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Conclusion

This simple modification of a conventional photographic method helps to give a more convincing demonstration of indented impressions. It should work equally well with silicon-rubber casts of indented impressions in which the letter-strokes appear as ridges rather than troughs.

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COMMENTARY

The interpretation of glass evidence. A practical approach

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The application of Bayesian inference to the interpretation of glass evidence is discussed in the context of four hypothetical glass-on-clothing cases. The emphasis is placed on generating a practical system that could be implemented readily rather than on rigour. The implications of the results on forensic decision making are discussed.

Key Words: Bayesian inference; Glass; Clothing; Interpretation

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Introduction

The desirability of data collections as aids to the objective evaluation of evidence is recognised almost universally among forensic scientists. Glass, in particular, is an evidence type to which much attention has been paid. The late sixties and early seventies saw a number of exciting initiatives: the clothing survey of Pearson, May and Dabbs [1]; the analysis of glass samples collected from fire scenes reported by Pearson and Dabbs [2]; studies of within source variation by Dabbs and Pearson [3]; and others. It was in response to initiatives from the Central Research Establishment (now the Central Research and Support Establishment (CRSE)) that the interlaboratory collaborative exercise to collect refractive index data was started in the United Kingdom. There have been many other valuable studies in intervening years which have provided information which should contribute to the interpretative process: the transfer/persistence studies of Smalldon and Pounds [4] and the casework clothing survey of Harrison, Lambert and Zoro [5] deserve particular mention.

Over the same period, new techniques for abstracting information from small quantities of glass have been successfully developed and implemented.

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Operational laboratories in the United Kingdom now have the facility for routine elemental analysis of casework sized fragments.

Progress has been slower, however, in the implementation of objective methods for evaluating the data in an individual case. Some advances have occurred—the concept of grouping measurements and the use of graphical data displays are now routine in most laboratories—but comparison and evaluation are still largely subjective. There is a wide variation in the use of data collections and, as an example, the Home Office Forensic Science Service collaborative control data collection has not been updated for several years. The main problem has been that of finding a framework for combining all the various sources of information to provide a casework evaluation. However, through a series of papers in the mid-eighties [6, 7] forensic scientists are becoming aware of the potential of Bayesian inference to provide such a framework.

In contrast to earlier work by Lindley [8] and Evett [7, 9], this paper sets out a compromise approach intended to make use of some of the benefits of the Bayesian philosophy while accepting that we still have a way to go before ideal treatments are possible.

There are three compromises. First, we assume that the examiner has a criterion for deciding whether or not two sets of glass fragments "match" in their properties. The assumption of a match criterion means that the quality of "match" is not catered for in this model. A good match will be assigned the same value as a borderline match. A full Bayesian analysis would work on probability density functions as in [8] and [7, 9]; considerably more efficient but complicated mathematically. Second, we assume that the examiner has applied criteria to decide how many different groups of recovered fragments there are: this again simplifies the mathematics considerably. Third, we assume that the examiner has a means of estimating the "frequency of occurrence" of glass of a given set of properties on the clothing of members of the population. In relation to the third assumption we use data for glass on clothing that have been abstracted from a survey carried out at the Belfast laboratory (McQuillan, personal communication), and show how such data can be combined with subjective assessments of other aspects of the evaluation.

To illustrate the interaction of various aspects of glass evidence, four different hypothetical cases are considered. These are all very similar in many respects but differ from each other in clearly identifiable features.

Case 1

A shop window has been smashed with criminal intent. There is an eyewitness who describes how he saw a man stand in front of the window, and smash it with a house brick and run away immediately. The dimensions and height of the window are known and the description of events is sufficiently good to enable an estimate of how close the offender was to the window. A suspect was arrested half a mile from the scene, who denies having been anywhere in the vicinity of the crime scene at any time in the last 24 hours. His woolly jersey and blue jeans were removed approximately 45 minutes after the crime. Standards of evidence collection, including the taking of a representative control sample, were excellent. Four fragments of glass are found on the clothing which match the control glass in all the measured properties. A search of a suitable database shows that approximately 3% of the glass found on clothing would match the control in those properties. There is nothing else of evidential value.

If such a case comes to court, it will be necessary for that court to assess various aspects of evidence. The eyewitness evidence will be considered, for example, to see how closely the description of the offender matches the suspect. There are complex issues involved in this process, but here we are concerned solely with the assessment of the glass evidence.

In a typical window smashing case it is necessary to weigh against each other two alternative hypotheses of the type

C: The suspect is the man who smashed the scene window(s).
$\bar{C}$: The suspect is not the man who smashed the scene window(s).

The Bayesian approach determines that it is necessary to evaluate the probability of the *evidence* under each of the two alternatives. The ratio of the two probabilities, called the *likelihood ratio,* is the measure of the relative support which the evidence provides for the two alternatives.

In relation to the numerator of the ratio the question is "What is the probability of the evidence given that the suspect was the man who smashed the scene window?", (or windows, as the case may be). Issues such as transfer and persistence need to be considered, which we return to later. The denominator presents something of a problem because the suspect is not obliged to offer any explanation for the presence of glass on his clothing. In this situation it is conventional to consider, in the absence of information to the contrary, that, as far as his clothing is concerned, he is a person selected at random from the population. This question then becomes "What is the probability of finding evidence of this nature on the clothing of a person selected at random from the population?". It is to answer questions of this nature that clothing surveys are carried out.

In Figures 1a and 1b are summaries of data taken from the Belfast clothing survey. The data are based on the quantities of glass found on pairs of garments (e.g., sweater/trousers) from persons who had no known connection with crime. The glass recovered from each clothing pair was analysed and so it was possible to infer how many distinct groups of glass occurred on

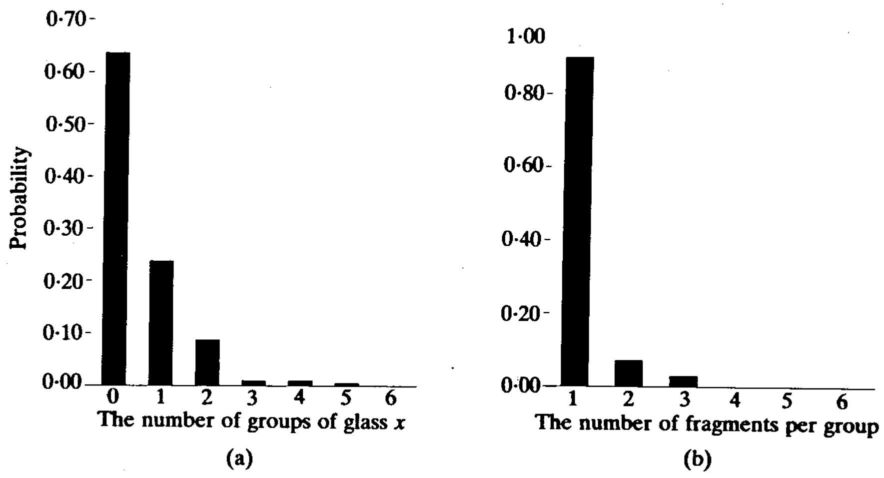

FIGURE 1 **Glass found on the surface of clothing showing probabilities of (a) the number of groups (*P* terms) and (b) the number of fragments per group (*S* terms).**

the clothing of each individual. Figure 1a shows the proportions of men in the survey who had no glass, one group of fragments, two groups and more than two groups present on the surface of their clothing. Figure 1b shows the distribution of quantity of glass in each group recovered; most groups consist of only one fragment, while only 2·9% have three or more fragments. On the clothing of men in the population, then, a group of three or more fragments could be termed "large". So, for the sake of this discussion, a group of one or two fragments is described as small and other groups as large. This may mean ignoring useful aspects of the evidence in an individual case, but it provides an adequate base for illustration.

Given the Belfast data, it is easy to evaluate the denominator for the present example. What is the probability that a person selected at random would have a single, large group of fragments on his clothing with the observed properties? This can be written as

$$P_1 \,.\, S_L \,.\, f_1$$

where P_1 is the probability that a person would have one group of fragments on his clothing (Figure 1a), S_L is the probability that a group of fragments found on clothing of members of the population is large (Figure 1b) and f_1 is the frequency of occurrence of glass of the observed properties on clothing (in this case 3%).

The numerator, the probability of the evidence given that the suspect was the man who smashed the window, must allow for two possibilities. Either the suspect had no glass on his clothing before the accident and the group was transferred, or the suspect had the glass on his clothing before the incident and none was transferred. The numerator is then

$$P_0 \,.\, T_L + P_1 \,.\, S_L \,.\, f_1 \,.\, T_0$$

where P_0 is the probability that a person selected at random would have no glass on his clothing (Figure 1a), T_L is the probability of a large group of fragments being transferred and T_0 the probability of no glass being transferred (see later). The likelihood ratio in this case is then

$$\frac{P_0 \,.\, T_L}{P_1 \,.\, S_L \,.\, f_1} + T_0$$

Case 2

The circumstances and details of this case are exactly the same as in Case 1, except that the recovered evidence consists of two groups of glass. One of these, consisting of four fragments, matches the control; the other, also consisting of four fragments, differs from the control. Again, approximately 3% of the glass found on clothing would match the control. The analysis for this case proceeds along similar lines to yield a likelihood ratio of

$$\frac{P_1 \,.\, T_L}{2 \,.\, P_2 \,.\, S_L \,.\, f_1} + T_0$$

where P_2 is the probability that a person at random from the population would have two groups of glass on his clothing (Figure 1a).

It may be noted that the size and frequency of occurrence of the second group do not occur in the expression; this is because they each occur in the numerator and the denominator and cancel out.

Case 3

This offence involved the smashing of two separate windows close to each other. Again there was an eyewitness who described the way in which the offender smashed the two windows. The other circumstances are as in the previous case. As in Case 1, just one group of four fragments is found on the jersey. The two controls have quite distinguishable properties and the recovered fragments match one of the controls. Approximately 3% of glass found on clothing would match that control.

In order to simplify the discussion as much as possible, the transfer probabilities are assumed to be the same for the two windows smashed in this case. The likelihood ratio can then shown to be

$$\frac{P_0 \,.\, T_0 \,.\, T_L}{P_1 \,.\, S_L \,.\, f_1} + T_0^2$$

Case 4

The circumstances and details are exactly the same as in Case 3, except that the recovered evidence consists of two groups of glass, each consisting of four fragments. One group matches one control, the other matches the other control. The frequencies of occurrence of both types of glass are each 3%.

Once again the same transfer probabilities for the two windows are assumed. The derivation of the likelihood ratio is more complicated than in the other cases but it can be shown to be

$$\frac{P_0 . T_L^2}{2 . P_2 . S_L^2 . f_1 . f_2} + \frac{P_1 . T_0 . T_L}{2 . P_2 . S_L . f_1} + \frac{P_1 . T_0 . T_L}{2 . P_2 . S_L . f_2} + T_0^2$$

where f_2 is the frequency of occurrence of glass with the properties of the second group on clothing.

Independence

In all the above derivations there are assumptions of independence. The combination of unconditional probabilities by multiplication is only possible where the events are independent. From a limited analysis made from the Belfast data, we have not detected evidence of dependence between the *P* and *S* terms among persons with up to four groups of glass on their clothing. The situation regarding Case 4 presents further assumptions of independence such as an assumption that the frequencies for the two groups on clothing are independent. The authors could not test these assumptions with experimental data at this stage.

Evaluation

In cases such as those being considered here it turns out that the first term in the likelihood ratio is dominant and the others can be ignored to a good approximation. The approximate analyses for the four cases can be simply summarised as in Table 1, where the terminology is also summarised.

All the data needed to calculate the likelihood ratios for the four cases are available except for the transfer probabilities. The literature on glass transfer and persistence is scant and the estimates in an individual case must depend critically on the expertise of the scientist concerned. Supposing that, after a careful consideration of the circumstances of the case, the scientist estimates

T_0: 0·2
T_L: 0·6,

the likelihood ratios for the four cases, given these transfer probabilities, are given in Table 2.

TABLE 1 Approximate analysis of the four cases and summary of probability terms relating to a person selected at random from the population

	Recovered glass	
Control	*One group*	*Two groups*
One window	Case 1: $\frac{P_0 T_L}{P_1 S_L f_1}$	Case 2: $\frac{P_1 T_L}{2 P_2 S_L f_1}$
Two windows	Case 3: $\frac{P_0 T_0 T_L}{P_1 S_L f_1}$	Case 4: $\frac{P_0 T_L^2}{2 P_2 S_L^2 f_1 f_2}$

$P_0 = 0{\cdot}636$: the probability that a person would have no glass on his clothing (Figure 1a)
$P_1 = 0{\cdot}238$: the probability that a person would have one group of fragments on his clothing (Figure 1a)
$P_2 = 0{\cdot}087$: the probability that a person would have two groups of glass on his clothing (Figure 1a)
$S_L = 0{\cdot}029$: the probability that a group of fragments found on clothing of members of the population is large (Figure 1b)
$f_1 = 0.03$: the frequency of occurrence of glass of the observed properties on clothing (in this case = 3%)
$f_2 = 0{\cdot}03$: the frequency of occurrence of glass with the properties of the second group on clothing
$T_0 = 0{\cdot}2$: the probability of no glass being transferred, retained and found
$T_L = 0{\cdot}6$: the probability of a large group of fragments being transferred, retained and found

Discussion

We have discussed elsewhere [10] ways in which the meaning of particular values of the likelihood ratio might be conveyed to investigator or to courts. The likelihood ratio is a factor which multiplies the odds which existed in relation to *C* before the scientific evidence was revealed. We do not expect that bald numerical values of the likelihood ratio would provide effective means of communicating evidential strength to non-scientists. It would be wrong to attribute more than order of magnitude precision to the numbers in Table 1; not only are the expert's probabilities imprecise but also the *P*s and *S*s are based on relatively small scale sampling. However, we do claim

TABLE 2 Likelihood ratios for the four cases

	Recovered glass	
Controls	*One group*	*Two groups*
One window	Case 1: 1843	Case 2: 943
Two windows	Case 3: 368	Case 4: 1,738,000

that for the scientist there is now a convenient numerical scale by which the relative strengths of the evidence may readily be compared between different situations and, indeed, between different evidence types.

In Case 1, the odds on C are multiplied about 2000 times by the scientific evidence. This factor takes account not only of the relative frequency of the glass but also of the fact that it was found on the suspect's clothing. In Case 2, the likelihood ratio is reduced relative to that for Case 1, the reduction attributable to the fact that two groups, not one, of glass were found on the suspect. In our discussions with operational scientists we have found that most, though not all, find this intuitively reasonable. In Case 3, the likelihood ratio is only about one fifth of its magnitude in Case 1; the fact that no glass has been found to match the second scene window is the cause of this substantial reduction in the strength of the evidence. We would expect the evidence to be stronger in Case 4 than in the other three cases but, even so, the likelihood ratio of almost two million may come as something of a surprise.

Conclusion

The Bayesian approach offers many benefits to the interpretation of evidence. The implementation of this powerful technique has, however, lagged due in part to the reluctance to take a compromise approach. The practical approach discussed here could be used to guide the decision making of forensic caseworkers.

The power of Bayesian inference and its advantages over the more conventional coincidence methods has been demonstrated. Some of the advantages revolve around the way in which different elements of the evidence can be combined. In the glass case this might mean combining the evidential value of the presence of glass with the added information from analytical techniques. In addition, consideration can be given to the effect on the evidential value of non-matching glass fragments, and to the effect of multiple groups of matching glass fragments.

The treatment given highlights the sort of survey and experimental data that are most needed for this type of evaluation. The assessment of transfer probabilities is an area that examiners find difficult. Each case is different and will have to be assessed individually; *nevertheless*, the need for experimental work in this area is clearly highlighted. Encouragement must be given to experimenters such as McQuillan, Harrison, Lambert and Zoro and it is hoped that the demonstration of what may be done with the data assists in promoting this kind of work.

A generalised treatment of the above style of analysis has been built into a user-friendly computer program which we shall describe elsewhere.

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