Forensic Science International: Genetics 44 (2020) 102186

Contents lists available at ScienceDirect

Forensic Science International: Genetics

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

Research paper

DNA commission of the International society for forensic genetics: Assessing the value of forensic biological evidence - Guidelines highlighting the importance of propositions. Part II: Evaluation of biological traces considering activity level propositions

Peter Gill[a,b,*,1], Tacha Hicks[c,d,1], John M. Butler[e], Ed Connolly[f], Leonor Gusmão[g,h,i], Bas Kokshoorn[j], Niels Morling[k], Roland A.H. van Oorschot[l,m], Walther Parson[n,o], Mechthild Prinz[p], Peter M. Schneider[q], Titia Sijen[j], Duncan Taylor[r,s]

[a] Department of Forensic Sciences, Oslo University Hospital, Oslo, Norway
[b] Institute of Clinical Medicine, University of Oslo, Oslo, Norway
[c] Faculty of Law, Criminal Justice and Public Administration, School of Criminal Justice, University of Lausanne, Lausanne, Switzerland
[d] Fondation pour la formation continue universitaire lausannoise (UNIL-EPFL), 1015, Dorigny, Switzerland
[e] National Institute of Standards and Technology, Special Programs Office, Gaithersburg, MD, USA
[f] Forensic Science Ireland, Garda HQ, Phoenix Park, Dublin 8. D08 HN3X, Ireland
[g] State University of Rio de Janeiro (UERJ), Rio de Janeiro, Brazil
[h] IPATIMUP, Institute of Molecular Pathology and Immunology of the University of Porto, Portugal
[i] Instituto de Investigação e Inovação em Saúde, University of Porto, Portugal
[j] Netherlands Forensic Institute, Division Biological Traces, P.O. Box 24044, 2490 AA, The Hague, the Netherlands
[k] Section of Forensic Genetics, Department of Forensic Medicine, Faculty of Health and Medical Sciences, University of Copenhagen, Denmark
[l] Office of the Chief Forensic Scientist, Victoria Police Forensic Service Centre, Macleod, VIC, 3085, Australia
[m] School of Molecular Sciences, La Trobe University, Bundoora, VIC, 3086, Australia
[n] Institute of Legal Medicine, Medical University of Innsbruck, Innsbruck, Austria
[o] Forensic Science Program, The Pennsylvania State University, PA, USA
[p] John Jay College of Criminal Justice, New York, USA
[q] Institute of Legal Medicine, Faculty of Medicine and University Clinic, University of Cologne, Germany
[r] Forensic Science SA, GPO box 2790, Adelaide, 5001, South Australia, Australia
[s] School of Biological Sciences, Flinders University, GPO Box 2100, 5001, Adelaide, SA, Australia

ARTICLE INFO

Keywords:
Activity level
Propositions
ISFG DNA Commission
Likelihood ratio

ABSTRACT

The value of the evidence depends critically on propositions. In the second of two papers intended to provide advice to the community on difficult aspects of evaluation and the formulation of propositions, we focus primarily on *activity* level propositions. This helps the court address the question of "How did an individual's cell material get there?". In order to do this, we expand the framework outlined in the first companion paper. First, it is important not to conflate results and propositions. Statements given activity level propositions aim to help address issues of indirect vs direct transfer, and the time of the activity, but it is important to avoid use of the word 'transfer' in propositions. This is because propositions are assessed by the Court, but DNA transfer is a factor that scientists need to take into account for the interpretation of their results. Suitable activity level propositions are ideally set *before* knowledge of the results and address issues like: X stabbed Y vs. an unknown person stabbed Y but X met Y the day before. The scientist assigns the probability of the evidence, if each of the alternate propositions is true, to derive a likelihood ratio. To do this, the scientist asks: a) "what are the expectations if each of the propositions is true?" b) "What data are available to assist in the evaluation of the results given the propositions?" When presenting evidence, scientists work within the hierarchy of propositions framework. The value of evidence calculated for a DNA profile cannot be carried over to higher levels in the hierarchy – the calculations given sub-source, source and activity level propositions are all separate. A number of examples are provided to illustrate the principles espoused, and the criteria that such assessments should meet. Ideally in order to assign probabilities, the analyst should have/collect data that are relevant to the case in

* Corresponding author at: Department of Forensic Sciences, Oslo University Hospital, Oslo, Norway.
E-mail address: peterd.gill@gmail.com (P. Gill).
[1] Joint first authors.

https://doi.org/10.1016/j.fsigen.2019.102186
Received 30 September 2019; Accepted 12 October 2019
Available online 14 October 2019

question. These data must be relevant to the case at hand and we encourage further research and collection of data to form knowledge bases. Bayesian Networks are extremely useful to help us think about a problem, because they force us to consider all relevant possibilities in a logical way. An example is provided.

1. Introduction

In part I [1], we discussed the evaluation of DNA results when the issue pertains to the possible contribution of an individual to a trace. We have seen that this question is important when forensic scientists act as both investigators and evaluators. These roles are defined by Jackson et al [2]. As investigators, the source of the DNA is of primary interest in order to generate leads. However, courts are often concerned with an interpretation of evidence that goes beyond the question of the source of the DNA; basically, the question shifts from “Whose cell material is this?” to “How did an individual’s cell material get there?” This problem is not new; it was previously addressed by Evett et al. [3]. In some cases, for instance, with low-template DNA there may not be an association of the profile with any known specific body fluid which could be informative on activity level analysis. The relevance of the DNA evidence in relation to an activity has to be considered in relation to features other than the profile itself such as the relative amount of DNA, its level of degradation and/or its complexity (e.g., multiple contributors). The findings of one or multiple DNA profiles must then be considered in light of the propensity for DNA to transfer and persist on objects, through potentially multiple intermediaries (often referred to as secondary, tertiary, quaternary, etc. transfer). It is the probability of the results given each of the competing activities (one of which will describe some component of the crime and the other will relate to a means of innocent acquisition that is then provided to the court). Thanks to high profile cases that have resulted in miscarriages of justice or wrongful arrests e.g. [4–6], there is much greater awareness of issues that could complicate the interpretation of the evidence [7–24]. A DNA profile from a crime stain may ‘match’ the DNA profile of a defendant, and a likelihood ratio assigned to determine the value of evidence to support the propositions that the person of interest contributed or not to the crime stain, but the relevant questions may be ‘how’ or ‘when’ did it get there or "Is the DNA associated with a particular body fluid, and/or a given activity?" These questions are entirely different to the assessment of the value of the DNA profiling evidence given sub-source level propositions. The biggest danger is that without sufficient guidance from the scientist, the court may simply carry-over the value of evidence of the DNA profile regarding its source to the ‘activity’ that led to the DNA transfer.

To prevent errors of this nature occurring, it is necessary to evaluate evidence within a coherent framework that is accommodated by the ‘hierarchy of propositions’ [3,25–27]. However, before dwelling on the ‘hierarchy’, let us revisit what propositions are and in what context they are used.

2. Context: our role as evaluators, assessing results given propositions

When forensic practitioners are asked by a mandating authority or party to examine and/or compare material (typically recovered trace material with reference material from known persons), they act as *evaluators*. As such, they are asked to assess the value of their results. They do so by assigning a likelihood ratio, which is defined as the ratio of two conditional probabilities: (i) the probability of the results given that one proposition is true and given the conditioning information; and (ii) the probability of the results given that the other proposition is true and given the conditioning information. Case information and propositions are essential to evaluation to such an extent that they are part of the three principles of interpretation described below ([28], chapter 2).

1 Interpretation takes place in a framework of circumstances.
2 We must evaluate our results given two mutually exclusive propositions representing the views of the two involved parties as understood.
3 Scientists must give their opinion on the *results* and not on the propositions.

We will consider the third principle in the subsequent sections, but would like to stress that propositions are different from explanations [29]. ‘DNA could have been secondarily transferred’ is an example of explanation. Listing the possible explanations for the presence of DNA is more suited to our role as *investigators* – which takes place during the period prior to a defendant being put forward for prosecution. As outlined by Jackson and Biedermann [30], if the jury is told that the DNA results are a billion times more likely if the DNA comes from the suspect rather than from some unknown person, and that they are then given a list of explanations, it will be difficult for them to decide what the DNA evidence means and how it impacts the case. They will be left with a huge number that might have no bearing on the case (i.e., the source of the DNA may not be contested), and with no value for the results that do have an impact (i.e., results support one proposition, the alternative or none). A typical example could be as follows: imagine that Ms A is accused of drug trafficking. A large package is discovered in her handbag at the airport. She does not deny that it is her handbag but says that she has not handled the package and that someone must have put it in her bag just before she went through security. A DNA mixture assigned as three persons with no clear major is compared to her profile, and a high LR given sub-source level propositions is reported. If, in court, the expert reports the LR and adds that the DNA could be present because of primary transfer, or that it could also be secondary transfer, as the bag could have acted a DNA reservoir, this does not help the court understand the significance of the sub-source LR. One would need to know if the results are more probable given one activity level proposition over the other and by how much, in order to help the court to address the matter in which they are interested.

Regarding case information, only the relevant case circumstances are necessary for the *evaluation of results* [31]: examples of relevant information would regard the alleged activities, the personal items in the bag, the timing, what the suspect says regarding the incident. An example of biasing information, that is not needed nor wanted, would be that a witness has recognised the suspect. A caveat will need to be applied to the statement to reinforce the point that the value of the results depends upon the case-information [28] that has been put forward:

“My approach to the examination and evaluation of the results in this case is crucially dependant on the information and data available. If any of the above information is incorrect or if further information is made known, it will be necessary for me to reconsider my interpretation.”

The value of forensic results also depends critically on propositions, as they are formulated based on the case information. As such, propositions are provisional[2] and may be subject to change: these points should be made clear in the statement.

Recommendation 1:

Providing a list of possible explanations for the results may be relevant during the investigation phase, but not in court, as it does not allow an assessment of the value of evidence. Evaluation of forensic biological results in court should be reported using a likelihood ratio based on case specific propositions and relevant conditioning information. Because the value of the results depends on the propositions and case information, this aspect should

[2] In particular, if the person has provided no comment.

be highlighted in the report.

3. The hierarchy of propositions

Cook et al. [25] describe the various levels of propositions at which evidence may be reported. There is detailed description in the "ENFSI guideline to Evaluative Reporting" [29] which is summarised here:

1. Sub-source level propositions help address the issue of "Who is the source of the DNA?" Here "the DNA" does not imply any relationship between that DNA and the body fluid (e.g. blood, semen, saliva, vaginal fluid) or the biological material (e.g. skin cells or hair root) that led to it. The nature of the biological source is not addressed with sub-source level propositions.

2. Source level propositions help address "Who is the source of a particular biological material, such as semen, muscle, bone?" Since body fluid/DNA mixtures are often encountered it may be difficult to deconvolve the separate contributions. Very often, the nature of the biological fluid will be the same in both propositions (e.g., the *blood* came from X, the *blood* came from some unknown person). If the stated nature is the same in both propositions (e.g. *blood*), then the origin of the biological material is not contested (or assumed not to be contested). Alternatively, its nature may be contested (e.g. the biological fluid from Ms. X is vaginal vs. the biological fluid from Ms. X is saliva). In that case, activity level propositions will generally be more helpful, as they would allow us to take into account transfer and background.

3. Activity level propositions refer to the nature of the activities, e.g. suppose a victim has been stabbed in an affray. One proposition could be: "The defendant stabbed the victim, the day following their meeting". And, the alternative: "An unknown person stabbed the victim, the day following that meeting". Additional information that would then be considered (but not necessarily as part of the short above-stated propositions) would be the timing and activities that the defendant and the victim had the day prior to the assault. Propositions are short summaries of the facts under dispute. The undisputed additional relevant information will however be disclosed in the statement.

4. The highest-level propositions deal with the offence that may involve several activities, and will be conditioned on an intent and/or on legal definitions. It must be noted that the difference between activity and offence level propositions might be very thin. An example of this would be: "Mr A stabbed the victim" (the activity) and "Mr A murdered the victim" (the offence).

4. Using the hierarchy of propositions

First, it is necessary to consider the case-circumstances in detail, to answer the following questions:

1) What is the issue in the case that forensic science can help with (i.e., how can we add value)?
2) What are the competing propositions based on the case information?
3) What are the expectations and can we assess the probability of these results given the propositions and case information?
4) Does one add value by considering propositions that are higher in the hierarchy?
5) Are there other issues, which the scientist should consider, such as the possibility of contamination?
6) What data are available in order to evaluate the results given the propositions?
7) What is the probability of the results given the alternative propositions that are considered?

Evidence at the lower end of this hierarchy (sub-source issues) relates solely to the DNA profile, irrespective of how or when transfer occurred, or of the body fluid type.

The different levels of the hierarchy rely upon different assumptions to consider and they are very case specific. A value of evidence calculation applied to the DNA profile cannot simply be carried-over to include the body fluid (section 3. above) unless there is no dispute that they are associated and that the body fluid is not in question and relevant to the case at hand [32].

At one end of the scale, this assumption may be justified if there is a small pool of blood, and there is a single DNA profile that is recovered from it. The propositions would then be: "The blood came from the person of interest (POI)" vs. "The blood came from an unknown individual". In those circumstances, it is safe to assume that the nature of the body fluid will not be disputed. There is therefore no risk that the results will be misinterpreted given the activities alleged in the case.

At the other end of the scale, there may be c. 50 pg of DNA recovered, along with a positive presumptive test for blood. The DNA profile could be a mixture; other cell types, e.g. epithelial cells may be present as well. Here it would be misleading to assume that the origin of the DNA is blood, and not disclose this assumption. It leads the recipient of information to believe that there is no issue regarding the origin of the body fluid and that the value of the evidence given sub-source propositions is the same as given source level propositions. An example is shown in the following statement:

"The evidence if the POI is the source of the blood is one million times more probable than if he is not the source of the blood".

It is indeed misleading because it is unclear what is meant by: "is not the source of the blood". Cook et al. [25] explicitly mentions the problematic use of the term 'not': to assign probabilities, propositions should not be vague, one needs to explain what is meant by 'not'. Could the defendant be the source of the DNA, but not of the blood? Is it not contested that the substance that led to the DNA profile is blood? As sub-source propositions do not allow the consideration of issues regarding the nature of the biological fluid, one cannot assess the results of presumptive and so-called confirmatory tests. If there is an issue regarding the nature of the biological fluid, the alternative has to reflect this aspect. And, because forensic knowledge is needed to assess these results, one cannot leave this burden to the court.

Taylor et al [33] presented a useful Bayesian Network to assess the value of evidence given source level propositions combining appearance of the stain, haemastix tests, quantity of DNA and expanded the model to consider mixtures. This work was extended by de Zoete et al [34] to examine how case circumstances can be considered, specifically if they indicate the potential presence of material that would give false positive reactions to tests for biological material. Peel and Gill [35] showed that presumptive tests for degraded blood can give a positive result while all the donor DNA had degraded – if the material had been recently touched by a different individual, leaving his DNA in epithelial cells, a false association between that person and 'blood' can be inferred. There is currently no presumptive test for epithelial cells, although mRNA tests exist for skin [36–38]. Consequently, where there is uncertainty of body fluid attribution, the likelihood ratios assigned given source level propositions are much lower than when considering sub-source level propositions. The court should be made aware of this aspect. This remark also applies to cases where differential extraction is performed: deriving a DNA profile from the spermatic fraction does not necessarily prove that the DNA is from sperm [39,40]. However, if there is clear enrichment of male DNA in the differential fraction, compared to the aqueous phase then this would be evidence that needs to/can be assessed given propositions higher in the hierarchy[3] .

Care is also needed to explain to a court that the mere presence of a DNA profile does not automatically imply an associated 'activity'. Thus, the discussion on the value of the results given activity level propositions needs to be addressed to prevent inadvertent carry-over of the evaluation given sub-source to activity level propositions. Biedermann

[3] The usual procedure is to first carry out a presumptive (e.g. acid phosphatase test); prepare slides to verify/grade sperm heads and then carry out differential extraction.

et al [41] state: “Not pursuing this topic bears the risk of leaving recipients of expert information without guidance. Reliance on recipients’ own devices is prone to conclusions that are based on (sub-) source level propositions being wrongly carried over to conclusions about activity”. For example, in the case of a possible sexual assault of a female, where the defence proposes that the DNA is the result of an innocent activity, the presence of semen identified by sperm-heads does not automatically imply sexual assault by a male. There may be other activities involved e.g. semen resulted from the activity of masturbation onto a towel that was subsequently used by the female. The results (e.g., number of sperm heads, coherence of the results obtained on the different swabs, DNA profiles) have to be considered in the light of the activity level propositions and the case circumstances (e.g., has the victim had previous recent sexual activities? Is there any possibility of contamination?). The Jama case and the Adam Scott case [5] are examples of miscarriages of justice because the value of the DNA results was demonstrably carried over from sub-source propositions to source, or even offence level propositions.

To make clear the limitations of providing a report that is restricted to sub-source level, the following caveat can be applied to statements:

"This report does not provide any information on the mechanisms or actions that led to the deposition of the biological material concerned. It only provides help regarding its origin. Should there be any issue regarding the activities that led to this material, we should be contacted to provide a new report."

There are some published examples of probabilistic approaches to evaluate evidence given ‘activity’ level propositions [3,13,22,29,41–44]. Perhaps the most challenging cases are those that involve trace DNA[4], due to the propensity for it to be transferred, and the numerous factors that can affect this. Consider an example where a victim has been murdered and her/his clothes are sampled in the hope of finding trace DNA of the offender who potentially grabbed the garments. A DNA profile is obtained and compared to a suspect. If the suspect lives with the victim then there will be a high probability of recovering DNA ‘matching’ him on the victim’s garments given the activities involved when living together [45]. If there is high probability of finding the suspect’s DNA on the victim’s clothes for legitimate reasons, then the LR assigned given activity level propositions will be low, when considering propositions such as: "Mr X stabbed the victim" and "Mr X has nothing to do with the stabbing, but lives with the victim".

Conversely, if the probability of finding non-self DNA on a person is remote (e.g. if instead, the case information is that the suspect does not live with the victim and further claims that they have never met each other), then this considerably *decreases* the denominator (i.e., the probability of the results given the alternative proposition), thereby *increasing* the LR.

Recommendation 2:

A likelihood ratio is assigned using propositions that address issues at a specified level within the hierarchy of propositions. It is recommended that the hierarchical level of the propositions used in the LR assignment be clearly understood and explicit within the report. It is not valid to carry over a likelihood ratio derived from a low level, such as sub-source, to a higher level such as source or activity propositions. If the LR is carried over there is a risk of overstating the strength of the evidence with regards to disputed activities because the LRs given sub-source level propositions are often very high and LRs given activity level propositions will often be many orders of magnitude lower. Note, however, that the issues that are considered at the activity level are much closer to the deliberations of the court and are therefore more relevant

4.1. Can a scientist help evaluate propositions such as “He stabbed the victim” or does this usurp the court’s function?

This issue is addressed in detail by Biedermann et al. [41]. The question is whether a scientist can or should help assess the value of evidence when propositions relate directly to the activity or even offence. The objection being that evaluation of evidence in relation to a proposition such as: “He stabbed the victim”, or “He fired the gun” is too close to the ultimate issue of guilt/innocence. We agree that giving a direct opinion on propositions is beyond the scope of the scientist: this is true for any propositions (sub-source level, source, offence or activity level). And, indeed, the authors in [41] point out that there is an important distinction between the role of the court and the role of scientist. A common misconception is to believe that scientists evaluate the propositions provided. However, the scientist’s report relates only to the value of the forensic results *given* that the propositions representing the views of the parties, as understood, are true. This rationale follows evaluation of the ‘probability of the evidence given the proposition’ principle embodied in the likelihood ratio described in part I, sections 4.1.1 and 7. Accordingly, a competing defence proposition is necessary. To reiterate, the scientist offers no opinion about whether a proposition such as “He handled the knife” or “He stabbed the victim” is true or not because this would fall foul of the prosecutor’s fallacy (probability of the hypothesis given the evidence [46,47]). Rather, the scientist’s role is restricted to assigning the value of the DNA evidence in light of these propositions.

Oral or written statements such as those provided in a recent UK court of appeal ruling discussed in Part I (Regina versus Tsekiri)[48] are problematic:

"Secondary transfer was an unlikely explanation for the presence of the appellant's DNA on the door handle"

and

"The expert evidence was that the likely reason for the defendant's DNA profile being on the door handle was that he had touched it".

In the two examples above, the results are interwoven with explanations leading to transposed conditionals[5] . This can lead the court to think that based only on the DNA one can infer that it is very probable that the appellant touched the door. Statements explaining the results should thus be avoided in court as explanations do not allow an assessment of the probative force of the results (Recommendation 1).

Recommendation 3:

Scientists must not give their opinion on what is the ‘most likely way of transfer’ (direct or indirect), as this would amount to giving an opinion on the activities and result in a prosecutor’s fallacy (i.e. give the probability *that* X is true). The scientists' role is to assess the value of the *results* if each proposition is true in accordance with the likelihood ratio framework (the probability of the *results if* X is true and *if* Y is true).

4.2. When is it of value to rise in the hierarchy of propositions?

When DNA is present in small quantities, most importantly when activities (but not the (sub-) source) that led to the DNA are contested, then transfer, persistence and background DNA will have a strong impact on the case. In section 4, recommendation 2, the dangers of carry-over of a potentially huge likelihood ratio from sub-source to activity level were discussed. If there is no dispute about the (sub-source) origin of the DNA contribution, then the activities that led to the deposition of the biological material are of interest. To help the court address these issues, a new evaluation is required. Consequently, when the issue is

[4] The term ‘trace DNA’ is preferred to ‘touch’ or ‘contact’ DNA since the latter terms imply a mode of transfer that may be misleading: we cannot know if the activity of touching has actually occurred; the term 'contact' is vague. Activity-level considerations must be provided in properly formulated propositions; the term 'trace-DNA' is used to refer to the presence of low quantity DNA, and nothing more.

[5] Previous courts of appeal in the UK have strongly denounced the transposed conditional, yet we see the fallacy here.

related to "How the DNA got there?", the court will need an indication of the value of the biological results in the context of the alleged activities. Forensic scientists assess their results given activity level propositions, taking into consideration factors such as transfer and persistence; they bring knowledge that would not otherwise be available to the court. Depending on the issue with the case at hand, the biological results can be the electropherogram (EPG) or a DNA sequence data from one or multiple swabs; the relative quantity of DNA; the results of preliminary tests (e.g. presumptive tests). The question when to rise in the hierarchy will therefore depend on identifying the issue which forensic science can help with and on the forensic examinations that have been agreed to be undertaken. In the ENFSI guidelines [29], guidance note 2, there is an explanation that describes when it is appropriate to assess results given activity level propositions[6] . Scientists must be careful to ensure that when doing so, that they add value by the use of their specialised forensic knowledge and by considering factors (transfer, persistence, recovery, background) that have a significant impact on the meaning of the results.

Recommendation 4:

Propositions should be formulated at a level in the hierarchy of propositions, where the forensic scientist brings knowledge that is required, but not readily available to the court. This is crucially important when transfer, persistence and background DNA have a significant impact on the case. Activity level propositions are always considered separately to sub-source propositions.

4.3. Formulation of propositions

Formulation of propositions will depend on the case and on the person writing the statement. There are however, basic criteria described, for example in [1,24–26,43,45] and in the England and Wales, Forensic Science Regulator guidelines on mixture interpretation [49] section 6.5.3. These are as follows:

- A proposition should be formulated in such a way that it is reasonable for the scientist to address a question of the form "What is the probability of the observations given this proposition and the framework of circumstances'?".
- Propositions should be as simple and concise as possible and must be clearly stated. In a criminal trial, one of them will represent what the scientist understands to represent the position that the prosecution will take at court and the other will represent that of the defence.
- Propositions should be mutually exclusive and represent the two competing positions within an accepted framework of circumstance.

To prepare a statement from the case information, one would formulate propositions that allow the assessment of all the results where we can add value because of our specialised knowledge. In the examples below, we avoid using a negation of one proposition to formulate the other, in order to provide context. However, negation of a proposition is acceptable provided that the context is clear from the case information – and one can only mention the points which are disagreed between the prosecution and defence in the propositions. The case information is long and will not often be repeated, whereas the propositions are frequently repeated and this allows them to be simple and concise.

How propositions ought to be formulated in a given case is a matter of judgement. In the document mentioned above [49], it is advised that: "A suitably competent interpretation specialist (or however this role is named) should be consulted for advice on the propositions chosen."

4.3.1. Distinguishing results from propositions

In the companion article, part 1, section 4.2.1 [1], there is a discussion on the need to distinguish results from propositions, with examples involving sub-source level propositions. Hicks et al. [50] explain that observations should not be interwoven with propositions. An example of this error with activity level propositions would be:

- DNA of S transferred to the handle of the knife by stabbing the victim
- DNA of S transferred to the handle of the knife while cutting bread

Both propositions state that DNA of S has transferred to the handle of the knife. The probability of finding a DNA profile compatible with S on the knife handle (assuming probability of recovery equals 1) is therefore 1 under both propositions.

Hence the evidence is neutral (LR = 1) and the results do not allow discrimination of the propositions.

Recall from [1] (section 4.2) that it is necessary for propositions:

a) To be formed *before* the comparison process involving a person whose DNA presence may be contested.
b) To be formed so that scientists can assess all their results and account for their knowledge on transfer of DNA and presence as background (i.e., for unknown reasons).

An example of formulations of propositions at activity level that would allow scientists to consider relevant factors (i.e., transfer of DNA) for the evaluation of their results are:

- Mr S stabbed the victim with the knife
- Mr S only[7] cut bread with the knife and has nothing to do with the victim's stabbing.

If both parties agree that Mr. S used the knife for cutting bread, then this could only be mentioned in the case information and propositions could be:

- Mr S stabbed the victim with the knife
- Mr S has nothing to do with the victim's stabbing.

Indeed, in a statement, the case information will be detailed, and one can then summarize the positions so that propositions are concise.

See recommendation 2 in part 1 [1]: "Results should be clearly distinguished from propositions, as DNA specialists assess the former and decision makers the latter. Avoid terms like: 'the matching DNA comes from X.' "

4.3.2. An example of formulation of activity level propositions

For a real example, the reader is referred to the case of Amanda Knox where the prosecution accused her of stabbing the victim with a knife, which was found in her boyfriend's apartment [4] in a cutlery drawer. It was common ground that Amanda Knox regularly visited her boyfriend and cooked food for him. There was no dispute that DNA from Amanda Knox was on the knife handle. The judges in the first trial known as the 'Massei motivation' [4], convicted on the grounds: "….appears more likely to have been derived from her having held the knife to strike, rather than from having used it to cut some food." However, this was reversed by a later court hearing and criticized as erroneous logic.

Background information:

a) Amanda Knox used the knife to cut food
b) It was common ground that Amanda Knox visited her boyfriend's flat regularly and prepared food.

[6] "*Activity level propositions should ideally be used when the consideration of transfer mechanisms, persistence and background levels of the material has a significant impact on the understanding of the alleged activities and requires expert knowledge.*"

[7] The word "only" is included to reinforce the view that the knife was not used to stab the victim and cut food either before or afterwards.

c) There was a smell of bleach in the flat. The investigators hypothesised that the knife had been cleaned with bleach to remove blood.
d) Prosecution alleged that Amanda Knox had stabbed the victim with that knife
e) Defence alleged that Amanda Knox had not stabbed the victim, and that the knife was not the murder weapon

The DNA profile attributed to Amanda Knox on the knife handle cannot be used to distinguish between the activity of stabbing vs. the activity of cutting bread because both activities are considered to lead to indistinguishable biological results and is an example of activities leading to very close expectations. However, the absence of any bloodstains, the small quantities of DNA, and the presence of clean starch grains on the blade[8] could be evaluated.

To formally assess the probative value of these results, the propositions could be:

- Amanda Knox stabbed the victim with the seized knife
- The seized knife was not the murder weapon

The important point is to show that forensic scientists could help address the issue of interest and that there was sufficient background information for the evaluation of the results given activity level propositions.

Recommendation 5:

It is essential that propositions are formulated in such a way that one can assess the probability of the results given the propositions. The case information can help to define propositions in more detail, so that they remain concise and simple.

4.3.3. Avoid using the terms 'primary or secondary transfer' in activity level propositions

We have discussed in section 4.1 that the probability of the propositions is the domain of the court, whereas the probability of the results is the domain of the scientist.

In 4.3.1, we pointed out that we must avoid evaluation of 'the probability of transfer given that there is transfer' because this will result in a probability of recovering DNA equal to one. The term 'transfer' (if meant as transfer, persistence and recovery of DNA) should not appear in propositions, as it is a factor that scientists take into account in their evaluation. Now, if the term transfer is associated with 'primary' or 'secondary', then because these terms are associated with activities, it is for the court to assess which is the most probable, based on the results and the other elements of the case. Because of this ambiguity, we recommend avoiding the use of the terms 'primary or secondary' transfer in propositions, or their corollaries (direct/indirect) described in section 6.1. Moreover, because of the vagueness of the words, it is best to focus on the activities.

Recommendation 6:

Results or factors that scientists take into account in their evaluation should not be interwoven into the propositions. The scientist should avoid the use of the term 'transfer' in propositions. Instead, there should be a focus on the alleged activities.

4.3.4. Pseudo activity level propositions

Propositions at the activity level, which are used to *only assess the DNA profiling results,* would generally be considered as 'pseudo' activity propositions [51]. They are called 'pseudo-activity' because they look as if they focus on more than the source of the DNA, but in fact only consider the DNA profiling results (so that the value is the same given sub-source or pseudo-activity level propositions).

Pseudo activity level propositions are characterised by their vagueness, particularly in terms of the activity and the time-frame when the alleged 'contact' occurred. The following example is adapted directly from Evett et al [51], who defined the concept. Consider the proposition:

- The suspect has recently been in contact with Ms. Y

This proposition may be informed only by the DNA evidence (an electropherogram) where the LR given sub-source propositions has been calculated and there is strong evidence to support the contention that the suspect has contributed DNA to the clothing of the victim (Ms. Y).

There are a number of problems with this that are pointed out by Evett et al. [51], summarised as follows:

1) It is difficult to know what the word 'contact' means: it could mean that the suspect had unbuttoned Ms. Y's blouse and touched her brassiere; or brushed against her whilst passing her in the street.
2) There is a difficulty with the word 'recent'. It is a vague term that could mean anything from 0 to 100 hours or more since the 'contact'.
3) It is not possible to state a clear mutually exclusive alternative proposition. If the alternative is proposed as: "The suspect has not recently been in contact with Ms Y", then the LR is the same as given sub-source propositions. This is unhelpful if the so-called 'contact' was 'innocent' social. There is no distinction between the two kinds of 'contact'.

In order to move forward to activity level, the propositions must be focused on the activity. With the above example, suppose the suspect denies the assault but says that he remembers brushing past Ms. Y In the street four days previously. The propositions can now be formulated against narrowed time-frames:

- The suspect unbuttoned Ms. Y's blouse and touched her brassiere on the day of the assault

- The suspect had brushed against Ms Y in the street, four days before the assault

In our evaluation (i.e. LR), we can now consider transfer, persistence and recovery of DNA, given the case information (e.g., respective timeframes) and this can be informed by data/knowledge. Evett et al. [51] conclude in an example where the activities were the same, but timing was different: "The closer the two time frames [be]come, the closer the LR necessarily approaches one and the deliberations of the court are governed by the non-scientific evidence." The same applies to the activities, the closer they are, the more difficult it is to discriminate them based on forensic results.

Recommendation 7:

Activity level propositions should focus on the alleged activities. If the proposition is too vague (this can be the case if the word 'contact' is used), it will be difficult to assign a probability to the results given the proposition.

5. Definition of DNA transfer

The term 'transfer' is very widely used in the forensic community, but its meaning is not necessarily clear within the context of DNA. Transfer is defined as "An act of moving something to another place" (Oxford English Dictionary), but in the context of activity level propositions, what forensic scientists need to do is assign the probability of their results, that is of *recovering* a given quantity of biological material **given** the alleged activities.

Fig. 1 illustrates the relationship between activities, transfer of DNA and its recovery. First, there is an activity between two individuals or objects where the direction of transfer of DNA is from A to B. Whether, and how much DNA is transferred will depend upon various factors. Then there is the question whether DNA from A will persist. This will depend upon factors like the environment in which the DNA/object is

[8] Starch grains are highly absorbent. There was no evidence that blood had been absorbed. The prosecution contended that the knife had been cleaned with bleach to remove the blood (but the defence countered, as a potent agent, that this would remove all traces of DNA as well).

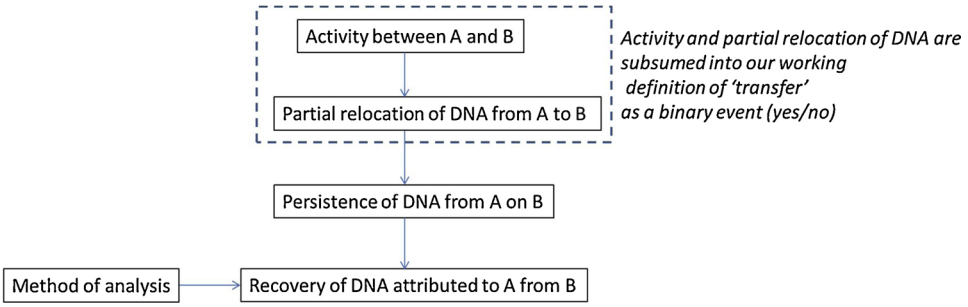

Fig. 1. legend: The flow chart shows the progression of DNA, from A to B, when an activity takes place and involves two objects or individuals. Each step is dependent upon the previous one, denoted by the arrows. In the final step the recovery of DNA is dependent upon the activity, partial relocation of DNA, its persistence and method of analysis. Note that partial relocation of DNA between B and A will also occur, but is not considered here.

located and any further activities with the object. In order to visualise DNA, there must be sufficient present to recover in the analysis so that it presents above the limit of detection threshold of the analysis. This will also depend upon the targeting of the right sampling location, method of sampling and analytical method. Modern multiplexes are much more sensitive than older versions, hence it is more likely to produce a DNA profile from low levels of starting material.

Consequently, the probabilities of a given (relative) quantity of DNA being transferred from a person given an activity, and subsequent persistence and recovery of evidence all have to be assigned [44]. The subsequent evaluation of DNA results may well require the consideration of different probabilities of so-called transfer (Fig. 1), under the two respective activities alleged by the parties. But the scientist must always ask: "What is the probability of *obtaining*[9] these DNA results if the person has done the alleged activity (e.g., stabbing)?"

Note that in the literature, the probability of transfer is usually used to mean the probability that material will transfer, persist and be recovered given some alleged activity. This has led to misunderstandings. Strictly, we should be thinking in terms of activities between individuals or objects as the event of interest. This is followed by transfer of DNA between objects/individuals. In order to be consistent with the literature, in the subsequent text we propose to retain the term 'transfer' as a general term used to describe the phenomenon or event as it can be observed in experiments (Fig. 1). But in case-work, to describe the *probability* that DNA has been *transferred*, has *persisted* on an item and has been *recovered* in quantities great enough to be profiled/genotyped, we propose to use the term *'probability of recovering biological material'* instead.

Consideration 1:

Probability of transfer is a term that has been used to describe two different concepts: when used with the terms primary/secondary transfer, this event is a direct consequence of an activity. But, the term 'transfer' is also used by scientists to designate the probability of a given (relative) quantity of DNA being transferred, having persisted and being recovered if the activity took place. The scientist can only assign the *probability of recovery* of DNA that is also conditioned upon an activity. Any further evaluation must be based upon properly phrased propositions specifying the alleged activities.

5.1. Definitions of types of transfer

In experiments, to summarize the activities and to explain the presence of DNA, transfer can be defined as a consequence of an activity with a person or object and subsequent movement of DNA between two persons/objects. Outside an experimental regime, if DNA is recovered as a result of an activity in case work, we do not know the mechanism of transfer but we can generalise two kinds:

1) Direct (primary) transfer: Where DNA is transferred from one person to another or to an object without an intermediary surface being involved ([52], page 432).
2) Indirect (secondary or further transfer): Where DNA is transferred from one person to another or to an object with an intermediary object/person involved.

An example of indirect transfer could be when DNA from person A is transferred onto a chair and subsequently picked up on the skin or clothing of person B who sits on the same chair. Tertiary and subsequent transfers can also occur [52], page 432. The term 'indirect transfer' is generic and subsumes secondary, tertiary and subsequent transfers.

Definitions of direct and indirect transfer are useful to describe the respective phenomena and can be used as a basis to think about the different explanations for the recovery of DNA to assign the value of the results. The reader will have noticed the use of the word 'explanations' and will therefore be aware that these are best suited to consider in our roles as investigators (part I, section 2.1 [1]). When planning experiments, it will also be useful to be aware of the different mechanisms of transfer. But, for *evaluative* purposes, we focus on the results e.g. the recovery of a given quantity of DNA. Recall from section 5, we chose to use the terms: 'recovering DNA' instead of 'transfer of DNA'. Hence direct and indirect transfers are generally the consequence of activities alleged in the case. It does not make sense to think in terms of 'direct and indirect *recovery* of DNA', instead the correct formulation is the 'probability of DNA recovery given the activity that implies direct transfer', and the alternate 'probability of DNA recovery given an activity that would involve indirect transfer'. It is important to avoid an expression: 'probability of direct transfer given DNA recovery' as this confusion is a transposed conditional.

Recommendation 8:

The assessment is always made on the basis of the probability of DNA recovery conditioned on the activity that generally implies events of direct (or indirect) transfer and the persistence of material.

5.2. Definition of DNA depositions: background and prevalent DNA

There are two kinds of DNA depositions that are unrelated to any crime event because they pre-exist as part of the natural environment[10]. They include *background* DNA and *prevalent* DNA which are defined as follows (with examples given):

1) **Background DNA:** DNA that is present from *unknown* sources and *unknown* activities. It can be described as 'foreign' (non-self). We don't know how or why it is there. For example:

[9] Strictly this is transfer, persistence and recovery of a given (relative) quantity of DNA.

[10] It is also possible that they can be added post-crime-event (e.g. accidentally by investigators or other actors). As this event can be avoided by protective measures, it is best to use a third term to describe. Contamination is defined by a previous ISFG DNA commission [[53]] as: "DNA introduced after the crime has happened and from a source that is unrelated to the crime scene: for example, the investigating officer, laboratory technicians, laboratory plastic ware ". Background DNA, on the other hand, cannot be avoided.

2) DNA underneath fingernails from unknown sources/activities
3) Non-self DNA on clothing from unknown sources/activities
4) Non-self DNA on a surface from unknown sources/activities

Background DNA can be assessed by experimentation, for example on control areas of the same exhibit [54].

1) **Prevalent DNA:** DNA that is present from *known* sources/activities that includes 'self-DNA'[11] . The analyst has a prior expectation of finding DNA from specific individuals. Specific examples of prevalent DNA are:
2) DNA from a person observed on swabs taken from underneath her/his own fingernails
3) DNA from clothing taken from a known wearer.
4) DNA from a surface where there are known occupants at a premises.

The context of prevalent DNA is case-specific. Its presence is based upon an expectation given close proximity of a known individual to the item of interest (e.g. the wearer of an article of clothing [55]). Samples may be taken to assess the prevalence of DNA of a known individual on an item or at a crime scene. A reference sample would usually be collected from the known individuals for comparison purposes and compared to samples from the item of interest.

Consideration 2:

At a crime-scene, DNA, not associated with the alleged activities, can be divided into two broad categories: *background* DNA from unknown activities and *prevalent* DNA from known sources (whose presence is not contested) and known activities.

6. Criteria that evaluation given activity level propositions should meet

Statements should be balanced, logical, transparent and robust [29]. We have discussed the necessity to consider our results in the light of two propositions; this achieves balance. To assess the value of the results we use the same metric (i.e. a likelihood ratio), as advocated by previous ISFG DNA commissions in relation to mixture analysis [53,56] or paternity cases [57]. The use of likelihood ratios in the context of forensic biology was advocated more than 30 years ago, and demonstrated by Ian Evett's publication in 1984 [58]. The application of the principles of interpretation (cited in our first paper [1]) ensure statements are logical. We discuss transparency and robustness below.

6.1. Transparency

Statements given activity level propositions ought to disclose all the important information and assumptions so that the conclusions derived are demonstrable and understandable by a large audience. Probabilities derived while considering results in the light of activity level propositions are often more largely based on personal knowledge than probabilities assigned when dealing with sub-source propositions. Therefore, it is crucial to explain in a transparent way how and on what basis probabilities were assigned.

6.2. Robustness

In order to ensure that our statements are robust (i.e., capable of sustaining scrutiny and cross examination), they ought to be based on data, knowledge and experience. These are discussed in detail later. Knowledge and experience imply that the scientists have received formal education on this topic and have performed (or are aware of) transfer experiments where the ground truth was known.

In a given case, because of *post-hoc* rationalisation, it will be important that one assigns the probability of recovering say 'a major profile' before knowing what the actual results are. Indeed, if one knows the result beforehand, then confirmation bias is needlessly introduced which makes it very difficult to separate observation from expectation. This will typically be done in the pre-assessment stage. To prevent bias, if testing is already completed, one can refer the case to a colleague[12] . This is facilitated with Bayesian Networks (discussed below) which are very valuable tools to pre-assess cases, because they are structured in an unbiased way, taking account of all possible outcomes, thereby allowing the probabilities to be assigned without prior knowledge of results.

Bayesian Networks can also show what impact lack of data or lack of information have on a specific case. Taylor et al [59] point out that the effect on the value of the results (LR) may be explored with sensitivity analysis as described in the supplement, Fig. 3. Sensitivity analysis [63] offers a transparent approach because the effect of different factors on the evaluation can be simulated. Taylor et al also recommend: "If there is a paucity of data used to assign a probability to which the LR is particularly sensitive, then this may indicate that the opinion of the scientists requires careful investigation of its robustness. This may lead to situations in which the scientist may decide not to report a result, because of concerns about robustness." These matters should be reported before being heard in court.

7. Research and data relevant to the case

Expert opinion must be underpinned by experimental data. The scientist should be transparent as to the experiments that have been used in order to assess the value of the results given both propositions. When deciding to use given data, the expert must use judgement and justify his/her choice. As Evett and Weir [28], page 47, state:" The theory of statistics […] operates within a framework of assumptions, but it needs to be applied to real-life problems. The forensic scientist needs to judge whether the assumptions appear reasonable in the individual case. […] In the final analysis, the scientist must also convince a court of the reasonableness of his or her inference within the circumstances as they are presented in evidence." There is an onus on the scientist to justify that the data used are appropriate for a given case.

7.1. Source of knowledge

As underlined in the "ENFSI guideline for evaluative reporting" [29], the two probabilities that make the likelihood ratio are assigned based on knowledge. Whenever possible, relevant published data should be used. The source of the knowledge should be disclosed and the limits of the data discussed. In the absence of published data, calibrated[13] experience, case tailored experiments, peer consultation can be used. In any case, the use of the data needs to be justified and the expert should be transparent on the limitations of the data. Viewpoints, based solely on personal casework experience should be avoided. The responsibility of the scientist when testifying to a court is to represent the 'view of the community of scientists' such that similar views should be expressed or held by different informed individuals, as far as is possible[14] .

[11] Self-DNA is from the known individual wearing an item of clothing, for example. Non-self-DNA would be from a partner who has had contact with the item of clothing – perhaps by hanging laundry out to dry.

[12] Case information management is reviewed by Taylor et al [59]:" Thompson et al [60] and Dror et al. [61] consider the option of introducing a case manager to 'filter' task-relevant from task-irrelevant information. Such a case manager would need substantial training in case assessment, as well as interpretation of DNA evidence, to be able to identify task-relevant information for evaluation of findings given activity level propositions [62]"

[13] Experience based on known ground truth experiments.

[14] Noting that it is impossible to achieve 100% consensus viewpoint of scientists. Peer reviewed articles is a good way to demonstrate consensus. Also, they offer an opportunity to stimulate debate.

Viewpoints must always be based on experimentation and peer reviewed literature. Intuition is a poor substitute to experiments, and practitioners should avoid giving opinions based on what they have 'seen' in cases, since the truth-state is always unknown.

Recommendation 9: In the statement, the source of the data that are used to provide the probabilities should be disclosed, as advised in the "ENFSI guidelines for evaluative reporting" [28].

7.2. Experimental design and reproducibility

Although there are now a large number of studies that investigate issues of transfer, persistence and prevalence of DNA, a question to consider is whether such studies can be utilised by other laboratories that are inevitably using different sample recovery methods, extraction methods, multiplexes and cycling regimes.

Multiplexes used prior to c. 2006 were markedly less efficient compared to modern versions. This means that the tests were not as sensitive as they are today. This will automatically translate into relatively low DNA recovery rates compared to modern multiplexes that are much more efficient to detect DNA from just a few cells. Consequently, when low-template protocols are used, detection thresholds should be broadly comparable (since we are approaching a theoretical limit of detection – a single haploid genome weighs 3 pg).

Therefore, caution is required when using pre-2006[15] data using the old systems to make inferences in cases where modern multiplexes are used, particularly if we are interested in quantitative recovery of DNA.

Studies that have collated levels of major/minor contributors in relation to activities such as victims scratching an attacker provide useful information about their relative contributions recovered underneath fingernails [64] – this kind of comparative information has lower dependency upon technique used. For example in a study by van den Berge et al [19] when considering activity scenarios (dragging or grabbing a victim), the overall percentage that the perpetrator represented the major contributor was 36% while the victim was the major in 24% of all 94 controlled activities (no major was observed in 39% of the profiles).

There are very few studies [45,65] where a concerted effort was made to assess the interlaboratory effect of transfer, persistence and recovery of DNA. The first exemplar [65] studied cable ties used to constrain a victim. Four different laboratories used different methods, for example, extraction methods included QIAamp, Chelex, Qiagen and DNA IQ; four different multiplexes were used and both AB3130 and AB3500 instruments were used. Likelihood ratios were calculated given the propositions “The POI has tied the cable tie” vs. “An unknown individual has tied the cable tie, but the POI has touched it a week before”.

The results were a single source DNA profile compatible with the POI. The source of the DNA was uncontested.

Three probabilities were determined by experimentation:

r = probability of recovery, transfer and persistence of DNA from the POI given prosecution proposition

r' = probability of recovery, transfer and persistence of DNA from the POI given defence proposition

r_0 = the probability of not recovering any DNA from the unknown offender given defence proposition

The LR formula would be $LR = r/r_0r'$.

The study showed that LRs were close (ranging between 60–290), despite the variation in techniques utilised, and this provides a basis for other laboratories to use these data.

Consideration 4:

There are some important points to be made about experimental designs used to determine probabilities:

a) **Be clear about the statistical model that will be used to assign the likelihood ratio beforehand, as this will dictate the factors to take into account and the data that will be needed.**
b) **Data within the same experimental design should ideally be used because *recovery* is dependent upon the sensitivity of the technique used in the analysis i.e. the probability of recovering DNA is increased given *both* prosecution and defence propositions with a more sensitive method. It could be misleading to take data from different experimental designs without any consideration of the difference in methods.**
c) **Alternatively, it has also been proposed** [43,66,67] **that laboratories could determine efficiency factors of commonly used collection devices and methods and extraction methods etc. If invariable, this may enable corrections to be applied across different techniques employed.**
d) **Experimental designs should at the same time, provide knowledge to assign for example the probability of DNA recovery given the activities alleged respectively by defence and prosecution.**
e) **Laboratories are encouraged to carry out comparative studies to parallel their results with others.**

It would be helpful to the forensic community if FSI: Genetics, the ISFG and other organisations support an open-data initiative in order to facilitate data-exchange and to aid the development of knowledge bases [68–70].

8. Examples of evaluation of DNA results given activity level propositions

Here, we will discuss two illustrative examples describing how one can assess biological results in the context of alleged activities: DNA recovered from underneath fingernails and the absence of ‘matching’ DNA.

8.1. DNA underneath fingernails

The circumstances - based on a real case [R v Weller [2010] EWCA Crim 1085 (UK)] - could be as follows: on December 31st, during a party Ms Doe was feeling unwell. The host, Mr Smith, brought her in one of the bedrooms upstairs so that she could lie down. All the other guests left the party. During the night, both parties agreed that Mr Smith had been looking after Ms Doe while she was unwell (she had vomited several times).

According to Ms Doe, while she was semi-conscious, someone had taken her underwear off, fondled her and had then inserted his fingers in her vagina. She believed it was Mr Smith. She reported the events to the police 6 h later, who immediately went to Mr Smith’s house.

Mr Smith declared that he had been in the room where Ms Doe was sleeping, but had not sexually assaulted her. He had however taken care of her, while she was vomiting in the bathroom. Specifically, he said he had to pull the hair out of her eyes to stop her vomiting on it. He had helped her into bed. When in bed he had checked her several times and on one occasion had to put her into the recovery position. He also had picked up her clothes, including her knickers which she had left on the floor. He strongly denied the account of the sexual assault that she had given. He suggested that she may have dreamt the whole story[16] .

The police swabbed underneath Mr Smith’s fingernails for DNA analysis. Intimate swabs were also taken from Ms Doe.

Ideally, the propositions are set before the results are known (following section 4. 3.1) and in this case they could be:

[15] Labs introduced new multiplexes at different times so this date is not a strict cut-off.

[16] Similar cases were reported in the Netherlands using RNA typing to help demonstrate the presence of vaginal cells: https://uitspraken.rechtspraak.nl/inziendocument?id=ECLI:NL:GHARL:2014:5505 https://uitspraken.rechtspraak.nl/inziendocument?id=ECLI:NL:RBNNE:2015:2145; https://www.recht.nl/rechtspraak/uitspraak/?ecli=ECLI:NL:RBOBR:2016:4724; https://www.recht.nl/rechtspraak/uitspraak/?ecli=ECLI:NL:GHAMS:2018:2656; https://uitspraken.rechtspraak.nl/inziendocument?id=ECLI:NL:RBROT:2019:3840

- Mr Smith inserted his fingers in Ms Doe's vagina
- Mr Smith did not sexually assault Ms Doe

Because the case information would be fully reported in the statement alongside with the background information, then it is clear what is meant by 'did not sexually assault'. In such a case, one can assess the probability of the results given the propositions and the case information, so that the use of term 'not' is not problematic.

Here we focus only on the DNA recovered from the fingernails of Mr Smith where the results show a mixture with a full female profile corresponding to Ms Doe. Both parties agreed that the DNA was from Ms Doe and on the fact that Mr Smith had been looking after Ms Doe while she was unwell. Given prosecution's view of events there is one main[17] possibility: the DNA from Ms Doe has been transferred and recovered because Mr Smith inserted his fingers in Ms Doe's vagina. Given the defence's account, this DNA was recovered because Mr Smith looked after Ms Doe while she was vomiting. It is therefore necessary to assign the probability of this DNA having transferred, persisted for 6 h and being recovered given both propositions. We seek the probability of the DNA results (i.e. full minor profile corresponding to Ms Doe) being obtained given the competing propositions. If Mr Smith carried out the activity alleged by prosecution, denote the probability of the results as *r*. We assign the probability of the same results but this time given the defence alternative and denote this probability as *r'*. The ratio *r/r'* allows us to assign the value of the results in the context of the alleged activities. An example of a conclusion based on a hypothetical case is as follows:

"*The probability of observing this relative quantity of DNA underneath fingernails, if Mr Smith inserted his fingers in Ms Doe's vagina, is in the order of 0.6. This assignment is based on the study of Flanagan, N. and C. McAlister* [71] *as well as on N experiments carried out in our laboratory using the same analysis method as used here.*

The probability of observing this quantity of DNA if Mr Smith did not sexually assault Ms Doe is in the order of 0.1. This assignment is based both on the publication of Dowlman et al. [72] *and N experiments carried out in our laboratory using the same analysis method as here.*

This means that, given the information at hand, it is in the order of 6 times more probable to observe this DNA result if Mr Smith inserted his fingers in Ms Doe's vagina, rather than if Mr Smith did not sexually assault her.

My approach to the examination and evaluation of the results in this case is crucially dependant on the information made available to me. If any are incorrect or if further information is made available, please contact me as I will need to reconsider the value of the results."

8.2. Absence of evidence

There is further debate on the probative value of 'absence of evidence' in Hicks et al [73] which explain how a formal evaluation can be carried out under this circumstance. We go back to the Amanda Knox case (discussed in section 4.3.2.), and consider only the absence of the victim's blood on the knife, or more precisely the fact that the test for blood was negative. What is the probability of this result if the knife had been used to murder someone and the knife had been subsequently cleaned with bleach? If we have negative results for blood, then this means that (a) there was no blood as background (which happens with probability b_0) and that there has been no blood that has been transferred, persisted and been recovered after the stabbing and bleaching. This event happens with probability r_0. This probability r_0 cannot be one, as it is complementary to the event 'blood is transferred, persists and is recovered'. If the probability of this event was zero, then one would not have analysed the knife in the first place. Clearly there is some probability, under the prosecution hypothesis, that blood should be detected on the knife (otherwise, why proceed with the analysis?).

Conversely, given that the seized knife was not the murder weapon, if one were to recover blood, it would be present for some unknown reason (i.e. background). There is high expectation of finding no blood as background, hence this probability (b_0) is high. The LR formula would be equal to $(r_0 b_0) / b_0$; if we consider that the probability of finding blood for unknown reasons on this knife is the same given both propositions, b_0 cancels hence the likelihood ratio must be less than one, supporting the proposition that the seized knife was not the murder weapon. With this example, we see that even if there are no structured data to allow assessment of r_0, it is possible to show that the absence of results supports the alternative.

Taylor [74] gives another example of evaluation of absence of evidence. In this case the significance of an absence of trace DNA on clothing items from a suspect and victim is evaluated. Under one proposition, the suspect attempted to drag the victim into his car whereas the alternative proposition was that the suspect had never touched the victim and defence even questions whether any offence took place. In this case, the absence of (matching) DNA also supports the proposition that the suspect never touched the victim. Taroni et al [75] also discuss the absence of evidence in different situations.

Recommendation 10:

a) **All findings (both presence or absence of biological material) relevant to the issue that is considered should be included in the evaluation.**

Consideration 3

1) **Absence of biological material from a person of interest (POI), where there is an expectation of an observation under prosecution's proposition, will generally support the competing defence proposition.**
2) **If an alternate, unprofiled, offender is being suggested then the presence of a profile that is different from the POI will generally add further support to the competing defence proposition.**

9. Using bayesian networks

There is considerable interest in the use of Bayesian Networks (BNs) as a tool to help evaluate evidence. The advantage of the BNs is that they can be used to evaluate complex results that would be very difficult to evaluate by deriving formulae. For detailed information about BNs, the reader is referred to the literature review of Biedermann and Taroni [76]. BNs are extremely useful to help us think about a problem, because it forces us to consider the relevant possibilities in a logical way. A further advantage of Bayesian networks is that (in the absence of data) they can be used to inform an experimental design.

A series of input probabilities are used to propagate an output that is conditioned upon the propositions representing respectively defence and prosecution views as understood.

The output probabilities provide information about the probabilities of the biological results (e.g. quantity and profile with given characteristics) conditioned on alternate activities, such as those described previously. For a comprehensive study and examples, using a clear methodology, the interested reader is referred directly to [77]. In addition, Supplement 1 provides a further discussion with examples following the lines detailed in the above publication.

[17] There are other possibilities (a) no DNA was transferred during digital penetration and DNA was transferred while he was taking care of her or (b) the DNA was transferred by both mechanisms. For simplicity we ignore this in our discussion here, but using a Bayesian Network we could account for all possibilities.

10. The use of verbal equivalents

Verbal equivalents to the likelihood ratio [29,78–80] are often used to express value of evidence. The verbal scale parallels orders of magnitude scaling. It must be emphasised that first one assigns a LR and then one can add a verbal equivalent. One cannot do the reverse. Indeed, the value of the results (a LR) is a number. Words can then be assigned to brackets of numerical values that are used as a descriptor of their support for a proposition. These 'verbal equivalents' are by nature subjective and a number of verbal equivalence tables have been published. So, it is above all a convention. The qualitative verbal scale is a secondary consideration to the compulsory (quantitative) likelihood ratio. There are many variations, but the categories of the scale published as an example by ENFSI [29], page 17, are neutral support (1) limited support (LR = 2–10); moderate support (LR = 10–100); moderately strong support (LR = 100–1000); strong support (LR = 1000–10000); very strong support (LR = 10,000–1,000,000) and extremely strong support (LR > 1,000,000). The verbal scale ends with likelihood ratios greater than one million because with large numbers it is difficult to describe with words in a meaningful way[18]

However, there is convincing evidence that use of a verbal scale alone does not properly convey the intended meaning of the expert [81,82]. When evidence is expressed as 'weak' or 'limited' this may be misinterpreted as providing support for the defence, hence this is called the 'weak evidence effect'. This effect was not observed if numerical evidence was provided. Conversely, if the value of evidence is high, there is little difference between numerical vs verbal equivalents in the conveyance of intended meaning. In this respect it is clear that more research is needed in order to discover the effect of the vagaries of language.

If the verbal scale is to be used in court, it is important that it is always accompanied by a numeric expression of the value of evidence, especially when the value of the evidence is weak/limited [83]. It makes no sense to give qualitative verbal evidence by itself that is not underpinned by a quantitative LR. Furthermore, some effort should be expounded to educate jurors so that the weak evidence effect may be mitigated. For example, by explicitly stating that a low likelihood ratio that is greater than one does not provide support for the defence proposition [83].

Recommendation 11:

The verbal scale is optional but cannot be used by itself. If it is used, then the numeric equivalents must also be available/provided. In practice, one would provide first one's likelihood ratio, then the verbal equivalent is applied afterwards.

An example would be: "My LR is in the order of 60. This means that - in my opinion - the results are much more probable (in the order of 60 times) if the proposition that 'X' is true than if the alternative 'Y' is true. According to the verbal scale used in our laboratory, these results provide moderate support for the first proposition rather than the alternative." These 'verbal equivalents' are by nature subjective and a number of verbal equivalence tables have been published. So, it is above all a convention.

11. Communication between scientists and the court

It is essential that the court environment is conducive and is flexible enough to allow scientific exchanges to occur. Interpretation of evidence is a complex area and there are many pitfalls for the unwary. One of the most difficult tasks is to convey that as scientists we give the value of the results and not our opinion on the propositions or activities or on the way the DNA was transferred. Some laboratories alert to this aspect in their statements. An example is given below:

" Please note that our laboratory does not provide any assessment on how likely it is that the first proposition or the alternative proposition is true. Indeed, this probability (e.g. The defendant opened the victim's door, i.e., the DNA resulted from primary transfer) is the domain of the court: one needs to combine all the information of the case in order to make such a statement."

Communication between scientists and the court can be compromised by the fact that they use different languages (i.e., lawyers and scientists might use the same terms to designate different concepts), different goals and different backgrounds. Consequently, education of judges and all actors in the criminal justice system in order to avoid miscarriages of justice could be highly beneficial to the society. Scientists working for the defence and prosecution should be educated to equivalent levels and have equal access to resources as part of the system of checks and balances. The EUROFORGEN Network's "Making Sense about Forensic Genetics" guide [6], the free 'massive open online course' (MOOC) entitled "Challenging Forensic Science: how Science should speak to Court"[19] and the "ENFSI guideline for evaluative reporting" [29] are steps forward to produce accessible documents/education that enhance understanding.

12. Concluding comments

In conclusion, we would like to underline that while sub-source level propositions are of great value for investigation purposes, they do not help to address questions on 'how' the DNA got there or 'why'. Said otherwise, evaluation of DNA given sub-source propositions does not provide any information on the mechanisms or actions that led to the deposition of the biological material concerned. It might be tempting for scientists to report a high DNA statistic and then explain their results in court. However, because this can be misleading, we urge scientists not to give explanations in court e.g., "the most likely explanation for this DNA quantity is primary transfer". Instead, most importantly when the source of the DNA is uncontested, biological results should be assessed given activity level propositions. The basis of the assignment of the value of these results must be explicit in the report and justified. Indeed, probabilities used to inform likelihood ratios are dependent on data, knowledge and case information. Stating the limitations both in terms of case information, as well as data to infer probabilities is essential. Indeed, there are many unknown variables associated with casework, as there is in the criminal trial or life in general. A caveat in the statement will reinforce the point that evaluation is strictly conditioned upon the case-information that has been put forward.

While knowledge is important, viewpoints, based solely on personal casework experience should be avoided. The responsibility of the scientist when testifying to a court is to represent the 'view of the community of scientists' such that similar views should be expressed or held by different informed individuals, as far as is possible. The use of Bayesian Networks as an exploratory tool can provide information about the impact of variables on the value of the evidence. If there is a lack of information that prevents assessing the value of the results given activity level propositions, and if transfer and background levels have a high impact in the case, then the court must be made aware of this aspect.

Because methods of analysis and retrieving evidence differ between laboratories, scientists must use their judgement and justify if the data used is fit for purpose (e.g., the experimental design used to collect the data need to be comparable to the methods used in the case). Compilations of experiments are encouraged as a basic validation of use of data from other laboratories, with details of methods used in order to derive the probabilities that can be utilised. An ENFSI supported inter-laboratory example is outlined by [65].

Access to data, for both defence and prosecution scientists, are important to ensure that the results have been assessed in a robust way.

[18] Strong; very strong; extremely strong – there are about three limits to the categories of strong that can be described.

[19] https://www.coursera.org/learn/challenging-forensic-science

Evaluation of biological results can be a challenge, in particular because the lack of funding for research and education on such aspects. We urge policy makers to consider this when making their decisions on prioritisation of projects. Education at all levels of the criminal justice system is a critical recommendation, not only for forensic scientists, but also for the court and the police. Indeed, in some cases, it may be important to establish background and prevalent DNA levels by taking additional samples from crime-scenes or items. It is essential to identify the key questions as early as possible in order to analyse the relevant samples to help answer the relevant questions.

Acknowledgement

We are grateful to Christophe Champod for reviewing an earlier draft of the manuscript and making some important and inciteful observations which greatly improved the final text.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.fsigen.2019.102186.

References

[1] P. Gill, T. Hicks, J.M. Butler, E. Connolly, L. Gusmao, B. Kokshoorn, N. Morling, R.A.H. van Oorschot, W. Parson, M. Prinz, P.M. Schneider, T. Sijen, D. Taylor, DNA commission of the International society for forensic genetics: assessing the value of forensic biological evidence - Guidelines highlighting the importance of propositions: part I: evaluation of DNA profiling comparisons given (sub-) source propositions, Forensic Sci. Int. Genet. 36 (2018) 189–202.

[2] G. Jackson, S. Jones, G. Booth, C. Champod, I.W. Evett, The nature of forensic science opinion–a possible framework to guide thinking and practice in investigations and in court proceedings, Sci. Justice 46 (1) (2006) 33–44.

[3] I.W. Evett, P.D. Gill, G. Jackson, J. Whitaker, C. Champod, Interpreting small quantities of DNA: the hierarchy of propositions and the use of Bayesian networks, J. Forensic Sci. 47 (3) (2002) 520–530.

[4] P. Gill, Analysis and implications of the miscarriages of justice of Amanda Knox and Raffaele Sollecito, Forensic Sci. Int. Genet. 23 (2016) 9–18.

[5] P. Gill, Misleading DNA Evidence: Reasons for Miscarriages of Justice, Elsevier, London, 2014.

[6] Making Sense of Forensic Genetics, Sense about Science, 2017, http://senseaboutscience.org/wp-content/uploads/2017/01/Making-Sense-of-Forensic-Genetics.pdf.

[7] R.A.H. van Oorschot, G. Glavich, R.J. Mitchell, Persistence of DNA deposited by the original user on objects after subsequent use by a second person, Forensic Sci. Int. Genet. 8 (1) (2014) 219–225.

[8] M. Goray, S. Fowler, B. Szkuta, R.A. van Oorschot, Shedder status-An analysis of self and non-self DNA in multiple handprints deposited by the same individuals over time, Forensic Sci. Int. Genet. 23 (2016) 190–196.

[9] M. Goray, R.A. van Oorschot, The complexities of DNA transfer during a social setting, Leg. Med. (Tokyo) 17 (2) (2015) 82–91.

[10] A.E. Fonneløp, H. Johannessen, T. Egeland, P. Gill, Contamination during criminal investigation: Detecting police contamination and secondary DNA transfer from evidence bags, Forensic Sci. Int. Genet. 23 (2016) 121–129.

[11] A.E. Fonneløp, T. Egeland, P. Gill, Secondary and subsequent DNA transfer during criminal investigation, Forensic Sci. Int. Genet. 17 (2015) 155–162.

[12] V.J. Lehmann, R.J. Mitchell, K.N. Ballantyne, R.A. van Oorschot, Following the transfer of DNA: How does the presence of background DNA affect the transfer and detection of a target source of DNA? Forensic Sci. Int. Genet. 19 (2015) 68–75.

[13] M. Breathnach, L. Williams, L. McKenna, E. Moore, Probability of detection of DNA deposited by habitual wearer and/or the second individual who touched the garment, Forensic Sci. Int. Genet. 20 (2016) 53–60.

[14] L. Samie, T. Hicks, V. Castella, F. Taroni, Stabbing simulations and DNA transfer, Forensic Sci. Int. Genet. 22 (2016) 73–80.

[15] A.K. Buckingham, M.L. Harvey, R.A. van Oorschot, The origin of unknown source DNA from touched objects, Forensic Sci. Int. Genet. 25 (2016) 26–33.

[16] C.M. Cale, M.E. Earll, K.E. Latham, G.L. Bush, Could Secondary DNA Transfer Falsely Place Someone at the Scene of a Crime? J. Forensic Sci. 61 (1) (2016) 196–203.

[17] B. Kokshoorn, B. Aarts, R. Ansell, L. McKenna, E. Connolly, W. Drotz, A.D. Kloosterman, Commentary, C.M. Cale, M.E. Earll, K.E. Latham, G.L. Bush, Could Secondary DNA Transfer Falsely Place Someone at the Scene of a Crime? [J Forensic Sci 2016;61(1):196-203], J. Forensic Sci. 61 (5) (2016) 1401–1402.

[18] M. Goray, K.N. Ballantyne, B. Szkuta, R.A. van Oorschot, Commentary, C.M. Cale, M.E. Earll, K.E. Latham, G.L. Bush, Could Secondary DNA Transfer Falsely Place Someone at the Scene of a Crime? [J Forensic Sci 2016;61(1):196-203], J. Forensic Sci. 61 (5) (2016) 1396–1398.

[19] M. van den Berge, G. Ozcanhan, S. Zijlstra, A. Lindenbergh, T. Sijen, Prevalence of human cell material: DNA and RNA profiling of public and private objects and after activity scenarios, Forensic Sci. Int. Genet. 21 (2016) 81–89.

[20] C.M. Pfeifer, P. Wiegand, Persistence of touch DNA on burglary-related tools, Int. J. Legal Med. 131 (4) (2017) 941–953.

[21] G.E. Meakin, E.V. Butcher, R.A.H. van Oorschot, R.M. Morgan, Trace DNA evidence dynamics: an investigation into the deposition and persistence of directly- and indirectly-transferred DNA on regularly-used knives, Forensic Sci. Int. Genet. 29 (2017) 38–47.

[22] B. Szkuta, K.N. Ballantyne, B. Kokshoorn, R.A.H. van Oorschot, Transfer and persistence of non-self DNA on hands over time: using empirical data to evaluate DNA evidence given activity level propositions, Forensic Sci. Int. Genet. 33 (2018) 84–97.

[23] B. Szkuta, K.N. Ballantyne, R.A.H. van Oorschot, Transfer and persistence of DNA on the hands and the influence of activities performed, Forensic Sci. Int. Genet. 28 (2017) 10–20.

[24] R.A.H. van Oorschot, B. Szkuta, G.E. Meakin, B. Kokshoorn, M. Goray, DNA transfer in forensic science: a review, Forensic Sci. Int. Genet. 38 (2019) 140–166.

[25] R. Cook, I.W. Evett, G. Jackson, P.J. Jones, J.A. Lambert, A hierarchy of propositions: deciding which level to address in casework, Sci. Justice 38 (4) (1998) 231–240.

[26] S. Gittelson, T. Kalafut, S. Myers, D. Taylor, T. Hicks, F. Taroni, I.W. Evett, J.A. Bright, J. Buckleton, A practical guide for the formulation of propositions in the bayesian approach to DNA evidence interpretation in an adversarial environment, J. Forensic Sci. 61 (1) (2016) 186–195.

[27] J. Buckleton, J.A. Bright, D. Taylor, I. Evett, T. Hicks, G. Jackson, J.M. Curran, Helping formulate propositions in forensic DNA analysis, Sci. Justice 54 (4) (2014) 258–261.

[28] I.W. Evett, B.S. Weir, Interpreting DNA Evidence, Sinauer, Sunderland, MA, 1998.

[29] ENFSI, ENFSI Guideline for Evaluative Reporting in Forensic Science: Strengthening the Evaluation of Forensic Results Across Europe (STEOFRAE), (2015) https://www.unil.ch/esc/files/live/sites/esc/files/Fichiers%202015/ENFSI%20Guideline%20Evaluative%20Reporting.

[30] G. Jackson, A. Biedermann, "Source" or "activity" what is the level of issue in a criminal trial? Significance 16 (2) (2019) 36–39.

[31] C. Aitken, A. Nordgaard, The Roles of Participants' Differing Background Information in the Evaluation of Evidence, J. Forensic Sci. 63 (2) (2018) 648–649.

[32] T. De Wolff, A. Kal, C. Berger, B. Kokshoorn, A probabilistic approach to body fluid typing interpretation: an exploratory study on forensic saliva testing, Law Probab. Risk 14 (4) (2015) 323–339.

[33] D. Taylor, D. Abarno, T. Hicks, C. Champod, Evaluating forensic biology results given source level propositions, Forensic Sci. Int. Genet. 21 (2016) 54–67.

[34] J. de Zoete, W. Oosterman, B. Kokshoorn, M. Sjerps, Cell type determination and association with the DNA donor, Forensic Sci. Int. Genet. 25 (2016) 97–111.

[35] C. Peel, P. Gill, Attribution of DNA Profiles to Body Fluid Stains, International Congress Series, Elsevier, 2004, pp. 53–55.

[36] M. van den Berge, A. Carracedo, I. Gomes, E.A. Graham, C. Haas, B. Hjort, P. Hoff-Olsen, O. Maronas, B. Mevag, N. Morling, H. Niederstatter, W. Parson, P.M. Schneider, D.S. Court, A. Vidaki, T. Sijen, A collaborative European exercise on mRNA-based body fluid/skin typing and interpretation of DNA and RNA results, Forensic Sci. Int. Genet. 10 (2014) 40–48.

[37] M. Visser, D. Zubakov, K.N. Ballantyne, M. Kayser, mRNA-based skin identification for forensic applications, Int. J. Legal Med. 125 (2) (2011) 253–263.

[38] C. Haas, E. Hanson, R. Banemann, A.M. Bento, A. Berti, A. Carracedo, C. Courts, G. Cock, K. Drobnic, R. Fleming, C. Franchi, I. Gomes, G. Hadzic, S.A. Harbison, B. Hjort, C. Hollard, P. Hoff-Olsen, C. Keyser, A. Kondili, O. Maronas, N. McCallum, P. Miniati, N. Morling, H. Niederstatter, F. Noel, W. Parson, M.J. Porto, A.D. Roeder, E. Sauer, P.M. Schneider, G. Shanthan, T. Sijen, D. Syndercombe Court, M. Turanska, M. van den Berge, M. Vennemann, A. Vidaki, L. Zatkalikova, J. Ballantyne, RNA/DNA co-analysis from human skin and contact traces–results of a sixth collaborative EDNAP exercise, Forensic Sci. Int. Genet. 16 (2015) 139–147.

[39] D. Taylor, Probabilistically determining the cellular source of DNA derived from differential extractions in sexual assault scenarios, Forensic Sci. Int. Genet. 24 (2016) 124–135.

[40] G. Alderson, H. Gurevitch, T. Casimiro, B. Reid, J. Millman, Inferring the presence of spermatozoa in forensic samples based on male DNA fractionation following differential extraction, Forensic Sci. Int. Genet. 36 (2018) 225–232.

[41] A. Biedermann, C. Champod, G. Jackson, P. Gill, D. Taylor, J. Butler, N. Morling, T. Hicks, J. Vuille, F. Taroni, Evaluation of forensic DNA traces when propositions of interest relate to activities: analysis and discussion of recurrent concerns, Front. Genet. 7 (2016) 215.

[42] R. Wieten, J. De Zoete, B. Blankers, B. Kokshoorn, The interpretation of traces found on adhesive tapes, Law Probab. Risk 14 (4) (2015) 305–322.

[43] D. Taylor, A. Biedermann, L. Samie, K.M. Pun, T. Hicks, C. Champod, Helping to distinguish primary from secondary transfer events for trace DNA, Forensic Sci. Int. Genet. 28 (2017) 155–177.

[44] A.E. Fonneløp, M. Ramse, T. Egeland, P. Gill, The implications of shedder status and background DNA on direct and secondary transfer in an attack scenario, Forensic Sci. Int. Genet. 29 (2017) 48–60.

[45] B. Szkuta, R. Ansell, L. Boiso, E. Connolly, A.D. Kloosterman, B. Kokshoorn, L.G. McKenna, K. Steensma, R.A.H. van Oorschot, Assessment of the transfer, persistence, prevalence and recovery of DNA traces from clothing: an inter-laboratory study on worn upper garments, Forensic Sci. Int. Genet. 42 (2019) 56–68.

[46] W.C. Thompson, E.L. Schumann, Interpretation of statistical evidence in criminal trials: the prosecutor's fallacy and the defense attorney's fallacy, Law Hum. Behav. 11 (3) (1987) 167.

[47] I.W. Evett, Avoiding the transposed conditional, Sci. Justice 35 (2) (1995) 127–131.

[48] J. R v Tsekiri, Court of Appeal of England and Wales (Criminal Division), EWCA Crim 40, Available online at: http://www.bailii.org/ew/cases/EWCA/Crim/2013/2.html, (2017) (2017).
[49] F.S. Regulator, DNA Mixture Interpretation, FSR-G-222, Issue 2, (2018) https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/752164/G222_DNA_Mixture_Interpretation_Issue2.pdf.
[50] T. Hicks, A. Biedermann, J.A. de Koeijer, F. Taroni, C. Champod, I.W. Evett, The importance of distinguishing information from evidence/observations when formulating propositions, Sci. Justice 55 (6) (2015) 520–525.
[51] I.W. Evett, G. Jackson, J. Lambert, More on the hierarchy of propositions: exploring the distinction between explanations and propositions, Sci. Justice 40 (1) (2000) 3–10.
[52] J.R. Robertson, C. Roux, K. Wiggins, Forensic Examination of Fibres, CRC Press, 2002.
[53] P. Gill, C.H. Brenner, J.S. Buckleton, A. Carracedo, M. Krawczak, W.R. Mayr, N. Morling, M. Prinz, P.M. Schneider, B.S. Weir, DNA commission of the international society of forensic genetics: recommendations on the interpretation of mixtures, Forensic Sci. Int. 160 (2-3) (2006) 90–101.
[54] M. van den Berge, L. van de Merwe, T. Sijen, DNA transfer and cell type inference to assist activity level reporting: Post-activity background samples as a control in dragging scenario, Forensic Sci. Int. Genet. Suppl. Ser. 6 (2017) e591–e592.
[55] A.M. Magee, M. Breathnach, S. Doak, F. Thornton, C. Noone, L.G. McKenna, Wearer and non-wearer DNA on the collars and cuffs of upper garments of worn clothing, Forensic Sci. Int. Genet. 34 (2018) 152–161.
[56] P. Gill, L. Gusmao, H. Haned, W.R. Mayr, N. Morling, W. Parson, L. Prieto, M. Prinz, H. Schneider, P.M. Schneider, B.S. Weir, DNA commission of the International Society of Forensic Genetics: recommendations on the evaluation of STR typing results that may include drop-out and/or drop-in using probabilistic methods, Forensic Sci. Int. Genet. 6 (6) (2012) 679–688.
[57] D.W. Gjertson, C.H. Brenner, M.P. Baur, A. Carracedo, F. Guidet, J.A. Luque, R. Lessig, W.R. Mayr, V.L. Pascali, M. Prinz, P.M. Schneider, N. Morling, ISFG: Recommendations on biostatistics in paternity testing, Forensic Sci. Int. Genet. 1 (3-4) (2007) 223–231.
[58] I.W. Evett, A quantitative theory for interpreting transfer evidence in criminal cases, Appl. Stat. 33 (1) (1984) 25–32.
[59] D. Taylor, B. Kokshoorn, A. Biedermann, Evaluation of forensic genetics findings given activity level propositions: a review, Forensic Sci. Int. Genet. 36 (2018) 34–49.
[60] W. Thompson, What role should investigative facts play in the evaluation of scientific evidence? Aust. J. Forensic Sci. 43 (2011) 123–124.
[61] I. Dror, Practical solutions to cognitive and human factor challenges in forensic science, Forensic Sci. Policy Manag. Int. J. 4 (2014) 105–113.
[62] W. Thompson, Determining the proper evidentiary basis for an expert opinion: what Do experts need to know and when Do they know too Much? in: C. Roberson, A. Kesselheim (Eds.), Blinding as a Solution to Bias: Strengthening Biomedical Science, Forensic Science, and Law, Academic Press, 2016, pp. 133–150.
[63] D. Taylor, T. Hicks, C. Champod, Using sensitivity analyses in Bayesian Networks to highlight the impact of data paucity and direct future analyses: a contribution to the debate on measuring and reporting the precision of likelihood ratios, Sci. Justice 56 (5) (2016) 402–410.
[64] M. Matte, L. Williams, R. Frappier, J. Newman, Prevalence and persistence of foreign DNA beneath fingernails, Forensic Sci. Int. Genet. 6 (2) (2012) 236–243.
[65] K. Steensma, R. Ansell, L. Clarisse, E. Connolly, A.D. Kloosterman, L.G. McKenna, R.A. van Oorschot, B. Szkuta, B. Kokshoorn, An inter-laboratory comparison study on transfer, persistence and recovery of DNA from cable ties, Forensic Sci. Int. Genet. 31 (2017) 95–104.
[66] T.J. Verdon, R.J. Mitchell, R.A. van Oorschot, Evaluation of tapelifting as a collection method for touch DNA, Forensic Sci. Int. Genet. 8 (1) (2014) 179–186.
[67] T.J. Verdon, R.J. Mitchell, R.A. van Oorschot, The influence of substrate on DNA transfer and extraction efficiency, Forensic Sci. Int. Genet. 7 (1) (2013) 167–175.
[68] B. Kokshoorn, L.H.J. Aarts, R. Ansell, E. Connolly, W. Drotz, A.D. Kloosterman, L.G. McKenna, B. Szkuta, R.A.H. van Oorschot, Sharing data on DNA transfer, persistence, prevalence and recovery: arguments for harmonization and standardization, Forensic Sci. Int. Genet. 37 (2018) 260–269.
[69] P. Gill, Interpretation continues to be the main weakness in criminal justice systems: developing roles of the expert witness and court, Wiley Interdisciplinary Reviews: Forensic Science 1 (2) (2019) e1321.
[70] A. Gosch, C. Courts, On DNA transfer: the lack and difficulty of systematic research and how to do it better, Forensic Sci. Int. Genet. 40 (2019) 24–36.
[71] N. Flanagan, C. McAlister, The transfer and persistence of DNA under the fingernails following digital penetration of the vagina, Forensic Sci. Int. Genet. 5 (5) (2011) 479–483.
[72] E.A. Dowlman, N.C. Martin, M.J. Foy, T. Lochner, T. Neocleous, The prevalence of mixed DNA profiles on fingernail swabs, Sci. Justice 50 (2) (2010) 64–71.
[73] T. Hicks, J.S. Buckleton, J.A. Bright, D. Taylor, A framework for interpreting evidence, in: J.S. Buckleton, J.A. Bright, D. Taylor (Eds.), Forensic DNA Evidence Interpretation, Taylor and Francis Group, Boca Raton, FL, 2016, pp. 80–81.
[74] D. Taylor, The evaluation of exclusionary DNA results: a discussion of issues in R v. Drummond, Law Probab. Risk 15 (3) (2016) 175–197.
[75] F. Taroni, S. Bozza, T. Hicks, P. Garbolino, More on the question' when does absence of evidence constitute evidence of absence?' how Bayesian confirmation theory can logically support the answer, Forensic Sci. Int. 301 (2019) e59–e63.
[76] A. Biedermann, F. Taroni, Bayesian networks for evaluating forensic DNA profiling evidence: a review and guide to literature, Forensic Sci. Int. Genet. 6 (2) (2012) 147–157.
[77] D. Taylor, A. Biedermann, T. Hicks, C. Champod, A template for constructing Bayesian networks in forensic biology cases when considering activity level propositions, Forensic Sci. Int. Genet. 33 (2018) 136–146.
[78] A. Nordgaard, R. Ansell, W. Drotz, L. Jaeger, Scale of conclusions for the value of evidence, Law Probab. Risk 11 (1) (2011) 1–24.
[79] Recommendations of the SWGDAM Ad Hoc Working Group on Genotyping Results Reported As Likelihood Ratios, (2019) Accessed September www.swgdam.org/publications.
[80] Department of Justice Uniform Language for Testimony and Reports for Forensic Autosomal DNA Examinations Using Probabilistic Genotyping Systems, (2019) Accessed September https://www.justice.gov/olp/page/file/1095961/download.
[81] K.A. Martire, I. Watkins, Perception problems of the verbal scale: a reanalysis and application of a membership function approach, Sci. Justice 55 (4) (2015) 264–273.
[82] K.A. Martire, R.I. Kemp, M. Sayle, B.R. Newell, On the interpretation of likelihood ratios in forensic science evidence: Presentation formats and the weak evidence effect, Forensic Sci. Int. 240 (2014) 61–68.
[83] R. Marquis, A. Biedermann, L. Cadola, C. Champod, L. Gueissaz, G. Massonnet, W.D. Mazzella, F. Taroni, T. Hicks, Discussion on how to implement a verbal scale in a forensic laboratory: benefits, pitfalls and suggestions to avoid misunderstandings, Sci. Justice 56 (5) (2016) 364–370.