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Probabilities and Human Hair Comparison

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ABSTRACT: Critical review shows that probability estimates regarding human scalp and pubic hair individualization are in error owing to defects in experimental design. The inherent bias is evaluated to preclude improper use of these probability estimates in the future.

KEYWORDS: criminalistics, hair, probability, human identification

Beginning in 1974, Gaudette and Keeping [*1*] and Gaudette [*2,3*] published a series of papers concerning the probabilities of human hair comparison. Their conclusions are cited by expert witnesses when asked about the certainty of a hair comparison [*4-6*]. Nonetheless, in the seven years that have elapsed since the publication of the first of these articles, there has been no attempt reported in the literature to confirm Gaudette's work or criticize his treatment of his data. This is particularly disturbing since valid probability statements regarding hair evidence would be a significant step in the analysis of a commonly occurring type of physical evidence. The methods of data collection and data manipulation used by Gaudette need careful scrutiny to determine the validity of the conclusions.

Introduction

Most of the evidence examined by criminalists falls into the category of associative evidence, that is, evidence that tends to associate one person, place, or thing with another person, place, or thing. Fired bullets, fingerprints, bloodstains, paint and fiber transfers, handwriting, and many other types of physical evidence fall into this category. In the process of individualization, the criminalist attempts to link the evidence with standards from another place (or person or thing). If the evidence and standard share common attributes suggesting they have a common source, they are said to match. Once the evidence and standard are determined to be a match, a decision must be made as to the significance of this finding.

The significance of the match between two objects requires knowledge about the frequency of occurrence of the measured attributes in the population. If the set of measured attributes occurs only in a single individual in the population, then the match results in individualization (the conclusion that the evidence could have originated only from the same source as the standard). On the other hand, if the set of measured attributes occurs in a

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large portion of the population, the fact that the evidence and standard match is of little significance.

A primary task facing criminalists in the evaluation of associative evidence is the determination of those attributes of the physical evidence useful to the task of individualization. In order to be useful the attributes must be capable of measurement and not shared by the entire population. If these attributes can be identified (that is, described and measured), and if the frequency of occurrence of the attributes in the population can be determined, then, in principle, probability estimates can be made to assist in evaluating the significance of the evidence. These probability estimates are used to determine the degree of certainty that the evidence originated from the same source as the standard.

To be useful, probability estimates should have several features. First, the estimated probability must be logically related to a relevant question about the evidence. Second, the estimated probability should be based on characteristics that have been, or are capable of being, measured. Third, the experiments performed to evaluate the probability estimates must be logically related to the probability statements.

The series of papers by Gaudette and Keeping [*1*] and Gaudette [*2,3*] describe experiments claimed to provide first estimates of certain probabilities useful for the individualization of human scalp and pubic hair. Unfortunately, the probability estimates are grossly in error because of experimental bias and improper statistical treatment of the data. The uncritical use of the probability estimates as a basis for opinions regarding the individualization potential of hair evidence can be misleading.

The bias in Gaudette and Keeping's data stems from their confusion of two distinctly different tasks: the task of discriminating between two (randomly selected) hairs and the task of correctly assigning an unknown hair to its true source. The distinction between these two different tasks is crucial to formulating any probability statement regarding the origin of a hair. The task facing the hair examiner is to determine simultaneously the degree of similarity and the degree of dissimilarity between the questioned and standard hairs. When a criminalist indicates that a match exists between two hairs, he means that the observable similarities between the two hairs outweigh significantly the observable dissimilarities between the two. The experimental design used by Gaudette and Keeping dealt solely with the ability to distinguish two hairs and failed to include any consideration of factors that allow hairs from the same individual to be individualized. Since there are always observable differences between any two hairs (even from the same individual), the experimental of method Gaudette and Keeping should have resulted in a high rate of success in distinguishing between any two hairs. The inherent bias, therefore, in the experiment was toward a low probability estimate—not of incorrectly identifying an individual but of failing to distinguish two hairs. It should not, therefore, be surprising that their probability estimates were low.

A critical bias in their experimental design derived from the use of a set of dissimilar hairs from each individual in the study. The process of individualization involves both matching the hair to its correct source and eliminating any other source for the hair. The use of dissimilar hairs from each individual placed the examiner in the position of knowing in advance that any match between two hairs was erroneous. Determinations with the comparison microscope (both in longitudinal and in cross-sectional aspects) required a subjective judgment as to whether the given pair of hairs matched. Even after microscopic comparison of those whole mounted hairs not distinguished by the initial coding, 19% of the total sample (163 of 861 hairs) could not be distinguished from other hairs in the sample. In each of these side-by-side comparisons, the examiner knew that any match found would be erroneous and obvious bias resulted.

Another bias present in the experimental design stemmed from their use of nonindividualizing features in the comparison of hairs. The characteristics of the root, for example, are diagnostic of the growth cycle of the hair and the manner in which it was removed from the scalp. Hair length and tip appearance are related to scalp location as well as to in-

dividual source. The use of nonindividual characteristics, the use of characteristics that have not been shown to be related to differences between individuals (for example, medullary index and medulla type), and the use of multiple measures of the same characteristic (for example, longitudinal and cross-sectional pigment density and size) created a bias for false elimination of otherwise similar hairs. Thus, although the magnitude of the bias cannot be assessed, it certainly tended to lower the probability estimate.

Using data that, by the design of the experiment, were bound to demonstrate a high rate of success in *discriminating hairs*, Gaudette and Keeping then proceeded to apply these data, and the probabilities derived from them, to the task of individualizing hair. Gaudette [*1,2*] said the probabilities of a matching hair having originated from someone else could be determined from his data. But probability estimates must be made from data inherently capable of testing the hypothesis under consideration. To determine if the data gathered by Gaudette and Keeping can be used to evaluate the significance of a hair match, several probability statements that can be made about hair comparisons should be examined.

Data Manipulation

To be useful, a probability statement should have one or more of the following attributes:

1. It should be capable of being answered.
2. It must be relevant to the task at hand.
3. Data should be available, or obtainable, to determine the probability.

With these restrictions in mind several probability statements can be posed regarding hair evidence:

I. What is the probability that a hair from a given individual will match another hair from the same individual, if the hair is compared to hair standards from a large number of individuals, including the correct individual?

II. What is the probability that a person will have a hair that cannot be distinguished from one hair from another individual?

III. Given samples of representative (that is, representative of the various hair types from each individual) hairs from a number of individuals, what is the probability that any randomly selected pair of individuals will have a matching pair of hairs?

IV. Given samples of different but representative hairs from each of a large number of individuals, what is the probability that a randomly selected pair of hairs will be found to match?

Gaudette and Keeping [*1*] posed probability statement II, but their derivation of probability was instead based on probability statement IV. This fact, coupled with the bias of the experiment, generated a probability estimate that was virtually meaningless with respect to hair individualization.

Each of these probability statements are discussed below and evaluated based on the data given by Gaudette and Keeping [*1*]. A summary of the data from Gaudette's first two articles [*1,2*] is given in Table 1.

Probability Statement I

> What is the probability that a hair from a given individual will match another hair from the same individual, if the hair is compared to hair standards from a large number of individuals, including the correct individual?

This question is essentially a management question dealing with the value of hair examinations in general. If the probability is very low, then the ritual of hair examination would not be justified in routine casework in the laboratory because of a low payoff. If the probability is

TABLE 1—*Data from hair comparisons (taken from Gaudette and Keeping* [1] *and Gaudette* [2]*).*

Hair Type	Individuals, *n*	Hairs, *n*	Hair Comparisons, *n*	Matching Pairs, *n*
Scalp	100	861	370 230	9 (13 individuals)
Pubic	60	454	101 368	16 (25 individuals)

reasonably high, then the routine examination of hair in the criminalistic laboratory may be justified. The experimental design of Gaudette and Keeping precludes estimating this probability.

Probability Statement II

What is the probability that a person will have a hair that cannot be distinguished from one hair from another individual?

This is clearly a relevant question, since its evaluation requires consideration of the criteria necessary for determination of a match or nonmatch in comparing two hairs. In Gaudette's studies, in which all of the hair matches were known to involve different individuals, 13% of the individuals had a scalp hair and 42% of the individuals had a pubic hair which was not unique. These figures are promising as they seem to indicate that most people have unique hair. The figures, however, are seriously flawed, since every match between hairs was known to be a nonmatch between individuals.

Probability Statement III

Given samples of representative hairs from a number of individuals, what is the probability that a randomly selected pair of individuals will have a matching pair of hairs?

This probability statement is very similar to II above, but the distinction is a crucial one. Statement II relates to all individuals involved in the study, whereas statement III relates to a randomly selected pair of the individuals involved in the study. The probability estimates P for this statement can be derived as follows, using Gaudette's data. For scalp hair, where n is the number of individuals in the study (100) and C is the number of pairwise individual comparisons,

$$C = \frac{n!}{2!(n-2)!}$$

$$= \frac{100!}{2!(100-2)!}$$

$$= \frac{(100)(99)}{2} = 4950$$

The probability is therefore

$$P = \frac{9}{4950} = 0.002$$

For pubic hair,

$$C = \frac{(60)(59)}{2} = 1770$$

and the probability is

$$P = \frac{16}{1770} = 0.009$$

Probability statement II cautions that there is a reasonable chance (13% if head hair, 42% if pubic hair) that the suspect may not have hair which is unique in the population. Probability statement III indicates that there is only a small chance, less than 1% even for pubic hairs, that any two randomly selected individuals will have a matching pair of hairs.

Even though the probability estimates for statement III seem low—indicating that hair is a useful type of evidence—the estimates are still much larger than those figures used by Gaudette. For comparison, these values are shown in Table 2. The differences between Gaudette's values and those derived above is one order of magnitude, and it must be noted that this derivation is based on data that are inherently biased owing to the experimental design.

Although probability statement III is relevant to the task faced by hair examiners, the probability given above is not relevant to the evaluation of an actual case. The actual situation can be better stated by a slightly, but very importantly, modified version of probability statement III.

> Given a match between a questioned hair and hair from a given individual, what is the probability that the questioned hair will match a hair of a randomly selected second individual?

This is a statement of the problem facing the criminalist with all types of associative evidence. It is a statement of conditional probability. The evaluation of this statement of conditional probability requires estimation of the probability of one event, denoted A, occurring given the occurrence of another event, denoted B. This can be expressed as

$$P(A|B) = \frac{P(AB)}{P(B)}$$

where, in this instance,

A = a single hair will be found to be similar to a sample of hair from a different individual,
B = a single hair will be found to be similar to a sample of hair from the same individual,
$P(B)$ = probability of B occurring,
$P(AB)$ = probability of both A and B occurring, and
$P(A|B)$ = probability that A will occur if B has already occurred.

TABLE 2—*Probability that hair from two individuals will match.*

Hair Type	Gaudette	Probability Statement III
Head	1/4500 = 0.00022	9/4500 = 0.002
Pubic	1/800 = 0.00125	16/1770 = 0.009

Thus, if $P(AB)$ and $P(B)$ can be determined, the probability estimate of the hypothesis can be evaluated. The evaluation of this probability, however, is not possible from Gaudette's data. It is axiomatic that no two hairs are truly identical. The problem facing criminalists is not the ability to distinguish between two hairs but the ability to determine when two hairs should not be distinguished (that is, they match). Criminalists are concerned with identifying and distinguishing people, not hair. The value of hair as evidence must be determined by its usefulness in identifying people, and the data presented by Gaudette and Keeping are of little use for that purpose.

Probability Statement IV

> Given samples of representative hairs from each of a large number of individuals, what is the probability that a randomly selected pair of hairs will be found to match?

This probability estimate, although of theoretical interest, is not of particular significance to the process of hair individualization. It is, however, the probability estimate derived by Gaudette and Keeping [*1*] for scalp hair and by Gaudette [*2*] for pubic hair. The uncritical use of these probability estimates can easily distort the value of hair evidence, particularly when presented to a lay jury hearing evidence that involves hair identification and could lead to a miscarriage of justice when hair evidence plays a prominent role in a case.

Discussion

The hair studies described by Gaudette and Keeping [*1*] and Gaudette [*2,3*] represent an attempt to provide an objective basis for opinions regarding the confidence level of hair individualization. Unfortunately, the bias in the experimental design and the failure to relate probabilities to the questions posed generated probability estimates that were irrelevant to hair individualization. Furthermore, the errors in the derivation introduced a problem to the administration of justice greater than that which the experiments attempted to solve. We have personally witnessed the giving of testimony to the effect that the matching of one evidential hair to hair from an individual signifies a high probability of individualization and that when more than one hair matches an individual the probability of individualization "skyrockets." Moreover, other criminalists have indicated that the probability estimates given by Gaudette and Keeping are used indiscriminately in many jurisdictions. Testimony is routinely given stating that, in effect, while the witness does not personally know the probabilities involved in hair comparison and while the witness cannot vouch for the validity of the data of Gaudette and Keeping, the probabilities of false identification derived by Gaudette and Keeping are 1/4500 for scalp hair and 1/800 for pubic hair.

In his 1978 paper Gaudette [*3*] cautions, "The significance of this research is not in the actual probability numbers found but in the experimental proof of the proposition that macroscopic and microscopic hair comparison is a useful technique and that hair evidence is good evidence." While it is good to recognize that the numbers themselves were not the important feature of the work, the magnitude of the values obtained were used by Gaudette to justify the use of hair as a means of personal identification. As has been pointed out above, these numbers and the experiments by which they are derived are seriously flawed. They do not justify the statement that "hair evidence is good evidence."

The probability estimates derived by Gaudette and Keeping [*1*] and Gaudette [*2*] are not relevant to hair individualization. The probabilities they derived refer to the process of distinguishing between two hairs that the examiner knows originated from two people—a task not at all related to the normal laboratory operation. The normal laboratory task involves comparison of a single unknown hair with hair from one or more individuals. This is done by an exhaustive search, involving pairwise comparisons of the unknown with all of the standard hairs until a match is obtained, or until no pairs remain to compare. This ex-

haustive comparison will, obviously, result in a higher probability of a false identification than the single, random comparison to which their data apply.

The critical information lacking from their data, and which makes their data useless for estimating the probability of a false identification, is how well the technique works for identifying the correct individual. Two anecdotes in the final article of the series [*3*] appear to indicate that it is possible to correctly identify a single hair in some instances. This falls far short, however, of validating the probability estimates previously derived by Gaudette and Keeping.

Gaudette and Keeping [*1*] and Gaudette [*3*] point out that different examiners get different results with the technique. This means that, even if the data are correct and usable, the numbers must be determined anew by each person who uses them. It is not clear, however, that the coding technique used in the first two articles was used in the experiments described in the third article. In fact, in the second experiment described in the third article, the hairs were compared directly—presumably this method was also used in the first set of experiments in the third article. Such an experiment cannot be used to validate the probability figures previously derived; yet, Gaudette [*3*] insisted

> The important point is that these experiments *do not contradict* [emphasis added] the previous results...(that) if one unknown hair is found to be similar to a representative standard...for an average case...the probabilities of that one hair having originated from someone else would be about 1 in 4500 for scalp hair and 1 in 800 for pubic hair.

The verification experiments neither verify nor contradict the probability estimates of Gaudette and Keeping. They merely indicate that the source of a given hair can, in some cases at least, be identified within a limited population.

The objective status of the individualization potential of hair evidence, unfortunately, has neither been improved nor defined by the studies of Gaudette and Keeping [*1-3*]. At the present time, the status of hair individualization can be stated as follows: When a match occurs between an evidence hair and standard hairs from an individual, the evidence hair could have come from that individual.

Editor's note: *B. D. Gaudette's response appears on p. 279 of this issue.*

References

[*1*] Gaudette, B. D. and Keeping, E. S., "An Attempt at Determining Probabilities in Human Scalp Hair Comparison," *Journal of Forensic Sciences*, Vol. 19, No. 3, July 1974, pp. 599-606.

[*2*] Gaudette, B. D., "Probabilities and Human Pubic Hair Comparison," *Journal of Forensic Sciences*, Vol. 21, No. 3, July 1976, pp. 514-517.

[*3*] Gaudette, B. D., "Some Further Thoughts on Probabilities and Human Hair Comparisons," *Journal of Forensic Sciences*, Vol. 23, No. 4, Oct. 1978, pp. 758-763.

[*4*] *People v. DiGiacome*, 388 N.E.2d 1281 (Illinois App. Ct. 1979).

[*5*] *State v. Carlson*, 267 N.W.2d 170 (Minn. 1978).

[*6*] *U.S. v. Massey*, 594 F.2d 676 (8th Cir. 1979).

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