{AO}_{Major} \vartheta t'^{POI}_{Minor} b_0}$$

As δis a million times smaller than the first term in numerator and the first term in the denominator, it can be considered as a negligeable factor, the formula can be simplified as follows:

$$LR = \frac{t^{POI}_{Minor} b_{Major} \vartheta}{t'^{AO}_0 t'^{POI}_{Minor} b_{Major} \vartheta + t'^{AO}_{Major} \vartheta t'^{POI}_{Minor} b_0}$$

As ϑ appears in both the numerator and denominator the LR formula can be simplified as:

$$LR = \frac{t^{POI}_{Minor} b_{Major}}{t'^{AO}_0 t'^{POI}_{Minor} b_{Major} + t'^{AO}_{Major} t'^{POI}_{Minor} b_0}$$

The terms of the likelihood ratio formula can be replaced by the numerical values summarized in Tables 5 and 6. Our likelihood ratio obtained given activity propositions is as follows:

$$\mathrm{LR} = \frac{0.06}{0.14} \cong 0.5$$

As the LR is smaller than 1, we reverse the propositions as suggested in [47]. The value obtained indicates that the results (a two person mixed DNA profile with a minor contributor aligning with the reference profile of the POI) are 2 times more likely if an AO opened/closed the door wearing the POI's gloves rather than the POI opened/closed it bare-handed. If using a verbal equivalent, one can say that these results support defense proposition rather than prosecution's; this support can be qualified as limited [49].

4. Discussion

First of all, some considerations have to be made on the experimental design. Data have been produced in specific conditions by following the case information available. Experiments have been designed to reproduce the case circumstances as closely as possible. Gloves were regularly worn by the owner during the winter period. In our mock case, the burglar claims that someone stole his gloves a day before the burglary. In our experiments, we considered that it was reasonable to have the burglar put them on during about 120 s. Based on Oldoni et al. [29] study on the evolution of the relative proportion of DNA deposited by different persons handling the same object, one can suppose that an increase of use by the burglar would have led to an increase in their DNA contribution to the DNA traces. One may hypothesize that storing the gloves in contact with items belonging to the burglar, or not, may also had an influence on the DNA profiles observed. However, the time of use, the storage environment and the number of times the gloves would be worn under defense proposition will always be unknown and experts will have to make a reasonable assumption based on the laps of time between when the gloves were stolen and the burglary. Furthermore, according to our study design, the person who was opening the door, opened some draws and touched some shelves prior to closing the door using the same handle and the same hand. The types of profiles generated may have been different if the person performing the burglary simulation didn't close the door or didn't touch the handle when closing the door. We could hypothesize that the second contact with the door handle may have added some additional DNA from within the office and potentially removed some of the POI's DNA added during the first use of the handle. In addition, the door handles used were on external doors of offices, handled almost daily by the occupant(s). Therefore, handles of internal rooms, of rooms or buildings with different histories of use may have yield results different from those that we obtained.

The total DNA quantification results, observed for the two series of experiments, show that the amount of DNA collected on the door handles was very low and there was a great variability between traces. The median value of DNA contained in the traces was in the range of 150 pg when the thief acted bare-handed and of 250 pg when s/he acted wearing gloves. These DNA quantities (total present in the extract) are similar given the range observed and do not allow to discriminate the activities. Because the quantity of DNA depends on the number of occupants opening the door, we have also considered the possibility of using the quantification data in addition to the proportion to assess quantity of the DNA from each known contributor (i.e., mixture proportion multiplied by total quantity of DNA in the extract). This did not allow further discrimination compared to our description where we consider that the POI can either align with the major/minor contributor or neither.

Like in [28] no correlation was detected between the quantity of DNA and the quality of the DNA profiles obtained, because of the low level of DNA. For the two series of experiments, unbalanced peaks height was observed on almost all profiles, the low reproducibility of the DNA profiles between replicates suggests the presence of drop outs. Generally, the weights assigned by STRmix™ were diluted over all the possible genotypes which reflects the low quality of the profile.

As a reminder, for the series of experiments where the POI acted bare-handed, 50% of the DNA profiles were not interpretable. In 30% of the cases, the major profile of the traces aligned with the DNA profile of the POI, and in 20% of the cases it aligned with the DNA profile of one of the regular users of the office.

For the second series of experiments the profile of the AO was never found as a major profile or as a contributor of the DNA trace. In 54% of the traces, no interpretable DNA profile was obtained. The DNA of the office occupant(s) was compatible with 20% of the traces, the DNA of the POI was compatible with 22% of the traces (in 8% of the cases it aligned with the major profile and in 14% it aligned with the second contributor); for 12% of the traces all the contributors to the mixed DNA profiles were unknown.

Pfeifer et al. [15] studied the persistence of DNA when several people touched 3 types of tools: personal tools; tools first used by the owner and then handled to undertake a burglary action by another person; and tools, which were first owned by a person and then handled in a moderate action by another user. Every second user handled the tool with and without gloves. They found out that when second users simulated a burglary by using a tool bare-handed, the first user was never detected as major component of the mixed DNA profiles, but they could "attribute" him to the DNA in about 2% of the cases. When second users simulated the burglary using gloves, the first user aligned with the DNA profile found on the tool in 37% of the cases [15]. Our results are a little different from the Pfeifer et al. [15] study, as the first users of the door handles (office occupant) align with the DNA traces in 20% of the DNA traces, in both when the thief had gloves or not. In the first case, when the burglar had no gloves, the higher proportion of traces aligning with the first user, which were found in our cases, could be explained by the fact that the door handle is more frequently (1 week) used by the office

occupants than the tools used in Pfeiffer's experiments. Inversely, in the experiments where the burglar was glove handed, the proportion of traces with a profile aligning with the first user of the object is smaller in our experiments. The difference between the findings could be explained by the type of gloves used. The glove material used in our experiments could have fostered the transfer of background DNA from the door handle to the gloves, reducing the probability of detecting the occupant's DNA in our cases. Another aspect could be the type of material (metal versus plastic) as shown in [50].

Otten et al. [37] performed experiments to evaluate their DNA findings in cases where a screwdriver and a glove would be found at a burglary scene. Confronted with the DNA evidence, as in our scenario the person concerned denies his/her presence on the crime scene and says that one of his/her glove has been stolen and that the real offender must have broken into the house wearing his gloves. The DNA profile found on both items aligns with the reference profile of a POI. In their study, Otten et al. first evaluated the shedder status of the participants and subsequently performed burglary simulations where one first person uses the gloves in order to simulate a house move and a second user manipulates a screwdriver with the same gloves. For each experiment, three DNA swabs were performed: inside and outside of the glove and on the screwdriver. In order to compare their results with our paper, we will only consider the DNA findings obtained from the screwdrivers. In Otten et al. the proportion of exploitable profiles was considerably higher (95%) in comparison to our study (50%). In 58% of the cases (11/19) no DNA transfer was observed form the person handling the screwdrivers, while in 42% of the cases (8/19) transfer had occurred. In 58% (11/19) of the cases no DNA from the first person using the gloves was found on the screwdriver while in the rest of the cases (42%) (8/19) a DNA transfer had occurred. In our study we never found the DNA of the burglar (here the second user of the gloves) on the door handle. Moreover, the reference profile of the POI aligned with the profile of the DNA trace less frequently, in 22% of the cases. These divergent results may be due to the different criteria selected to define the exploitability of the DNA profiles and to the different analytical parameters used, as for example the analytical threshold. Moreover, the difference between the two studies could be due to the type of activities performed (door opening versus screw driving), the surface of the object that was used [50] and/or the glove material. In addition, in the present study, the POI regularly wore the gloves during at least three months. We may therefore expect a lot of opportunities for the POI's DNA to be transferred on the gloves. Alternatively, the AO used the gloves during about 120 s. In Otten et al., the gloves were worn by both, the first and by the second user, only for a limited time and only during the simulation.

Another recent study on burglary simulations using gloves worn by two different people was carried out by Tanzhaus et al. [38]. Tanzhaus et al. simulated the experiments with gloves made of different materials (cloth, rubber and leather) and varied the transfer surface (wood, metal, glass). Out of the 81 transfer experiments, they detected only one case where DNA was transferred through gloves and recovered (1,2%). This result is very different from what we found in our case, where the profile detected aligned with the gloves owner in 24% of the cases. As in Tanzhaus' experiment the gloves were worn by the first user for a long period of time prior to the burglary simulation, and the "perpetrator" wore the gloves between 4 h and 4 weeks. The time during which the gloves were worn by the second user could have cause a loss of the DNA of the first users on the gloves. Another explanation could be the sampling protocol performed by Tanzhaus et al. on the gloves. Indeed, two successive samples were collected on the gloves used in the experiments. The first and second sampling were performed respectively before and after the "perpetrator" wore the gloves, but prior to the use of the burglary tool. Therefore, the number of swabs performed on the gloves could have lessen the DNA quantity available for transfer onto the surface of interest.

In this paper, we have also assessed the influence of considering the office occupants profiles for the comparison of the DNA traces with the reference profile of the POI. The results indicated that when the profile of the office occupant was considered as known under both propositions, this added further discrimination for some of the traces. This result was predictable, since the more information we consider for the evaluation of DNA traces, the better the discrimination. These observations are also in accordance with Kalafut et al. [51], which recommend the use of conditioning in order to obtain better sensitivity and specificity when assigning LRs with STRmix™ [51].

According to the existing literature in the field, transfer/persistence/recovery (transfer for short) and background are often assumed to be independent when assessing the value of transfer evidence given activity level propositions. However, depending on the circumstances, this may not be the case, especially for DNA as the presence of background may lead to the detection of complex mixtures, that may not be interpretable [40]. An example could be for a computer used in an internet café : the presence of background could impact the probability of observing a DNA transfer of a person using that computer.

In the Appendix A.1 to A.2, we have presented two different Bayes Networks to illustrate the different types of models depending on the assumptions (i.e., considering transfer and background probabilities as dependent or independent). We have also provided two sets of data (probabilities considering dependence or not), obtained from our experiments. These may be used for the evaluation of cases using the first or the second model presented.

For assessing the results in our casework scenarios, we have considered that transfer and background were dependent for two reasons. First, as mentioned above, because we consider that the probability of observing a DNA profile on the door handle will be affected by the background DNA: if the object is cleaned, there is a higher probability of detecting DNA, rather than if there is a large amount of DNA of multiple donors present as background, as described in Lehmann et al. [40]. Secondly, the definition of the results itself includes the background, indeed if - for example - we consider a "single DNA profile", this means *de facto* that there is no detectable DNA background (given the method utilized). In the Appendix A.3, we also provided the evaluation of the two examples using Bayesian Networks. We noted in this Appendix A.3 that the results obtained using the formulae developed in this paper (modelized by the BN in Appendix A.1) or using the Bayesian Network considering transfer and background events as independent (Appendix A.2), lead to LRs of the same order of magnitude. Therefore, the assumption of dependence or independence of transfer and background events has only a limited effect on the LRs obtained for our two case examples.

In our experiments, the evaluation of the observations given sub-source level propositions produces high likelihood ratios. However, if the sub-source of a given trace is not contested and we evaluate the quantity and quality of the profile considering the activities (opening the door bare or glove handed), our LRs are much reduced (< 10).

These findings underline the importance of adequately evaluating the observations in order to avoid misleading the court [10,52,53].

5. Conclusion

The present work simulates burglary cases, where the obtained DNA profile would share similar components as the person of interest's. Sixty burglary simulations, with and without gloves, were carried out within offices. We observed that in 30% of the cases when the door was opened/closed with bare hands, the DNA trace recovered on its surface lead to a mixed DNA profile with the POI's DNA aligning with the major contributor. For the experiment where the AO acted wearing the POI's gloves, the glove owner DNA aligned with 22% of the mixed DNA profiles recovered on the door handles. In none of these experiments involving gloves, did one observe the DNA profile of the person wearing the barely worn stolen gloves. We assume that these results are due to the short wearing time of the gloves by the POI (i.e., about 120 s) and to the type of activities they were engaged in during this short period.

Conversely, the owners of the gloves have worn them during about 3 months. We would expect less DNA from the owner if the wearing time was shorter. Even if wearing time is often unknown in real cases, in futures studies it would be useful to extend the glove wearing time by the burglar in order to assess the influence of this parameter on the DNA results.

In the paper we also provided data for the evaluation of the DNA findings by considering the probabilities of the observations or by modelling transfer and background events separately. Using our data, we developed the formulae of the LRs given activity level propositions for two examples. Given the low LRs obtained, and the limited support provided to the alternative propositions, this work brings additional evidence on the importance of evaluating the results at that level when appropriate, as it is indicated in several guidelines. This would avoid experts over evaluating the DNA findings.

Conflicts of interest

The authors have no conflicts of interest to declare.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.fsigen.2022.102823.

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