Algorithms on Trial: Does evaluative probabilistic reporting of forensic evidence infringe the presumption of innocence?☆

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ABSTRACT

Scientific evidence plays an important role in criminal justice. Recent technological developments including the use of AI and advanced computational forensic software have made possible forensic examinations and expert opinions that previously would have been impossible. Alongside benefits, the use in criminal trials of forensic evidence based on computational technologies such as Probabilistic Genotyping (PG) DNA, is posing difficult problems for courts and has been met with controversy. This study focuses on one important aspect of the criticism surrounding the use of PG DNA evidence, which relates to the probabilistic reporting of the forensic evidence results. It explores whether the use of likelihood ratios to report evaluative expert opinions infringes the presumption of innocence. This is a fundamental question that concerns not only evidence based on advanced computational technologies such as PG DNA but all forensic disciplines where the use of likelihood ratios and probabilistic assessments of the evidence are being actively promoted. This article argues that the criticism on the use of probabilistic methods for evidence evaluation encountered in legal practice, scholarly debate, policy and legal reform documents, is founded on misunderstandings of the role and limitations of the forensic evidence, of the processes involved in arriving at an evaluative expert opinion, as well as of the meaning and scope of the presumption of innocence itself. An enhanced understanding of these fundamental issues will lead towards a better regulation of AI and forensic algorithms across jurisdictions, without diminishing the impact of the scientific evidence in criminal proceedings and beyond.

1. Introduction

Forensic science plays an essential role in the prevention, investigation, and prosecution of crime. Advancements in science and technology have led to the evolution and refinement of forensic methods and techniques, and of the evidence produced as a result. The use of AI, computational algorithms and of probabilistic methods for the evaluation and reporting of the results are actively being promoted across several areas of forensic science including DNA profiling, fingerprinting systems, digital forensics, facial recognition, iris recognition, voice analysis, handwriting comparisons and friction ridge pattern disciplines.[1] As new forms of evidence are entering criminal proceedings the level and type of contribution that a forensic expert can give in the context of criminal proceedings has also been evolving. The use of various types of purposely developed computational forensic software[2] has enabled the forensic analysis of evidence that previously would have been impossible to be done via traditional methods.

One example of the use of advanced computational algorithms in

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[1] On the use of AI and algorithms see e.g. Refs. [1,2]. Probabilistic methods for evaluative expert reporting will be discussed further below. See e.g. Ref. [3].

[2] The term "computational forensic software'' means software that relies on an automated or semiautomated computational process, including one derived from machine learning, statistics, or other data processing or artificial intelligence techniques, to process, analyze, or interpret evidence – see Ref. [4].

forensic science is Probabilistic Genotyping software (PG DNA) which is considered as one of the most recent advancements in forensic DNA analysis.[3] Over the past decade, developments to both chemistry and detection technology have resulted in more sensitive DNA profiling techniques, leading to the generation of complex mixtures with multiple contributors and profiles exhibiting artefacts making the forensic analysis and interpretation particularly complex. DNA samples recovered from crime scenes and physical objects are far from pristine. The absolute amount of DNA present and the relative amount contributed by the various contributors can differ significantly. Uncertainties regarding the number of contributors to a DNA mixture, allele sharing among contributors, allelic drop-out or drop-in, the presence of stutter, and the phenomenon of degradation are all factors that result in the complexity and limitations of the DNA mixture analysis.[4]

The use of PG software enables the interpretation of more complex low level and higher order mixtures that were previously considered too complicated. PG DNA uses "biological modelling, statistical theory, computer algorithms, and probability distributions to calculate likelihood ratios (LRs) and/or infer genotypes for the DNA typing results of forensic samples" [13]. The software performs hundreds of thousands of calculations, which cannot be performed by hand and weighs potential genotypic solutions for a mixture by utilizing more DNA information and accounting for uncertainty in random variables within the model, such as peak heights [13]. The software then generates *likelihood ratios* (*LRs*) to express the weight of the DNA evidence given two user defined propositions and the number of contributors, which is selected by the analyst.[5] The use of PG software to conduct analysis of complex mixtures arguably offers efficiency and increased objectivity by reducing subjective, human decision making, in various aspects of the technical analysis.[6]

Alongside benefits however, the use in criminal proceedings of complex forensic evidence based on advanced computational technology such as PG DNA continues to present challenges for the judicial system and has been met with controversy.[7] Courts across different jurisdictions are having to not only adjudicate complex legal questions, but also have to consider increasingly complex technical and scientific issues in order to determine the admissibility and probative value of such evidence. This article is based on this author's broader research[8] which examines challenges related to the foundational validity of AI and algorithmic based forensic methods, their transparency,[9] interpretability, complexity, as well as their impact on disclosure, access to expertise, the principle of confrontation, due process and fair trial rights. These aspects present difficult evidential and procedural challenges that affect not only the admissibility and weight of forensic evidence produced through advanced computational technologies, but also the fundamental rights and principles of the criminal justice.

To date, attention from scholars, practitioners and policymakers has principally been given to the use of AI by law enforcement authorities (LEAs), for intelligence and investigative purposes, risk assessment and pretrial decision making.[10] The use of AI, algorithms and advanced computational technologies in forensic science to produce evidence which is adduced in criminal proceedings, directly affecting the lives of the concerned individuals and the societal values embedded in criminal justice principles and procedures, remains an underexplored area. This author's research seeks to contribute to the dialogue that must take place among key stakeholders in the general interest of the development and refinement of AI and forensic computational technologies and the regulation of their application conform the criminal justice standards and requirements. Regulation of these technologies by litigation alone is not desirable and it should not be entirely left to the post-hoc testing of reliability in the context of a criminal prosecution, where the ultimate question is the guilt or innocence of the accused.

Based on an extensive review of the litigation practice, scholarly debate, policy and legal reform papers, this article focuses only on one important aspect of the controversy surrounding the use of PG DNA evidence in criminal trials which concerns the expert's use of the probabilistic assessments and the likelihood ratio (LR) approach for the evaluative reporting of the strength of forensic evidence. Critics of this approach claim that the LR *appears* (emphasis added) "to answer the question the jury is trying to answer"[11] and that "by purporting to represent the relative likelihood of the lab's proposed defence hypothesis against the proposed prosecutor's hypothesis, LRs usurp the jury's function in a criminal trial, conflict with the presumption of innocence, and undermine the requirement that the prosecutor bears the burden of proving each and every case beyond a reasonable doubt."[12] Most importantly, critics call that LR ratios such as those used in PG DNA (should) "have no place in criminal trials"[13] indicating that the controversy is much broader, surpassing the confines of PG DNA to other forms of forensic evidence that adopt similar probabilistic approaches for evidence evaluation. This is also evident as the criticism supposedly directed solely to the use of LRs in the context of PG DNA,[14] encompasses other, more general aspects of the use of LRs such as the use of Bayesian approach of evidence evaluation in criminal trials, the use of Bayes theorem to combine the evidence in the case and more generally the use of statistics in criminal trials, rehashing well publicised 'trial by

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[3] For an introduction see Ref. [5]. Some definitions of AI cover software packages that use data analysis, statistical and logic-based approaches, without necessarily needing to use machine learning; see e.g. Ref. [6] according to which "Probabilistic genotyping (PG) is the use of artificial intelligence algorithms to analyze DNA samples collected in police investigations or criminal prosecutions". A broad definition of AI is also adopted in the EU AI Act [7]. In the context of DNA mixtures, machine learning software is developed eg. to determine the number of contributors, see Refs. [8–10].

[4] Dropout is a consequence of low template, degraded, or inhibited DNA that results in partial DNA profiles, where the DNA from one or more contributors is not present at all loci. Drop-in is the presence of low amounts of DNA within a profile that are not inherent to the DNA extract. Stutter is a by-product of the amplification of the STR loci whereby a minor product, typically one repeat smaller than the primary allele is generated. See Refs. [11,12].

[5] For a review see Ref. [14]. Some programs (such as STRmix) allow a range of values to be entered. Currently, PG software can routinely perform LR calculations up to four person mixtures, however, some programs can, to date, perform five and six persons mixture calculations. See Refs. [15,16].

[6] See Ref. [5]. PG is a tool to assist the DNA analyst in the interpretation of forensic DNA typing results and is not intended to replace the human evaluation of the forensic DNA typing results or the human review of the output prior to reporting, see Ref. [13].

[7] It can be argued however that many of these challenges are not very different from the ones courts traditionally have faced when novel type of forensic technologies and evidence were first introduced in criminal proceedings. The validity of scientific techniques is challenged from time to time, and novel forms of evidence or innovative applications of established techniques are especially likely to attract adversarial objections and closer judicial scrutiny, see Ref. [17].

[8] Research project 'Evaluating the Impact of Forensic Evidence based on AI technologies in Criminal Proceedings' partially supported by a British Academy grant (2024–25). This author's broader study is based on a legal analysis of a sample of 80 court cases related to PG DNA in four common law jurisdictions (US, Canada, Australia and the UK), an extensive literature review and a series of interviews with forensic, law enforcement and legal practitioners on the impact of AI and probabilistic reporting of evidence in criminal proceedings.

[9] Several forensic programs operate as black box with no access to source code. For a discussion from the PG context see e.g. Refs. [18–20]. More broadly on the opacity of machine learning algorithms see Ref. [21].

[10] See e.g. Refs. [22–30].

[11] [31] at p. 112.

[12] Ibid. See also [6] criticising the use of the LR approach adopting similar arguments.

[13] [31] p.133.

[14] [31] p.112 - see at footnote 2.

mathematics' discussions.[15]

It is imperative to address this criticism for several reasons. Firstly, the LR approach as it will be discussed below forms the basis of forensic evaluative practices in several disciplines and is actively promoted across the forensic sector.[16] This author posits that the use of forensic technologies, methodologies, and any resulting contribution of forensic science in criminal proceedings should only take place in accordance with the procedural rules and in line with the fundamental values and principles of criminal justice, particularly the presumption of innocence (hereafter POI), due process, and fair trial rights. From this perspective *this study examines whether the LR approach for evaluative expert opinions infringes the presumption of innocence, as one of the most fundamental principles of criminal justice.*

In order to adequately address this question, it is important initially to establish a theoretical framework on the meaning and scope of POI based on the way it manifests in the criminal justice processes. This is in and of itself an area of controversy and debate. Any attempt to reconcile the scholarly controversy surrounding the definition and the scope of POI is not only beyond the limits of this article but also arguably futile. Section 2 of this study introduces a framework of POI which meets the aims of and serves as a theoretical basis for this research. The following analysis and discussion aim to contribute to the current theoretical debate on POI through a legal interpretation of the significance of POI from the perspective of forensic evidence and the use of evaluative expert opinions in criminal proceedings.

Secondly, this article aims to expose and clarify several misconceptions concerning the way forensic evidence generally, and PG DNA specifically is produced, evaluated, reported and subsequently used in criminal trials as well as the role of the expert, court and parties in criminal proceedings. To that effect, sections 3, 4 and 5 throw light on the confusion surrounding the limitations, significance and weight of forensic evidence and its impact for the trial process and make recommendations how it should be addressed. This clarification is particularly important and necessary as misconceptions encountered in litigation practice[17] and in academic commentary[18] are also appearing in policy papers and reform recommendations.[19] The danger is that such confusion concerning fundamental aspect of forensic evidence evaluation could result in counterproductive procedural changes and regulatory reforms aimed at AI based forensic evidence, that may undermine other important initiatives made by the scientific community over the recent years to ensure that the best evidence is presented in court in accordance with the standards of logic and proof, and ultimately the interests of justice.[20]

The difficulties surrounding the use of complex forensic evidence in criminal trials and the need to regulate the use of forensic computational technologies in criminal justice cannot be ignored. The following sections propose that the challenges arising require any jurisdiction to address at least three key aspects: a. the sufficiency of existing evidential rules to regulate the admissibility of forensic evidence including those based in forensic algorithm technologies; b. the regulation of forensic algorithm technologies (and forensic technologies generally) to promote their validity, transparency, accountability and respect for the criminal justice fundamental principles; c. expert reporting and evidence reception in court through improved communication between stakeholders at various stages of the criminal justice process, continuous training and education. Through the identification and clarification of the misconceptions observed in the criticism of the use of the LR approach for the evaluation of PG DNA results and beyond, this article seeks to contribute to a better regulation of the AI and computational forensic technology in criminal justice in a manner that does not diminish or unproportionally affect the role and contribution of the scientific evidence in criminal proceedings.

2. Interpreting the presumption of innocence

Prior to embarking on an analysis whether the evaluative reporting of forensic evidence based on the Likelihood Ratio (LR) approach – similar to that used in PG DNA analysis - affects the presumption of innocence (POI), it is important to establish a foundational theoretical framework concerning POI that clarifies its meaning and refers to the way it is manifested in the criminal justice processes where the work of an expert is involved. In absence of a clear scope and definition POI is prone to misuse and misinterpretation. As Roberts puts it: "Claims that a particular legal doctrine or official practice offends the presumption of innocence might be little more than visceral reactions to perceived—but unanalysed, unexplained and unrationalised—intuitions of 'unfairness.'"[21]

There are undeniable differences in the interpretation of POI in theoretical debate which become particularly problematic in interdisciplinary discussions. The difficulties of 'setting aside one's disciplinary assumptions'[22] become obvious when scientific, technical, legal concepts, doctrines and practices come together in the context of criminal justice.[23] As argued in depth elsewhere, these disciplines 'speak different languages', adhere to different rules and principles, make different assumptions which in turn produce tensions that become manifest in the criminal trial setting and are difficult to reconcile [17]. However even within the same discipline such as law, there are differences regarding the meaning and conceptualisation of the same principles which become more evident in cross jurisdictional research. This is partly due to the terminology as "the same terms are being used with different meanings, and … different terms being used to mean the same thing"[24] and party due to differences in procedural rules, principles and values of different legal systems.

While doctrinal propositions always relate to particular territorial jurisdictions, some are general enough and apply to most of the world's legal jurisdictions.[25] The presumption of innocence is one such, centuries-old, principle which is broadly recognised. It is an integral component of the 'fair trial' rights recognised in contemporary international human rights treaties, such as the European Convention on Human Rights (ECHR) and the International Covenant on Civil and Political Rights (ICCPR)[26] and upholds the status of a constitutional principle in many jurisdictions across the world.[27]

The criticism related to the use of LRs, addressed in this article, arises from the perspective of the common law tradition litigation practice – specifically that on the admissibility of PG DNA evidence in criminal cases – therefore the discussion of POI as a legal principle will be from that same perspective. POI however embeds core values that are

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[15] [31] relies in great part to the criticism raised by Refs. [32–36].

[16] See Refs. [3,37].

[17] E.g [38].

[18] see e.g. [31].

[19] see e.g. [6].

[20] Such initiatives include guidelines for evaluative reporting in forensic science [3] based on Case Assessment and Interpretation guiding principles, which at the heart have the (same) LR approach as the one used for PGDNA, see Refs. [39,40].

[21] [41] at p.8902.

[22] Ibid.

[23] For an in-depth discussion see [17].

[24] [41] at p.8902.

[25] [41] at p.8907.

[26] See Refs. [42,43]. Article 6(2) of the ECHR provides that: 'Everyone charged with a criminal offence shall be presumed innocent until proved guilty according to law.' In almost identical terms ICCPR Article 14(2) provides that: 'Everyone charged with a criminal offence shall have the right to be presumed innocent until proved guilty according to law'. See also [44] The Charter of Fundamental Rights of the European Union (2007/C 3003/01), Article 48: Presumption of innocence and right of defence.

[27] For an analysis of the principle see Ref. [45].

recognised and shared more broadly across jurisdictions even though the institutional instantiation of those values may vary.[28] Addressing the normative value of POI from a broader perspective is therefore important as the forensic practices analysed in this study cross jurisdictional boundaries. Forensic case assessment and interpretation including the use of LRs to reach expert evaluative opinions on the strength of the evidence are equally promoted and followed by forensic practitioners in jurisdictions pertaining to common law[29] and civil law[30] traditions. It is beyond the scope of this article to examine whether specific jurisdictional differences, especially between adversarial and inquisitorial systems, may provide grounds for a (perceived) different level of impact (if any) of such forensic practices on POI, however it is recommended that this aspect be pursued elsewhere.[31] One observation can be safely made in that the litigation practice is richer and much more significant in those jurisdictions where the rules of evidence provide for clear admissibility criteria based on the reliability of the scientific methods used by the expert.[32]

While international human rights instruments clearly assert adherence to POI, they do not specify what it entails. In English criminal procedure the values encapsulated in the POI have traditionally found their doctrinal expression in judicial treatments of the burden and standard of proof. As per Viscount Sankey LC speech in *Woolmington v DPP*: 'Throughout the web of the English Criminal Law, one golden thread is always to be seen, that it is the duty of the prosecution to prove the prisoner's guilt … If, at the end of and on the whole of the case, there is a reasonable doubt … the prosecution has not made out the case and the prisoner is entitled to an acquittal '.[33] Similarly, in 1895, the United States Supreme Court declared that 'The principle that there is a presumption of innocence in favour of the accused is the undoubted law, axiomatic and elementary.'[34] In its landmark *Winship* opinion, the Supreme Court found that the requirement of proof beyond reasonable doubt is mandated by the Due Process Clause of the Fourteenth Amendment: "The reasonable-doubt standard plays a vital role in the American scheme of criminal procedure. It is the prime instrument for reducing the risk of convictions resting on factual error. The standard provides concrete substance for the presumption of innocence—that bedrock 'axiomatic and elementary' principle whose 'enforcement lies at the foundation of the administration of our criminal law."[35]

While there is general consensus that POI is normatively significant and plays a central role in discussions concerning fair trial rights and due process, there has been considerable academic debate on the scope of this safeguard.[36] A number of commentators argue in favour of a 'narrow' or 'thin' procedural interpretation of POI according to which the latter only concerns the distribution of probative burdens and standard of proof as trial procedural devices for allocating the risk of error in the adversarial criminal adjudication.[37] These 'orthodox' doctrinal interpretations equate POI with the concept of the burden of proof and evidentiary presumptions.[38] Other commentators approach the concept of POI from the perspective of penal or normative theory and argue that the presumption should be accorded a substantive as opposed to a solely procedural role, thus influencing the definition of criminality itself.[39] According to what is termed as a 'substantivist' approach, POI has implications for criminalization in the sense that the presumption is violated when a person is convicted of conduct that should not be subject to punishment.[40] In similar lines commentators supporting 'expansive proceduralism' and the 'purpose theory' maintain that the presumption has some influence on the definition of criminality.[41]

These theoretical interpretations of POI however have been met with criticism and are seen as lacking doctrinal impact considering the practical reality of criminal proceedings.[42] Advocates of a narrow, procedural reading argue that it gives the POI a clearer and more specific meaning that expresses a concrete categorical right, whereas broader interpretations "risk turning it into empty rhetoric that can do no substantial work in constraining the exercise of state power".[43] According to Lippke "A bewildering variety of claims have been made about the meaning and implications of the presumption of innocence in criminal law. Given its apparent elasticity, it is natural to wonder whether the presumption is an honorific concept, one that is mostly empty and therefore adaptable to the needs and interests of legal theorists of diverse kinds."[44] In turn therefore "POI ought to be confined to the trial context, where what it means, how it functions, and what are the consequences of its rebuttal can be tolerably well-defined and defended …. Only in the trial context does a full-on presumption of innocence, on the part of those tasked with rendering verdicts, have a defensible role to play."[45]

On the other hand, however, this 'narrow' or 'thin' conceptualisation of POI is problematic because it does not fully capture the role and

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[28] [46].

[29] Also referred to as the Anglo - American tradition, see Ref. [47].

[30] Also referred to as the 'continental tradition' [47].

[31] The criticism of the LR approach in PG cases in terms of presumably infringing the POI, comes primarily from the US and Canadian jurisdictions as opposed to European jurisdictions. The promotion of the use of LR evaluative opinions has been especially significant in European jurisdictions which also pertain to different procedural traditions albeit core values of criminal justice including POI are similar.

[32] Particularly in the US where e.g. the *Daubert* standard specifically concerns the reliability of the expert evidence adduced in a case and the judge acts as a gatekeeper [48]. For a discussion from the perspective of English law see Refs. [17,49,50].

[33] [51], at 481, per Viscount Sankey. The 'the golden thread' is considered as a 'constitutional' principle of English criminal law; 'the Woolmington principles', referring both to the allocation of the burden of proof and to the standard of proof, are the English law's predominant institutional manifestation of the presumption of innocence. For a discussion see Ref. [45].

[34] [52] at 453.

[35] [53], quoting [52].

[36] For a brief review of alternative views and a discussion of POI from the context of reverse burdens see Ref. [54].

[37] Ibid.

[38] See Ref. [45] p.239; [55–57]. See further below.

[39] See e.g. Refs. [58–62] at 133–137.

[40] See Ref. [54]. Under this reading, the presumption of innocence would confer upon the courts the power to scrutinize the legislator's criminalization choices, possibly based on substantive principles that are entrenched in criminal law discourse, e.g. the voluntary act requirement, the fault principle, and the principle of proportionality between crime and punishment. By doing so, courts would safeguard innocence, where this concept is understood as the status of an individual who has not committed conduct deserving of punishment, see Ref. [59] at 1370–1379.

[41] According to the 'proceduralist' view, POI is violated when an element of the crime is not proved regardless as to whether the conduct, with or without this element is deserving of punishment, [54]. See Refs. [63–66].According to the 'proceduralist' view, POI is violated when an element of the crime is not proved regardless as to whether the conduct, with or without this element is deserving of punishment, [54]. See Refs. [63–66].According to the 'purpose theory' POI is violated when a person is convicted for conduct that is not the real aim of the lawmaker. A reverse burden is incompatible with the presumption of innocence if the occurrence of the particular fact that the defendant is required to prove would make the conduct fall outside that which the lawmaker intends to punish, see Ref. [54];see also [67 – 68] and [69] in particular, at 9–11, 13–16.

[42] [41] at p. 8910 notes the possibility of (limited) substantive effect in legal systems, such as the USA, where proof beyond reasonable doubt is conceptualised as being mandated by federal constitutional due process. See Refs. [59,70,71].

[43] [46]. See e.g. Ref. [72]. See also [73] for a similar narrow view according to which POI must be differentiated from the privilege against self-incrimination and the right to silence.

[44] [72] p.11.

[45] [72] pp. 4, 9.

significance of the principle beyond the confines of the criminal trial as manifested into the practices of the criminal justice process. As Roberts and Zuckerman put it: "A purely doctrinal approach cannot fully capture the full significance of the burdens and presumptions in modern criminal adjudication. It does not clarify the structural relationships between burdens of proof and adversarial criminal procedure. Nor does it address the presumption of innocence as a human right enjoying constitutional protection in many domestic legal systems."[46] Advocates of a broader interpretation argue that POI incorporates all the demands of due process [74] that it applies to pre-trial detention and post-conviction practices beside the trial process itself [75,76] and that should be conceptualised as "an aspect of a broad 'principle of civility' that governs our civic dealings with each other" [77]. Therefore, "if we are to understand the significance of the POI within the criminal trial, we must see it as an expression of deeper values"[47] and "only by exploring the political morality of the presumption of innocence can its true jurisprudential significance be appreciated."[48]

The aim of this article is not to settle complex academic debates surrounding the scope of POI. It is however necessary to choose a workable definition of POI based on the purpose and the nature of the problem that this study seeks to investigate. "Choice of definition in this sense extends to the domain of the inquiry and its 'problematic', i.e., the specification and nature of the problem to be investigated or, phrased more generically, the research question(s) to be answered."[49] The aim of this article is to explore the potential impact of the LR approach of forensic evidence evaluation on POI. It aims to clarify any observed misconceptions surrounding the interpretation and presentation of forensic evidence in criminal trials and any 'unjustified presumptions' about the presumption of innocence itself. It is hoped that this clarification will ultimately contribute towards a better regulation of PG DNA and similar computational technology based forensic evidence, towards better founded litigation claims and improved admissibility rules, without infringing the potential and without undermining the contribution of scientific evidence and the role of the expert in criminal trials.

Critics of the LR approach, which is the focus of this article, adopt a narrow, procedural view of POI as manifested through the burden that the prosecution bears in adversarial criminal trials to prove a case beyond reasonable doubt. If the theoretical approach of this study were to be limited solely to the allocation of burdens and the standard of proof in criminal trials, addressing the research question as to whether the LR approach of forensic evidence evaluation infringes the POI would arguably be less challenging, as any erroneous reasoning and misinterpretations become directly obvious. This study will however adopt a broader theoretical framework of the POI to capture its significance more fully. In line with the Roberts 'political morality' approach [41] this author sees POI operating at the level of a general principle which grounds several institutional doctrines and practices that concern not only the criminal trial itself but also criminal investigations, prosecutions and post-conviction procedures. As such 'the general presumption of innocence … though by no means confined to the criminal law, pervades the whole of its administration' [78]. This broader conceptualisation of POI is suitable for the purposes of this study considering that the work of an expert and much of the contribution forensic practices give to criminal justice take place pre-trial. It is those practices that form the foundation of the evidence subsequently presented on trial therefore it is necessary to question whether they are compatible with the requirements of POI.

POI is indeed "an expression of deeper values that should structure the state's dealings with its citizens".[50] These deeper values include first

and foremost, a commitment to protect the innocent from wrongful convictions, sometimes expressed as the 'Blackstone ratio' that "it is better for 10 guilty people to go free than for one innocent person to go to prison".[51] The normative ground of the presumption of innocence lies in the injustice of convicting the innocent or harming without cause any person's important interests, particularly in liberty, property and reputation. It is the serious public wrongfulness of convicting the innocent that which provides justification for a range of procedural safeguards and judicial risk management mechanisms such as the allocation of the burden of proof and the asymmetric standard of proof at trial.[52]

The commitment to protect the innocent is organically linked to the aim of accurate fact-finding. Criminal trials operate under uncertainty; the judicial verdict should conform as nearly as possible with the truth which in turn requires the fact finder getting the facts as straight as possible "while criminal procedure manages residual forensic doubt".[53] This author supports the view that the goal of protecting the innocent is best achieved by enhancing the reliability and the probative value of the evidence presented on trial "such that apparent guilt, on the evidence, is reliably indicative of actual guilt, in fact."[54] Powerful forensic technologies (such as DNA profiling) if valid and reliable, and providing that their evidential value is properly understood and interpreted by all those engaging with them in the criminal justice processes, have indeed the potential to enhance more "the accuracy of criminal adjudication without materially increasing the risks of mistaken convictions of the innocent than any marginal tinkering with formalised proof standards could ever hope to achieve".[55]

POI is closely linked to and grounds the principle of liberty or minimum state intervention and the principle against self-incrimination [45]. The normative core of POI is the injustice committed by officially and publicly condemning a person for a crime of which they have not (yet) been convicted and of which they might be innocent. The POI entails that the formal process of criminal adjudication must not be side-stepped or pre-empted and precludes officials from treating any person as though they are guilty of a crime when they have not been formally convicted of it.[56] It serves to limit officials' intervention in life, liberty, security and property in the exercise of lawful powers to prevent, investigate, prosecute and punish crime. The principle of minimum intervention underpins many of the guarantees for suspects regarding the collection and admissibility of the evidence[57]; the reasonable expectation that innocent people come forward with their exculpatory explanations if they have any; the police duty to search for exculpatory as well as incriminating evidence, the prosecutor's application of the 'realistic prospect of conviction' test [81][58] in deciding whether to continue with a prosecution and the judicial power to direct an acquittal without hearing from the defence, where there is 'no case to answer'.[59]

Closely related to POI is the principle of humane treatment reflected in the rules of evidence affording the accused a fair opportunity to answer charges against them whilst at the same time respecting their right to remain silent and placing the burden of proof on the prosecution. This means 'treating the accused as thinking, feeling, human subjects of official concern and respect, who are entitled to be given the opportunity to play an active part in the procedures that have a direct

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[46] [45] p.240.
[47] [46] p.171.
[48] [45] p.240.
[49] [41] p. 8903.
[50] [46] p.171.
[51] see Ref. [79] (1765: Book IV, ch. 27).;.9.
[52] [45] p.239.
[53] [45] p.20.
[54] [41] p.8913.
[55] [41] p.8913.
[56] Similarly, from treating a legally innocent person as if they were convicted see Refs. [46,80].
[57] See for example Police and Criminal Evidence Act 1984.
[58] According to Ref. [81] in England and Wales, where there is no realistic prospect of conviction on the evidence, proceedings must be discontinued, in line with s 23 of the Prosecution of Offences Act 1985 [82].
[59] See Ref. [83] Criminal Procedure Rule 25.9 (2) (e).

impact on their lives, rather than mere objects of state control to be manipulated for the greater good'.[60] Defendants in criminal trials are not to be seen merely as objects of a judicial inquiry that aims to determine whether they are guilty of the crime charged, but as active participants in the process who, alongside rights and protections also incur material, psychological and normative burdens in virtue of their role as defendants [46]. A defendant (generally) must attend trial and is summoned to answer to the charge, to answer for his conduct if it is proved that he committed the crime, and to accept (and respond appropriately to) the court's verdict [46]. While defendants are not legally required to say anything in their own defence, they risk conviction if they do not respond to the prosecution case or offer a defence if the prosecution proves the commission of the offence. 'Defendant' is thus a distinctive normative role, with its own particular rights and responsibilities which manifest in various forms in different stages of the criminal justice process [46].

All these values together ground a broader conceptualisation of POI as a principle of political morality [41] based on which the following sections will address the key question that this study seeks to answer, that is, whether the LR approach for forensic evaluative reporting infringes POI. First it is important to set out the key aspects of the LR approach, to which the attention now turns.

3. Understanding likelihood ratios (LRs)

The use of LRs is a central element of the evaluative reporting of forensic evidence [37,39,84] widely being promoted across the forensic science sector with the aim of improving the quality of the scientific work underpinning expert reports and the communication of the value and the limitations of the forensic findings to the criminal justice stakeholders including police, lawyers, judges and juries. Over the past decades, the formulation of standard, common principles of forensic science evaluative reporting that can be shared across disciplines has been an important step towards achieving these aims.[61] Evaluation of forensic findings for the purpose of criminal proceedings uses probability as a measure of uncertainty and it is based on the assignment of a LR.[62] Probabilistic calculations initially were widely perceived by the legal community as a special characteristic of DNA evidence.[63] Traditionally, other forensic disciplines including fingerprinting claimed to be able to identify individuals as the unique source of physical evidence.[64] In the past decades however, concerns have been raised over the high reliance on subjectivity, lack of statistical foundations supporting the interpretation of results, as well as over the expression of conclusions asserting a level of certainty that implies infallibility.[65]

There has been a "growing realisation that all scientific evidence is probabilistic and that no current forensic technology supports unique identification of individuals with their probabilistic foundations concealed in binary concepts such as match/no match".[66] The forensic community gradually begun to address the "transparency deficit" in other areas of forensic disciplines beside DNA, calling for the introduction of probabilistic reasoning and the use of validated statistical methods into forensic practices to formally recognize and articulate the

uncertainties inherent in forensic interpretation and to reduce the heavy reliance on subjective judgment.[67] A number of reputable efforts have been made to explore the optimal approach for expressing forensic conclusions to facilitate lay fact-finders' interpretation[68] and to introduce probabilistic models, often through the use of computational algorithms, to provide statistical foundations to the analysis and evaluation of evidence.[69]

Understanding the proper context of the introduction of the LR approach across the forensic sector is important because it has been (mis)interpreted by critics[70] as laboratories' and prosecution's search 'for ways to give some sort of quantitative evidentiary weight' to results which otherwise would have been inconclusive.[71] In the case of PG DNA, there has been a gradual shift over the past two decades to the LR approach for evidence interpretation in order to address the shortcomings of the earlier methods.[72] The concept of Random Match Probability used in relation to the interpretation of single person DNA profiles is *not* applicable to mixed profiles and Low Template DNA profiles for which multiple genotype probabilities are assigned and factored in the calculation of the LR.[73]

A LR is a measure of the relative strength of support that particular findings (also referred to as observations or evidence) give to one proposition (also referred to as hypothesis) against a stated alternative [37,99]. It is defined in terms of the ratio of two conditional probabilities: (i) the probability of the findings given that one proposition is true and given the conditioning information; and (ii) the probability of the findings given that the other proposition is true and given the conditioning information. In other words, the LR is not a probability but rather a ratio of two conditional probabilities[74] that evaluates the evidence (i.e. forensic observation of findings) given two (or more pairs of) alternative, mutually exclusive propositions which in the context of a criminal case *usually* represent the respective views of the prosecution and of the defence.[75] LR can be expressed as follows:

$$LR = p\,(E|H1, I)\,/\,p\,(E|H2, I)$$

where LR stands for likelihood ratio, 'p' means probability, E stands for evidence (or observation e.g. a DNA profile) and H1 and H2 are the opposing propositions. These propositions are formulated based on the case context (also referred to as case information or the 'framework of circumstances') that is the conditioning information denoted here by I. If LR is more than 1, the evidence supports H1; if it is less than 1 it tells against H1 and supports H2. If the ratio is exactly 1, then the evidence is neutral, i.e. equally likely under both opposing propositions. The strength of the evidence is thus measured by how much LR differs from 1 in either direction.

Probabilistic genotyping programs rely on models that seek to

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[60] See Ref. [45] p.22.

[61] See Refs. [85,86]. These standards are adopted in Ref. [3]. See also [40,87].

[62] [3] p.6. See also [40].

[63] When interpreting single-source DNA samples for example, the statistical analysis of a match between the evidence and the person of interest (POI) can be expressed in the form of a *Random Match Probability* (RMP) or the *Likelihood Ratio* (LR). The RMP estimates the probability of a matching DNA profile (not the person of interest's) within a chosen population. On LR see below [14,17, 88].

[64] [88,89] p.15. For the current persistence on this approach among fingerprint examiners see Ref. [90].

[65] See Refs. [91–93] at p. 348. See also [94].

[66] See Ref. [88] at page 15 [95].

[67] [91–94,96].

[68] For a review see e.g. [97].

[69] See [95].

[70] Arguably 'only' from the perspective of PG DNA evidence but this is debatable as pointed out in the introduction.

[71] See Ref. [31] e.g. at p.118 and p.120.

[72] For a historical perspective see Ref. [5]. See Ref. [98]; the commission recommended the LR approach as the preferred method for profile interpretation over the CPI or RMNE method partly due to their wastefulness of information. The LR approaches were recognised as the only method that could assess stutter and dropout probabilistically. The report gave guidance on DNA profile interpretation and recommended the use of a stochastic threshold when interpreting low-level DNA mixtures.

[73] [88] p.93.

[74] According to Ref. [3] the two conditional probabilities forming the likelihood ratio shall be assigned based on published data or a body of data that can be made available for peer review. Additionally, and in the absence of such data, experience or knowledge may be used. In any case all bases used should be disclosed.

[75] These concepts have been discussed in detail elsewhere; see e.g. [3,17,100].

explain some of the inconsistent results in DNA testing, including stochastic effects[76] by using biological modelling that will predict when, where, and how often these effects occur[77] and by using the LR approach. The LR approach enables the analyst to take into account for example whether the observed missing allele are because the defendant is not a contributor to the mixture or because of allelic drop-out; or if two of the observed defendant's alleles are the same as in the mixture but are of a different size, is it because the defendant is not a contributor to the DNA mixture or because of peak high imbalance [103].The use of the LR approach accounts for stochastic effects which contributes to a greater accuracy of the evidence and may benefit the defendant. As it has been pointed out the LR approach "represents a shift away from other statistical approaches such as the combined probability of inclusion where labs would merely throw out exculpatory data when allelic drop-out was suspected."[78]

It can be argued that an enhanced accuracy and ability to consider and account for exculpatory (aspects of) evidence is one of the major contributions of the PG DNA methods, which is certainly compatible with POI. Undoubtedly these methods need be reliable, valid, transparent, and explainable to deliver this contribution, however this is a discussion that needs be made in detail elsewhere. As noted above, enhancing the accuracy of the verdict is one of the main contributions that forensic science can make to delivering justice and to upholding the presumption of innocence. Views that LRs are used to "give some prosecutorial value to evidence that would otherwise be reported as inconclusive"[79] are dangerous and based on a limited understanding of what LRs mean, and how the admissibility of forensic evidence should be regulated. Advocating in favour of inconclusive results, as opposed to forensic technological advancements that enable expert analysis that previously would not have been possible, does not serve the interests of justice nor does it promote respect for the presumption of innocence. The admissibility of complex pieces of evidence, of limited or specific probative value such as DNA mixtures, should be controlled via the respective legal mechanisms and evidentiary rules. Calls for the inadmissibility of the evidence because it incorporates the LR approach to express the strength of the evidence (which could still result as inconclusive or insignificant) lack legal and logical foundation.

3.1. PG DNA and the 'prosecutor's fallacy'

The outputs of all PG software used for DNA mixture analysis are expressed in the form of LRs. As explained above the LR is a ratio of the probability, the probability density, or quantities proportional to either probability or density of some specific observations (i.e. findings) when considering two alternative (i.e., mutually exclusive) propositions [15]. This is extremely important and need be properly understood as often by mistake the LRs are referred to as the ratio between two hypotheses rather that of the probabilities of obtaining the observation/evidence given the two opposing hypotheses. This is known as the 'prosecutor's fallacy' or the fallacy of the 'transposed conditional' which unfortunately is still routinely made not only by lawyers and lay persons but also by experts themselves.[80]

The impact of fallacious reasoning is of great significance when one considers any implications for the POI as it implies that the expert is reporting on the probability of the hypothesis, thus addressing what the court/fact finder ought to address. This is however incorrect because the expert is reporting on the probability of the observation given the proposition instead. As the court noted in *State v Lewis* [104]:

> "It is of critical importance to understand what the likelihood ratio represents and what it does not represent. The likelihood ratio is not a statistic of inclusion or exclusion. It does not measure the probability that the defendant in fact contributed to the DNA mixture. Rather, it measures how likely the observed mixture is to occur if the defendant is assumed to have contributed to it than if the defendant is assumed not to have contributed to it. Likelihood ratios greater than 1 support the hypothesis that the defendant is included in the DNA mixture; likelihood ratios less than one support the hypothesis that the defendant did not contribute to the analyzed mixture. Depending on the magnitude of the likelihood ratio, the support for one hypothesis or the other is stronger or weaker."

What can be noted in the PG criticism however is precisely this fallacious reasoning whereby LRs are referred to as ratio between two hypotheses rather than ratio of the likelihood of observing the evidence *given* each of the two opposing hypotheses: "These computer programs generate something called a likelihood ratio. These likelihood ratios purport to express the probabilistic relationship between two hypotheses, the hypothesis that the suspect is in the DNA sample compared to the hypothesis that the suspect is not included in the sample."[81] "In these mixed samples, the hypotheses proposed are, for example, "given this piece of evidence, it is x times more likely that the sample came from the suspect and two unknown unrelated individuals than if the sample came from three unknown unrelated individuals."[82] "The complicated math and science distracts judges, lawyers, and surely jurors from the essential nature of this evidence — that it expresses the relative probability of two hypotheticals."[83] "The two hypotheses are compared, with a view to determining which is more probable."[84] "The LR that results from PG analysis expresses a relationship between two hypotheses in relation to their relative likelihood, but it does not tell us how objectively likely either hypothesis is in the real world."[85] "LRs are problematic because they present the relative likelihood that the prosecution's hypothesis is correct, as compared to the defendant's, on the issue of the originating identity of a DNA sample. However, disbelief of a hypothesis does not prove its opposite."[86]

While it is true that lack of credibility or proof of one proposition does not prove the opposite, it is not what the expert is reporting on via the LR approach. The expert is not seeking to prove a specific hypothesis; instead, the expert reports on the strength of the evidence, its degree of support for either opposing hypothesis, leaving any inferences

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[76] *Stochastic effects* are the random effects that occur in the DNA examination process. They are more prominent when testing low quantities of DNA. Even if a mixture sample has plenty of DNA for testing, one of the contributors to the mixture may only be present in trace amounts. Four common stochastic effects are: *Allelic Drop-Out* -when individual pieces of DNA (i.e. "alleles") fail to be detected in the testing process; *Allelic Drop-In* - contamination of the evidence sample by individual pieces of DNA; *Exaggerated Stutter:* An "echo effect" from a common copying error in DNA testing. Stutter appears as an allele next to the true allele. While the "echo effect" in standard DNA testing is so small that it can easily be identified as stutter, the stochastic effects of complex DNA mixtures often will increase the height of the stutter peak so that it can be mistaken as a true piece of DNA. *Peak Height Imbalance*: When pieces of DNA (alleles) from the same person at the same genetic location are copied so randomly that they are not of the same size. Peak height imbalance can confuse which allele originated from which contributor in a DNA mixture. See Refs. [13,101]. See also [102] for a discussion of stochastic effects in the context of the admissibility of a probabilistic genotyping program.

[77] For a review of some key legal challenges see Ref. [103]. Different programs use different biological models and it is argued that the assumptions behind their biological modelling make a difference in each program's reliability. See also [11,12].

[78] [103] at *13.

[79] See Ref. [31] at p.120.

[80] These issues have been discussed in depth elsewhere, see Ref. [17].

[81] [31] at p.112.

[82] [31] at p.120.

[83] [31] p.132.

[84] [6] p.11.

[85] [6] p.12.

[86] [6] at p.17.

concerning proof to the fact finder.[87] As acknowledged by critics "this is, of course, a somewhat simplistic way to describe LRs. There will always be an inference needed to get from the defendant's DNA being in the mix to the defendant's guilt. However, in many cases, where identity is at issue, for example, as a practical matter, this is how LR evidence is received."[88] It can be argued that this is not a 'simplistic' but a rather dangerous way of describing technical concepts with important legal consequences.[89] It is even more concerning that this can actually be observed in criminal litigation practice.[90]

The above quotes serve as a reminder that if lawyers themselves do not understand the meaning of LRs or the probative value of forensic evidence there is a real danger that the expert's evidence will be misunderstood and misrepresented in court.[91] Moreover, in the confrontational context of the adversarial criminal trial, some element of confusion might be part of the opposing advocate's deliberate cross examination strategy, which highlights the importance of a well-informed expert to not make erroneous statements and to clarify any distortions to their evidence [17]. Even where the expert statements are accurate and clear there is a mounting challenge of successfully communicating the true probative value of the evidence to the trial judge and the jurors.[92] Lay jurors will likely need guidance to help them understand the significance of the evidence expressed in probabilistic terms. This has implications for the presentation of the evidence in court and the way judges sum up the evidence and direct the jury at the end of the trial. An effective summing up requires that the judges themselves properly understand the evidence [88].

It can be recommended that the use of verbal equivalents to express LRs which has the potential to facilitate the fact finder's understanding of the expert's report, need be further discussed and agreed within the forensic community.[93] Lawyers on the other hand, should be careful to adopt the wording used by the expert in a particular case and not alter it when questioning witnesses or addressing the court [108]. Even a seemingly small 'simplistic' alteration could change entirely the meaning of the evidence, mislead the factfinder and bring significant unwanted legal consequences, thus threatening POI. Lawyers in a case should carefully review any draft opening speeches or case summaries to ensure that no misleading statements have been made and preferably seek expert assistance to do so [108]. In addition, it is important to appreciate that even if the case is worded properly to avoid the fallacies, there is a danger that the jury may commit them inadvertently. Therefore, it is recommended that where evidence that uses the LR approach such as PG DNA is presented, it should be accompanied by an explicit judicial warning against such misinterpretation.

As it will be argued further below, challenges associated with the complexity of LRs and probabilistic evidence do not by themselves provide a proportionate justification for reforms that call for a statutory 'presumptive inadmissibility' of PG DNA and similar forensic techniques.[94] As the science and technology advance, increasingly complex forensic evidence is expected to contribute to factfinding in criminal proceedings. The scrutiny of such evidence in admissibility proceedings is essential, however presuming the evidence inadmissible as a starting point due to complexity would not be a proportionate measure. These challenges highlight inter alia, the need for the legal community to share into the responsibility for an adequate reception and use of forensic evidence and in determining the type of contribution it can make in criminal trials. At the same time the forensic community should ensure the evidence is presented in a way that does not mislead legal stake-holders or 'invade judicial territory'.[95] There is a clear need for greater collaboration between the legal and forensic communities to bridge the differences and to deal with forensic evidence in ways that meet both the legal and scientific principles.

3.2. Do LRs usurp jury's role?

A related issue to fallacious reasoning can be observed in critics' claims that the use of LRs usurps the function of the jury: "By purporting to represent the relative likelihood of the lab's proposed defence hypothesis against the proposed prosecutor's hypothesis, LRs usurp the jury's function in a criminal trial".[96] This criticism relates to the 'ultimate issue rule' according to which an expert should not be allowed to express their opinion on issues that the court has to decide in order to dispose of the case.[97] Such issues may include elements of *actus reus*, *mens rea*, or defences e.g. identity, intention, diminished responsibility, loss of control and other matters on which an expert may be instructed to give an opinion. The rationale of the rule is to prevent witnesses from usurping the role of the factfinder. The rule has been opened to criticism on several levels and has almost disappeared from the modern law of evidence.[98] It has been argued inter alia that the 'usurpation' claims rely on 'the spurious assumption that giving evidence in an issue is the same as deciding that issue'.[99] This appears to be precisely the problem with the criticism of the LR approach from the context of PG DNA evidence. What lies beneath is the confusion as to how LRs are arrived at and what they mean, which in turn leads to fallacious reasoning and unfounded claims of usurpation of the fact finder's role.

As already discussed, the role of the expert is to present the probability of the observation/evidence *given* the proposition (e.g. that the defendant was a contributor to the DNA mixture together with another unknown person). If the expert presents the probability of the proposition i.e. that the defendant is a contributor to the DNA mix, or worse, that the defendant is guilty given the evidence– as suggested by critics – then the expert would be committing the prosecutor's fallacy which is not what the LR approach of evidence evaluation entails. In fact, the LR approach for evidence evaluation upholds the principle that the

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[87] As it will be discussed further below these propositions need be not the only relevant propositions in the case – they only need to be mutually exclusive.

[88] [31] at p.113 and footnote 4.

[89] As mentioned above even where identity is the key issue, the use of the LR approach to evaluate and report the strength of the evidence should be preferred rather than unfounded categorical opinions of identity.

[90] For details and concerns see e.g. Ref. [105].

[91] See Ref. [17] for a detailed discussion of these aspects.

[92] E.g. in *R v T* (2010) EWCA Crim 2439 such misunderstanding and the judge's preference for "could have" instead of "moderate support" as used by the expert evidence led to both prosecutor's fallacy and confusion [106] although the court's interest in transparency in how the expert calculated the LR was a good thing; for a commentary see Ref. [107].

[93] See Ref. [3] p.17; [85,105]. This is a contentious topic that requires further attention elsewhere.

[94] [6] p. 22–23 It is acknowledged that there are a number of factors that have led to such proposals including concerns regarding the validity and transparency of the evidence, but the focus here is the complexity surrounding the LR approach.

[95] For a commentary see [109].

[96] [31] p.112.

[97] On the ultimate issue rule and expert evidence see Refs. [17,110,111].

[98] In civil cases in England the rule has been abolished by s 3 Civil Evidence Act 1972 and in many criminal cases experts have been permitted to testify to the ultimate issue e.g. *DPP v A & BC Chewing Gum Ltd* [1968] 1 Q.B. 159 at 164, DC; *R v Stockwell* [1993]97 Cr.App.R. 260, CA.The rejection of a formal ultimate issue rule can be seen clearly in other common law jurisdictions eg Rule 704 of the US Federal rules of Evidence 1976 established that 'testimony in the form of an opinion or inference otherwise admissible is not objectionable because it embraces an ultimate issue'. Similarly in Australia, s 80 of the Evidence Act 1995 (NSW) provides that 'Evidence of an opinion is not inadmissible only because it is about – (a) a fact in issue or an ultimate issue [112–116].

[99] [117] p. 1734.

likelihood of a proposition is a matter which should be addressed only by the factfinder and any decisions on the ultimate issues can be achieved by the factfinder after having considered all other evidence in the case. This approach is both logically correct and non-controversial from a legal standpoint. In fact, it can be argued that the LR approach used for forensic evidence evaluation exemplifies a form of necessary 'survival' of the ultimate issue rule in the modern law of evidence [110]. It shapes up the role of the expert in a criminal trial to pronouncing on the strength of evidence and not to addressing the ultimate issue. Unlike traditional reporting formats associated with categorical opinions, the LR model is ideally suited to do just that: it 'requires' the expert to report on the probability of the findings under a set of propositions and leaves the determination of the probability of the propositions to the trier of fact.

4. Presuming guilt or considering inclusion? Two fundamentally different issues

4.1. The role of hierarchy of the propositions

The core of the arguments that the LR approach infringes the POI is that "LRs are created by assuming the defendant is in fact guilty (his DNA is in the mix), and then weighing that assumption against the assumption that the defendant is not in fact guilty (not in the mixture)."[100] In addition "… in order to generate that LR, the analyst tests the assumption that the suspect is in fact a contributor to the mixture. The question being asked is one inference away from the question the jury is trying to answer, 'is this the person who committed this crime?' "[101]

These statements require unpacking because they touch on several important matters. They reflect underlying fundamental misunderstandings of the role of the expert, how the expert evaluative opinions are arrived at, the limitations and the significance of the resulting evidence. In addition to committing the prosecutor's fallacy by referring to the 'testing' of the propositions, the commentators underplay the role of inferences that the factfinder should make based on the evidence, and in equating findings of sub-source level attributions (discussed below) with findings of guilt they by-pass the adjudication process. While it is important to raise awareness on the significance of forensic evidence in the trial process, on the risk of it not being properly reported and/or understood, and the potential to unduly influence the trier of fact, this cannot be achieved based on an inaccurate representation of (or by ignoring) what these processes - forensic and legal - entail.

Being a potential[102] contributor to a DNA mixture and being guilty of an offence are two fundamentally different issues, regardless of the real or perceived role of scientific evidence in influencing factfinder's decision-making process. This misunderstanding relates to a central concept for evaluative expert opinions [3,85] that is *the hierarchy of the propositions*.[103] In general, propositions that arise in a case can be classified in four levels: offence, activity, source, and sub-source levels - where the offence level is the highest and sub-source the lowest. With regard to DNA mixtures, it has proven useful to use a fifth level: a sub-sub-source level proposition which refers to the origin of part of the DNA mixture, for example the major donor [16]. *At sub-source level,*

propositions address issues such as the origin of the DNA e.g. whether the DNA came from the defendant (D) or another person of interest. At the *source level* they address the origin of material e.g. whether the semen recovered from the victim (V) came from the defendant (D). At the higher, *activity level*, propositions consider the activity that deposited the trace material e.g. whether D had intercourse with V. At the activity level the issues considered by the propositions often have to do with the acts of the D or another person of interest, or with alternative explanations for the presence of the trace material in question e.g. whether D's DNA presence in a mixture is related to transfer and persistence[104]. Ultimately, at the *offence level* a proposition considers whether an offence has been committed e.g. whether D raped V. It is a well-established principle of forensic evidence evaluation approach that offence level propositions are strictly for the fact finder to consider. The issue of guilt or innocence of the defendant[105] is NOT within the remit of the forensic scientist.

From this it can clearly be seen that when the principles concerning the hierarchy of the propositions for forensic evaluative reporting are respected, the expert's contribution does not infringe the POI, as the issue of guilt or innocence is outside of the expert's remit. In most cases an expert contributes at the lower levels of the hierarchy of the propositions. Probabilistic genotyping (PG DNA) for instance only provides information at sub-source and sub-sub-source levels. In order to make inferences at source[106] and activity levels, where this is *possible* and *requested* by the legal stakeholders in the proceedings,[107] separate calculations and analysis are required. According to ENFSI "activity level propositions are to be used when expert knowledge is necessary to evaluate and establish factors such as transfer mechanisms, persistence and other materials that could have an impact on the understanding of scientific findings relating to alleged activities".[108] Source level propositions are adequate in cases where there is no risk that the court will misinterpret them in the context of the alleged activities in the case i.e. where for example transfer and persistence are not an issue.[109]

There is a danger that the potentially large LR for source level propositions could be misinterpreted in court as extremely strong support for an alleged activity which is a different legal issue. In the context of DNA evidence for example there is a difference between an expert witness telling a jury that the *victim's blood* was found on the accused's

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[100] [31] p.113.

[101] [31] p.120.

[102] As explained above, LR statements do not report on the likelihood of propositions but of obtaining the evidence/observation given the propositions e.g. that D is or not a contributor to the DNA sample.

[103] The concept of the hierarchy of propositions is well established. See Refs. [86,118].For a discussion from a legal perspective see Ref. [17] chapter IV. See also [16,119]. The ISFG DNA Commission provides an extensive review with recommendations for practitioners [120].

[104] Such as innocent or secondary transfer and persistence (not related to the crime commissioning), see further below.

[105] According to the concept of the hierarchy of the proposition guilt and innocence are considered as offence level propositions. As argued further below, however, guilt or innocence are not presumptions/hypotheses but *decisions* made by the factfinder.

[106] As the Royal Statistical Society notes, the conceptual distinction between (iii) source level propositions and (iv) sub-source level propositions is especially significant in relation to DNA profiling evidence. There is a difference between saying: (a) the suspect (or another person of interest) left the body fluid at the scene of the crime (or other location of interest); or (b) the suspect (or another person of interest) donated the unattributable cellular material from which DNA was extracted. To ask whether a particular person is the donor of an identifiable body fluid is a source level inquiry. To ask whether a particular person is the donor of DNA extracted from unattributable cellular material is a sub-source level inquiry. See Ref. [88] at 3.18. An important initial consideration when trying to determine the probative value of DNA evidence will therefore always be whether the evidence is probative of source level propositions or only of sub-source level propositions.

[107] Be it the prosecution, the defence or the court in those jurisdictions (e.g. civil law jurisdictions) where judges play an active role in seeking and assessing evidence in criminal proceedings.

[108] [3] p.11.

[109] In several forensic analysis areas (e.g. bullet and cartridge case comparisons, handwriting, speaker recognition, physical fits) there is no distinction between source level and activity level propositions and can safely be assumed that the issue of source (bullet originated from a specific gun) is directly related to an activity (bullet was fired from that specific gun) [3] p.12.

clothing (a source level proposition), from testifying instead that the *victim's DNA* was recovered from the accused's clothing (a sub-source level proposition). Depending on the case circumstances, there may be innocent explanations for the presence of DNA which could not plausibly be extended to the presence of blood. A similar distinction between DNA and semen might be equally important in the context of sexual offence prosecutions, and so on.[110]

A DNA match may inform decisions about the source of the DNA, but decisions about an activity, such as sexual intercourse vs. social contacts, involve additional considerations beyond the DNA profile.[111] This is important as part of the criticism directed to PG DNA does not relate to what the evidence actually conveys which is an evaluation of the evidence at the sub-sub-source or sub-source level, but rather to alternative explanations for the presence of D's DNA in the mixture which in fact concern activity level propositions: "When dealing with such small amounts of DNA, there is much greater ambiguity as to how the DNA ended up on the object. For example, the DNA could have been left by someone who touched the object, or even by someone who touched the person who then touched the tested object." "Because of this, finding someone's DNA on an object is less significant to a determination of guilt or innocence of a suspect …. Although the possibility of transfer clearly affects the evidentiary weight of these small DNA samples, this is not accounted for when LRs are reported to a jury."[112]

These statements raise important concerns, but they are misdirected and confound separate issues. Explanations or propositions related to transfer and persistence of DNA are relevant for an activity level evaluation of the DNA results, whereas PG software and other interpretation and statistics methods evaluate the DNA results at the sub-source level. A sub-source level evaluation of the DNA results may be necessary for evaluating the findings with regard to a pair of activity level propositions[113] but they are far from the same. Discussions of transfer and persistence therefore have little if anything to do with the admissibility of PG DNA based on its reliability or the infringement of the POI. Instead, they demonstrate how important it is to properly understand the evidence, to avoid inaccurate inferences as to what the evidence means and what decisions the fact finder must make. A proper understanding of the limitations of DNA mixture analysis, alongside an adequate awareness of the transfer and persistence issues associated with DNA evidence and the sensitive DNA technology is paramount. This should not a priori make the evidence inadmissible or lead to an exclusion[114] unless the evidence is irrelevant (or insufficiently relevant) and/or unreliable.[115] Issues related to the evidential value and strength

(or lack of) of the evidence concern the weight of the evidence to be determined by the factfinder.

Critics' comments demonstrate that it is easy to misunderstand what the evaluative expert opinions deal with. The distinction between different levels in the hierarchy and the type of contribution an expert can and cannot make in a case need be properly understood and communicated to the fact finder, be it via trial narratives or jury directions. Due attention must be paid to the position in the hierarchy of propositions that can be and has been considered. The evidential significance of a likelihood ratio always depends on the level of the proposition i.e. the issue addressed.[116] This information must be effectively conveyed to the court to avoid the risk that an evaluation at one level is translated uncritically and without modification to evaluation at a higher level. Particularly in cases where forensic evidence adduced by the prosecution is framed in terms of sub-source or source level, in absence of balancing information and context at activity level, its probative value could easily be overestimated by the factfinders. It may lead to a "carry-over" of the LR from one level of the hierarchy to another which in turn can lead to miscarriages of justice [3].

The 'burden' to enhance this understanding should be mutually shared by both the legal and the forensic community. The forensic examiner should explicitly state that the findings do not address questions of a different level.[117] The legal stakeholders should not simply 'hide' behind the complexity of the forensic evidence to demand inadmissibility[118] but need to actively take responsibility for their own adequate understanding and the use of forensic evidence in their case strategy. In the context of this study, it can be argued that it is precisely the lack of understanding that what the expert reports on and what the jury has to decide are on different levels altogether, which leads to the claims that the LR approach undermines the POI. It is important to not underplay the significance of the inferences that need be made by the jury in interpreting the expert's statement dealing with lower-level propositions to decide on matter of guilt or innocence at the offence level – a decision that ultimately is made by the factfinder (not the expert) based on all the evidence in the case. Greater efforts should be made to improve the communication between experts and legal stakeholders, and to facilitate the understanding of the scientific evidence by all those involved in the process.

4.2. Understanding the role of the expert

Part of the criticism of the LR approach for evidence evaluation relates to the role of the expert and that of the parties in selecting the propositions for the evaluation of the evidence. It has been argued that "in selecting a hypothesis, the analyst proposes a specific defense theory to explain the evidence, without the defendant."[119] In addition it has been argued that "the expert should not assume what the defence proposition may be"; that "the defence is entitled to all propositions consistent with exoneration and should not be constrained to one proposition", and that "the defence is not obligated to provide a proposition."[120] These claims form the basis of the argument that the LR approach infringes POI therefore will be discussed below.

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[110] [88] at 3.18.
[111] See Ref. [121] p.46 A number of factors impact the evaluation of DNA. Transfer events require a source, opportunity and mechanism – the scientist may be able to consider these parameters in the context of each case and the information supplied by the instructing authority or party. A scientist may or may not be able to attribute the DNA profile to a source, that is a bodily fluid which in turn could assist with activity level propositions i.e. by what activity the DNA came to be present in a sample. Where dealing with 'touch DNA' depending on a number of factors including the type of the surfaces, the intensity of the contact, time passed, individual variability etc. there could indeed be primary, secondary and even tertiary DNA transfers. In some cases, it is not possible for a scientist to assist the party or the court with regard to how or when DNA came to be present, but in other cases, considering case specific circumstances, a comparative assessment can be made between alternative explanations. It is important in these cases that the underlying assumptions are stated clearly by the scientists carrying out any evaluations. The instructing authority needs to let the scientist know of the circumstances of the case, after the interpretation and the comparison process has been conducted, to facilitate any possible evaluations of the transfer scenarios. Such evaluations need to be well founded and contextualised in the latest relevant research.
[112] [31] p.116.
[113] [15] p.395.
[114] E.g. as recommended by Ref. [6] pp.22-23.
[115] See further below.

[116] See Ref. [84] p.48.
[117] See Ref. [3]; this addresses the concerns raised by Ref. [31] at pp.115–118. It is acknowledged that this is problem which seems to persist in practice and experts often find themselves in a difficult position when interpreting the results for the court see Ref. [17]. At times legal practices and rules themselves, such as Streamlined Forensic Reporting (SFR) do not facilitate the necessary early communication between experts and legal stakeholders, the understanding of the evidence in the context of the case and/or its scrutiny, see Ref. [122].
[118] Unless of course there are issues with the validity and reliability of the evidence, but the point here is that the use of LRs and the complexity of the evidence do not by themselves make the evidence unreliable.
[119] [31] p.122.
[120] [15] p.394.

First it is important to clarify the role of the expert in this process. The use of the LR approach[121] for evidence evaluation is promoted from the perspective of the duty that forensic practitioners have, to assist the court by explaining the significance of their findings within the context of the case. Where possible this is done by considering the findings from the perspective of at least two competing (alternative) *propositions* (or hypotheses) which are mutually *exclusive* but not necessarily *exhaustive*.[122] Since the probability of the evidence (i.e. observed findings) given only one proposition is uninformative and potentially misleading – two opposing propositions are needed for the evaluation of forensic evidence. As the RSS notes "the probative value of the evidence cannot be logically assessed by considering only half of the equation".[123] In absence of these opposing propositions an expert may be able to contribute to the proceedings via an *investigative report* based on a range of potential *explanations* for the findings. These explanations however are different from formal propositions[124] and the role of the expert is on a different level: investigative rather than evaluative.[125] Alternatively, the expert can simply state the findings in a *technical report*.[126] In the absence of (at least) two alternative propositions, it is impossible to evaluate the probative force of the findings.[127]

As discussed above the level of the propositions to be considered (and the propositions themselves) need be carefully selected with relevance to and should remain anchored to the case information (also referred to in the literature as case context, background information, conditioning information or the framework of circumstances).[128] Conditioning information is the relevant case information that helps the expert to recognize the pertinent issues, select the appropriate propositions and carry out the case pre-assessment. It could include the nature of the alleged activities from the information and evidence collected in the case, both inculpatory and exculpatory, victim's or suspect's account of their activities, known or admitted facts etc. It also includes the facts in issue (also referred to as 'key issues') that is those aspects of the case on which the court seeks to reach a judgment.[129] This context provides the general framework under which the instructions to forensic practitioners and propositions for evaluative reporting are based and formulated.[130] Most importantly, the case information is provisional and, if it changes, the propositions may need to change; consequently the findings will need to be re-evaluated by the expert in the light of those changes.

The competing or alternate propositions usually will correspond with the prosecution and the defence positions respectively (which is why they are referred as such in the literature) however it is important to understand that, while desirable, it is not necessary for the defence to advance any affirmative propositions for the LR to be calculated. Where the defence's position is unclear the forensic practitioner may propose the most reasonable propositions based on the case circumstances and produce an evaluative report clarifying that any changes to the propositions may impact the assessment of the strength of the forensic findings and necessitate further evaluations to be conducted. There are a few important aspects to be noted here: First, in the case of DNA mixtures matters could indeed be more complex than single source samples – and as critics have argued, both the selected opposing propositions could be untrue.[131] As ENFSI (2016)[132] notes the use of a LR does not generally imply that one of the two propositions must be true. Propositions need not be exhaustive so both could be false. It is important that lawyers, the court and the factfinder understand this. Depending on the case information, a range of issues may need to be considered by the expert such as: which, if any, of the known individuals may be reasonably assumed to be contributors; the number of contributors to the profile; how to deal with multiple persons of interest; how to deal with evidential items associated with neither the person of interest nor the victim.[133] More than one pair of propositions may therefore need to be considered.

Second, when conducting case assessment interpretation, the expert will initially decide on the number of contributors and on any conditioning profiles. After that the scientist will consider the genotype of the person(s) of interest to provide a preliminary assessment of whether there is a straightforward exclusion. If the outcome for a given person of interest (e.g. the defendant) is a straightforward exclusion, then no further analysis will be required for that individual and reporting is also

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[121] Known also as Bayes theorem in its odds form – see below.

[122] [3] p.11. An alternative proposition is *mutually exclusive* with respect to another competing proposition with which it forms a pair i.e. they cannot be both true at the same time, ibid p.24 Though the considered propositions are those deemed the most relevant based on the case circumstances, they may not be *exhaustive*, thus they both can be false. The expert need not consider propositions that have no basis on the case information or are very unlikely or impossible given the case information - see Ref. [3] p.22. For two different approaches on the issue of exhaustiveness which ultimately convey the above point see Refs. [123,124]. See also [15]. Depending on the circumstances of the case more than a pair of propositions may need to be considered by the expert. However alternative explanations and formal propositions are not the same in that the later are founded on case circumstances. As it will be discussed further below, the expert is under no duty to consider hypotheses that have no basis in the case information.

[123] [88] at para 3.19. p.38.

[124] Explanations are an intermediate consideration for use when exploring less formal alternatives. They are generated after the forensic findings have been obtained; they may be statements of the obvious, speculative or fanciful – see Ref. [3] p.20. Whereas propositions are statements that are either true or false, are formulated in pairs against a background of information and assumptions; they are amenable to a reasoned assignment of credibility by a judicial body and useable for rational inference - see Ref. [3] p24.

[125] Forensic experts routinely provide various, significantly different kinds of assistance to criminal justice practitioners, depending on the stage that a particular investigation or prosecution has reached from crime-scene through to court. This contribution can be related to intelligence, can be investigative, evaluative or simply factual/technical - see Ref. [3]. There are fundamental differences between investigative and evaluative roles of the expert. They require different kinds of inferential reasoning leading to distinct analytical products and forms of communication – see Ref. [84] p.29.

[126] This is referred to as the 'factual' reporting of a test outcome based solely on technical competence of the expert or analyst. No inferences, explanation, or opinion are drawn from the test results/observations. See Ref. [85] p.161.

[127] [3] p.13.

[128] [3] p.15 Propositions should not be adapted from one level to the other in the light of the forensic results obtained during a pre-assessment - with exceptions to investigative reports completed in the early stages of investigations.

[129] Such information would generally include relevant parts of witness statements, chronological information about the timings of relevant events or actions, the proposed or actual charges in the case, and any pertinent disclosures or contentions by a suspect or defendant, as well as procedural target dates. By contrast, examples of information that forensic scientists generally do not need to know (always ultimately depending on particular case circumstances) include matters pertaining to suspect's or the accused's character (including previous criminal convictions), domestic circumstances, movements prior to the time of the offence, or formal or informal witness identifications. Whatever information is relayed to the expert, there should be procedures in place to minimise the risk of contextual biasing of an expert's expectations and subsequent opinions - see Ref. [84] p.62; see also [125].

[130] [3] p.20.

[131] [31] p.122: "Not only are there multiple alternative hypotheses that could explain the evidence, but both hypotheses in the equation could in fact be wrong, and there would still be an LR reported. The number produced is the relative likelihood of two specific hypotheses, not the probability that either hypothesis is in fact correct." Except for the prosecution fallacy being committed, the rest of this statement is correct.

[132] [3] at p.22.

[133] For a summary of the effects of these considerations see Ref. [15] p. 395. Again, the difference between investigatory and evaluative expert opinions must be made clear. Explanations of the evidence which are considered in the investigative stage differ from formal propositions to be used in evaluative opinions which are embedded in the framework of circumstances i.e. case information.

straightforward. An expert will proceed with a full mixture evaluation (i. e. assignment of propositions and calculation of LRs) *only if an exclusion is not straightforward or cannot be made.*[134] This step cannot be emphasised enough as it addresses the criticism that the LR approach introduces 'guilt' and thus infringes POI: in absence of a straightforward exclusion of D as a contributor during the pre-assessment phase of the experts' work, the key issue to be determined remains whether D is or not one of the contributors, which is why a proposition of inclusion is considered. This proposition of inclusion corresponds to what the prosecution would usually allege. One of the opposing propositions could then be that D is not a contributor (or that another person is the contributor) which represents what the defence would usually argue.[135]

The 'defence proposition' is therefore simply the negation of the 'prosecution proposition', which, as argued further below, 'is a function of the relevance of the evidence in purporting to prove the accused's guilt'.[136] It does not matter whether the defence intends to rely on or to advance this proposition at trial. "The negation of the prosecution's assertion is already logically implicit as a possibility regardless as to whether anyone actually articulates it in the case."[137] Since the use of the terms prosecution and defence proposition may contribute to some contention and to the (uninformed) criticism of the LR approach for evidence evaluation, the use of alternate propositions without such descriptors e.g. P1 and P2 instead of Pp and Pd is advisable, to avoid the implications of the P (prosecutor) and D (defence) labels.[138] This approach would address to some degree concerns expressed in the literature to the effect that the expert is surpassing his role by proposing a defence's theory of the case or that the LR approach obliges the defence to forward an alternative proposition.

On the other hand, even if it were necessary that the alternative propositions came (only) from the defence, it is worth questioning whether the LR approach for evidence evaluation would impose on the defence a duty that is incompatible with its role in the proceedings thus interfering with POI. At the heart of the LR approach for evidence evaluation rests the essential requirement for an efficient and safe contribution of forensic evidence in criminal proceedings that is efficient communication between the forensic practitioner and parties in the proceedings: be it the police, prosecution and/or the defence.[139] Good communication (and ideally early collaboration) would bring forth any exculpatory information or alternative explanations which the expert can take into account for evidence evaluation alongside any other (inculpatory) information; it helps to bring out the most relevant aspects of the case and to achieve the best evidence which will ultimately contribute to safer verdicts thus upholding POI.[140]

According to the broader view of POI adopted in this study, defendants carry 'normative burdens' that is duties and responsibilities associated with their 'role' as defendants. As previously argued 'Defendant' is a distinctive normative role, bearing its own particular rights and responsibilities. A defendant is not merely an object of a judicial inquiry that aims to determine whether they are guilty of the crime charged, but an active participant in the process. While D can remain silent pretrial and give a no comment police interview, they risk adverse inferences of guilt to be drawn by the jury if, on trial, they rely on a fact that they could have reasonably been expected to have mentioned earlier.[141] If they were to raise an affirmative (active) defence, they

could bear an obligation to produce evidence to satisfy the judge that the issue should be put before the jury.[142] While defendants are not legally required to say anything in their defence, they risk conviction if they do not respond to the prosecution case, or do not offer a defence if the prosecution proves the commission of the offence.[143] At times a statute may even require impliedly or explicitly that defence proves particular facts in issue.[144] From this perspective it is not unreasonable to talk about the defence actively forwarding an exculpatory proposition, or the expert assigning the most suitable alternative propositions to the one forwarded by the prosecution, compliant with an exculpatory account of the events and facts in issue, based on the case circumstances and contextual information as known up to the moment the evaluation of the evidence is carried out.

There are a few aspects therefore that critics of the LR approach seem to be missing. Evaluative opinions in the form of LRs should and will be produced only when an expert is requested by the instructing authority or party in the proceedings to examine or compare trace material with a reference material from known potential sources. Therefore, the responsibility for the introduction of these opinions in the courtroom and to ensure their scrutiny as well as the correct subsequent use of the expert evidence in accordance with procedural rules and evidentiary principles rests primarily with the legal actors in the proceedings. The LR approach requires the expert to formulate one or several pairs of propositions which best reflect and are relevant to the case circumstances. When this conditioning information changes, the assessment of the evidence may also have to change. Investigatory explanations for the forensic observations (evidence) are different from the formal propositions that form the basis of the evaluative expert opinions which are conditioned on the case circumstances. It is paramount therefore that the *context* the evidence is arrived at is reported and properly understood as it is a vital component in any probabilistic reasoning process.[145] The responsibility for adequately setting out the case context and informing the expert on any changes remains with the legal actors in the proceedings. The alternative propositions that form the basis of an expert evaluative opinion do not necessarily need to be conceptualised as representing the prosecution and the defence positions. Most importantly, the evaluative work of a forensic scientist does not impose on defence any duties, burdens or obligations that are incompatible with POI and/or defence's traditional normative role in criminal proceedings.

5. Bayes theorem, prior odds, and POI

The criticism[146] concerning the use of LRs as in the case of PG DNA is partially linked to the possibility of the use by the jury of statistical methods such as *Bayes Theorem*,[147] to combine the entirety of the evidence in the case to reach a decision as to whether D is guilty. *Bayes Theorem* is a mathematical formula that enables the adjustment of one's belief in the likelihood (probability) of a given proposition (hypothesis) in the light of new evidence. When used in the context of a criminal trial, this theorem can be expressed as:

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134 See Ref. [40] at 6.8.7–6.8.9.
135 [3] p.13.
136 [88] p.88.
137 [84] p.45.
138 [15] p.394.
139 Discussed at length in Ref. [17].
140 Ibid. as confirmed by participants interviewed for this research.
141 As per section 34 CJPOA 1994 in England and Wales for example [126].

142 Referred widely in evidence scholarship as 'evidential burden' or 'burden of production' of sufficient evidence to 'pass the judge', see e.g. Ref. [45].
143 This relates to what is referred to in evidence scholarship as a the 'tactical burden' that defendants bear in the proceedings, and which corresponds to what happens in adversarial criminal trials where the two opposing parties 'battle' for the favourable decision of the factfinder.
144 Known as 'reverse onus' provisions and referred to as a 'shift' of the burden of proof for those particular elements from the prosecution to the defence.
145 [3] p.21 [127] notes that mathematical models *must consider the context of the hypothesis* and its connecting evidence to ensure that the model provides accurate information relevant to it. Berger notes the lack of discussion by the legal community of this vital component in any probabilistic reasoning process.
146 [31] at p.132; see also [6] pp.12-13.
147 On statistical issues and an explanation of Bayes' Theorem see Refs. [99, 128]; see also [129,130].

Prior odds x LR = Posterior odds

In relation to a criminal trial the *prior odds* may be taken to be the jury's assessment of the probability of a proposition (e.g. D being a contributor to a DNA mixture sample *or* D having committed the offence) prior to taking into account a particular item of evidence (e.g. DNA evidence; eyewitness testimony; real evidence etc.). When the probative value of the evidence which is presented in the form of LR, is combined with the prior odds it will provide the jury with the posterior odds, i.e. *the likelihood of that particular proposition after the evidence*. This posterior probability can then be treated as a new prior probability to which a further additional piece of evidence in the LR form can be added and a new posterior probability calculated. The process can be repeated for each item of evidence in the case resulting in a final posterior probability conditioned on the entirety of the evidence presented in the case.[148]

Proponents of this approach argue that Bayes theorem is a 'codification of the reasoning that should be applied in the assessment of the evidence' which ensures that evidence is assessed rationally [128]. The prior odds are estimated before the evidence (e.g. DNA) is presented and the posterior odds are estimated after the evidence is presented. Thus, the *Bayes Theorem* enables one to comprehend the importance of each item of evidence in the case, how the likelihood of guilt (i.e. the ultimate posterior odds) is affected by the evidence and how it is arrived at. According to this approach, it is for the fact finder to determine the prior odds, while the expert reports on the LR which shows how the odds change with the introduction of new evidence.[149] The roles of the expert and the jury are thus well defined. It has been proposed that the Bayesian approach can be used to link all of the evidence in the case - expert and non-expert, quantitative and non-quantitative - with one coherent chain of calculations.[150] It has been described as the only logical and legitimate way to ' transpose the conditional'[151] in order to enable the jury to arrive at what it needs to know - that is the posterior odds in favour of a proposition which ultimately could be the guilt of the defendant.

Critics argue that the use of LR approach as employed by PG DNA tools can violate the presumption of innocence because it *necessitates* the use of the Bayes theorem, which in turn requires the jury to presume D's guilt before all the evidence in the case has been heard: "In order to understand the significance of this evidence, the jury must consider the prior probability of guilt … They must decide, before hearing about the LR, what they think the probability of guilt is."[152] "Without Bayesian probability analysis, the LRs produced by PG do not provide evidence of the probability that an individual's DNA is contained in a sample. In order for the Bayesian probability analysis to provide evidence of such probability, the presumption of innocence and the Crown's burden of proof must be violated".[153] "If we assume zero prior probability of the defendant contributing to a sample, consistent with the presumption of innocence, the result will be zero posterior probability. Any number multiplied by zero equals zero. If, however, we assume prior probability that the defendant contributed DNA to the sample, we are presuming guilt. This violates the presumption of innocence."[154]

Several misconceptions can be observed in these statements. First, any inferences whether defendant's DNA is present in a crime scene sample, is left with the fact finder. The expert only reports on the LR that is the ratio between the probability of the evidence (e.g. DNA profile) given two opposing propositions (e.g. if D rather than an unknown individual is the source of the DNA). Moreover, the issue of D contributing or not to a DNA profile is not equal with guilt (or assumptions of guilt) especially in the context of complex DNA mixtures where the level of the propositions considered is of sub-sub source or sub-source - not offence. The key here is to facilitate a correct understanding of the expert opinion, to avoid erroneous reasoning.[155] In particular, the probative value of a piece of evidence e.g. PG DNA evidence in the context of the case as a whole and any limitations, need be properly understood. Other supporting evidence of guilt besides D's likely contribution to a DNA mixture would be necessary for the case to progress at court and especially to form the basis of a conviction. It is recommended that this aspect be regulated in each concerned jurisdiction in accordance with the rules of evidence related to admissibility and corroboration, and that the jury be adequately directed on the significance of the evidence based on the expert's report.[156] All these aspects could be dealt with via existing, new or amended statutory provisions and/or through judicial practice guidelines as necessary.[157]

Second, while LRs are an organic component of the Bayes Theorem, a distinction need be made between the use of LRs to evaluate (the strength of) the forensic observations and to present to the factfinder the probative value of a piece of evidence with the controversial[158] use of Bayes theorem (also referred to as the Bayesian model in literature) in court to assist the fact finder with the reasoning process in combining all the evidence in the case (probabilistic and non-probabilistic) to arrive at the ultimate posterior probability of defendant's guilt.[159] As the RSS notes:

"Likelihood ratios are a strictly rational and mathematically validated mechanism for quantifying evidential weight or probative value, i.e. *the strength* of evidential support for a particular proposition. They are

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[148] See Ref. [128] p.44.

[149] RSS notes that 'experts are not absolutely precluded from stating posterior probabilities relating to intermediate facts proving or constituting the offence, if invited to do so by the court and providing that such statements are appropriately qualified and contextualised.' See Ref. [128] at p.43. Furthermore 'Experts normally testify to relative frequencies (to inform likelihoods of the occurrence of evidence), or occasionally to base rates (prior probabilities), rather than to the truth or falsity of contested issues in the trial (posterior probabilities). Where experts depart from the norm by testifying directly to posterior probabilities, they should do so deliberately and advisedly, not merely through confusion. Insofar as experts do testify to posterior probabilities, they must spell out and justify the conditioning assumptions and prior probabilities supposedly warranting them.' Ibid at p.43. Berger [127] notes that even if the expert offers a suggestion of a posterior probability for the ultimate hypotheses, this is not a 'trespass on the province of the jury' so much as a vital communication of the context of the LR calculations 'K'. The jury ultimately can decide whether to accept or reject the weight of the evidence reported by the expert after the examination and cross-examination of the witness have taken place, to allow the jury to scrutinize the values inherent in the model.

[150] For an analysis of the use of Bayes in the context of key DNA cases see Ref. [17].

[151] [128] p.47.

[152] See Ref. [31] pp.132-3 and again at p.136.

[153] [6] p. 13. The critics do concede that in criminal cases only the LR is presented as evidence and not the 'subsequent Bayesian analysis' (Ibid) A similar misconception was evident in court's decision in *State v Skipper* [131] at 623: "Bayes theorem can only work if the presumption of innocence disappears from consideration".

[154] [6] p.13 citing [31].

[155] See the prosecutor's fallacy or the fallacy of the reverse conditional discussed above.

[156] Some jurisdictions have corroboration rules in place e.g. Scotland.

[157] Such as the Practice Directions in England and Wales for instance Ref. [132].

[158] E.g. the use of the Bayes theorem was rejected twice in *R v Adams* [1996] 2 Cr.App.R 469; *R v Adams* (No.2) [1998] 1 Cr.App.R 377, and *R v T* [2010] EWCA 2439 [133–135].

[159] This point is also made in Ref. [37].

employed by many forensic scientists in their case-work. Although likelihood ratios also feature in Bayes' Theorem, there is nothing inherently or distinctively 'Bayesian' about the use of likelihood ratios or the importance of considering the probability of evidence under competing propositions. It is simply a matter of elementary logic that evidence compatible with guilt could also be compatible with innocence, and one cannot therefore assess its relevance or probative value without first considering how a particular item of evidence might bear on *both* sides of the argument, for and against. This inquiry is inescapably probabilistic."[160]

Regarding the issue of 'priors' in the context of Bayes theorem, misunderstandings can be observed as to what they mean, how they are to be determined and what is or not compatible with the POI. Criminal trials operate under conditions of uncertainty. A factfinder facing a defendant at the start of trial does not know whether he is in fact innocent or guilty - both the possibilities are equally likely. It is for the criminal trial process to reveal the outcome, by enabling the factfinder to make decisions on proof, guilt and innocence. What POI requires is that the factfinder approach the case without having formed any views regarding D's guilt or innocence and only convict the defendant as guilty if the prosecution proves its case beyond reasonable doubt. However, one important aspect is often misunderstood: to be *presumed innocent* is not the same as being *in fact innocent* i.e. not guilty. In other words, approaching the case *as if D were innocent* does not mean that 'the priors odds of guilt' should be 0 to ensure compatibility with POI as critics suggest.[161] Priors would only be 0 if D were factually innocent, which the factfinder does not know at the start of the trial before any evidence being presented.

In the criminal justice processes, D is someone against whom there are reasonable suspicions (or probable cause) of guilt and sufficient inculpatory evidence that makes for a 'realistic prospect of conviction'.[162] Closely linked to and manifested through the principle of minimum state intervention, POI protects a person having to stand trial where there is no sufficient evidence of guilt to constitute a case to answer.[163] This does not mean however that any prior determinations of factual guilt or innocence need actually be made as 'discharging their institutionally allocated responsibilities in the administration of justice does not, in general, require police, prosecutors or defence lawyers to form any view about suspects' or the accused's factual guilt or innocence'.[164] Similarly 'jurors are never told to presume innocence in the epistemic sense.'[165] If they were to be asked at the start of the trial 'to state truthfully what they believed about the accused's guilt or innocence—a question which, in reality jurors are *never* asked—the only rational response would be that the accused is probably guilty.'[166]

What POI requires therefore is that the defendant be treated neither as *factually* innocent, nor as guilty, 'but as a citizen against whom there is a reasonable suspicion of guilt, based on evidence grounding a reasonable prospect of conviction'.[167] If POI would indeed require treating someone as *factually innocent* – there would never be any justification for them having to stand to trial or to convict them. If the prior probability of guilt would indeed be 0, no amount of evidence would ever change the posterior (which would always be 0, as 0(prior) x LR = 0 (posterior)) and lead to any other decision other than D being innocent. The issue of 'priors' relates to a common misunderstanding of POI itself: POI is not the type of evidentiary presumption often considered to be. As Roberts puts it "the presumption of innocence may support a range of

evidentiary doctrines and institutional practices including particularised evidentiary presumptions, but it does not itself have any direct evidentiary (including epistemic) applications. As Evidence specialists have always maintained, 'the presumption of innocence' is not *that kind of* presumption."[168] POI does not authorise a verdict that would not otherwise be achievable on the proven facts. POI does not mean that the defendant *is* actually innocent: no factual inference can be automatically drawn due to POI.

The very purpose of criminal proceedings, from investigation to trial is to identify the guilty. The police[169] have a duty to collect evidence – be it inculpatory or exculpatory - based on which the prosecution decides whether to bring a case to trial. It is on the basis of the incriminating evidence that the prosecution argues on trial that the defendant has committed the offence and that is guilty. The prosecution would not be able to present any evidence on trial in fulfilment of its role, be it a witness testimony, real evidence or an expert report if POI would not allow it to argue guilt. It is important to note that *arguing that D is guilty* and seeking to prove to the factfinder D's guilt based on incriminating evidence - which is what the prosecution does - is different from factually *presuming guilt* - which critics wrongly argue that the LR approach promotes. The LR approach of evidence evaluation is not about presuming guilt or innocence; it serves to evaluate the strength of the evidence *given* two opposing propositions of the hierarchy determined by case circumstances, forensic observations and the type of contribution the expert is able to give in a case, as requested by and in agreement with the instructing authority or party (parties) in the proceedings. It is the suspicion and the belief on the likelihood of guilt based on the information and evidence collected pretrial - that form part of the 'context of the case' or 'framework of circumstances' - which 'warrants requiring the person to take on the distinctive normative role of 'defendant', and the burdens that it brings'[170].

The defendant is thus selected from a 'suspect population', that is the number of people who could possibly have committed the offence, based on evidence that may have to do for instance with the whereabouts at the time of crime i.e. location, opportunity,[171] witness description, motive, DNA analysis results etc. While it is for the jury to determine whether the prosecutorial evidence on basis of which D is on trial, 'translates' to proof and ultimately supports a guilty verdict, at the start of the trial, before the evidence is heard, as far as the jury (and everyone else) is concerned, D is equally likely as any other member of the suspect population to having committed the offence. As Aitken and Taroni put it: ' … before any evidence is heard, 'innocent until proven guilty' means that every person in the relevant population is equally likely to be guilty. If the relevant population were taken to be the population of the whole world it is fairly straightforward to think of evidence that will eliminate most of the people in the world from serious consideration as potential suspects.'[172] As an extreme example therefore, the 1/WP[173] prior satisfies the POI 'since before evidence is heard, the defendant has a uniform probability of equal guilt with that of the rest of the world population'.[174] Given the framework of the circumstances (i.e. case

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[160] [88] at p.88.

[161] See the [6] p.13 citing [31].

[162] E.g Ref. [81] at 4:6.

[163] Ibid.

[164] [41] p.8916.

[165] [41] see pp. 8915-17.

[166] [41]. p 8917.

[167] [46] p.175. See Ref. [81] parts 3 and 4.

[168] [41] p. 8928. According to Roberts, the conceptual distinction embedded in traditional common law thinking between 'evidentiary' and 'jurisprudential' presumptions is often not acknowledged nor respected. See also Laudan [136] at p. 359: 'The presumption of innocence is a double misnomer. It is patently not a presumption but an assumption; and, at least in a system with a proper standard of proof, the PI has little or nothing to do with 'innocence' in the sense in which that term is almost certainly construed by lay jurors. Properly understood, the PI is little more but no less than an assumption of no-proof-of-guilt at the outset of a criminal trial'.

[169] Or any other investigatory authority.

[170] [46] p.175.

[171] For a discussion see [137].

[172] [138] at p.187.

[173] WP stands for world population.

[174] [127] p.147.

context) the prior odds may reflect the number of people in a city or even in a country. The prior odds of .000001 for example would correspond to the jury's belief that the perpetrator of the crime could be anyone in a city with a population of one million [139]. In a Bayesian model therefore, the suspect population evidence would be combined with the LR (e.g. of the DNA evidence) to produce an overall posterior probability of guilt. Critics' argument that no valid priors compatible with POI can be attributed is therefore without basis.

It is beyond the scope of this article to discuss the utility, usability and appropriateness of the probabilistic models such as Bayes theorem in criminal trials. Theoretical debate and criminal litigation practice have made it clear that formal methods of reasoning, regardless of their benefits, cannot easily be carried over to the conceptual problems encountered from a legal perspective.[175] For some commentators the reluctance to accept Bayes in the law is 'the latest manifestation of a long-time historical reticence to accept any statistical analysis as valid evidence' based on its misuse on a number of well reported cases, its limitations and difficulties in interpretation.[176] A number of social, legal and logical impediments to the use of Bayes in legal proceedings and in more general policy decision making have been widely discussed.[177] For others, the problem lies on the differences between what the forensic expert does and what the legal actors and the fact finder need to do. While forensic scientists use the LRs and probabilistic approaches to assess the probative value of selected items of evidence, lawyers and factfinders are faced with the issue of 'proof' on the level of the case as a whole and must reach a decision on innocence or guilt [150]. Any attempts therefore to assess the 'probability of D's guilt' in the light of evidence via Bayes Theorem arguably misunderstand what need be modelled, as guilt is not a proposition but a decision to be reached in the light of uncertainty about the proposition of whether the defendant is the person who committed the acts of interest in the case at hand [150].

This author supports the view that the decision-making process in legal proceedings is complex and demands more than a probabilistic approach to reasoning about the evidence in the case. As Taroni et al. note for instance, one does not *only* decide based on what one believes (i. e., one's probability for a proposition of interest), but also based on one's preferences among the possible consequences.[178] Conceptual frameworks such as the Bayesian approach however, provide standards of reasoning that can be used to examine whether a given argument has the necessary credentials to be considered sound and, thus, whether those who reason are logically entitled to their conclusions. They help to define and clarify the role and limitations of the use of scientific evidence within the broader perspectives of legal evidence and proof, and have the potential to improve the efficiency, transparency, and fairness of criminal justice processes.

6. Does the LR approach lower the standard of proof in criminal cases?

Alongside the allocation of burden of proof on the prosecution, a second important aspect of the POI is that the prosecution must prove its case *beyond reasonable doubt*.[179] In civil cases, and each time the defendant bears the obligation to prove a fact in issue in criminal cases, the standard of proof is on the preponderance or *balance of the probabilities*. This standard follows a rational approach to decision making as the preponderance of evidence points to the most probable scenario i.e. that which is most likely to be true.[180] The epistemically rational standard of balance of probabilities suitable in civil litigation however does not serve as the prosecutor's standard of proof in criminal adjudication. In criminal procedure the steeply asymmetric standard of proof derives inter alia from a commitment to respect POI and to minimise the risk of wrongfully convicting an innocent, which is considered as far worse than the risk of acquitting the guilty.[181]

Human decision-making generally, including reaching a verdict in a criminal trial, occur under conditions of unavoidable uncertainty. The fact that 'all empirical propositions are probabilistic' and that 'there is no such thing as absolute, complete, unimpeachable and non-revisable certainty in the empirical world'[182] is clearly reflected in the criminal standard of proof. Proof beyond reasonable doubt does not mean beyond *all* doubt, or every conceivable doubt. As per Lord Denning[183] the criminal standard needs not reach certainty, but it must carry a high degree of probability. Proof 'beyond reasonable doubt' does not mean proof 'beyond the shadow of doubt'. According to POI an accused is not required to prove his innocence but only needs to establish a reasonable doubt that he might be innocent in order to secure an acquittal. This 'doubt' needs to be reasonable, that is probable under the facts and evidence in the case. As per Lord Denning, the law would fail to protect the community if it admitted fanciful possibilities to deflect the course of justice. If the evidence is so strong against the defendant as to leave only a remote possibility in his favour which can be dismissed with the sentence 'of course it is possible, but not in the least probable', the case is proved beyond reasonable doubt; nothing short of that will suffice.[184]

Lord Denning's reasoning is particularly important in the context of the evaluative opinions which are based on opposing propositions conditioned on the framework of circumstances. There is no obligation on the expert to consider propositions or alternative explanations that do not find support on the case context. It is well recognised that 'the duty of the prosecution to prove an accused person's guilt… does not involve that the prosecution must speculate as to and specifically anticipate every conceivable explanation that an accused person might offer'.[185] As discussed above, first, the opposing propositions need not be exhaustive for evaluative reporting of the evidence based on the LR

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[175] The suitability of the approach has also been questioned from a probabilistic perspective; see e.g. Ref. [127] p.182 who argues that Bayesian Networks cannot assist in combining evidence across different types due to a discrepancy in the value K across the evidence types. Moreover, it can be argued that the (un)suitability is not (only) due to an oversimplification of the legal arguments in the probabilistic models and/or due to complexity - which could be addressed via computerised methods as argued e.g. in Ref. [140].

[176] Eg Dreyfus Case in 1894 see Ref. [141]. See also *People v. Collins* [142] where the use of statistics was characterised by two errors: 1) It underestimated the probability that some evidence would be observed if the defendants were innocent by failing to consider dependence between components of the evidence; and 2) It implied that the low probability from the calculation in 1) was synonymous with innocence (the 'prosecutors' fallacy). Since then the same errors (either in combination or individually) have occurred in well reported cases such as [143–145]. As Fenton et al. [140] note, the use of statistics in a correct way exposed errors in the original calculations and enabled the convictions to be reversed on appeal, yet the incorrect use of statistics is the one that leaves an 'indelible stain'; moreover the role of legal professionals who allow expert witnesses to commit the same well-known statistical errors repeatedly is rarely questioned.

[177] See e.g. [32,140,146–149].

[178] [150] at p.261 referring to Kaplan's decision theory which defines the optimal decision in terms of the relative desirability of the various possible decision consequences, weighted by their probability of occurrence, see Ref. [151].

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[179] On the complexity of the standard from a US perspective see Ref. [152].

[180] On the jurisprudential foundations of English criminal law's steeply asymmetric standard of proof, see Ref. [45].

[181] See the above mentioned 'Blackstone ratio'. Criminal procedure ideally seeks to achieve a balance between competing values and objectives and to ensure the equality of arms regardless of the practical inequalities and imbalances.

[182] [88] at p.39.

[183] Lord Denning in *Miller* v *Minister of Pensions* [153], 373–4.

[184] Lord Denning [153]. Note that juries in England and Wales are directed that they should be "sure" of the accused's guilt before convicting which arguably is a more effective way of communicating the meaning of the traditional standard to juries – for a commentary see Ref. [45].

[185] As per Lord Morris in *Bratty* v *Attorney General of Northern Ireland* [154].

approach but must be based on the case circumstances. Second, it would benefit the defence to contribute any information based on which one or more opposing propositions can be selected to be considered by the expert. At the same time the defence is not automatically entitled to every possible explanation compatible with innocence being considered as a formal proposition if this is without basis.

Part of the criticism surrounding the use of probabilistic evidence reported via LRs relates to the (erroneous) perception that the consideration of the opposing propositions (often but not necessarily always representing the prosecution and the defence case respectively) 'waters down' the POI and transform the standard of proof to one akin to the civil standard. "In criminal trials, triers are prohibited from putting a defence hypothesis into a contest with the prosecution's case, as such an approach is inconsistent with the presumption of innocence. The Crown prosecution must establish its case beyond a reasonable doubt. It is not a question of which hypothesis as to DNA identity is more likely to be true."[186] "… LRs are created by assuming the defendant is in fact guilty (his DNA is in the mix), and then weighing that assumption against the assumption that the defendant is not in fact guilty (not in the mixture). The possibility of guilt and innocence (inclusion or exclusion) are treated equally, thus shifting the burden of proof to something more akin to a civil standard."[187] "… the two positions are not supposed to be weighed against each other in a criminal trial".[188] "… the introduction of probability evidence in criminal trials invites the jury to render a guilty verdict with proof less than beyond reasonable doubt."[189] In *State v Tyrone* [38] the defendant asserted that 'probabilistic genotyping violates … the United States Constitution because it shifts the burden of proof because likelihood ratios prompt juries to convict "without proof beyond a reasonable doubt," thereby altering the State's burden of proof' [38].

Several misinterpretations can be observed in the above criticism surrounding the use of LRs - some of which have already received attention above. First, adversarial criminal trials "are not objective inquiries into past events, but adversarial contests, in which parties, who have a vital interest in the outcome, not only decide what evidence they wish to present and prevent from being presented, but also present the evidence in as persuasive a manner as possible, a manner calculated to win them the sympathy and support of the court. Each party also seeks to persuade the court, by means of partisan, persuasive argument, to interpret the evidence in a light favourable to his case".[190] The adversarial contest nature of the criminal trial[191] should thus not be ignored, nor should it be interpreted as a dilution of the standard of proof.

Most importantly, there can be observed a tendency to equate expert evaluation of an item of evidence based on one or more pairs of alternative propositions with the factfinder's assessment of the prosecution and defence cases. The evaluative reporting of the strength of the evidence does not affect the prosecution's duty to prove the case beyond reasonable doubt.[192] From the context of the use of the LR approach of evidence evaluation, the matter is not one of the probabilities of guilt and innocence being treated equally for the purposes of proving the case. Guilt or innocence are beyond an expert's remit; nor does an expert

directly engage with which alternative (pro)position (prosecution or defence) is more probable.[193] A defendant's contribution to a DNA mixture or lack thereof, are mutually exclusive alternatives in relation to which the relevance and the probative value (i.e. strength) of the evidence itself is assessed: a defendant either is a contributor or is not a contributor to a DNA mixture. A neutral or inconclusive evidence would be lacking probative value and thus would be irrelevant and inadmissible. The LR approach of evidence evaluation provides an assessment of the strength of support *the evidence* gives to one proposition against a stated alternative.[194] It answers the key questions as to, first, whether the evidence is relevant i.e. whether it affects the respective probabilities of the opposing propositions and second, what is the probative value of the evidence i.e. what is the size of impact of the evidence on the probabilities of the opposing propositions. As the RSS observes, in absence of the two opposing propositions the analysis of the probative value of the evidence cannot even begin [88].

The LR approach can be seen as a manifestation of the fundamental evidentiary principle of relevance according to which any evidence adduced in the proceedings can only be admitted if (sufficiently) relevant. In *DPP v Kilbourne* Ld. Simon of Glaisdale held that "Evidence is relevant if it is logically probative or disprobative of some matter which requires proof. It is sufficient to say … that relevant (i.e. logically probative or disprobative) evidence is evidence which makes the matter which requires proof more or less probable" [156]. It is clear therefore that for any evidence to be relevant and admissible in legal proceedings, it must affect the probability that a fact in issue is true or false.[195] Incriminating evidence increases the probability that the accused is guilty and reduces the probability that he is innocent. On the other hand, evidence which reduces the probability that the accused is guilty and increases the probability that the accused is innocent – is exculpatory. Evidence that neither increases nor decreases the probability that the accused is guilty is irrelevant and therefore inadmissible.

Relevance and probative value are relative, not absolute, concepts. They depend on the facts that the evidence purports to prove and on the type of contribution that the evidence makes in proving them [88]. PG DNA can contribute at the sub-source level of inquiry i.e. whether D is or not one of the contributors to the DNA mixture. However, depending on the type of the offence, circumstances of the case, the facts in issue, the level and type of propositions to be evaluated,[196] the probative value of the same item of evidence i.e. the support it provides for the prosecution or the defence case can vary from one case to another. This is especially important also in terms of how it affects the admissibility of the evidence. Where the identity of the offender is the key issue in the case, the DNA evidence may provide significant support to prove or disprove that issue. In cases of complex mixtures, the limitations of the probative value of the evidence even in terms of identification need be fully understood and appreciated in order for determinations on relevance and admissibility to be made. Where the issue that requires proof relates to an activity level proposition,[197] where there are alternative explanations for the presence of D's DNA in the mixture related to transfer and persistence, or where the fact in issue relates to specific elements of the *actus reus* or *mens rea* of an offence e.g. consent in a sexual offence case, or to defences that may be raised e.g. a claim of self-defence, the contribution of the DNA evidence could be minimal if at all relevant.

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[186] [6] at p.17.
[187] [31] at p.113.
[188] [31] p.142.
[189] [31] p.139.
[190] [155] at p.3.
[191] At least in the Anglo- American tradition which is the focus of this study.
[192] The prosecution cannot simply argue that its case is more likely than the defence's case. In fact, if the jury finds the prosecution's case is equally or more likely to the defence case, in line with POI, the defendant should be acquitted as surely there will be a reasonable doubt in favour of his innocence and the prosecution would not have proved its case.

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[193] See above the discussion on 'prosecutor's fallacy' – the matter is about the probability of observing the findings/evidence given each alternative proposition not of the probability of the propositions themselves.
[194] [3] p.22.
[195] [88] p.40.
[196] See above the discussion on the hierarchy of the propositions.
[197] On challenges surrounding activity level propositions and transfer/persistence/recovery issues see Ref. [157]. This study shows variance between laboratories which raises questions about the reliability of the results, presenting additional challenges for courts and all the stakeholders involved.

Relevance is a legal not simply a logical concept. Technically, once the evidence is relevant, it could be admissible – even if it only slightly increases/decreases the probability of a fact. The probative value of the evidence i.e. the weight of the evidence is a question for the factfinder to determine. Issues concerning the use of LR approach such as the selected propositions, calculations done by the expert, the strength of the evidence, would usually affect the weight of the evidence. However, sometimes evidence will be deemed "irrelevant" or "insufficiently relevant" where, though technically relevant, its strength in this regard is outweighed by the costs of admitting the evidence. Costs may include the risk of prejudice to the defendant; the evidence being superfluous or too remote; where the evidence is likely to mislead or confuse the jury; where the evidence is likely to result in a multiplicity of issues or to cause unnecessary expense or delay. If the evidence does not have a *sufficient* degree of relevance to outweigh the costs of admitting it, the evidence may either be deemed inadmissible or be dealt with by judicial discretion to exclude otherwise admissible evidence.[198]

It is strongly recommended that all these evidentiary considerations affecting the admissibility of evidence, alongside requirements that specifically relate to the reliability and validity of the scientific methods[199] should be carefully taken into account and applied by courts when deciding on the admissibility of forensic evidence generally and algorithmic based ones, such as PG DNA. In many cases existing evidentiary safeguards applicable to all types of (forensic) evidence may be sufficient and offer robust protection to fair trial rights, however in some (if not all) jurisdictions, statutory reform may be necessary to prescribe the scope of the use of particular items of evidence.[200] For instance specific requirements may be introduced, where they do not already exist, that the prosecution case and especially a conviction should not be based solely on PG DNA evidence, but needs to be supported[201] by other incriminating evidence of a different source. Statutory reform may also be necessary to regulate and to promote the validity and accountability of forensic methods and systems especially those that engage advanced computational technology which raise additional challenges to fairness, due process and fundamental criminal justice principles.[202] Requirements related to the defence rights to disclosure and access to justice should also be taken into consideration to determine the admissibility of the evidence and which party bears the burden of proving the validity and reliability of the scientific methods

used.[203]

The main aim of forensic science regulation is to ensure that accurate and reliable scientific evidence is used in criminal proceedings and to minimise the risk of a quality failure. As noted above, forensic evidence can contribute to enhancing the accuracy of the verdict thus upholding POI only if valid and reliable. In this author's opinion, calls for reform that seek to introduce presumptive inadmissibility provisions for (algorithmic) evidence such as PG DNA based on its inherent complexity and due to the use of LRs approach for evaluative reporting of the results, exceed what needs be achieved.[204] Concerns with the way LRs are calculated, the propositions considered in specific cases and the strength of the evidence, usually affect the weight rather than the admissibility of the evidence. Any regulatory reform proposals should be free from fallacious reasoning about evidence, its value and limitations and about the role of the expert in criminal proceedings. The use of the LR approach does not infringe POI. It is important that the true meaning of the expert's evaluative reports and its limitations must be properly understood and be clearly communicated. Adequate sharing of the responsibility between the legal and forensic communities, effective training and education that aims to improve the communication between different communities and actors in the criminal justice system and especially the understanding of the evidence, limitations and the processes involved, will lead to a safer reception of scientific evidence and delivery of justice.

7. Conclusion

The criticism surrounding new algorithmic based forensic technologies such as PG DNA, encountered in litigation practice, legal commentary and regulatory reform initiatives for advanced AI technologies in criminal justice, concerns inter alia the way the expert results are reached and reported. It extends to the probabilistic evaluation and presentation of evidence via LRs which in recent years has been promoted by the forensic community as the correct way to reach evaluative expert opinions and as a shift from unfounded categorical results traditionally associated with many areas of forensic science. Having considered whether evaluative reporting of forensic evidence via the use of LRs infringes POI, this study revealed underlying fundamental misunderstandings of the role of the expert, how the LR calculations are arrived at, the significance and limitations of the evidence as well as the very meaning of POI in the context of the forensic evidence and formal methods of reasoning. Given these misconceptions, it is dangerous to call for a ban, restriction or presumed inadmissibility of particular types of forensic evidence on the basis of their underlying complexity and because they use the LR approach for evaluating the results. These evidentiary measures would be unproportionate and risk undermining broader important initiatives made by the forensic community to ensure the integrity, validity and reliability of forensic evidence in the criminal proceedings.

As the basis of forensic expert evidence evaluation, the LR approach does not infringe POI in and of itself. It does not introduce a 'presumption of guilt' nor does it dilute the standard of proof. In fact the LR approach ensures a clear division between different stakeholder roles in the criminal justice setting: while the expert reports on the value of the evidence given one or more pairs of alternative propositions framed in the case context, it is for the instructing party to decide how the evidence fits within and/or supports its case and whether it should be adduced; it is for the trial judge to decide on its admissibility given fundamental considerations such as the relevance and reliability of the evidence. Finally, it is for the factfinder/the jury to make the necessary inferences

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[198] In such cases, the evidence is deemed relevant, but the judge exercises discretion to exclude relevant evidence. See e.g. Ref. [158] pp. 32-34.

[199] Some jurisdictions have specific admissibility requirements related to the reliability of the evidence - for a review see e.g. Ref. [159]. In England and Wales, expert evidence as to forensic science activities is also potentially subject to the Forensic Science Regulator Act 2021 ("FSR Act") and the Forensic Science Regulator Code of Practice ("FSR Code") [160,161]. When applicable, the Act and the Code apply to both prosecution and defence experts. Compliance with the FSR Code and the FSR Act is a mark of reliability for prosecutors, the courts and others. Where the FSR code does not apply, or forensic evidence is not FSR Code compliant closer scrutiny is required by instructing parties and the courts. Courts may follow the Criminal Practice Directions [132] to assess the reliability of expert evidence. In many cases the issue is likely to be the weight to be given to the evidence rather than its admissibility although that will ultimately be a matter for the court.

[200] In Canada e.g. Parliament has enacted Criminal Code provisions to expressly set out preconditions to admissibility of certain types of evidence. See, e.g., Criminal Code, RSC 1985, c. C-46, section 276, section 269.1, section 277, section 278.92, section 320.31, and section 320.32. See [6,162].

[201] In Scotland, two sources of reliable and credible evidence are required to corroborate that an offence was committed i.e. the case against the accused, not the separate elements of the offence individually [163].

[202] See for instance Ref. [4] The application of these requirements needs be explored elsewhere.

[203] These relate inter alia to the heavily litigated 'source code' disclosure for PG Software and whether particular evidence falls within the parameters of validation studies.

[204] See Ref. [6].

that may transform an evaluative forensic opinion at the sub-source, source or activity level to proof of a particular fact which could, together with all the other considerations and evidence in the case ultimately support a decision of guilt or innocence.

A broad view of POI sees the defendant as an active participant throughout the criminal justice process with rights and duties. While forensic evaluative opinions do not demand defence contribution, they are framed on the case framework of circumstances which includes any exculpatory information or alternative explanations. As such expert evaluative opinions would certainly benefit from the defence contribution, which is in line with its normative duties and the way POI is manifested throughout the criminal justice process. At the same time the defence benefits by an evaluative approach to evidence that considers not only inculpatory but also exculpatory information and propositions.

Alongside the application of existing evidentiary safeguards, statutory reform to prescribe the scope of use of specific types of evidence and any related conditions, as well as regulatory frameworks that promote the validity and the accountability of forensic methods and systems - especially those that engage advanced computational technology – is recommended. In addition, the way forward should see a better sharing of the responsibility between the legal and forensic communities to address the complexity of the evaluative approach and probabilistic reporting of the evidence; to ensure that the evidence, its meaning and significance in the context of a case are adequately reported, communicated and understood. This needs be achieved from the investigatory phase, the pre-trial communication between the instructing authority or party with the forensic scientist. Forensic evidence has the potential to immensely contribute to the criminal trial commitment to accuracy which best serves POI. A commitment to accuracy should be shared by both the legal actors and experts; it needs to be reflected in trial narratives and any misunderstanding should be clarified. The jury need be educated as far as the trial process allows and is practicable but above all, it should be properly directed by the trial judge on the meaning of the evidence and potential misinterpretations of its significance. This requires that judges (and other legal stakeholders) themselves gain an adequate understanding of these matters to ensure a safer reception of forensic evidence through training and cooperation with the forensic community.

Efficient communication between different stakeholders is fundamental to preserve POI, the integrity of the criminal justice process and to avoid miscarriages of justice. An adequate communication of case information by the investigating authorities/instructing party to the forensic expert will lead to more accurate, reliable and relevant results. The adequate communication of the value and limitations of the evidence by the forensic expert will lead to better investigations and better prepared cases, as well as to a better understanding of the evidence at trial, improved trial narratives, accurate judicial directions and ultimately just and safe decisions. It is hoped that the clarifications made in this study on some misconceptions concerning the use of PG DNA, will lead to an improved reception of forensic evidence generally and a better regulation of AI and advanced computational technology based forensic evidence in a way that promotes the relevance and reliability of the evidence and upholds POI as a core principle of the criminal justice.

Declaration of competing interest

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

References

[1] Algorithms used in federal law enforcement. https://www.gao.gov/assets/710/706849.pdf, 2020.
[2] Galante, et al., 'Applications of artificial intelligence in forensic sciences: current potential benefits, limitations and perspectives', Int. J. Leg. Med. 2023 (137) (2022) 445–458, https://doi.org/10.1007/s00414-022-02928-5.
[3] Guideline ENFSI, For evaluative reporting in forensic science. http://enfsi.eu/wp-content/uploads/2016/09/m1_guideline.pdf, 2016.
[4] Text - H.R.2438–117th Congress (2021-2022): Justice in Forensic Algorithms Act of 2021 | Congress.Gov | Library of Congress.
[5] M. Coble, J.-A. Bright, 'Probabilistic genotyping software: an overview', Forensic Sci. Int.: Genetics (Austin, Tex.) 38 (2019) (2019) 219–224, https://doi.org/10.1016/j.fsigen.2018.11.009.
[6] Law Commission of Ontario, AI case study: probabilistic genotyping DNA tools in Canadian criminal courts LCO reports june 2021. https://www.lco-cdo.org/en/our-current-projects/ai-adm-and-the-justice-system/ai-case-study-pg/, 2021.
[7] EU AI Act https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A5 2021PC0206&qid=1721039415370.
[8] M.A. Marciano, J.D. Adelman, 'PACE: probabilistic Assessment for Contributor Estimation—a machine learning-based assessment of the number of contributors in DNA mixtures', Forensic Sci. Int. Genet. 27 (2017) 82–91.
[9] C.C. Benschop, J. van der Linden, J. Hoogenboom, R. Ypma, H. Haned, 'Automated estimation of the number of contributors in autosomal short tandem repeat profiles using a machine learning approach', Forensic Sci. Int. Genet. 43 (2019) 102150.
[10] M. Kruijver, H. Kelly, K. Cheng, M.-H. Lin, J. Morawitz, L. Russell, J. Buckleton, J.-A. Bright, 'Estimating the number of contributors to a DNA profile using decision trees', Forensic Sci. Int. Genet. 50 (2020) 102407.
[11] Forensic Science Regulator Guidance DNA Mixture Interpretation FSR-G-222 Issue 3 available at https://www.gov.uk/government/publications/dna-mixture-interpretation-fsr-g-222.
[12] Forensic Science Regulator Guidance Software Validation For DNA Mixture Interpretation FSR-G-223 Issue 2 available at https://www.gov.uk/government/publications/software-validation-for-dna-mixture-interpretation-fsr-g-223.
[13] Scientific Working Group on DNA Analysis Methods (SWGDAM), Guidelines for the validation of probabilistic genotyping systems. www.swgdam.org/publications, 2015, 4344b0_22776006b67c4a32a5ffc04fe3b56515.pdf (swgdam.org).
[14] R. Puch-Solis, S. Pope, Interpretation of DNA data within the context of UK forensic science — evaluation, Emerging Topics in Life Sciences 5 (2021) (2021) 405–413, https://doi.org/10.1042/ETLS20200340.
[15] J. Buckleton, et al., 'The probabilistic genotyping software STRmix: utility and evidence for its validity', J. Forensic Sci. 64 (2) (2019) https://doi.org/10.1111/1556-4029.13898. March 2019.
[16] P. Gill, et al., 'A review of probabilistic genotyping systems: EuroForMix, DNAStatistX and STRmix™', Genes 12 (2021) 1559, https://doi.org/10.3390/genes12101559, 2021.
[17] O. Sallavaci, The Impact of Scientific Evidence on the Criminal Trial: the Case of DNA Evidence, Routledge, London, 2014. ISBN 978-0-415-72020-5.
[18] J. Matthews, et al., 'The right to confront your accusers: opening the black box of forensic DNA software', in: Proceedings of S '19, 2019, ACM, New York, NY, USA, 2019 https://doi.org/10.1145/3306618.3314279. January 27–28, Honolulu, HI, USA (AIES'19).
[19] K. Kwong, 'The Algorithm Says You Did it: The Use of Black Box Algorithms to Analyse Complex DNA Evidence' Harvard J Law Tech 31 (1) (2017) 275–301.
[20] E.J. Imwinkelried, 'Computer source code: a source of the growing controversy over the reliability of automated forensic techniques' DePaul Law Rev. 66 (1) (2017) 97.
[21] J. Burrell, How the machine 'thinks:' understanding opacity in machine learning algorithms', Big Data & Society (2016) 1–12, https://doi.org/10.1177/2053951715622512. January–June 2016.
[22] A. Babuta, M. Oswald, C. Rinik, Machine Learning Algorithms and Police Decision-Making: Legal, Ethical and Regulatory Challenges, Royal United Services Institute for Defence and Security Studies Whitehall Report, 2018, pp. 3–18. https://www.rusi.org/explore-our-research/publications/whitehall-reports/machine-learning-algorithms-and-police-decision-making-legal-ethical-and-regulatory-challenges.
[23] J. Cino, 'Deploying the secret police: the use of algorithms in the criminal justice system' GA. ST. U, Law Review 34 (4) (2018) 1073.
[24] Fair Trials, Regulating artificial intelligence for use in criminal justice systems in the EU - policy paper. https://www.fairtrials.org/app/uploads/2022/01/Regulating-Artificial-Intelligence-for-Use-in-Criminal-Justice-Systems-Fair-Trials.pdf, 2022.
[25] Law Commission of Ontario, The rise and fall of AI and algorithms in American criminal justice: lessons for Canada, (toronto: october 2020) available at. https://ssrn.com/abstract=3773651, 2020.
[26] House of Commons Science and Technology Committee, Current and Future Uses of Biometric Data and Technologies Sixth Report of Session 2014–15, 2015. House of Lords Justice and Home Affairs Committee (2022) Technology rules? The advent of new technologies in the justice system 1st Report of Session 2021–22 HL Paper 180.
[27] United Nations Interregional Crime and Justice Research Institute (UNICRI) and The International Criminal Police Organization (INTERPOL), Artificial intelligence and robotics for law enforcement. http://unicri.eu/in_focus/on/interpol_unicri_report_ai, 2019.
[28] United Nations Interregional Crime and Justice Research Institute (UNICRI) and The International Criminal Police Organization (INTERPOL), Toward responsible AI innovation: second INTERPOL-UNICRI report on artificial intelligence for law enforcement. http://unicri.eu/in_focus/on/Towards_Responsible_Artificial_Intelligence_Innovation, 2020.

[29] A. Završnik, 'Criminal justice, artificial intelligence systems, and human rights', ERA Forum 20 (2020) 567–583, https://doi.org/10.1007/s12027-020-00602-0, 2020.

[30] B. Pearsall, Predictive policing: the future of law enforcement? NIJ Journal (266) (2010) 16.

[31] B. Stiffelman, 'No longer the gold standard: probabilistic genotyping is changing the nature of DNA evidence in criminal trials', Berkeley Journal of Criminal Law 24 (1) (2019) 110, https://doi.org/10.15779/Z384Q7QQ6X.

[32] L. Tribe, 'Trial by mathematics: precision and ritual in the legal process', Harv. Law Rev. 84 (6) (1971) 1329–1393.

[33] M. Finkelstein, W.B. Fairley, 'A Comment on "Trial by Mathematics"', in: 84 Harvard. L. Rev, 1801, 1971.

[34] M. Finkelstein, W.B. Fairley, 'A Bayesian Approach to Identification Evidence', in: 83 Harv. L. Rev., 489, 1970.

[35] C. Kingston, P. Kirk, 'The Use of Statistics in Criminalistics', in: 55 J. Crim. L. & Criminology, 516, 1964, 1964.

[36] L. Tribe, 'A Further Critique of Mathematical Proof', in: 84 Harv. L. Rev., 1810, 1971.

[37] C. Aitken, C.E.H. Berger, J.S. Buckleton, C. Champod, J. Curran, A.P. Dawid, I. W. Evett, P. Gill, J. Gonzalez-Rodriguez, G. Jackson, A. Kloosterman, T. Lovelock, D. Lucy, P. Margot, L. McKenna, D. Meuwly, C. Neumann, N.N. Daeid, A. Nordgaard, G. Zadora, Expressing evaluative opinions: a position statement, Sci. Justice 51 (1) (2011) 12, https://doi.org/10.1016/j.scijus.2011.01.002.

[38] State of Maryland v Tyrone Harvin, Circ. Court Baltimore City CASE NO. 118261014, 2021.

[39] R. Cook, I.W. Evett, G. Jackson, P.J. Jones, J.A. Lambert, 'A model for case assessment and interpretation', Sci. Justice 38 (3) (1998) 151–156. July 1998.

[40] Forensic Science Regulator, Guidance: development of evaluative opinions. https://www.gov.uk/government/publications/development-of-evaluative-opinions, 2021.

[41] P. Roberts, 'Presumptuous or pluralistic presumptions of innocence? Methodological diagnosis towards conceptual reinvigoration', Synthese (Dordr.) 198 (2021) 8901–8932, https://doi.org/10.1007/s11229-020-02606-2, 2021.

[42] The European Convention of Human Rights (ECHR).

[43] The International Covenant on Civil and Political Rights (ICCPR).

[44] The Charter of Fundamental Rights of the European Union (2007/C 3003/01).

[45] P. Roberts, A. Zuckerman, Criminal Evidence 3rd Edn OUP, 2022.

[46] R.A. Duff, Who must presume whom to be innocent of what? Netherlands Journal of Legal Philosophy 42 (3) (2013) 170–192.

[47] M. Damaska, Evidence law adrift. New Heaven, Yale University Press, 1997.

[48] Daubert V. Merrell Dow Pharmaceuticals Inc., 1993, 509 U.S. 579.

[49] O. Sallavaci, C. George, 'New proposed regime for the admissibility of expert evidence: the impact on digital forensics', Int. J. Electron. Secur. Digital Forensics 5 (1) (2013) 67–79.

[50] O. Sallavaci, C. George, 'Procedural aspects of the new regime for the admissibility of expert evidence: what the digital forensic expert needs to know', Int. J. Electron. Secur. Digital Forensics 5 (3/4) (2013) 161–171.

[51] Woolmington V. DPP [1935] A.C. 462.

[52] Coffin V. United States 156 U.S. 432, 1895.

[53] In Re Winship, 397 US 358, 1970, p. 363.

[54] F. Picinali, 'Innocence and burdens of proof in English criminal law', Law Probab. Risk (13) (2014) 243–257, https://doi.org/10.1093/lpr/mgu007, 2014.

[55] J.B. Thayer, Presumptions and the law of evidence, Harv. Law Rev. 3 (4) (1889) 141–166.

[56] J.B. Thayer, The presumption of innocence in criminal cases, Yale Law J. 6 (4) (1897) 185–212.

[57] J.B. Thayer, The present and future of the law of evidence, Harv. Law Rev. 12 (2) (1898) 71–94.

[58] R.J. Allen, 'Mullaney v.Wilbur, the Supreme court, and the substantive criminal law–an examination of the limits of legitimate intervention', Tex. Law Rev. 55 (1977) 269.

[59] J.C. Jeffries, P.B. Stephan, 'Defenses, Presumptions, and Burden of Proof in the Criminal Law', in: (1979) Yale Law Journal, 88, 1979, p. 1325.

[60] R.J. Allen, 'Structuring Jury Decision Making in Criminal Cases: A Unified Constitutional Approach to Evidentiary Devices', in: (1980) Harvard Law Review, 94, 1980, p. 321.

[61] L.B. Schwartz, '"Innocence" – A Dialogue with Professor Sundby', in: (1989) Hastings Law Journal, 41, 1989, p. 154.

[62] R.A. Duff, 'Strict liability, legal presumptions, and the presumption of innocence', in: A.P. Simester (Ed.), Appraising Strict Liability, OUP, Oxford, 2005, 2005.

[63] S.E. Sundby, 'The Reasonable Doubt Rule and the Meaning of Innocence', in: (1989) 40 Hastings Law Journal, 40, 1989, p. 457.

[64] S.E. Sundby, 'The virtues of a procedural view of innocence – a response to professor schwartz', Hastings Law J. 41 (1989) 161.

[65] P. Roberts, 'The presumption of innocence brought home? Kebilene deconstructed', Law Q. Rev. 118 (2002) 41.

[66] P. Roberts, 'Drug dealing and the presumption of innocence: the human rights act (almost) bites', Int. J. Evid. Proof 6 (2002) 17.

[67] P. Tomlin, 'Extending the golden thread? Criminalisation and the presumption of innocence' Journal of Political Philosophy 21 (1) (2013) 44–66.

[68] V. Tadros, 'Rethinking the presumption of innocence', Criminal Law and Philosophy 1 (2007) 193.

[69] V. Tadros, 'The ideal of the presumption of innocence', Criminal Law and Philosophy (2013) https://doi.org/10.1007/s11572-013-9253-6.

[70] A.C. Michaels, Constitutional innocence, Harv. Law Rev. 112 (4) (1999) 828–902.

[71] D.A. Dripps, The constitutional status of the reasonable doubt rule, Calif. Law Rev. 75 (5) (1987) 1665–1718.

[72] R.L. Lippke, Taming the Presumption of Innocence, OUP, Oxford, 2016.

[73] P.J. Schwikkard, Presumption of Innocence, RSA, 1999.

[74] Hock Lai Ho, 'The presumption of innocence as a human right,', in: Paul Roberts, Jill Hunter (Eds.), Criminal Evidence and Human Rights, Hart Publishing, Oxford, 2012, p. 259, 2012.

[75] S. Baradaran, 'Restoring the Presumption of Innocence,' Ohio State Law Journal 72 (2011) (2011) 723.

[76] L. Stevens, 'Pre-Trial detention: the presumption of innocence and art. 5 of the European convention on human rights cannot and does not limit its increasing use,', Eur. J. Crime Crim. Law Crim. Justice 17 (2009) 165.

[77] D.A. Nance, 'Civility and the Burden of Proof,' Harvard Journal of Law & Public Policy 17 (1994) 647.

[78] Sir J.F. Stephen, A History of the Criminal Law of England (Vol. I), Routledge, London, 1883, p. 438.

[79] W. Blackstone, Commentaries on the Laws of England, Clarendon Press, Oxford, 1765.

[80] M. Coleman, The Presumption of Innocence in International Human Rights and Criminal Law, 2021. Routledge ISBN 9780367512118.

[81] The Code for Crown Prosecutors available at https://www.cps.gov.uk/publication/code-crown-prosecutors.

[82] The Prosecution of Offences Act, 1985.

[83] Criminal Procedure Rules https://www.legislation.gov.uk/uksi/2020/759/contents.

[84] G. Jackson, C. Aitken, P. Roberts, "Practitioner guide 4. Case assessment and interpretation of expert evidence; royal statistical society's working group on statistics and the law,". https://rss.org.uk/RSS/media/File-library/Publications/rss-case-assessment-interpretation-expert-evidence.pdf, 2015.

[85] Association of Forensic Science Providers, "Standards for the formulation of evaluative forensic science expert opinions," Science and Justice 49 (2009) 161–164.

[86] 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) 231–239.

[87] National Institute of Forensic Science, 'An introductory guide to evaluative reporting' (online) available at. www.anzpaa.org.au/forensic-science/our-work/projects/evaluative-reporting-project/evaluative-reporting, 2017.

[88] R. Puch-Solis, P. Roberts, S. Pope, C. Aitken, 'Practitioner guide no 2-assessing the probative value of DNA evidence - royal statistical society's working group on statistics and the law,". https://rss.org.uk/RSS/media/News-and-publications/Publications/Reports%20and%20guides/rss-assessing-probative-value.pdf, 2012.

[89] S.A. Cole, 'More than zero: accounting for error in latent fingerprint identification', J. Crim. Law Criminol. 95 (2005) 985.

[90] H.J. Swofford, S.A. Cole, V. King, "Mt. Everest - we are going to lose many": a survey of fingerprint examiners' attitudes toward probabilistic reporting" law,, Probability and Risk 2021 (2021) 1–37.

[91] Expert Working Group on Human Factors in Latent Print Analysis, Latent print examination and human factors: improving the practice through a systems approach. https://nij.ojp.gov/library/publications/latent-print-examination-and-human-factors-improving-practice-through-systems, 2012.

[92] President's Council of Advisors on Science and Technology (PCAST), Report to the President, Forensic Science in Criminal Courts: Ensuring Scientific Validity of Feature-Comparison Methods, Executive Office of the President of the United States, Washington, D.C., USA, 2016 online, https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/PCAST/pcast_forensic_science_report_final.pdf.

[93] National Research Council, Strengthening Forensic Science in the United States: A Path Forward, The National Academies Press, Washington, D.C. USA, 2009.

[94] The American Association for the Advancement of Science (AAAS), Forensic science assessments: a quality and gap analysis–latent fingerprint examination. https://www.aaas.org/resources/forensic-science-assessments-quality-and-gap-analysis, 2017.

[95] H. Swofford, C. Champod, 'Probabilistic Reporting and Algorithms in Forensic Science: Stakeholder Perspectives within the American Criminal Justice System', Forensic Science International Synergy, 2022 https://doi.org/10.1016/j.fsisyn.2022.100220.

[96] The fingerprint inquiry: Scotland. https://web.archive.org/web/20150113040832/, 2011. http://www.thefingerprintinquiryscotland.org.uk/inquiry/3127-2.html.

[97] H. Eldridge, 'Juror comprehension of forensic expert testimony: a literature review and gap analysis', Forensic Sci. Int.: Synergy (Faversham) 1 (2019) 24–34, https://doi.org/10.1016/j.fsisyn.2019.03.001.

[98] 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, https://doi.org/10.1016/j.forsciint.2006.04.009, 13 July 2006.

[99] C. Aitken, F. Taroni, Statistics and the Evaluation of Evidence for Forensic Scientists, second ed., John Wiley & Sons, Chichester, 2004.

[100] The Royal Society and The Royal Society of Edinburgh, "The use of statistics in legal proceedings – a Primer for the courts," available at. https://royalsociety.org/-/media/about-us/programmes/science-and-law/science-and-law-statistics-primer.pdf, 2020.

[101] J. Butler, Advanced Topics in Forensic DNA Typing: Interpretation, Elsevier, 2014. ISBN: 9780124052130.

[102] People V. Collins, 49 Misc.3d 595, Kings Co. Sup. Ct, 2015, pp. 605–606.

[103] J. Goldthwaite, C. Hughes, R. Torres, 'Mixing it up: legal challenges to probabilistic genotyping programs for DNA mixture analysis', Champion (42) (2018) 12. May 2018, https://www.nacdl.org/Article/May2018-MixingItUpLegalChallengestoPro.

[104] State V Lewis Special Master Report at 44-45, Docket No. 113.

[105] NISTIR report, Forensic DNA interpretation and human factors: improving practice through a systems approach. https://tsapps.nist.gov/publication/get_pdf.cfm?pub_id=956787, 2024.

[106] R v T, EWCA Crim 2439, 2010.

[107] C.E.H. Berger, J. Buckleton, C. Champod, I.W. Evett, G. Jackson, Evidence evaluation: a response to the court of appeal judgment in R v T, Sci. Justice 51 (2) (Jun 2011) 43–49.

[108] CPS 'Legal Guidance' available online at https://www.cps.gov.uk/legal-guidance/expert-evidence.

[109] A. Biedermann, N. Kotsoglu, 'Scientific imperialism : "The judge made me do it!"', Sci. Justice 65 (2025) 119.

[110] O. Sallavaci, 'The Bayesian approach of forensic evidence evaluation: a necessary form of 'survival' of the ultimate issue rule' Journal of Forensic Identification 63 (5) (2013) 539–560.

[111] J. Jackson, 'The ultimate issue rule: one rule too many', Crim. Law Rev. 52 (1984) 75–86.

[112] Civil Evidence Act 1972.

[113] DPP V A & BC Chewing Gum Ltd [1968] 1 Q.B. 159 at 164, DC;.

[114] R V Stockwell [1993]97 Cr.App.R. 260, CA.

[115] US Federal Rules of Evidence 1976.

[116] Evidence Act 1995 (NSW).

[117] B. Mahendra, 'Usurped by experts?', New Law J. (1996) 1734. November 29.

[118] I.W. Evett, G. Jackson, J.A. Lambert, 'More on the hierarchy of propositions: exploring the distinction between explanations and propositions' Sci, Justice 40 (2000) 3–10.

[119] S. Gittelson, T. Kalafut, S. Myers, D. Taylor, T. Hicks, F. Taroni, 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 (2016) 186–195.

[120] P. Gill, T. Hicks, J.M. Butler, E. Connolly, L. Gusmão, B. Kokshoorn, N. Morling, R. A. van Oorschot, W. Parson, M. Prinz, et al., 'DNA commission of the International Society for Forensic Genetics: Assessing the value of forensic biological evidence—Guidelines highlighting the importance of propositions' Forensic Sci. Int. Genet. 36 (2018) 189–202.

[121] Royal Society, Forensic DNA analysis: a Primer for courts. https://royalsociety.org/~/media/about-us/programmes/science-and-law/royal-society-forensic-dna-analysis-primer-for-courts.pdf, 2017.

[122] O. Sallavaci, 'Streamlined Reporting of Forensic Evidence in England and Wales: Is it the way forward?' The International Journal of Evidence and Proof 20 (3) (2016) 235–249, https://doi.org/10.1177/1365712716643549.

[123] N. Fenton, D. Berger, D. Lagnado, M. Neil, A. Hsua, 'When 'neutral' evidence still has probative value (with implications from the Barry George Case)', Sci. Justice 54 (2014) 274–287.

[124] A. Biedermann, T. Hicks, F. Taroni, C. Champod, C. Aitken, 'On the use of the likelihood ratio for forensic evaluation: Response to Fenton et al.', Sci. Justice 54 (2014) 316–318.

[125] Forensic Science Regulator, Guidance cognitive bias effects relevant to forensic science examinations FSR-G-217 issue 2. https://assets.publishing.service.gov.uk/media/5f4fc26ce90e074695f80977/217_FSR-G-217_Cognitive_bias_appendix_Issue_2.pdf, 2020.

[126] Criminal Justice and Public Order Act 1994.

[127] D. Berger, 'Improving Legal Reasoning Using Bayesian Probability Methods', 2014. PhD thesis, Queen Mary University of London.

[128] C. Aitken, P. Roberts, G. Jackson, 'Fundamentals of Probability and Statistical Evidence in Criminal Proceedings', Royal Statistical Society, 2010. https://rss.org.uk/RSS/media/News-and-publications/Publications/Reports%20and%20guides/rss-fundamentals-probability-statistical-evidence.pdf.

[129] B. Robertson, G.A. Vignaux, C.E.H. Berger, Interpreting Evidence: Evaluating Forensic Science in the Courtroom, second ed., 2016. Wiley, ISBN: 978-1-118-49243-7.

[130] M. Redmayne, 'Presenting probabilities in court: the DNA experience', Int. J. Evid. Proof 1 (4) (1997) 187–214.

[131] State V Skipper, 228 Conn. 610, 1994.

[132] Criminal Practice Directions https://www.judiciary.uk/wp-content/uploads/2022/07/cpd-2015-consolidated-with-amendment-no2-nov2016.pdf.

[133] R V Adams [1996] 2 Cr.App.R 469.

[134] R V Adams (No.2) [1998] 1 Cr.App.R 377.

[135] R v T [2010] EWCA 2439.

[136] L. Laudan, The presumption of innocence: material or probatory? Leg. Theor. 11 (4) (2005) 333–361.

[137] N. Fenton, D. Lagnado, 'Bayesianism: objections and rebuttals', in: C. Dahlman, A. Stein, G. Tuzet (Eds.), Philosophical Foundations of Evidence Law, 2021. OUP ISBN: 9780198859307.

[138] C. Aitken, F. Taroni, Fundamentals of statistical evidence: a primer for legal professionals, Int. J. Evid. Proof 12 (3) (2008).

[139] M. Redmayne, Doubts and burdens: DNA evidence, probability and the courts, Crim. Law Rev. (1995) 464.

[140] N.E. Fenton, M. Neil, D. Berger, "Bayes and the Law," Annual Review of Statistics and Its Application 3 (2016) 51–57.

[141] D.H. Kaye, 'Revisiting "Dreyfus": a more complete account of a trial by mathematics' minn, Law Rev. 91 (2007) 825–835.

[142] People V. Collins, 438 P. 2d 33 (68 Cal. 2d 319 1968) (N 6).

[143] R V Sally Clark [2003] EWCA Crim 1020;.

[144] R. V. Barry George [2007] EWCA Crim 2722;.

[145] R. Lucia de Berk see Meester, M. Collins, R. Gill, M. van Lambalgen, 'On the (ab) use of statistics in the legal case against the nurse Lucia de B.', Law Probab. Risk 5 (2007) 233–250.

[146] D.L. Faigman, A.J. Baglioni, 'Bayes' theorem in the trial process' Law Hum, Beyond Behav. 12 (1988) 1–17.

[147] S.E. Fienberg, 'Bayesian models and methods in public policy and government settings' stat, Science (New York, N. Y.) 26 (2011) 212–226.

[148] S.E. Fienberg, M.O. Finkelstein, 'Bayesian statistics and the law', in: J. M, J. O. Berge, A.P. Dawid, A.F.M. Smith (Eds.), Bayesian Statistics Bernardo, Oxford University Press, 1996, pp. 129–146.

[149] P. Tillers, E. Green, in: Probability and Inference in the Law of Evidence: the Uses and Limits of Bayesianism Kluwer Academic Publishers, 1988.

[150] F. Taroni, S. Bozza, A. Biedermann, The logic of inference and decision for scientific evidence, in: C. Dahlman, A. Stein, G. Tuzet (Eds.), In Philosophical Foundations of Evidence Law, 2021. OUP ISBN: 9780198859307.

[151] J. Kaplan, "Decision Theory," Stanford Law Review 20 (1968) 1065–1092.

[152] L. Laudan, 'Is reasonable doubt reasonable?', Leg. Theor. 9 (2003) 295.

[153] Miller V Minister of Pensions [1947] 2 All ER 372.

[154] Bratty V Attorney General of Northern Ireland [1963] AC 386, 416, HL.

[155] R. Glover, Murphy on Evidence, 15, OUP, 2017.

[156] R V Kilbourne [1973] AC 729 at 756.

[157] Gill, et al., 'The ReAct project: analysis of data from 23 different laboratories to characterise DNA recovery given two sets of activity level propositions'. https://www.sciencedirect.com/science/article/pii/S187249732500002X, 2025.

[158] A. Keane, P. Mc Keown, The Modern Law of Evidence, 15th, OUP, 2024.

[159] The Law Commission, Expert evidence in criminal proceedings in England and Wales, in: https://lawcom.gov.uk/project/expert-evidence-in-criminal-proceedings/, 2011.

[160] Forensic Science Regulator Act, Forensic Science Regulator Act 2021 ("FSR Act"), 2021.

[161] Forensic Science Regulator Code of Practice Forensic Science Regulator Code of Practice ("FSR Code").

[162] Criminal Code, RSC 1985, c. C-46 https://laws-lois.justice.gc.ca/eng/acts/c-46/page-1.html.

[163] Reference by HM Advocate V CLB [2023] HCJAC 40 ("CLB").