How to assign a likelihood ratio in a footwear mark case: an analysis and discussion in the light of \( R \nu T \)

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This article analyses and discusses issues that pertain to the choice of relevant databases for assigning values to the components of evaluative likelihood ratio procedures at source level. Although several formal likelihood ratio developments currently exist, both case practitioners and recipients of expert information (such as judiciary) may be reluctant to consider them as a framework for evaluating scientific evidence in context. The recent ruling \( R \nu T \) and ensuing discussions in many forums provide illustrative examples for this. In particular, it is often felt that likelihood ratio-based reasoning amounts to an application that requires extensive quantitative information along with means for dealing with technicalities related to the algebraic formulation of these approaches. With regard to this objection, this article proposes two distinct discussions. In a first part, it is argued that, from a methodological point of view, there are additional levels of qualitative evaluation that are worth considering prior to focusing on particular numerical probability assignments. Analyses will be proposed that intend to show that, under certain assumptions, relative numerical values, as opposed to absolute values, may be sufficient to characterize a likelihood ratio for practical and pragmatic purposes. The feasibility of such qualitative considerations points out that the availability of hard numerical data is not a necessary requirement for implementing a likelihood ratio approach in practice. It is further argued that, even if numerical evaluations can be made, qualitative considerations may be valuable because they can further the understanding of the logical underpinnings of an assessment. In a second part, the article will draw a parallel to \( R \nu T \) by concentrating on a practical footwear mark case received at the authors’ institute. This case will serve the purpose of exemplifying the possible usage of data from various sources in casework and help to discuss the difficulty associated with reconciling the depth of theoretical likelihood ratio developments and limitations in the degree to which these developments can actually be applied in practice.

Keywords: footwear marks; likelihood ratio; informed judgment; forensic science.

1. Introduction

The recent court ruling \( R \nu T \) (2010) seriously questioned the ability of forensic scientists to assess and present results of comparative examinations of footwear marks. The judgement touches on a broad range of issues including aspects such as transparency. As a matter of interest and importance to both forensic and legal practitioners, several articles have since then argued in support of the necessity of continuing a logical approach to evaluation, based on probability (Redmayne et al., 2011; Berger et al., 2011; Robertson et al., 2011). These position statements have taken great care in reuniting a broad scope of existing arguments for clarifying the rationale and meaning of probability theory as a generic

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¹ Court of Appeal — Criminal Division, EWCA Crim 2439, 2010.
framework and tool for dealing with uncertainty, independent of the area of application. On pain of infringing on fundamental principles in logic, it remains uncontroversial that probability ought to continue to set the standard framework for legal reasoning. As such, the aforementioned writings introduce no unprecedented material or argument. Their arguments will hence not be reiterated here.

While there is a widespread consensus on the general principles of logical reasoning under uncertainty, some room for discussion remains for the topic of how one actually ought to apply the agreed framework, so as to set the meaning of results of forensic examinations appropriately into context. Professional bodies, such as the Association of Forensic Science Providers (2009), have recognized the importance of this topic and issued concise recommendations, but that initiative remains a general one without coverage of a case-based example.

In view of this, this article intends to address this subject by adopting a perspective that touches on open questions that currently tend to trouble the communication and mutual understanding between forensic scientists and recipients of expert information. As a main running example, this article will consider footwear mark examinations from a generic and applied point of view, comparable to what was encountered in RvT (2010). In order to bring this topic also to the reach of less technically informed readers, the presentation here will be accompanied by some general indications on the kind of forensic marks that are going to be discussed, along with methodology for their comparative examination. On the main, this covers aspects as detailed below.

Many cases will typically involve a forensic scientist attending a scene of a crime and recovering footwear marks of interest. These may be found in a position on the crime scene where the offender is thought to have acted. It is for this reason that marks are considered as potentially relevant. Marks then are collected using appropriate techniques and retained for subsequent comparisons with potential sources. Much of such work is part of the bulk tasks of many footwear mark examiners. Further, it may be the case that subsequent investigations lead to the apprehension of a suspect based on information completely unrelated to the footwear mark evidence. In addition, investigators may search the suspect’s home in such a setting. Any pertinent items of footwear will be seized and forwarded to the examining scientist. On taking a broad view, there are a some generally agreed ways that footwear mark examiners may then take from such a starting point. That is, less technically speaking, the work of a footwear mark examiner will cover two main stages. Initially, marks left by a shoe’s manufacturing features2 will be examined. A main parameter at this stage is the general sole pattern. When this comparative level is compatible with the aspects observable on test prints performed with the suspect’s shoe (hereafter also referred to as ‘potential source’), further examinations may be undertaken. Examiners may then compare features thought to originate from damages due to the shoe’s wear. The surface of a shoe sole actually bears a distinctive set of acquired features that originate mainly from repeated contact with the walking surface, but it may also depend on the extent of use, cleaning habits and storing conditions.

In the case introduced here in due course (Section 2), attention will primarily be confined to manufacturing features, in particular general sole pattern and size. This is due to the fact that the quality of the marks is such that only general features can reliably be assessed. This compares well with RvT (2010), where the scientist’s examinations revealed that the marks recovered on the crime scene and the footwear seized at the suspects home exhibited the same sole pattern and size. That

2 In order to simplify verbal explanations, the term ‘manufacturing features’ (and similarly for the descriptor ‘wear’) will also sometimes be used hereafter for referring to discernible aspects in marks even though, strictly speaking, manufacturing features are (and ‘wear’), actually, surface traits of a given shoe sole. By extension, we thus use a single expression here to designate both, visible aspects in marks as well as their respective counterpart features in the sole (that ‘caused’ the mark).
pattern type was reported as one of the most commonly encountered. Further, it was reported that the scene marks showed less wear than the suspect's shoes. Such difference was explained by the time delay between the offence and the seizure of the shoes. In addition, there appeared to be features in the marks for which no corresponding feature was observed in the submitted footwear. That difference was also explained by wear in the intervening period. The objective here will not be to discuss the specificity of this case that is not ours, but we will rely on an adaptation of a case from our own practice that was dealt with in our laboratory and for which we were asked to provide a case-based assessment in relation to the rarity of the combination of size and general sole pattern.

2. Case description

In the case chosen for this article’s discussion, the examining forensic scientist analysed and compared marks recovered from a murder scene that occurred in 2008. The marks were recovered from the tiles of the bathroom floor and the top surface of the toilet below the bathroom window. The shoes of the principal suspect were also provided for comparison purposes. The footwear mark examiner obtained (inked) test prints under controlled conditions from the submitted shoes. The two sets of elements — material from the crime scene and reference material from the suspect — were found to correspond in terms of general sole pattern, size and level of wear. However, due to the quality of the marks, no fine acquired features were visible. The general pattern of the sole corresponded to a Nike model Multicourt III that, according to the manufacturer’s information, was produced and sold between 2000 and 2002. Based on particular aspects of the sole design, that is how the structural elements of the design were spatially positioned to each other, and by reference to soles of various sizes produced in the model series of interest, the examiner was in a position to indicate that the marks had been left by a pair of shoes of size EU 47.5 (US 13). It happened that this also was the size of the suspect’s shoes. More generally, the marks showed very limited amount of wear and so did the shoes of the suspect.

Because of the lack of acquired features, the footwear mark examiner limited his conclusion, in part, to a statement of ‘compatibility’ between evidential marks and the suspect’s shoes. Interestingly, such an outset is well in agreement with a recommendation actually emphasized by the court in R v T. Notwithstanding, in the case of interest here, the investigating authorities requested a full evaluative report on the rarity (or, occurrence) of footwear of such model and size. The main reason for this was the somewhat ‘exceptionally’ or uncommonly large size of the crime mark. It was felt that a more nuanced conclusion should be possible, beyond the restriction of a statement of ‘compatibility’. In R v T, too, the expert examiner was also interested in addressing this aspect of the footwear mark evidence and took on him the challenge to extend his conclusion in order to offer more than only a restriction to ‘cannot exclude’, ‘could have from’ or ‘consistent with’ — but this was precisely the part of the reporting that underwent harsh critique.

3. Scope and aims

Assessing the probative strength of results of scientific examinations requires participants of a judicial proceeding to take a position on several key questions. The notion of ‘target actors’ or ‘participants of judicial proceedings’ is intentionally understood here in a broad sense because the coherent placement

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3 The circumstances of the actual case were slightly more complex, but we have decided to alter them here in order to focus on the arguments of interest to this article.
into context of scientific evidence involves an inter-subjective and agreed understanding on main aspects of an inference framework. This discussion is not restricted to a confined area of expertise of a forensic scientist, but also extends to recipients of expert information, such as judges and jurors. Principal questions cover the following:

- Which are the propositions of interest? Although this may seem a straightforward matter, it is often useful to be clear enough about the formulation of propositions because (i) they are conditioned on the extent and quality of available information in the framework of circumstances and (ii) they have a crucial bearing on the choice or formulation of a particular expression for the probative value. In the discussion here, it will be assumed that the probative value of results of forensic examinations is appropriately conceptualized in terms of a likelihood ratio.

- Which form of the likelihood ratio (formula) is appropriate for this setting? A discussion of this question is important because aspects such as the chosen propositional level (Cook et al., 1998; Evett et al., 1998) affect the scope of parameters that need to be taken into account. For example, an assessment at source-level propositions does not involve issues of evidential relevance, whereas a development at crime level would (Evett et al., 1998).

- Which database(s) is (are) needed to assign a likelihood ratio? Often, scientists retain convenience data collected through casework or they may have access to some kind of market survey. But the utility of such data may be questionable unless one can demonstrate that there are well-defined components (or parameters) within a given form of the likelihood ratio that require the kind of data at hand, rather than other data.

In the forthcoming sections of this article, these questions will be examined in view of situations and applications that working scientists may encounter in practice. In part, the author’s motivation for this analysis and the ensuing discussion also stems from teaching and workshop experiences on the topic of likelihood ratio (LR) assignment. In fact, while there is well-documented writing in scientific literature on technical aspects of likelihood ratio development as well as the assessment of numerical values for various LR components (e.g. Champod et al., 2004), practitioners often raise challenging questions about the feasibility of implementing the results and insights from such theoretical analyses in practical casework. For example, there are LR developments at source level that may typically suggest the need of more than one database for deriving case-tailored probabilities. That is, while it is possible to specify — from a theoretical point of view — the requirements to which databases should conform, it may not be feasible in practice to set these up precisely in that way. Limiting factors such as temporal, monetary, legal and/or institutional constraints often present the main obstacles.

In this article, the main argument put forward will be that such concerns — although real — should not be taken as an argument to compromise or avoid an evaluation in a particular case at hand. The proposed analyses will emphasize that useful insight in the properties of a given LR formula may be gained even though ‘precise’ values for some parameters may not be available. This refers back to previous discussion on the allowance to be made for the lack of data (e.g. Biedermann and Taroni, 2006). It will also be shown here that in some settings and under some general assumptions, the actual value of given parameters may not be relevant, only the way in which different values compare with each other. Insight from such analyses provides further assistance in situations where one needs to decide whether simplifying assumptions can be made in an acceptable way.

The remaining sections in this article are organized in two main parts. First, Section 4 offers a brief recall of the LR that is going to be retained for subsequent discussion. Further details on the derivation and underlying logic of this form of the LR are confined to Appendix A. Section 5 will then proceed by
discussing the examination of simplifying assumptions for the LR as well as issues relating to the choice of relevant datasets. A second major part, confined to Section 6, will apply these ideas in the context of the case study introduced earlier in Section 2. Section 7 will present a general discussion and conclusion.

4. Relevant propositions and LR for footwear mark evidence

A derivation for a general LR for inference about propositions at source level, such as $H_p$, ‘the footwear mark found on the crime scene was made with the suspect’s shoe’, and $H_d$, ‘the footwear mark found on the scene was made with some other unknown shoe’, is confined here to an appendix (Appendix A) as it stems from existing literature on the topic (Champod et al., 2004). Attention will rather concentrate, hereafter in Section 5, on the rationale, analysis and assessment of the various LR components. Prior to proceeding with this, it appears important to include a note on formulating propositions. In fact, a critical question in source-level settings is to define from whom the so-called ‘other unknown shoe’ comes from (Lempert, 1993). In the case discussed here, the defence argued that the victim was not killed by the suspect, but by a burglar gaining entry through the bathroom window. At source level, this represents key information, not related to the footwear mark, that is required for framing a relevant alternative proposition. It is worth emphasizing at this juncture that this should not be understood — contrary to what is thought in large quarters of the expert community — as an assessment or evaluation of circumstantial information. Instead, elements of the framework of circumstances take the role of a condition for formulating a proposition. In the currently discussed case, an appropriate alternative proposition thus is of the following form: ‘$H_d$: the shoe marks do not come from the suspect’s shoes, but from shoes worn by a burglar.’

Denoting by $I_c$ and $I_s$ the framework of circumstances relevant to, respectively, the crime and the suspect, and writing $E_c$ and $E_s$ for, respectively, the set of retained features observed on the crime mark and reference material obtained from the suspect’s shoes, the LR applicable for the purpose of the current discussion thus is (Champod et al., 2004):

$$LR = \frac{Pr(E_c, E_s | H_p, I_c, I_s)}{Pr(E_c, E_s | H_d, I_c, I_s)} = \frac{1}{Pr(E_s | H_d, I_c)} \times \frac{Pr(E_s | H_p, I_c, I_s)}{Pr(E_s | H_d, I_s)}.$$ (1)

Notice further that it is common notation to consider the outsole design $D_{f_{c,s}}$, the size $S_{f_{c,s}}$ and the degree of wear $W_{f_{c,s}}$, with the subscripts $c$ and $s$ referring to the crime the reference material from the suspect, as the components that make up the variables $E_c$ and $E_s$. Written in full length, this amounts to $E_c = \{D_c, S_c, W_c\}$ and $E_s = \{D_s, S_s, W_s\}$. Prior to using Equation (1) in order to assist the analysis of the case outlined in Section 2, Section 5 will focus on some general implications for the structure of reasoning and argument.

5. Simplifying assumptions and the choice of relevant databases

5.1 Preliminaries

Equation (1) emphasises distinct considerations of descriptive features of the crime mark ($E_c$) and of the potential source (i.e. footwear of the suspect, $E_s$). From a practitioner’s point of view, this raises

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4 See also, e.g. paragraph 64 in R v T (2010).
5 It is worth mentioning that the value 1 in the numerator of the first fraction in Equation (1) is an idealized assessment that may not hold in the general case. See also discussion on this aspect at the end of Appendix A.
two main questions. On the one hand, scientists may ask ‘How is one to deal with the two fractions in this product?’ On the other hand, ‘Can this result be further simplified?’ The forthcoming sections will consider these questions in some further detail. Section 5.2 will discuss potential equivalence considerations, whereas Section 5.3 will concentrate on the choice of relevant datasets. Section 5.4 will pursue this analysis in a qualitative and staged approach, followed by an analysis of the notions of absolute and relative numerical values presented in Section 5.5.

5.2 Analysing the LR: can it be further simplified?

The result obtained in A, reproduced as Equation (1) in Section 4, is sometimes felt as troubling at first sight. One may be familiar with the component that asks for the probability of the evidential marks given that a source other than one belonging to the suspect is the origin of the evidential marks (i.e. \( \Pr(E_c | H_d, I_c) \)). However, one may not be familiar with the additional fraction that focuses on the probability of observing the features \( E_s \) present on the reference prints (obtained under controlled conditions from the potential source belonging to the suspect). A question of interest thus is: ‘Is there a need to reason about the probability of the features in the reference print given varying conditionals of \( H \) and \( P ? \)

Equation (1) is a result of a ‘logical’ development so that the very presence of additional factors, such as \( E_s \), suggests that these components are potentially relevant for evidential assessment. Notwithstanding, it may appear natural to ask whether there are possibilities for invoking some reasonable and generally acceptable assumptions, which may allow one to further simplify the LR. This could facilitate the practical usage of the approach as a whole.

One way to do this, mentioned in Champod et al. (2004), is to examine a potential equivalence between the two terms \( \Pr(E_s | H_p, I_c, I_s) \) and \( \Pr(E_s | H_d, I_s) \). These two probabilities amount to a consideration of the following:

- \( \Pr(E_s | H_p, I_c, I_s) \) asks for the probability of the observations pertaining to the material associated with the suspect’s shoes (i.e. the features observed in the test prints), if that potential source has, in fact, left the mark found on the scene and given knowledge of details pertaining to the incident (\( I_c \)) and the suspect (\( I_s \)). Stated otherwise, one is directed to think about shoes that are used during the commission of crimes of the appropriate kind.

- On the other hand, \( \Pr(E_s | H_d, I_s) \) refers to the probability of the observations \( E_s \) on shoe prints of someone unconnected with that offence, but given circumstantial information about the suspect (\( I_s \)).

Can these two terms be considered equivalent? There seems no obvious answer to this. In essence, one is required to ask if the observation of the particular pattern produced by a shoe’s manufacturing features is more or less ‘typical’ for a shoe used in the commission of a crime (of the appropriate kind) than for a shoe not used in crime (i.e. for a shoe that belongs to an innocent individual). Stated otherwise, the question is whether or not the probability of observing a particular combination of manufacturing features varies according to the propositions according to which the seized pair of shoes was or was not used during the commission of a crime (as well as according to what is known about the crime at hand, \( I_c \)). In practice, it may well be that the probability of observing given manufacturing features among shoes worn during the commission of crimes differs from that pertaining to shoes worn by innocent suspects (but who have, however, come to police attention). To some extent, this appears reasonable because the commission of the incriminating act requires some extent of ‘physical
flexibility’. That is, a shoe chosen to be worn during a crime of the kind considered here should allow its wearer to move easily. Ideally, it can be expected to be one that is also suitable for running. One can thus expect some selectivity in the choice of footwear. This preference may be different for innocent suspects who may not feel compelled to discard footwear that may not be well suited for flexible movements such as running or jumping. Stated otherwise, the scope of types of footwear of interest to criminal and non-criminal individuals may vary, and so may their preference for one or another exemplar of that range of types of footwear. For the time being, assume thus that one cannot admit a general equivalence between the two terms mentioned above.

One thus is directed to a second question which focuses on examining a potential equivalence between the two terms $\text{Pr}(E_s \mid H_p, I_c, I_e)$ and $\text{Pr}(E_c \mid H_d, I_c)$. Here, again, the term $\text{Pr}(E_s \mid H_p, I_c, I_e)$ refers to the kind of shoes used during the commission of crimes of the appropriate kind. On the other hand, $\text{Pr}(E_c \mid H_d, I_c)$ refers to the probability of observations made on marks recovered on crime scenes. Again, it does not seem obviously conceivable to admit a general equivalence between these kinds of entities, that is the probability of observations made on a crime mark and observations on test prints made with a suspect’s shoe. In summary, it thus appears that there is no immediate way to further simplify the LR formula considered so far [Equation (1)].

5.3 CR, OR and IS databases

The various terms that make up the LR (1) suggest the relevance of different kinds of datasets known in the context as CR, OR and IS ‘databases’ (Champod et al., 2004). The term $\text{Pr}(E_c \mid H_d, I_c)$, for example, may be informed by a database referred to as a CR (‘crime related’) dataset. It compiles features observed on marks recovered after crimes of comparable nature. Or, more generally formulated, a CR database relates to a collection of materials associated with crimes of the appropriate nature. In turn, the term $\text{Pr}(E_s \mid H_p, I_c, I_e)$ may be informed by an OR (‘offender related’) database. Here, the collection of data should concentrate on shoes of people who commit the kind of crime of interest here (in the relevant locality). Finally, the term $\text{Pr}(E_s \mid H_d, I_c)$ may be informed by an IS (‘innocent suspect’) database. This collection covers data on footwear of individuals who are known not to have an association with a crime of the relevant kind, but yet have come to the notice of the police. In the case at hand, the collection of data should focus on shoes of people from the area in question and who, like the suspect, come to police notice during the investigation of the crime — even though not being the authors of that crime.

Up to this point, the proposed formal analysis appears tractable and uncontroversial from a purely argumentative point of view. Despite the somewhat cumbersome form of the LR (i.e. a product of two fractions), it may be reassuring to see that the definition of the various LR terms allows one to set forth, in a concise manner, requirements to which data for parameter assignment should conform. Complications may, however, arise when one tries to actually find or compile appropriate data and assign values to the various terms that make up the LR.

The CR database may represent an exception in that respect because, generally, compilations of materials recovered on crime scenes are readily available. Footwear mark evidence is a particularly good example for this since police attend (and investigate) systematically, in principle (as far as incidents come to their knowledge) such scenes. Most practitioners would thus agree to say that data on the occurrence of characteristics on footwear marks recovered on crime scenes should be readily available. Operational laboratories usually keep computer searchable libraries that contain detailed registries of characteristics seen on crime scene materials. In addition, given the systematic
processing of serious incidents, such collections can be regarded as providing a reliable image of the occurrence of characteristics on this sort of crime scene material.

The situation may be different for OR and IS databases. Here caseworkers often raise concerns. In particular, it is often asked how one is actually to proceed in order to compile OR and IS data appropriately. While it may be considered feasible to set up a record of the characteristics of footwear seen on individuals that come to police attention, the design, maintenance and utilization of such a collection may be far from obvious. Consider the following:

- Not all individuals that come to police attention have their footwear recorded (i.e. establishment of inked impressions under controlled conditions).
- A search may fail to recover relevant footwear in possession of an individual (e.g. because a suspect’s vehicle or his home are not searched).
- Results of searches (i.e. the finding or not of any footwear) may not be communicated to those in charge of maintaining the database (e.g. if there is a organizational separation between investigators and database managers).
- It may be impossible to track individuals that came to police attention and to record whether, at a later point, they will be charged or convicted for the crime at hand. Stated otherwise, it may be difficult to maintain a proper IS database if one cannot conceive of a procedure that assures that individuals that have later been convicted are eliminated from an IS collection.

In view of the above difficulties and as a consequence of the absence of data, it is often argued that one should abandon any attempt to address a LR of the kind given by Equation (1). While the article here will not attempt to touch on practical issues such as how to compile OR and IS data, a main concern is that of a more general claim according to which the proposed LR is not applicable in practice, due to a lack of data. This is not meant to suggest that questions on how to compile OR and IS data in practice are not worth the effort of further study, but the principal point is another one, rooted in methodological considerations. In fact, it seems inappropriate to argue for skepticism towards an inferential procedure solely on the basis of missing data without considering whether appropriate data, if they were be available, were actually that helpful. Stated otherwise, judging the relevance of data requires an assessment of the degree to which variation in data may affect evidential value. This is considered in further detail in the forthcoming sections.

5.4 A staged qualitative approach to LR assignment

Following discussion from the previous paragraphs, it is assumed here that reliable CR data are available so that robust assessments can be derived for the term \( \Pr(E_c \mid H_d, I_c) \). Hereafter, the analyses and discussion will thus focus on the terms \( \Pr(E_s \mid H_p, I_c, I_s) \) and \( \Pr(E_s \mid H_d, I_s) \). This allows one to deal with the LR in Equation (1) in a staged approach:

- On the one hand, there is an ‘undisputed’ core part given by the fraction \( 1/\Pr(E_c \mid H_d, I_c) \). We can write this part of the LR more shortly as \( \text{LR}_c \).  
- On the other hand, there is a second fraction given by \( \Pr(E_s \mid H_p, I_c, I_s) / \Pr(E_s \mid H_d, I_s) \). This is the part on which discussion concentrates, written more shortly as \( \text{LR}_s \).

The LR given by Equation (1) can thus be considered as a product of two component LRs: \( \text{LR} = \text{LR}_c \times \text{LR}_s \). There is nothing particular in this view but it will be helpful for directing further analyses of the LR as such. For example, this structured view allows one to point out that the
conditional probabilities $\Pr(E_s \mid H_p, I_c, I_s)$ and $\Pr(E_s \mid H_d, I_s)$ affect the overall value of the LR in the form of a multiplication factor for $LR_c$. Although this does not yet tell one anything about how to deal with these conditional probabilities, a comprehension of how they may affect the overall value of the LR is an important aspect of dealing with the problem at hand. Thus, even without focusing on any particular numerical value, a further conclusion that can readily be drawn from these general considerations is that the overall value of the LR will

- increase if $\Pr(E_s \mid H_p, I_c, I_s) > \Pr(E_s \mid H_d, I_s)$,
- decrease if $\Pr(E_s \mid H_p, I_c, I_s) < \Pr(E_s \mid H_d, I_s)$ and
- remain unaffected if $\Pr(E_s \mid H_p, I_c, I_s)$ and $\Pr(E_s \mid H_d, I_s)$ take the same value.

The availability of ‘hard’ numerical data thus is not a necessary requirement for characterizing a LR. That is, stated otherwise, it is possible to consider the LR through qualitative reasoning. For the setting studied here it may be said, for example, that the fraction $LR_c = 1/\Pr(E_s \mid H_d, I_c)$ provides an ‘anchor value’ for the LR. Around that anchor value is a range of LR values, given by $LR_c$ times a factor which has a magnitude that depends on one’s personal beliefs about the respective values of the two target conditional probabilities $\Pr(E_s \mid H_p, I_c, I_s)$ and $\Pr(E_s \mid H_d, I_s)$.

An intermediate conclusion at this point thus is twofold. On the one hand, the absence of explicit values for the uncertain LR components does not imply that nothing can be said about the LR. Given qualitative expressions of beliefs about the way in which the two conditional probabilities $\Pr(E_s \mid H_p, I_c, I_s)$ and $\Pr(E_s \mid H_d, I_s)$ compare to each other, one can indicate in which direction and to what degree the ‘undisputed’ core value $LR_c$ is affected by multiplication. On the other hand, the LR should not exclusively be considered as a point value, but as a balanced expression of evidential support that provides an indication about the direction of inference. This idea is pursued in further detail in the next section.

### 5.5 Absolute values versus relative values

The conclusions and insight presented in the previous Section may be interesting from a general point of view, but practitioners may argue that it is of little use if one is not able to say what ought, at least approximatively, to be actual values for $\Pr(E_s \mid H_p, I_c, I_s)$ and $\Pr(E_s \mid H_d, I_s)$ that make up $LR_c$. Although this seems a plausible standpoint and a legitimate expression of skepticism, it may be asked whether particular numerical values for the two conditional probabilities represent a necessary requirement for assigning a LR.

From a methodological point of view known in the context as ‘from the general to the particular’, there is a further step that may be investigated prior to focusing on distinct numerical point values. In particular, one may ask if it is actual values that are needed or if it is sufficient to have a comparison between the value for one conditional probability relative to that for the other conditional probability. In order to investigate this idea, let us rewrite $LR_s$ as follows:

$$LR_s = \frac{\Pr(E_s \mid H_p, I_c, I_s)}{\Pr(E_s \mid H_d, I_s)} = \frac{\alpha}{\phi \times \alpha}, \quad \text{for } 0 < (\alpha, \phi) \leq 1. \quad (2)$$

This way of writing $LR_s$ is an expression of the view that the value of the denominator, $\Pr(E_s \mid H_d, I_s)$, is a proportion $\phi$ of the value $\alpha$ assumed by the numerator, $\Pr(E_s \mid H_p, I_c, I_s)$. It seems important to emphasize, however, that this proportionality relationship is invoked here only on a functional level, not on a conceptual one (because the reference populations to which the two conditional
probabilities of the numerator and denominator of LR, refer are distinct). This allows one to observe the following:

- Logically, if \( \phi = 1 \), then, whatever the value taken by \( \alpha \), the two uncertain parameters have the same value and \( LR_c = 1 \). Consequently, the LR in Equation (1) reduces to \( LR_c \).
- For any value \( \phi < 1 \), the factor \( LR_s \) is also a constant, independently of the actual value taken by \( \alpha \). Generally, as may be seen from Equation (2), that constant is given by\(^6\):

\[
LR_s = \frac{\alpha}{\phi \times \alpha} = \phi^{-1}.
\]

The reason for this is that the crime mark sole pattern is thought, potentially, to be more readily observed on footwear of criminals rather than innocent suspects. That is, as mentioned earlier in Section 5.2, innocent individuals may not direct their attention only to shoes that assure ‘easy wear’ during criminal activities. Their range of models of shoes is potentially larger which may tend to reduce the probability of seeing the particular crime mark pattern among these individuals.

The qualitative reasoning about the way in which the numerator and the denominator of the component \( LR_s \) compare, as presented in the previous Section 5.4, can thus be specified in further detail. Most importantly, in thinking about the relative magnitude of the numerator and the denominator one is not required to ‘search’ for absolute numerical values. It is sufficient to direct thinking and discussion about how much the two values diverge from each other, that is by which proportion one value is represented by the other, whatever that other value is.

Given the limited importance of \( \alpha \), it thus appears more informative to think of \( LR_s \) as a function of \( \phi \). For a setting in which \( Pr(E_s | H_p, I_c, I_s) \geq Pr(E_s | H_d, I_s) \), that is Equation (2), this way of looking at the problem allows one obtain an indication about the values \( LR_s \) associated with particular values \( \phi \) by which the denominator deviates from the numerator. For the purpose of illustration, consider that a value of \( LR_s \) equal to 1.5 (which would increase the ‘core’ \( LR_c \) by 50%) is obtained when the denominator is 2/3 of the value taken by the numerator.\(^7\)

5.6 Evaluation without numbers: how to proceed in practice?

The previous sections have focused on ways to analyse the LR when one has no immediate or direct access to ‘hard’ numerical data. This has led to some insightful conclusions. Notably, it has been seen that the availability of explicit numerical assignments is not a necessary requirement for assessing a LR. This is not an entirely new claim in forensic science literature (e.g. Biedermann and Taroni, 2006; Taroni et al., 2006). Notwithstanding, a recurrent question in this context is: ‘how is one to use this in practice?’.

In order to pursue this topic in some further detail, consider again the scenario introduced earlier in Section 2. Following the proposed analyses, it appears that a LR as in Equation (1) is appropriate and

\(^6\) Notice further that the transformation in Equation (2) can also be made for a situation in which the numerator is thought of as a fraction \( \phi \) of the value \( \alpha \) assumed by the denominator.

\(^7\) Such general indications can be useful, for instance, to gain an idea about the relative importance of the values \( \phi \). For the example considered here it could be said, for example, that \( LR_s \) will not tend to increase \( LR_c \) by 50% as long as the denominator of \( LR_s \), that is \( Pr(E_s | H_d, I_s) \), is not smaller than 2/3 of the value of the numerator (i.e. \( Pr(E_s | H_p, I_c, I_s) \) ). Generally, other combinations of values may obviously be discussed. In addition, notice again that this observation applies for whatever value \( \alpha \) is assumed by the numerator and that analogous arguments may be developed for situations in which the numerator is thought to be smaller than the denominator.
that a main issue is that of the relative values of the two terms $\text{Pr}(E_s \mid H_p, I_c, I_s)$ and $\text{Pr}(E_s \mid H_d, I_s)$. This will determine whether their fraction, $LR_s$, will tend to increase or decrease the ‘core’ $LR_c = 1/\text{Pr}(E_c \mid H_d, I_c)$, and, consequently, the overall LR. In this case, a possible line of argument could be as follows. Start by considering that the manufacturing features $E_s$ relate to a sole pattern of a running shoe of a well-known brand, commonly marked in sport stores.\(^8\) A relevant question thus is: does one expect to observe this more often among people who commit the kind of crime of interest (in the relevant locality) or among innocent suspects? There is reason to believe that such findings could be more typical for true offenders because they may be thought to select shoes for their ease of wear and support (and not for any other reasons). Sport shoes are specially designed to meet such requirements. They could, therefore, represent a preferred choice for offenders. The situation may be different for innocent suspects. This category of individuals may choose footwear not or not exclusively for the same reasons. That is, among innocent suspects one could also have individuals who wear shoes for their nice look, because of fashion trends and so on. They may thus be in possession of a greater variety of categories of shoes (other than sport/running shoes) and also exhibit distinct preferences to wear them. On the whole, this may make it less likely to encounter a given kind of sport shoe among this sort of individuals.\(^9\) It is worth noting, however, that this represents a particular interpretation of the relative values that the two target terms could assume. The intention here is not to suggest this as a compulsory view. Indeed, alternative arguments may readily be found. For example, one could consider athletic shoes so commonly worn by people in the age range of burglars that the suggested difference is negligible. The fact that arguments may point in different directions is not a problem in principle. It rather emphasizes that there is room for negotiation and potential to find agreed assignments. In addition, this does not represent any hindrance for the formal framework of probability. On the contrary, the very important point is that probability is a flexible template that can accommodate assignments motivated by a broad scope of arguments.\(^10\)

In view of these arguments, one may thus consider that observations referred to as $E_s$ are less common for innocent suspects than for offenders. Consequently, one could argue that one is in the case of Equation (2) as far as $LR_s$ is concerned. Knowing that Equation (2) defines values greater than, or equal to, 1 (which will tend to increase to overall value of the LR), then there are two possibilities.

- One option may consist in retreating from an assessment of $LR_s$ altogether and remain with only $LR_c$. It could be said that such a strategy will lead to a conservative assignment for the overall LR. The analysis would thus stop at this point so that no data for assigning probabilities other than $\text{Pr}(E_c \mid H_d, I_c)$ would need to be searched.
- Another option could consist in proceeding with an assignment of values to the component parameters of $LR_s$. Given the results of the previous sections, this amounts to specifying the degree to which $\text{Pr}(E_s \mid H_p, I_c, I_s)$ differs from $\text{Pr}(E_s \mid H_d, I_s)$.

\(^8\) In $R v T$ (2010), the observed pattern type was also reported as common, at paragraph 22 (i).

\(^9\) This tendency is perhaps more marked for other categories of evidence. For the purpose of illustration, take firearm evidence. Here, one could even consider that the very fact of possessing a firearm may be different for offenders and innocent suspects. This is a principal difference with respect to footwear mark evidence. All people usually possess shoes, and probably multiple pairs, but not necessarily firearms.

\(^10\) This point is also noted by Garbolino (2001) who argues that, in legal reasoning, one has to deal with unique and singular events, which require assignments for which one cannot require everybody to share the same view. However, one can require anybody to have justified standpoints.
For this latter situation, a question that remains thus is that of how one is to conceptualize the degree of divergence between the two key parameters. Again, pursuing an approach that goes from the general to the particular, one could start by considering whether or not the discrepancy between the two values is such that the magnitude of the resulting multiplying factor \( LR_s \) is great enough to actually provoke a shift in a chosen verbal scale of conclusions. This obviously depends on the current value of \( LR_c \). But if the plausible magnitude of \( LR_s \) is not such that a change in the qualitative (verbal) conclusion is to be expected, then, again, a viable option could consist in restricting the evaluation to \( LR_c \) alone.

6. Case scenario: a discussion of argument in statement writing

This section aims to exemplify ideas discussed in the previous section with respect to the practical case introduced earlier in Section 2. The purpose is not to reproduce the examining scientist’s full report, but only those parts that represent an interest from an evaluative point of view. There is also no attempt to introduce the formal approach outlined so far in an explicit and stringent manner. On the contrary, the presentation will tend to avoid reference to notions such as ‘formula’, ‘LR’ or ‘Bayes’ theorem’. The purpose is that of demonstrating that the relevant questions can be introduced and discussed without actually telling the reader that they can — if needed — be conceptualized and, thus, justified as components of a mathematical development in logical analysis.

Broadly speaking, the discussion will be directed towards assessing probabilities for the component \( LR_c \) [Equation (1)]. The subtlety associated with the extension \( LR_s \) will not be developed because, with reasonable assumptions, the effect of this multiplicative factor remains within an acceptable range. More formally, using notation introduced earlier in Section 4, the analyses discussed hereafter are based on the implicit development

\[
Pr(D_c | \bigcup_j S_j) \times Pr(S_j | D_c) \times Pr(W_c | D_c, S_j),
\]

which is also that followed by the footwear mark expert Mr Ryder in \( R \cup T \).

As a major aspect, the discussion will concentrate on finding a value for the denominator, that is the probability of the crime mark given the proposition that some pair of shoes other than those of the suspect are the source of the crime marks. As will be seen, there is not a single ready-to-use database from which relevant quantitative statements may directly be derived. Instead, possibly various sources of information may need to be consulted and their content be aggregated in some meaningful way. The feasibility of such an approach is highlighted and summarized here below in terms of main elements of statement writing.

6.1 Framework of circumstances and statement of the purpose

In the case at hand, it was accepted that, following manufacturer information on production dates, sales distribution and technical details about the production process (i.e. injection and use of a single mould for each size), that the crime scene marks were left by a Nike Multicourt III model of size 13US. In view of this, the recipients of expert information requested a written report on the following question: ‘Under the assumption that the crime marks were left by some person other than the suspect, what is the probability that the crime marks would show a feature pattern of a Nike Multicourt III of size 13US?’.

6.2 Data and information

Given the request, three items of quantitative information appeared potentially relevant:

1. A survey conducted among 23 police services nationwide indicated a total of 33,669 shoe marks recovered from crime scenes during the years 2003 to 2009. Among these
traces, there was one occurrence with the same general pattern (information on size was not available).

(2) During the same period of time, the same authorities registered a total of 21 621 pairs of inked reference prints from footwear seized during criminal investigations. There were four instances where the same general pattern was observed, but each time of a different size. Actually, there was one occurrence of a size 13US.

(3) According to the manufacturer, the model Multicourt III of size 13US made up 3.3% of the sales in Austria, Germany and Switzerland.

6.3 Evaluation and assessment

In order to assess the occurrence of the target sole pattern and size in the relevant population, it is necessary to specify that population in some further detail. In the case here, the proposition put forward by the defence is that some person other than the suspect — i.e., an intruder — acted on the scene. According to this version, the crime marks came from that other, unknown person (a burglar). The relevant population to consider thus is that covering individuals that could have committed this kind of activity. Consequently, one is directed to inquire about the occurrence of the target sole pattern and size among this category of individuals. In view of this, data collected by police forces during their crime scene examinations and subsequent investigations thus appear to be a relevant source of information (see also bullet points 1 and 2 in the previous paragraph).

Looking at the data on marks recovered on crime scenes, there is only one count of a mark with a comparable general pattern, found among a total of 33 669 crime marks. The general pattern of interest can thus be regarded as uncommon. Moreover, no ‘serial effect’ appears to affect these data. This information provides a first indication on the occurrence of the sole general pattern among individuals that leave marks at crime scenes, but it does not include information about size. This can be supplemented by considering data on footwear seen on individuals that came to police attention. In fact, there was one occurrence of a Multicourt III general pattern of size 13US encountered among the 21 621 standard reference prints established from footwear of police arrestees. This observation differs from the data on marks recovered on crime scenes because it accounts for both, general pattern and size. The data on crime marks accounted solely for general pattern. Although the former figure thus provides a closer approach to the kind of crime mark encountered in this case, it should be recognized that a probability assignment based on the relative frequency of 1 in 21 621 represents a vague, initial assignment which is very sensitive to the number of comparable observations.11 It suffices to notice that a second observation would already suggest a probability of occurrence twice as high, whereas zero observations would tend to suggest an extremely rare event.

In order to find a more robust expression of the rarity of the crime mark observations, data on general pattern and size can be considered separately. In fact, the police data on footwear observed on potential offenders counts four occurrences of a compatible Multicourt III pattern. An assignment of 4 in 21 621 represents a figure less ‘sensitive’ to changes in the number of observations, and may thus be retained for characterizing the rarity of the general pattern. With regard to data on size, it is of interest to inquire about the occurrence of size 13US among shoes with Multicourt III pattern. This can be characterized

11 The formulation is tentative at this point because, in a strictly belief type interpretation of probability, the identification of frequency as a probability is objectionable.
by the data provided by the manufacturer, as it is correctly conditioned on general pattern. In fact, these data refer to a proportion of 3.3% for 13US sizes among Multicourt III shoes sales. The joint assessment of general pattern and size thus is given by \((4/21626) \times 0.033\), which corresponds to approximately 1 in 160,000. In view of this, it appears very improbable to encounter a Multicourt III shoe of size 13US, and, thus, a crime mark of this kind, if these marks were made by some person other than the suspect, but who has also come to police attention.

6.4 Conclusions

In the case examined here, marks from Nike Multicourt III shoes of size 13US were recovered on the crime scene. A pair of shoes of this kind was available from the suspect and was found to be compatible with the crime marks along with no unexplainable discrepancies.

The credit that this correspondence provides to the proposition according to which the suspect’s shoes left the crime marks crucially depends on the probability that marks of such kind would be found under the assumption that the footwear of some person other than the suspect is at the origin of the crime marks. According to the proposition put forward by the defence, the person who left the crime marks is a burglar, so that the occurrence of shoes of the relevant kind among individual with such background is of interest. Data on footwear seen on people that came to the notice of police, associated with manufacturer sales data, indicate that this particular combination of general pattern and size is very rare.

In conclusion, the observed agreement in general pattern and size between the crime marks and inked reference impressions obtained from the suspect’s shoes very strongly support (the LR is in the order of 160 thousand) the proposition according to which this pair of shoes is at the source of the crime marks, rather than a pair of shoes from someone else.

This means that, stated otherwise, whatever the odds held by the recipient of expert information prior to the consideration of this report, those odds are very strongly reinforced (multiplied by a factor of about 160 thousand) by the results of the comparative examinations presented here.

This conclusion is based on an assessment of the probability of encountering the target footwear features on the shoes of another person of the population of potential sources. It is important to emphasize that this is a statement of the probability of the observations, and not a statement about the probability of the proposition that some other pair of shoes left the crime marks. There is also no expression throughout this report of an opinion about the probability of the proposition that the suspect’s (or some other person’s) footwear is the source of the crime marks.

That is, the probative value of the results of the comparative examinations reported in this statement amounts to an expression of the degree of support for one proposition versus a specified alternative proposition. This is intended to direct recipients of expert information in how to adjust their odds for the competing propositions of interest held prior to the consideration of this report.

Further, it is important to emphasize that both the definition of the relevant population and the evaluation of the results of the comparative examinations crucially depend on the framework of circumstances as given to the examiner. In any case in which that information, or part of it, should turn out to be appropriate or change, it will be necessary to review the evaluation and discussion presented in this report.
7. Discussion and conclusions

Various LR developments currently exist that provide guidance in the evaluation of scientific evidence. Throughout this article, the discussion focused on the example of footwear marks, but the underlying rationale applies also to other categories of forensic subject matter. The exact form of the component parameters of LR formulae direct one to relevant questions (i.e. populations) that need to be addressed. But because such formulae are typically given in mathematical form, it is regularly thought that they cannot be employed unless precise numerical assignments are provided. Indeed, practitioners often attempt to work with such formulae directly on a numerical level, and, if that level cannot be addressed, would leave aside the approach as a whole. In particular, no consideration is given to other levels of detail at which the formulae may be used. Such a view is limited and misconceived to some degree with possibly detrimental effects when communicated as such to recipients of expert information. There is reason of concern for this, as pointed out by the recent court decision in R v T, which appeared to have explicitly adopted such a position.

This exclusively quantitative level of requirement seems both unnecessarily demanding and incorrect from a methodological point of view. It seems too demanding in that it asks for numerical data as if these were a necessary preliminary for LR assignment. This is methodologically questionable essentially because ‘problems’ relating to data-gathering are invoked without considering whether such data could actually have a substantial impact on the overall evaluation.

The purpose of the present article was not to give recommendations on how to use LR formulae, but to argue in support of the view that they should not be approached in a purely ‘mechanical’ perspective, that is the desire to address them on a numerical level, to the exclusion of other modes of analysis. Further, the aim was to point out that the very potential of formal LR approaches lies in their underlying logical structure and their capacity to direct one to the relevant questions in the construction of verbal arguments. In summary, the analyses proposed here show the following.

- Uncertainty in relation to the reference material $E_s$ from a suspect affects a ‘core’ LR (which focuses on uncertainty about the crime object $E_c$) in terms of a multiplication factor LR$_s$. So, independently of any particular numerical assignment to that value LR$_s$, it is already possible to explain how it functionally affects the overall value of the LR (i.e. the combination of LR$_c$ and LR$_s$).
- The magnitude of LR$_s$, which is the fraction of the probability of the observations on the reference material $E_s$ given particular assumptions (e.g. the competing propositions at source level), depends on the relative value of the component parameters of this term (i.e. the conditional probabilities in the numerator and the denominator). In order to obtain an indication about the direction in which LR$_c$ is affected by LR$_s$, that is an increase or a decrease, it is sufficient to address the numerator and denominator of LR$_s$ in qualitative terms. In particular, it can be shown that their qualitative relationship does not need to be determined on the basis of actual numerical values. In a first step, it can suffice to scrutinize one’s belief about a single value, that is the proportion by which one of the two values is represented by the other, whatever that other value (i.e. a probability) is.
- For settings in which LR$_s$ is expected to take values greater than one, one may choose to leave that factor aside and to restrict the evaluation to $E_c$. This may be considered as a conservative assignment of the overall LR.

These insights suggest that LRs should not be looked at within a perspective that focuses on the mere purpose of calculating numerical expressions of evidential value. Where this can be done because relevant data are available, so much the better, but in essence the very strength of LR approaches lies in
their potential to clarify and further the comprehension of the logical structure of reasoning in the process of scientific evidence evaluation. Even if numerical assignments can actually be made, general and qualitative considerations may still be valuable and beneficial for consideration because they can help to place evidence evaluation appropriately in context. That context pertains to the understanding of a scientist’s evaluation among recipients of information. It is verbal and argumentative in nature. Numbers may be a part of that, but not a necessary one. This allows one to rejoin Glenn Shafer’s well-known quotation ‘Probability is not about numbers. It is about the structure of reasoning’.

In $R \lor T$, the scientist was challenged on grounds of using numbers that were informed by data considered inappropriate. The appropriateness of the data are a separate matter of discussion, but in view of the overall framework of reasoning for evidential assessment, the methodology used by the scientist conforms well with the general principles of logical reasoning. The degree to which this was made, or perceived to be, transparent is, again, a separate issue that does not invalidate the structure of reasoning as such. On the whole, transposing a framework of reasoning into practical applications requires scientists to exert personal judgement, and it appears to us that is what the scientist has pursued in this case.

On a more general view, it is also worth emphasizing that it would be simplistic to believe that dealing with a case involving footprint evidence could be reduced to the task of drawing a single numerical value from a database. The actual challenge is far more subtle than this because it involves a detailed consideration of the competing propositions of interest, a critical examination of available data and incorporation of information from the framework of circumstances. Conceptually, there is nothing wrong in approaching such aspects in a way that does not exclusively rely on precise numerical values.

Appendix

**LR derivation: consideration of the validity of assumptions**

A detailed analysis on how to choose relevant data for assigning a likelihood ratio (LR) at source level is proposed in Champod et al. (2004). This approach is followed here for the discussion presented in the main part of this article. The purpose is to find a form of a LR that is suitable for evaluative assessments at source level.

To start, consider some initial notation and definitions. In particular, let $E_c$ and $E_s$ denote the observations made on, respectively, the mark recovered on the crime scene and the test prints obtained from the suspect’s shoes under controlled conditions. The assumption made here is that shoes with obviously different general pattern are left aside, and that they can safely be discarded from further consideration. Suppose also that one can agree on the following pair of propositions at source level:

- $H_p$: The footwear mark found on the crime scene was made with the suspect’s shoe.
- $H_d$: The footwear mark found on the scene was made with some other shoe.

The discussion is restricted to the source level, which means that questions of relevance are not a compulsory issue (whereas they would be at the crime level Evett et al., 1998). It is worth noting,

12 Recent literature on the topic concludes that the database used by the scientist can be considered as pertinent (Redmayne et al., 2011).

13 Evidential relevance as it is understood here is a probabilistic notion that defines a connection with the true offender (Stoney, 1994).
however, that crime marks are often retained for further investigation because they were left in positions where the offender can reasonably be supposed to have walked or stood, and because marks may clearly be distinguished from the footwear of people with legitimate access to the premises.

For ease of language, discussion hereafter will refer to one given crime mark, taken as most representative, rather than several marks. It appears safe to consider that, even though there may be several fragmentary marks with comparable general pattern, these may be grouped if they are found in a ‘logical sequence’ (i.e. position), that is a ‘trail’, on which the offender is thought to have moved.

It is conceded at this point that the wording ‘was made’ in the statements of the propositions implies an action so that one may be tempted to consider the above pair of propositions as one at activity level. Let us notice, however, that for the kind of evidence considered here (i.e. marks on a floor) as well as its associated process of generation, the question of ‘source’ necessarily requires a well-defined action (i.e. the process of walking). Notwithstanding, the stated propositions are interpreted as source-level propositions here essentially because no factors (or phenomena) such as transfer, persistence and recovery — typically addressed in genuine activity level evaluations (e.g. for glass and fibre evidence) — are considered in the setting discussed here.

Besides, let $I_c$ and $I_s$ refer to the framework of circumstances relevant to the crime and the suspect, respectively. For example, $I_c$ pertains to aspects of the crime under investigation (such as the number of offenders), whereas $I_s$ accounts for relevant descriptors of the suspect (such as his occupation or his lifestyle). Considering that $E_c$ and $E_s$ refer to the same corresponding set of markings left by manufacturing features, the LR can be written, in its general form, as follows:

$$LR = \frac{Pr(E_c, E_s \mid H_p, I_c, I_s)}{Pr(E_c, E_s \mid H_d, I_c, I_s)}.$$  

Given the proposition $H_d$, that is the mark recovered on the crime scene was made by a shoe other than that of the suspect, the observations $E_c$ and $E_s$ can be regarded as independent so that the denominator can be rewritten as follows:

$$Pr(E_c, E_s \mid H_d, I_c, I_s) = Pr(E_c \mid H_d, E_s, I_c, I_s) \times Pr(E_s \mid H_d, I_c, I_s)$$  

Moreover, given $H_d$, the observations on the crime material $E_c$ can be considered independent of information pertaining to the suspect, $I_c$. Conversely, observations on the test prints made by the suspect’s shoes are not affected by information about the crime if the suspect’s shoes are not the source of the crime mark. Arguably, the denominator can be further reduced to:

$$Pr(E_c \mid H_d, I_c) \times Pr(E_s \mid H_d, I_s).$$

Next, consider the numerator in some further detail. With respect to the aspects originating from general sole pattern as considered in this setting, it seems reasonable to accept the idea that such features are sufficiently ‘stable’. The assumption is thus made that there were no events that could have caused substantial changes to such major constituent features. This assumption can further be supported, for example, if the time lapse between the commission of the crime and the seizure of the suspect’s shoes is short. Therefore, given knowledge of the characteristics of the suspect’s shoes, these characteristics can be expected to be discernible in the crime mark in the same way (i.e. in agreement)

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14 Such an assumption may be supported, for instance, by eyewitness evidence or CCTV footage.

15 The analysis readily extends to take into account the joint occurrence of several levels of comparative features, but this is not pursued here for the ease of presentation.
as in the ‘known’ comparison prints — if the suspect’s shoe is in fact the source \((H_p)\). Therefore, \(\Pr(E_c \mid H_p, E_s, I_c, I_s) = 1\) so that the extended form of the numerator, i.e.

\[
\Pr(E_c, E_s \mid H_p, I_c, I_s) = \Pr(E_c \mid H_p, E_s, I_c, I_s) \times \Pr(E_s \mid H_p, I_c, I_s)
\]

can be written more concisely as

\[
\Pr(E_c, E_s \mid H_p, I_c, I_s) = \Pr(E_s \mid H_p, I_c, I_s) .
\]

Combining the results for the numerator and the denominator, one thus obtains the following LR:

\[
LR = \frac{\Pr(E_c, E_s \mid H_p, I_c, I_s)}{\Pr(E_c, E_s \mid H_d, I_c, I_s)} = \frac{1}{\Pr(E_s \mid H_d, I_c)} \times \frac{\Pr(E_s \mid H_p, I_c, I_s)}{\Pr(E_s \mid H_d, I_s)} .
\]

It is worth noting that \(\Pr(E_c \mid H_p, E_s, I_c, I_s) = 1\) is an assumption that may not generally hold by default. When considerations are extended to particular acquired features, for instance, then it may not be taken as certain that a given configuration of markings will necessarily be observed. In fact, repeated applications of a given shoe sole may lead to different sets of marks featuring in the traces thus produced. That is, due to factors such as pressure, direction of application or walking surface characteristics, some aspects may preferentially be reproduced, rather than others. In a strict sense, such considerations could also be applied for more general aspects, such as sole pattern. Indeed, footwear marks are often fragmentary and the general pattern of a sole is rarely reproduced in its entirety. Therefore, such kind of characteristics may also show up differently in repeated applications of a given shoe sole. In other words, the extent of reproduction of a given sole pattern is subject to variation. These considerations imply that the probability of observing a given configuration of markings is less than one.

It should also be noted that the common statement according to which given footwear features are ‘compatible’ with features observed in a mark does not necessarily imply that \(\Pr(E_c, E_s \mid H_p, I_c, I_s)\) should be 1. A judgement of ‘compatible with’ merely says that \(\Pr(E_c, E_s \mid H_p, I_c, I_s)\) is not zero. In fact, as noted above, there is much reason to consider that this probability should take a value lower than one.

Acknowledgements

The authors wish to thank the anonymous referees for their constructive comments.

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