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A Contribution to the Discussion of Probabilities and Human Hair Comparisons

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ABSTRACT: The paper by Gaudette and Keeping on "An Attempt at Determining Probabilities in Human Scalp Hair Comparison" in the *Journal of Forensic Sciences* (Vol. 19, No. 3, July 1974, pp. 599-606) has provoked considerable controversy. This paper highlights two of the sources of the controversy and shows how the probability, 1/4500, quoted by Gaudette and Keeping should be treated with caution. The necessity of the use of a likelihood ratio statistic is described. It is suggested that the hair examination form resulting from the responses to the questionnaire recently distributed by the authors and also the discussions at Quantico (*Proceedings of the International Symposium on Forensic Hair Comparisons,* 25-27 June 1985, Quantico VA) should be used to facilitate the collection of the data which will be necessary to enable a likelihood ratio statistic to be estimated effectively.

KEYWORDS: forensic sciences, hair, probability

There has been considerable controversy in the last ten years surrounding the statistical evaluation of the evidential value of human hair comparisons.

There have been two main points of contention.

1. Is the probability of interest:

(a) the probability that two hairs will be found to be similar, given the hairs came from two different people, or

(b) the probability that the hairs came from two different people, given that the hairs are found to be similar?

2. In considering the first question should we be asking:

(a) what is the probability of encountering two corresponding objects (generally)? or

(b) what is the probability of encountering a corresponding object, given the crime object?

It is the purpose of this paper to try to clarify these issues and to suggest future lines of enquiry.

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Notation

We wish to measure the evidential value of human head hairs. For ease of discussion some notation has to be introduced. Let

1. $Pr(A)$ be the probability that the item in question did, in fact, come from the suspected source before consideration of the observed correspondence;
2. $Pr(N)$ be the probability that the item in question did not come from the suspected source before consideration of the observed correspondence;
3. E be the observed correspondence between the item in question and a suspected source;
4. $Pr(A|E)$ be the probability that the item came from the suspected source, given the observed correspondence;
5. $Pr(N|E)$ be the probability that the item did not come from the suspected source, given the observed correspondence;
6. $f(E|A)$ be the likelihood of the observed correspondence, given the item came from the suspected source; and
7. $f(E|N)$ be the likelihood of the observed correspondence, given the item did not come from the suspected source.

The two expressions $f(E|A)$ and $f(E|N)$ are used when the data are continuous, such as measurements on the refractive index of glass. If the data are discrete, then these likelihoods are probabilities and we change the notation so that $f(E|A)$ is denoted by $Pr(E|A)$ and $f(E|N)$ is denoted by $Pr(E|N)$ [1].

Measurement of the Value of E

The value of E can be measured by comparing the prior odds $Pr(A)/Pr(N)$ with the posterior odds $Pr(A|E)/Pr(N|E)$. This comparison can be measured by the odds ratio V which may be defined as the value of the evidence and

$$V = \frac{Pr(A|E)/Pr(N|E)}{Pr(A)/Pr(N)}$$

A simple application of Bayes' Theorem gives

$$V = f(E|A)/f(E|N)$$

The importance of this ratio, known as the likelihood ratio statistic, to forensic science investigation is discussed by Evett [2] and Stoney [3].

Evaluation of the likelihood ratio statistic $f(E|A)/f(E|N)$ requires knowledge of the population from which the evidence may have come in each of two possible situations, that in which the evidence came from the suspected source and that in which the evidence did not come from the suspected source. Further discussion of these points is left till later.

The refractive index of glass provides an example where the data forming the evidence are continuous. There is considerable information on the distribution of the refractive index of glass [4], and thus, knowledge of the population from which the evidence may have come. No such information is available for hair comparisons, and the only information available to help towards estimating V is that collected by Gaudette and Keeping [5] and Gaudette [6].

However, in order that some progress can be made, we will assume that the data are discrete and the value V of the evidence may be written as

$$V = [Pr(A|E)/Pr(N|E)]/[Pr(A)/Pr(N)]$$

$$= [Pr(E|A)/Pr(E|N)]$$

Notice that the likelihood ratio V measures the effect of the evidence on the prior odds of association to yield the posterior odds of association. It should not be thought of as saying that "a particular suspect is V times as likely to be the source of the crime evidence as not."

What Is the Probability of Interest?

Gaudette and Keeping [5] carried out a series of pairwise comparisons between hairs from different individuals. They made 366 630 comparisons and 9 pairs of hairs were found to be indistinguishable. This provides an estimate of the probability that a hair taken at random from Individual A is indistinguishable from a hair taken at random from Individual B as 9/366 630 or 1/40 737. Thus, it is argued, if 9 dissimilar hairs are independently chosen to represent the hairs on the scalp of Individual B, the chance that a single hair from A is distinguishable from all 9 of B's may be taken as $[1 - (1/40\ 737)]^9$ which is approximately $1 - (1/4500)$. The complementary probability, the probability that a single hair from A is indistinguishable from at least one of B's hairs, is 1/4500.

Notice that this calculation involves a further assumption of independence. The probability that a hair from A is indistinguishable from a hair from B is assumed to be independent of knowledge that the hair from A has already been found to be indistinguishable from another one, two, or three hairs from B. The independent choice of hairs from B is not in itself sufficient to guarantee this. It may well be the case that all the hairs on B's head are so closely related that for a hair from A to be found to be similar to one hair from B means that the hair from A will be found to be similar to all the hairs from B. Alternatively, if the hair from A is dissimilar to one hair from B then it may mean that the hair from A will be found to be dissimilar to all the hairs from B. Other values for the degree of dependence between these extreme values are possible. Thus, the figure of 1/4500 which assumes independence in the comparisons of hairs from A with hairs from B should be interpreted with caution.

With or without this assumption of independence, the method of Gaudette and Keeping [5] may be used to provide a probability which in some sense provides a measure of the effectiveness of human hair comparison in forensic hair investigations. It may appear that the probability of interest is the probability that the people are different, conditional on the fact that a single hair from one person is indistinguishable from at least one of nine hairs from one person; in more general notation this is $Pr(N|E)$. However, examination of the expression for V shows that this is only important in relation to $Pr(A|E)$ and to the prior odds $Pr(A)/Pr(N)$. Ultimately the important relationship is

$$V = Pr(E|A)/Pr(E|N)$$

There are, therefore, two probabilities of interest and they are the probability the two hairs are similar assuming they came from the same person and the probability the two hairs are similar assuming they came from different people.

Gaudette [7] stated that for an *experienced examiner* $Pr(E|A)$ is very close to 1 and thus

$$\hat{V} = 1/Pr(E|N)$$

may be taken as a reasonable estimate of V. However, this is so only for an experienced examiner. In general, the two probabilities $Pr(E|A)$ and $Pr(E|N)$ are required.

What Is the Question We Should Be Asking?

Stoney [*3*] considered six questions which are related to the significance of a correspondence between what he called the crime object and the suspect object. Four of the questions need not concern us here; the other two, however, do. The first one is:

> "What is the probability of encountering two corresponding objects (generally)?"

This is the question asked and answered by Gaudette and Keeping [*5*] and, as Stoney [*3*] said, "has considerable potential for error." The other question, Stoney's Question 4, is

> "What is the probability of encountering a corresponding object, given the crime object?"

This is partly the question to which we are seeking the answer and refers to the denominator $Pr(E|N)$ of V.

A very good discussion of the difference between these two questions is given by Stoney [*3*]. Gaudette's calculation of $Pr(E|N)$ was based on the intercomparison between each of a number of individuals of hairs deliberately chosen to be microscopically different within each individual. However this is not exactly what is required. In crimes where there is a victim, then evidence found on the victim may not be thought of as random, rather it is fixed; similarly, evidence left at the scene of the crime by a criminal is not random; again it is fixed. In both cases, the suspect is chosen from a particular subset of people who could have committed the crime. Thus, even though the suspect may be completely innocent, the relationship of the suspect and the criminal is not that of two randomly chosen individuals. In a criminal investigation the police look for a suspect. This suspect will have certain features in common with the criminal, otherwise he would not be a suspect. The police then look for similarities between evidence found on the suspect and the evidence found at the scene of the crime. This is not the same as the situation where the police select two individuals *at random* from a population and then look for similarities. The laboratory examination of the evidence is not a random selection process, but rather, a process of exhaustively searching a sample of hair for a match with the crime object.

What Should Be Done?

The aim is to achieve the best possible estimate of V. To do this, we require knowledge of $Pr(E|A)$ and $Pr(E|N)$. How should this knowledge be gained?

At present, the only work to have been done towards gaining this knowledge is that of Gaudette and Keeping [*5*]. Gaudette [*6*] points out that the probability he evaluates is "an average case of the probabilities" for "an experienced examiner." However, as discussed above, in our opinion Gaudette and Keeping [*5*] have not evaluated the appropriate probability. We remarked earlier about the "considerable potential for error" in this approach. A simple numerical example will illustrate this.

Gaudette and Keeping [*5*] chose 6 to 11 mutually dissimilar hairs from each individual from an initial sample of 80 to 100 hairs. Choosing the hairs to be mutually dissimilar may well destroy the randomness of the original sample and alter the estimate of $Pr(E|N)$.

Consider two people, $P1$ and $P2$. Each has hair on their head of nine different types. The types associated with $P1$ are labelled $t_1, \ldots, t_9$; the types associated with $P2$, $r_1, \ldots, r_9$. Types t_1 and r_1 have frequencies of 25% of the hairs on the heads of $P1$ and $P2$. Types $t_2, \ldots, t_9$ and $r_2, \ldots, r_9$ are each equally represented in the remaining 75%, that is with relative frequency $(1/8)(3/4) = 3/32$. Suppose that one hair type of $P1$ is indistinguishable from one hair type of $P2$.

Using Gaudette's sampling procedure each of the 9 mutually dissimilar hairs from both $P1$ and $P2$ is equally represented for the comparisons. The 81 comparisons between the 2 individuals will result in 1 indistinguishable comparison. The probability of a match is thus estimated as 1/81 or 0.0123.

However, if a sampling is made which is representative of the proportion of each hair type then there are three possible outcomes. Suppose that types t_1 and r_1 are indistinguishable, and that Types $t_2, \ldots, t_9$ and $r_2, \ldots, r_9$ are all distinguishable. Then the chance of a correspondence is 0.0625. Suppose that Types t_1 and r_9 are indistinguishable, and that Types $t_2, \ldots, t_9$ and $r_1, \ldots, r_8$ are all distinguishable. Then the chance of a correspondence is 0.0234. Finally, suppose that the Types t_9 and r_9 are indistinguishable, and that Types $t_1, \ldots, t_8$ and $r_1, \ldots, r_8$ are all distinguishable. In this case the chance of a correspondence is 0.008 79. These three probabilities are all very different from the figure 0.0123 based on Gaudette's reasoning.

The average probability of Gaudette is obtained when each of the three cases described in the above paragraph is weighted by the number of times it would occur using Gaudette's sampling method. In this method it is assumed that each hair type is equally represented. There would be one pair where both hairs are of the common type, sixteen pairs where one is common and one is rare, and sixty-four pairs where both pairs are of rare types. Thus the probability of a match would be estimated by

$$[(0.0625 \times 1) + (0.023\,44 \times 16) + (0.008\,79 \times 64)]/81 = 0.0123$$

This is an average probability but does not bear much resemblance to any of the figures calculated assuming sampling proportional to the frequency of hair types.

Thus, the probabilities estimated by Gaudette can only be used as broad guidelines. Two approaches may be of value in attempting to produce more accurate estimates of *V*. First, from a theoretical statistical stance, estimates of $Pr(E|A)$ and $Pr(E|N)$ should be calculated. This may be done in the following manner.

1. $Pr(E|A)$ This could be estimated by considering pairs of samples of hairs from the same individual. In how many of these pairs are the samples indistinguishable? Two samples of hairs are taken from each of a set of individuals. Comparisons are only made between samples of hairs from within the same individual.
2. $Pr(E|N)$ Gaudette [6] described an experiment which goes some way towards estimating this probability. In this experiment, 100 representative scalp hair samples from 100 individuals were taken. One sample was selected at random and from this sample a single hair was selected at random. The experiment was then repeated. On both occasions, it was found that the unknown hair was similar to hairs from one and only one standard—the correct one. This seems a reasonable description of a criminal investigation. The single hair, of unknown origin, represents the hair found at the scene of the crimes, the 100 samples could represent 100 suspects.

A second method of evaluating the value of hair evidence would involve the collection of frequency data. The recent questionnaire that was distributed by the authors [8,9] has enabled a hair examination form to be drawn up. Consistent use of this form in conjunction with a microcomputer on the investigator's bench linked directly to a central computer that would store and collate the data would enable frequency data to be collected and analyzed more readily than has been presently possible. If such a data bank were to be of value, the perceived subjective nature in the assessment of microscopic characters of hairs needs to be removed. Recent meetings of hair examiners give considerable encouragement to the view that standardization and definition of hair characteristics is an achieveable goal.

Only then can a meaningful estimate be made of the distribution of characteristics both within individuals and between individuals. Any previous suggestions that this be done have tended to be dismissed rather airily as not practical or by the comment that there is as much variation between hairs from within an individual as between hairs from different individuals—and yet Gaudette's [6] work described above shows that hair evidence can have considerable value. It is not the purpose of this paper to suggest that the approach of Gaudette to the evaluation of hair evidence is misguided, although there are in our view limitations in his statistical treatment. What would be potentially dangerous and certainly misguided would be the wholesale use of Gaudette's probability estimates by all forensic hair examiners. These estimates of association or nonassociation are a measure of the ability of the hair examiners who took part in that study to discriminate hairs. Considerable emphasis and time is expended on the training of hair examiners in the Royal Canadian Mounted Police (RCMP) laboratories and it would be wrong to assume that all examiners can achieve the same level of discrimination.

Thus, for this approach to be of value, every forensic hair examiner would need to test their own ability to discriminate hairs in a study similar to that devised by Gaudette. The benefit of following the second method of evaluating hair evidence, that of using a data base, would be that it would encourage the use of standardized nomenclature and a uniform approach to hair examination should improve the overall ability of hair examiners to discriminate hairs. However, it must be stated that the production of such a data base lies some way in the future, and to date, there has not been the willingness on the part of funding agencies to support such a scheme. Evett [10] commented on the criticism "We don't have enough information available to make meaningful numerical estimates in actual casework." "True," he said, "—and the sooner we start collecting it the better for everyone!"

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