Further observations on glass evidence interpretation

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This is a continuation of discussions in other papers in this journal by the authors. A Bayesian perspective is used to explore issues of glass evidence interpretation. Data from two surveys of glass on clothing are used and there is a discussion of transfer/persistence probabilities, by considering the sensitivity of the likelihood ratio, leading to some remarks on knowledge elicitation. An analysis is suggested for dealing with *post hoc* explanations for the presence of glass on a suspect's clothing.

Die bisher in dieser Zeitschrift vorgelegten Erörterungen des Authors zum Thema werden fortgeführt und die Interpretation des Beweiswertes von Glasspuren unter den Bedingungen des Theorems von Bayes untersucht. Die rechnerischen Grundlagen hierzu liefern zwei Untersuchungsreihen zür Häufigkeit von Glaspartikeln auf Kleidungsstücken. Die Wahrscheinlichkeit einer Übertragung und des Verbleibs von Glaspartikeln wird auf der Basis der Likelihood Verhältnisses und dessen Aussagekraft betrachtet. Hieraus ergeben sich auch Hinweise wie Tatsachenwissen zu gewinnen ist. Für 'post hoc' Erklärungen von Glaspartikeln auf der Bekleidung eines Tatverdächtigen wird ein Analysengang vorgeschlagen.

Il s'agit d'une suite de discussions parues dans d'autres articles de ce journal par les mêmes auteurs. Une perspective bayesienne est utilisée pour explorer l'interprétation du verre en tant qu'indice. Les données de deux études concernant la présence de verre sur les habits sont mises à profit pour discuter les probabilités de transfert et de persistance en observant la sensibilité du facteur de vraisemblance (LR = likelihood ratio) et introduire quelques remarques sur la connaissance qui en découle pour l'expert. Une analyse suggère comment expliquer *post hoc* la présence de verre sur les habits d'un suspect.

Esta es la continuación de las discusiones mantenidas en otras partes de esta revista por los autores. Se usa una perspectiva bayesiana para explorar casos de interpretación de evidencias de cristales. Se emplean los datos de dos revisiones de vidrio en ropa y se hace una discusión sobre las probabilidades de transferencia/persistencia teniendo en cuenta la sensibilidad del cociente de probabilidad y lo que lleva a algunas consideraciones sobre el conocimiento de la obtención. Se sugiere un análisis para tratar con explicaciones 'post hoc' la presencia de cristales en la ropa de un sospechoso.

Key Words: Glass; Probability; Statistics; Likelihood ratio; Bayesian; Evidence interpretation.

Introduction

An earlier paper by Evett and Buckleton [1] (hereafter referred to as EB) in this journal discussed aspects of the Bayesian approach to glass evidence, making use of a survey of glass found on the clothing of people unconnected with crime, since reported by McQuillan and Edgar [2] (hereafter referred to as ME). This paper extends the discussion in three ways: by considering new aspects of the process by which an expert might be encouraged to think about transfer probabilities, i.e., *knowledge elicitation*; by utilising data on glass on clothing from a recently reported survey by Lambert, Satterthwaite and Harrison [3] (hereafter referred to as LSH); and by assessing the potential impact on the strength of the evidence if the suspect later offers an alternative explanation for the presence of glass on his clothing.

As in the previous paper, it is assumed that refractive index (RI) measurements from the control and recovered samples are compared by means of a simple match criterion, preceded by the application of a method for determining how many groups of glass of recovered glass are present; for example, as described by Evett and Lambert [4]. It is also assumed that the examiner has the means of estimating the relative frequency with which groups with a given RI occur on clothing.

A full Bayesian analysis of the measurements would not follow a two-stage match/frequency of occurrence approach. Rather, a continuous one-stage analysis would be used, following the principles which were clearly established by Lindley [5]. However, those aspects of the interpretation presently under consideration can successfully be exposed using the mathematically simpler two-stage approach.

The following case example is essentially the same as *Case 1* in the previous paper (EB).

Case example A witness saw a man stand about 1.5 metres in front of a shop window and smash it with a house brick. The man was disturbed and ran away. About 30 minutes later, two policemen detained a man about half a mile from the incident because he resembled the eyewitness' description. He was taken to the police station and his outer clothing—a woolly jumper and a pair of jeans—were confiscated about one hour after the arrest. The suspect denied having been anywhere near the scene of the crime that day. The clothing was submitted for scientific examination together with an adequate control sample from the broken window. Correct procedures for ensuring the integrity of evidence were followed at all times. There was no prospect of contamination. In the laboratory four fragments of glass were recovered from the surface of the clothing, none with original surfaces. RI measurements were carried out and the recovered fragments formed a group which matched the mean of the measurements on the control sample.

First Evaluation

As in the previous paper, there are two competing explanations for the evidence E, that four fragments were found on the suspect's clothing:

C: the suspect is the man who smashed the window
$\bar{C}$: the suspect is not the man who smashed the window

If E denotes the evidence found as a result of the scientific examination of the suspect's garments then it is necessary to evaluate the likelihood ratio:

$$\frac{P(E \mid C,I)}{P(E \mid \bar{C},I)}$$

where I denotes all of the background information (or circumstances) known to the scientist which is relevant to the interpretation of the evidence. It follows that it is necessary to address two questions:

What is the probability of the evidence given that the suspect smashed the window, and given the background information?

and

What is the probability of the evidence given that the suspect did not smash the window, and given the background information?

The answer to the first question involves consideration of the mechanisms of transfer and persistence of glass fragments, evaluated in the light of I. The second question poses something of a problem because there is no obligation on the part of the suspect to explain the presence of glass on his clothing. If I contains no information about the personal circumstances of the suspect then, as far as the glass evidence is concerned, the underlying factors relating to the acquisition of glass are unknown and, in this regard, he has to be considered to be a random selection from a population. The next question, of course, is 'which population?' To help answer the question there are two surveys of glass on clothing which are based on two quite different populations. ME [2] examined the outer clothing of people who had no involvement in crime. LSH [3], on the other hand, surveyed the clothing of people who had come to police attention because of their suspected involvement in crime involving breaking glass. LSH removed data from glass which clearly matched controls in individual cases to give a background distribution of the glass which can be expected to be found on the clothing of such people. Figures 1a and 1b have been abstracted from the two surveys. Figure 1a shows the chance of finding 0, 1, 2, 3, etc., differing groups of glass on the surface of a pair of outer garments estimated from the two surveys. Figure 1b, again estimated from the two surveys, shows the chance that a group will consist of 1, 2, 3, etc., fragments. Not surprisingly, more glass was found on the clothing of the subjects of the LSH survey. The consequences of referring to the two distributions will be illustrated later.

If one follows lines of reasoning similar to that of EB [1] then the LR for the case example can be shown to be:

$$\frac{P_0 T_4}{P_1 S_4 f} + T_0 \qquad (1)$$

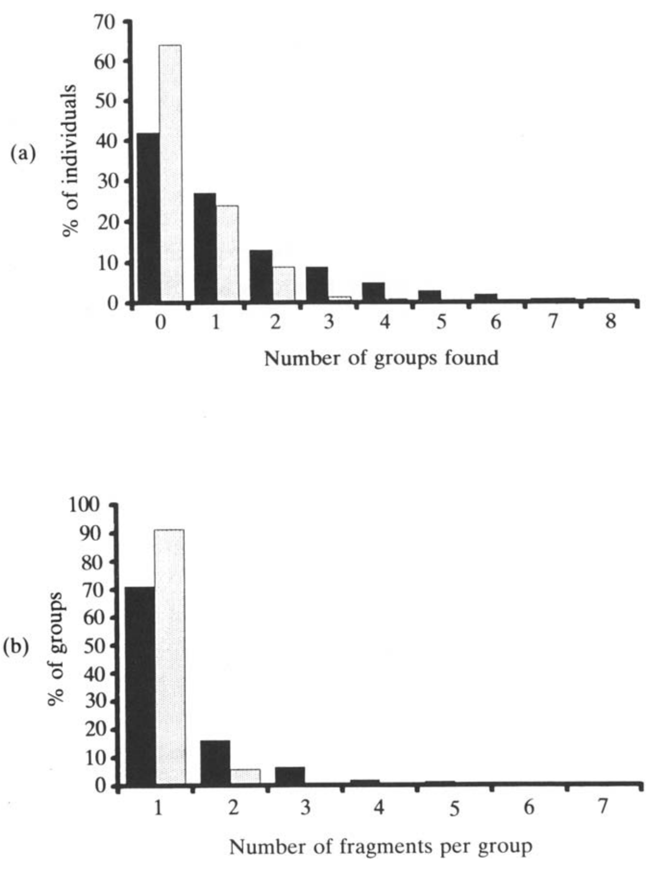

FIGURE 1 Data from two surveys of glass on clothing ■ LSH [3] ▒ ME [2] (a) Number of groups found on the surface of a pair (upper/lower) of garments. (b) Distribution of the size of groups.

where: P_0, P_1 are, respectively, the probabilities of finding no glass and one group of glass on the surface of a person's clothing; S_4 is the probability that a group of glass fragments on the surface of a person's clothing consists of 4 fragments; T_0, T_4 are the probabilities that zero, 4 respectively fragments of glass would be transferred, retained and found on the suspect's clothing if he had smashed the scene window; and f is the probability that a group of fragments on a person's clothing would match the control sample.

In a fully Bayesian treatment, following the philosophy established by Lindley [5], f would be a probability density. However, following the compromise approach, the RI distribution has to be regarded as discretized—as in a histogram; f is then the relative frequency of glass falling in an interval whose width is related to the size of the criterion used for matching, analogous to the method that is conventionally followed for interpreting DNA evidence.

Expression (1) differs from that in the EB paper by the specification of the number of matching fragments. In the previous paper, there were only three conditions considered: no glass; a small group (1 or 2 fragments); a large group (3 fragments or more). This was done mainly because there were only very few occasions in the ME survey on which the group sizes were three fragments or more. It has been remarked that Figures 1a and 1b show that rather more background glass was found on the clothing of people who had come to police attention (LSH) than on those who had no known connection with crimes or their investigation (ME). The new data enable the transfer/persistence probabilities to be specified more finely.

It is also necessary to remark that the treatment is an approximation, based on the assumption that grouped recovered fragments have all come from one source. A more general treatment, as in Evett [6], would sum over all possibilities i.e., 0, 1, 2, 3, and 4 transferred fragments. The overall effect on the LR is not likely to be great, at the expense of considerable complexity, and would obscure the principles that otherwise become clearer.

For evaluating Case 1, the LSH survey suggests values of: 0·42 and 0·26 for P_0 and P_1 respectively (Figure 1a); and 0·02 for S_4 (Figure 1b). The ME survey suggests values of: 0·64 and 0·24 for P_0 and P_1 respectively; and 0·01 for S_4. Note that the values for S_4 are particularly tentative. In the ME survey there was one group in 100 of this size and in the LSH survey two groups in 100. As in the EB paper, f is taken to be 0·03 for illustrative purposes, though it is worth noting that the LSH survey includes an RI distribution for glass on clothing which could, in principle, be used for this purpose.

The transfer probabilities are a matter for expert judgement, though this subject was not discussed in any detail in the EB paper. Experiments that have been carried out on glass transfer and persistence (Pounds, personal communication) suggest that the persistence of glass fragments on clothing can be described by mixtures of exponential decay curves. A possible model for the probability distribution for the number of fragments remaining at time t is then a Poisson distribution:

$$T_j^{(t)} = \frac{e^{-\lambda_t}\lambda_t^j}{j!} \, (j = 0, 1, 2, 3 \ldots)$$

in which λ_t, the Poisson parameter, is the expected number of fragments remaining at time t, and $T_j^{(t)}$ is the probability that j fragments would be found at time t. For simplicity in the present discussion, as only one time interval is being considered, the t suffices and superscripts are omitted:

$$T_j = \frac{e^{-\lambda}\lambda^j}{j!}$$

In this framework, the problem then becomes that of determining an estimate for the parameter λ. There are many factors to take into account and experimentation in the individual case is not feasible, so that the best available estimate comes from the judgement of the expert. Imagine that, before starting the case, the expert was asked how many matching fragments would be expected to be found if C were truly the case and that the reply was 'about 4'. Then the Poisson distribution with $\lambda = 4$ is shown in Figure 2 and this gives the probabilities:

$$T_0 \approx 0{\cdot}02$$
$$T_4 \approx 0{\cdot}20$$

It is stressed that this is a simplification, made for exploring concepts. There are other methods for modelling knowledge (and the authors are grateful to one of the referees for helpful suggestions) which it is hoped to discuss in a future paper. Substituting the exact T s into (1) together with the other probabilities from the ME survey gives LR = 1740 and the LSH survey gives LR = 526. It is not surprising that the latter survey leads to the more conservative assessment of the evidence.

However, for both surveys this represents the maximum value for the LR because the expert happened to predict precisely the number of fragments which were actually found. It is instructive to explore the sensitivity of the LR to the expert's prediction. Figure 3 shows how the LR varies given different values for the expected number of fragments, remembering that the number actually found was 4. The graphs behave in an intuitively reasonable manner. Not surprisingly, they have their maxima when the number found is exactly equal to the expert's prediction. As is to be expected, the LR is smaller when the number found is less than expected. What may not have been so readily obvious is that the

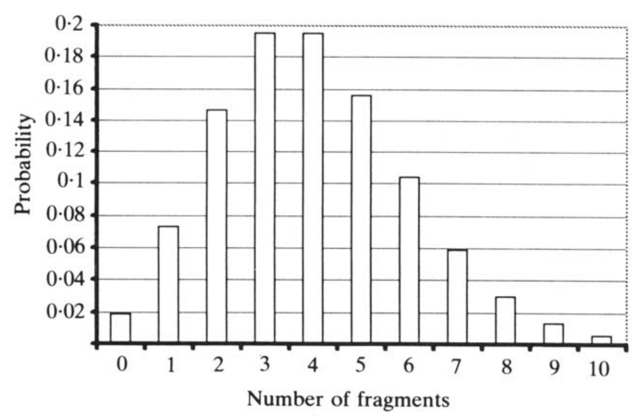

FIGURE 2 Poisson distribution which shows the probability of finding different numbers of fragments, when the expected number is 4.

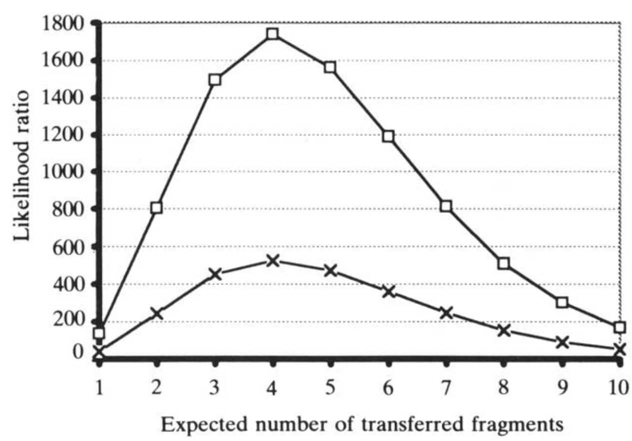

FIGURE 3 Dependence of the LR on the expert's expectation of the number of fragments to be found, when the number actually found is 4. (—□—) ME survey (—×—) LSH survey.

LR is less than the maximum when *more* are found than expected.

Knowledge Elicitation

The process of encouraging an expert to express his expectation in numerical terms, related to the process known as *knowledge elicitation*, is complex and straddles the boundaries between statistics and psychology. This sort of exercise is carried out as part of interpretation workshops held within the Forensic Science Service; an exercise in relation to fibres evidence was described by Cook *et al* [7].

An essential principle of this approach is that the expert should consider his expectations *before* the search for evidence is carried out. There are two main reasons for this. First, the expert could otherwise later be accused of retrospectively modelling his expectation to meet what was actually found. Second, this process is merely focusing attention on what the expert should be doing anyway: the expert's judgement about whether or not an examination is going to be worthwhile must depend on what he expects to see if C is the case.

A last remark relates to the use of the Poisson distribution. It has the advantage of simplicity, requiring only one parameter, but that simplicity brings its own problems. The expected value λ fixes not only the mean of the distribution but its variance also and thus the expert may be constrained to greater, or less, precision than he considers justifiable. For this reason, other methods of knowledge elicitation need to be explored for this kind of problem.

Alternative explanations for presence of glass

Assume that the case under consideration had been reported on and had come to trial, the scientist's evidence being used by prosecution to support their case. Often, in British courts, it happens that defence counsel offer alternative explanations for the evidence for consideration by the scientist. Of course, on occasion such an explanation will be perfectly genuine and, indeed, may provide a cogent alternative explanation for the evidence. On other occasions the explanations will be largely hypothetical as part of a legitimate defence strategy for weakening the evidence. Little has been written about how the scientist can best help the court in this situation. An attempt is made here to do so within the context of the present hypothetical case, when the new alternative is likely to be that the suspect had recently been near to another glass object when it was smashed.

It is first necessary to emphasise that if the suspect had made it clear at the outset that he had been near to some other breaking glass object some time previous to the crime, then that information could well have influenced the way in which the case examination was carried out and would certainly have influenced the alternative explanation, $\bar{C}$, for the evidence. But now we consider the *post hoc* explanation, advanced after the evidence has been found as follows:

A: the suspect had recently been near another breaking glass object.
$\bar{A}$: the suspect had not recently been near another breaking glass object.

There are a few ways of approaching this problem, only one of which is presented here. It is intended to make a more comprehensive coverage the subject of a separate paper. The LR which has so far been under consideration is:

$$\frac{P(E \mid C,I)}{P(E \mid \bar{C},I)}$$

The laws of probability can be used to show a way of extending the terms in the LR to include the new events. It is sometimes known as 'the rule of the extension of the conversation' and its proof is simple, though not given here. Then:

$$LR = \frac{P(E \mid ACI)P(A \mid CI) + P(E \mid \bar{A}CI)P(\bar{A} \mid CI)}{P(E \mid A\bar{C}I)P(A \mid \bar{C}I) + P(E \mid \bar{A}\bar{C}I)P(\bar{A} \mid \bar{C}I)}$$

So now the evidence can be considered given four composite explanations for it:

AC: The suspect smashed the scene window and the explanation that he was recently near another breaking glass object is true.
$\bar{A}C$: The suspect smashed the scene window and the explanation that he was recently near another breaking glass object is false.
$A\bar{C}$: The suspect did not smash the scene window and the explanation that he was recently near another breaking glass object is true.
$\bar{A}\bar{C}$: The suspect did not smash the scene window and the explanation that he was recently near another breaking glass object is false.

The second explanation will be the prosecution alternative. The third is the defence alternative. Neither side will advance the first alternative (certainly not defence!) Likewise, if the suspect is innocent of the alleged incident, then there is no reason to believe the fourth alternative. So from these practical considerations:

$$P(A \mid CI) = P(\bar{A} \mid \bar{C}I) = 0$$

and

$$P(\bar{A} \mid CI) = P(A \mid \bar{C}I) = 1$$

Then this view leads to a new likelihood ratio:

$$LR' = \frac{P(E \mid \bar{A}CI)}{P(E \mid A\bar{C}I)}$$

For n recovered fragments the numerator follows from the same argument as that in EB:

$$T_0.P_1.S_n.f + T_n.P_0.$$

For the denominator, there are two alternatives:
either: the group of fragments were transferred from the unknown object—in which case, the suspect could not have had any other glass on his clothing before;
or: no glass was transferred from the unknown object but the suspect already had the group of glass fragments on his clothing.

Let T'_0, T'_n denote the probabilities that 0 and n fragments respectively would have been found on the suspect's clothing if he had recently been in the vicinity of another breaking glass object. Assume, realistically, that the nature of the breaking object is specified in the alternative explanation, e.g., beer glass, bottle, another window, and also assume that there is a database which gives the frequency f_g of glass with the observed properties in the population of glass objects of the specified type. Then, from these two alternatives, the denominator is:

$$T'_0.P_1.S_n.f + T'_n.P_0.f_g.$$

The new LR is then:

$$LR' = \frac{T_0.P_1.S_n.f + T'_n.P_0}{T_0.P_1.S_n.f + T'_n.P_0.f_g}$$

whereas, if there had been no new explanation, it could be written as:

$$LR = \frac{T_0.P_1.S_n.f + T_n.P_0}{P_1.S_n.f}$$

and

$$LR' = LR\left\{T'_0 + \frac{T'_n P_0 f_g}{P_1 S_n f}\right\}^{-1}$$

So the factor $Z = \left\{T'_n + \frac{T'_n P_0 f_g}{P_1 S_n f}\right\}$ determines whether the glass evidence is weakened or strengthened by the new explanation. If $Z > 1$, the support for C decreases, conversely it increases. Not surprisingly, Z depends on the probability that fragments would be found from the other breaking object and also the frequency with which the observed characteristics of the recovered glass occurs among glass objects of the type to which the new object is alleged to belong. Figure 4 demonstrates the nature of this variation. Z is plotted against the number of fragments expected to be found from the other source for $f_g = 0{\cdot}03$ and 0·003. This is for the case where 4 fragments were expected to be found from the scene window, given C; and the P and S terms are taken from the LSH survey—giving an unmodified LR of 526 (Figure 3).

If the properties of the recovered fragments are as common (frequency = 0·03) among objects of the type specified in the new alternative explanation as they are in the distribution of fragments found on clothing, this can have a substantial effect on the LR, provided that the explanation leads to an expectation of the observed number of fragments. If, on the other hand, the properties of the recovered fragments are unusual (frequency = 0·003) among objects of the type specified, then the effect is small. Indeed, if the observed properties are still rarer than in this illustration, the effect is to *increase* the LR—simply because the original default explanation used by the scientist for the denominator better favoured the defendant.

If the alternative explanation is to affect substantially the quoted LR, it follows that the type of the

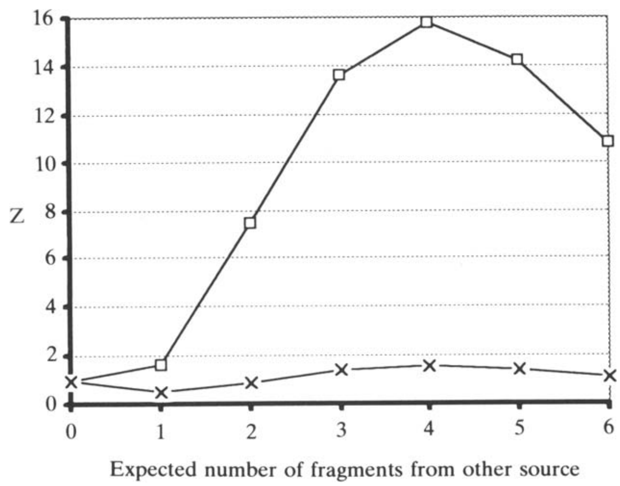

FIGURE 4 Effect on the likelihood ratio of a new explanation for the presence of glass. Z is a factor which reduces the LR. Expected number from scene window = 4; f = 0·03; P and S terms from LSH; f_g = 0·03 (—□—), (—×—).

suggested other glass object should be of a type which can be expected to have similar properties to the recovered glass: and the scenario must be such that transfer and persistence can reasonably be expected. In other words, the explanation which will have greatest effect, not surprisingly, will probably be that the defendant was near to some other smashing window around the time of the offence. Whether the explanation is credible is, of course, a matter for the court and this will in part determine the prior odds.

Discussion

There are various ways of developing the preceding analyses. First, we consider that the concept of knowledge elicitation offers exciting prospects which may, in conjunction with other aspects of knowledge management [8], radically change the way in which forensic scientists approach their casework. The use of the Poisson distribution as described here has the advantage of simplicity but other methods may prove practically more satisfactory. Second, although the data in the ME and LSH surveys have yet to be exploited to the full, the authors believe that, in this paper, they have demonstrated their value and hope that this provides incentive for further surveys of a similar nature. Third, they are conscious that they have only touched upon the issues of dealing with alternative explanations but hope that sufficient has been done to shed new light and stimulate new discussion of this difficult subject.

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