REVIEW

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Earmarks as Evidence: A Critical Review

REFERENCE: Champod C, Evett IW, Kuchler B. Earmarks as evidence: a critical review. J Forensic Sci 2001;46(6):1275–1284.

ABSTRACT: The use of earmarks as evidence in criminal trials appears to be expanding, but there is something of a dearth of peer-reviewed scientific publications to support the pursuit. This paper is a critical review of the current literature in which we emphasize the weaknesses of the present state of knowledge. Some research directions are proposed to gather statistical knowledge of the within-source and between-source variability of earmarks and earprints. Its ultimate goal is to be able to assess likelihood ratios in relation to this type of evidence.

KEYWORDS: forensic science, earprint, earmarks, identification, individualization, likelihood ratio

In the United Kingdom earmarks are gaining a status as identification evidence that is becoming comparable to that of fingerprints. This is principally because of initiatives by Kennerly (1) and Vanezis (2). Recently, an earmark left on the window of a 94-year-old victim's home led to the conviction of Mark Dallagher for the murder of Dorothy Wood (3). The British examiners were assisted in that case by the Dutch police officer Cornelius van der Lugt, who has been involved in this field for more than ten years. In Holland, police regularly use earmarks to identify offenders, and such evidence seems to be accepted by the courts, although recently the Dutch Court of Appeal has rejected ear identification in one case.[4] There is also general acceptance of the practice in various cantons of Switzerland (e.g., Geneva, Vaud, Neuchâtel, Bern), where the use of earmarks as a mean of identification, supported by the work of Hirschi (4), dates from 1965.

In contrast with an apparent consensus on the European scene, a recent murder case in the United States brought more critical attention to the use of earmarks for identification (5,6). A successful *Frye* hearing was followed by the conviction of D. W. Kunze, based mainly on an earmark left on the crime scene; but this was reversed by the Court of Appeals of Washington (Division 2), which ordered a new trial on the grounds that earmark identification had not gained a general acceptance throughout the scientific community (State v. David Wayne Kunze, 97 Wash. App. 832, 988 P.2d 977 (1999)) (7). Van der Lugt was one of the experts, and he testified that there was a strong probability that the recovered mark had been left by Kunze's ear.

Because of increasing interest in the field, the authors decided to undertake a literature review of the field. The aim of this paper is to focus on the identification of earmarks rather than on more technical issues such as developing marks (8), taking standards from known persons (9), or estimating the height of the donor based on the height of the recovered mark (4,10–12); these three subjects have already been covered elsewhere (13). Moreover, our purpose is not to attempt to mention all of the contributors to the field, but rather to provide a critical perspective on the body of knowledge that can underpin the individualization of earmarks. In this respect, the present paper is more critical than other recent review papers have been (14–16).

Individualization/Identification: The Nature of the Process

Paul Kirk carefully explained the distinction between *identification* and *individualization* (17). In the present context, the latter term is the more appropriate, but, recognizing what is widespread usage, we will use the former term.

The essentials of the earprint problem that we discuss in this paper are as follows. We assume that an impression of a human ear has been recovered by some means from the scene of a crime: we will call this an *earmark.* A suspect X has been apprehended and control impressions are taken from his ear or ears—we will call these *earprints.* The distinction thus made between marks and prints is analogous to that made in the U.K. in the field of fingerprint identification.

Then the purpose of a scientific comparison between the earmark and the control earprints is to help to address the two propositions: C = the earmark was made by X: $\overline{C}$ = the earmark was made by some unknown person.

We must note that considerable confusion exists among laymen, indeed among forensic scientists also, about the use of words such as *unique, identical,* and *identity.* The phrase "all ears are unique" has been used to justify earprint opinions. But this is no more than a statement of the obvious—every entity is unique. No two entities can be identical. An entity may only be identical to itself. Thus, to say "this mark and this print are identical to each other" invokes a profound misconception: they might be *indistinguishable* but they cannot be identical. In turn, the notion of indistinguishability is intimately related to the quantity and quality of detail that has been revealed. The question for the scientist is not "are this mark and print identical" but, "given the detail that has been revealed and the comparison that has been made, what

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[4] See http://www.forensic-evidence.com/site/ID/IDEarNews.html.
Received 9 Nov. 2000; and in revised form 28 Feb. 2001; accepted 1 March 2001.

inference might be drawn in relation to the propositions that I have set out to consider."

Broadly speaking, there are three interrelated factors that determine the nature of the inference that may be made: the quantity of relevant detail; within-source variation; and between-source variation. Any logical basis for inference must recognize these three factors. Kwan showed how the identification process was inductive and thus necessarily probabilistic (18). A logical analysis of the problem shows that weight of evidence is a function of the likelihood ratio (*LR*).

$$LR = \frac{Pr(E\,|\,C)}{Pr(E\,|\,\overline{C})}$$

Where *E* represents the evidence, i.e., the outcome of the comparison between the mark and the prints based on a given set of features. The likelihood ratio embodies our three above-mentioned factors. The numerator is the probability of the observed degree of correspondence between mark and print, taking into account within-source variation. In the present context we mean the variation that will inevitably be observed between marks and prints from the same individual. Even when taken under controlled conditions, two ear prints/marks will not be the same. Furthermore, when a mark is made under crime scene conditions there will be several factors, particularly distortion, that will affect the features of the mark. The denominator is the probability of the observed degree of correspondence taking into account between-source variation, the variation of the relevant features among earmarks from different individuals.

The form of the likelihood ratio directs the scientist to express conclusions in terms of degree of support for C versus $\overline{C}$ and prohibits any statements on the issue itself (19,20). Statements in the form: "Kunze probably made the latent print taken from McCann's door" are then logically inconsistent and should be avoided. A more adequate formulation could be that "evidence provides strong support for the proposition that Kunze left the earmark."

In the individualization context, a key issue to be addressed is whether, and under what circumstances, an expert might be justified in expressing a categorical opinion of the form "I am satisfied that the earmark was made by X." Such practice has been accepted for a century in the fingerprints field, so it is tempting to ask when our state of knowledge will justify such opinions in the earprints field. By recognizing that the identification process is probabilistic and inductive by nature, it becomes clear that categorical conclusions can hardly be scientifically supported. Even in a field such as fingerprint identification, categorical conclusions are difficult to sustain from a scientific point of view (21). It is also useful to take a lesson from DNA profiling. This is a field where the understanding of the statistics of between-source variability has expanded to a remarkable degree. The weight of evidence in a DNA case can consequently be given by means of a statistic. This almost inevitably has led to the question how small must the match probability be to enable an opinion of identification to be given. This issue has been discussed extensively (see, for example, Ref 22), but there is no answer to the question. The correct procedure, where a statistic can be calculated, is to present it to the court together with an explanation of how that statistic might be set into the context of the other evidence. The likelihood ratio provides a solution to that problem.

Review of the Literature

Compared to established identification fields, such as fingerprints or handwriting comparison, the body of literature pertaining to earmarks identification is limited. About 60 papers have been published, very few in recent peer-reviewed journals.

A good starting point is the paper published by Hirschi in 1970 that described how earmarks were used to solve numerous burglary cases in Switzerland in 1965 (4,11). In Switzerland, Hirschi's paper is considered to be a landmark in the field and is cited in both experts' reports and in training manuals (23). Other case reports or descriptions of practice have been published since Hirschi, but none gives much detail about the foundation of the identification process (24–30). Hirschi describes how a suspect P was identified as the donor of an earmark recovered on the entry door of a flat. Recognizing his lack of experience in this new field (he worked mainly with fingermarks), Hirschi justified the transition from the observation of a good match to the conclusion of positive identification as follows:

- The use of the morphology of the ear as a mean of establishing identity of persons was well known at the beginning of the century. Bertillon and the prominent forensic scientists at that time considered the ear to be the most distinctive part of the body (31–36).[5]
- To corroborate his conclusion of identification, Hirschi compared the mark with earprints taken from about 48 individuals. No earprints from different persons were found to match to the same extent as the match recorded between the mark and the known print from the suspect.

Hirschi implied that the variability of the ear can be extended without any further question to the problem of the identification of marks. It is a frequent tendency among forensic scientists to confuse source variability with the expressed variability in marks (see Ref 38). The loss of quality caused by the transition from a three-dimensional organ to a two-dimensional revealed mark is often ignored or minimized in the identification process. Yes, the morphology of the ear is individual and has been suggested[6] or has served[7] for the identification of unknown persons, but its ability to be a reliable means of inferring the identity of the source of a recovered mark is poorly treated in the literature.

Hirschi's attempt to acquire experience through collecting earprints from known persons was praiseworthy, but, without a standardized scientific approach to the comparison, it is little more than anecdotal evidence. We will see that the approach adopted by Iannarelli and Van der Lugt, two main players in this field, suffers from the same drawback.

Earmarks have been presented as a mean of personal identification (44–46) for some time in Germany. The research done by German (or German-speaking) researchers offers the most scientific approach to date. Initially, research was focused on photographs of ears, without any references to marks. In 1906, Imhofer confirmed the opinion of the Bertillon school that the ear was the most identifying part of the individual (47). Using a database of 500 photographs of ears, he selected two ears with, respectively, three and

[5] Locard proposed to use the ear for establishing identity based on photography. But in neither of his two volumes on marks (Vol. 1 and Vol. 2) did Locard mention the possibility of using earmarks to associate a suspect with a scene (37).

[6] Ear photographs taken from newborns have been studied as a mean of personal identification by Fields et al. (39). The examination of 206 sets of ears led them to conclude that ear morphology was unique and sufficiently stable.

[7] Two famous cases need to be cited: the false Grand Duchess Anastasia Nicolai évna of Russia dispute (40,41,42, pp. 44–63) or the Will and William West case (43). In both cases, the potential inheritance of morphological features of the ear is assumed and used to draw conclusions.

four selected features and searched the database for matching candidates. In the first case, he found another occurrence of the joint features; in the second no other match was found. This led Imhofer to the conclusion that the identifying value of the ear was high.[8] Imhofer also stressed the possibility of using ear characteristics for assessing familial relationships, because the morphology of ears tends to be hereditary. More recently in Germany, some cases have been solved by earprints: in 1975 (by Nitsche and Hammer) and in 1982 (by Trube-Becker) (48). These cases promoted research in the area, most of them devoted to the identification of individuals based on ear photographs and very few dealing with marks left at crime scenes.

Oepen studied the external ear from an anthropological point of view and gathered data from the ears of 500 male and 500 female subjects (49,50). She recorded the relative frequencies of various features observed on ears, distinguishing between gender and right and left. She provided also a limited analysis of the correlation among features. These values are valuable to demonstrate the variability of the three-dimensional organ itself, but, because the transfer phenomenon was not fully investigated, they are of limited help for assessing comparisons between earprints and earmarks.

In a case where the issue was the identification of a robber based on a photograph of a partial ear of the perpetrator, Georg and Lange associated to the ear a "wertungsindex" of 1 in 300 billion (51). The present authors inferred from this that the selected set of 30 features had a relative frequency of 1 in 300 billion. This value was obtained by applying a simplistic independence model to calculate the joint probability of the features. The 30 features retained by the authors were visible in the photograph of the offender and again encompassed more than the features that could be observed in a potential mark. The smallness of the statistic depends critically upon the independence assumptions that cannot possibly be supported by the small amount of data available.

Kritscher et al. (52) dealt also with a case where the offender had been identified after comparing the ear image captured on a video system with ear photographs taken from a suspect. The authors gave no details regarding the identification process, except to state that it followed from a perfect superposition of the questioned and known ear images. Because the quality leap from the actual three-dimensional organ to the two-dimensional mark was not addressed, we consider that these case reports are of limited value for assessing between-source variation in earmark to earprint comparisons.

In a case report presented by Hammer, the probability for the random occurrence of four concordant features was estimated to be 1 in 7800 (48). The paper is not explicit about the way by which this value is obtained; it is possible that it follows research published later (53,54), though these papers do not mention it. Based upon a sample of 609 males and 534 females, various occurrences of ear features have been counted. It is not clear to us whether the sample was made of ear photographs or earprints and whether right ear or left ear or both ears were studied. But considering the features selected, we suspect that photographs have been used. The features correspond in some respect to the features used to describe the ear in Bertillon's "portrait parlé" (35). They are:

- the size of the ear (mm);
- the general form (4 classes considered);
- the form of the lobe (4 classes considered);
- the position of the lobe compared to the cheek (5 classes considered);
- the form of the antihelix (3 classes considered).

The association between the named features (such as lobe, antihelix, etc.) is given in Fig. 1.

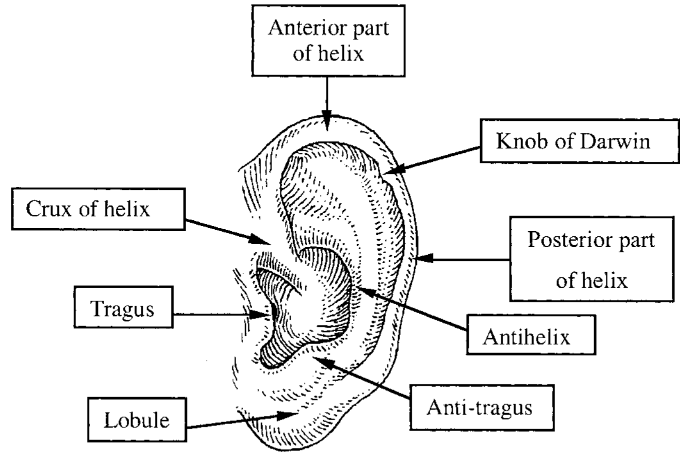

FIG. 1—*Parts of the ear considered.*

The possibility of using these relative frequencies when dealing with marks is remote, because the chance that the average mark clearly displays the retained features is low. The authors recognized this fact and undertook a study on the effect of pressure of application on the resulting mark (12). The study comprised ears from 25 males and 25 females whose ear photographs (and then prints) were obtained after pushing the ear against a glass plate using weak and strong pressure. Measures were taken on the following 8 attributes:

- length and width of ear;
- length and width of earlobe;
- maximal and minimal width of helix;
- maximal and minimal width of antihelix.

The effect of pressure is substantial, especially for the upper part of the helix and the lobe. According to the authors, the eight measurements made in the study allowed them to distinguish all ears (100 ears). It was not meant to be sufficient to infer the individuality of the external ear, but it allowed the author to attach high evidential value to ear comparison when the marks are of sufficient quality. In our opinion, this study represents the first attempt to investigate systematically within-source and between-source variability of earmarks. But the study suffers from two main limitations: the limited size of the sample and the absence of a clear specification of the comparison process.

Alfred V. Iannarelli devoted most of his career to the study of the ear as an identifying organ. His book is entirely devoted to the subject (55,56). It is almost the only piece of work on earmarks found in the United States[9]. Although the ear was presented also in classic forensic textbooks as an important feature of human morphol-

[8] For Imhofer, this observation corroborates the statement made by the French Boulland (1890, cited by Imhofer) that eight concordant features without discrepancy were sufficient to establish identity.

[9] Osterburg (57, pp. 33–35 and 229–239) proposed a case study on earmarks based on a case published by Medlin in the *Military Police Journal* (58). Medlin relied on Iannarelli's work to ascertain ear individuality.

ogy within the Bertillonnage system (59), Iannarelli was the first to study it in a systematic way. He proposed to apply a measurement (anthropometric) system to the ear. Then a classification was possible using a Vucetich-like filing system. All measurements were taken on standardized photographs of ears. Throughout his book, Iannarelli claims that the external ear is individual, invoking Quetelet's rule that nature never repeats itself and his experience of the examination of thousands of ears.

In relation to the identification of marks, Iannarelli's book is disappointing. The transition from the photograph to the two-dimensional mark or print is made without any reconsideration of the distinguishability between marks even though Iannarelli admitted that no classification scheme was available for earprints or earmarks and acknowledged the difficulties caused by the effects of pressure and distortion. The methodology of comparison is nonexistent: a visual inspection side by side, followed by a superposition of transparencies, is advised, but no criteria are given for forming an opinion. Iannarelli's view of the power of earmark identification is clear (p. 156): "earprint identification is an exact science that can be used to prove beyond any reasonable doubt and to a moral certainty that an unknown earprint found at the scene of a crime is that of the known suspect." Yet this dogmatic statement is supported more by polemic rather than reasoned argument and the book seems to have been received with scepticism in the forensic community. A reviewer argued that: "The claim that thousands of ears were compared and classified without finding two alike does not provide scientific support for the theory espoused throughout the text" (60, p. 448). We tend to agree with this latter opinion. Unfortunately, Iannarelli's response failed to address this criticism (61).

Van der Lugt began to be involved in the identification of earprints in 1986 in collaboration with Nicos Dubois. Dubois reported a case in Holland where earmarks were used to identify an offender (62). Like Hirschi, Dubois carried out additional experiments for this case using 100 earprints from unrelated individuals and the earprints from the suspect's relatives. Comparisons were carried out using measurements and pressure points. No match (an undefined concept in the paper) was found when comparing prints and when comparing the marks obtained in the above case with the prints. The influence of pressure and rotation on the prints was noted on measurements, but their effect on the position of the centers of the pressure points was declared to be low. Van der Lugt reported on a study carried out by him in 1987 (63). A collection of photographs from the right and left ears of 500 men was classified according to defined measures (ear length, ear width, length of the lobe, distance between the tragus and the antitragus) and morphological features (general shape, knob of Darwin, curving of the antihelix, size of the tragus and antitragus, form of the antitragic notch). Useful relative frequencies are provided, but again, as we noted for the work by Oepen and Hammer et al., they pertain to the examination of photographs; their application to the interpretation of marks is not straightforward and would need additional research. Moreover, the subjectivity of the chosen classification of morphological features (i.e., small, medium, large) adds to the difficulty.

Van der Lugt is nowadays the most prolific author and expert in this field (10,14,15,64). He has been involved as an expert witness in various cases in the Netherlands, in the United Kingdom, and in the United States. He is the initiator of courses on earmarks organized with the support of the European Committee [the first was organized in 1998] that aim to promote the use of earmarks in Europe (1,65,66). Following agreement between the EU practitioners involved in the courses, a database has been set up that contains earprints of some 1200 persons (an increase to 3200 is planned). It is administered by the National Training Centre (NTCSSCI) in Durham (67). The database offers the possibility of digitally storing the earprint images (obtained at various pressures) along with data as sex, ethnic origin, and kinship.

The database does not, at present, offer any way of classifying earprints by means of their intrinsic features. Moreover, the digital images are acquired in a bitmap format (black and white) and at such a low resolution (120×210 pixels) that it could not be the basis of the design of an automatic recognition system.[10] The database has the limited merit of providing a computer-assisted way for looking at low-resolution earprints images.

Rochaix also made an attempt in 1988 to extract and classify features from earprints (general form, tragus incline, antitragus form) in order to design a database (69). However, the approach was never fully implemented in practice because of the high subjectivity of the proposed categorizations and the fact that marks rarely displayed in an adequate way the retained features.

The identification process is described briefly in Refs 14 and 70. More details are given in Refs 71 and 72 and has been confirmed to us by Swiss practitioners. Nevertheless, the level of detail with regard to the process of confirming identity of source remains low. The main steps can be summarized as follows:

- The marks and the prints are respectively evaluated in order to assess which parts/features are visible and constitute pressure points.
- The mark is compared with the print using overlays. The examiner looks at agreement in pressure points and measurements. The more specific and stable features are the tragus, the crux of the helix, the antitragus, the form of the antihelix and finally the helix rim.
- Because the ear is a flexible three-dimensional object, consisting of cartilage and covering skin, pressure of application and rotation of the head cause differences between the successive prints or marks from the same individual. Differences in the comparison process are evaluated in the light of the work done by Hammer and Neubert on pressure distortion (12) and by Saddler (68). Saddler studied 10 ears (5 right and 5 left) and observed that as pressure increases so does the ear length and width as well as width of the upper helix rim and anti-helix.
- The demonstration of the identification is provided either by transparency overlays or using montages made of cut out photographs (mark and print) as described by van der Lugt (14).
- The opinion of identification is nowhere given any kind of formal basis—we return to this in the discussion.

Discussion of the Literature

One striking feature from the literature, that was also pointed out by Moenssens (6,73), is the constant confusion between the between-ear variability with the variability that is expressed in marks. It is a statement of the obvious to affirm that all external ears are different (even when twins, triplets, and quintuplets are compared) but high variability between *ears* (39,50,56,63) does not imply necessarily that a high variability is expressed in *marks.* This "clarity bridge"[11] from a three-dimensional malleable organ to a two-dimensional mark revealed on a surface needs to be investigated in

[10] However, Saddler designed a prototype using four measurements on earprints and suggested the use of flesh lines but without any implementation (68).

[11] A term introduced by Ashbaugh (74).

much more detail than heretofore. Until now this problem has been inadequately tackled in the literature on earprints. Some studies have attempted to compare sets of earprints from different persons (4,53,54,62) and all have led to the conclusion that no matches have been found. But it is difficult to assess the credibility of such studies because: (1) the concept of match is always badly defined; and (2) they all suffer from the same strong methodological bias in that examiners knew beforehand that they were comparing prints from different people.

The features used for comparison are poorly described and clearly vary from one set of prints (or marks) to the other. When such features are disclosed, their selectivity is never investigated by documented empirical research and the assessment of the rarity of the shared features relies solely on the examiner's experience. The assessment of discrepancies is generally solved by invoking the unique work published in this respect by Hammer and Neubert (12). The identification process is described mainly as a matching process, an assessment of the adequacy of superposition between the mark and the prints, but the crucial question of the value to be given to a match is never addressed and is left to the examiner's appreciation.

This last issue is a fundamental weakness that is addressed nowhere in the literature. Iannarelli (12, p. 140) says, for example, that once you are satisfied that you have a match, the identification is complete. The EU course tutorial (71) says: "if all details more or less come together you may come to the conclusion that they are from the same source." There is a parallel in the fingerprints field, as we have remarked elsewhere (21): Ashbaugh, who has done more than most to establish the pursuit as a science, leaves the fundamental issue as follows (75): "Finding adequate friction ridge formation in sequence that one knows are specific details of the friction skin, and in the opinion of the friction ridge identification specialist that there is sufficient uniqueness within those details to eliminate all other possible donors in the world, is considered enough." Here the obvious question relates to the meaning of the phrase "sufficient uniqueness" and how such a state is arrived at. Unless this issue is formally addressed in an exhaustive and logical analysis the status of earprints identification as a scientific pursuit cannot be established.

Attempts to build a database have failed to address the basic questions of earmarks and earprints classification, offering as an end product a gallery of images without a forensic structure.

In the next section, we will attempt to expose some research possibilities in the field, focused on a systematic approach to the comparison problem. We then go on to discuss the development of a culture based on the assessment of the proficiency of examiners in the field.

Research Possibilities in This Field

Very few systematic approaches to the analysis of images of ears have been carried out. Burge and Burger have constructed a "proof of concept" for a biometric system based on ears that allows a passive verification based on features extracted from a distance (76–79). The matching system is based on the comparison of topological relations between extracted curve segments. Unfortunately, the system was designed for handling images of ears and not images of earprints or earmarks.

A recent joint project to study earprints was carried out by the Swiss Polytechnic School (EPFL) and the Institut de Police Scientifique et de Criminologie (IPSC). Valvoda developed image-processing algorithms to extract features from the antihelix area (80).

The antihelix area was chosen because of its prevalence on marks found on crime scenes as attested through a survey among 1364 earmarks collected on crime scenes from 1989 to February 2000 by the scientific service of Geneva Police. The survey consisted of counting specific parts of the ear (Fig. 1) when visible on marks. The results (Table 1) show that the proportion of marks showing the antihelix area is the highest.

The processing can be summarized as in Fig. 2. Hence for each image, a vector of features is extracted as shown in Table 2.

Valvoda showed, based on a small sample of 9 individuals, that discrimination was achievable. This work constitutes an excellent starting point towards obtaining assessment of within-source and between-source variability. Technically, the way forward encompasses the following:

- an extension of the test database;
- an assessment of the efficiency of the features retained by Valvoda. A clear drawback is that the features extracted are not invariant and depend on orientation:
- the improvement of the discrimination by adding other features such as the relative position of the crux of helix;
- the investigation of the combination of an approach based on specific feature selection with the extraction of global image information such as fast Fourier transform (FFT) or image correlation analysis.

But, more fundamentally, the matching system should aim at assessing likelihood ratios that could be used in casework. Indeed, with regard to the outcome of a comparison, there is a need to keep in mind the possibility of combining earmarks evidence with other forensic evidence. With the development of DNA technology, a DNA profile could be obtained from a swab made on earmarks. For that reason (and others), there is a need to express the strength of evidence in terms of likelihood ratios.

A proposal for a way to compute them is then given below.

Provided we have a match algorithm that allows distance computation between features, a likelihood ratio (LR) for given evidence, in our case a computed distance d between an unknown ear mark M and a known print P, can be obtained by the ratio of two probability densities:

$$LR = \frac{p(d \mid C)}{p(d \mid \overline{C})}$$

TABLE 1—*Results from the survey among 1364 earmarks.*

Part	Crux of Helix	Anterior Part of Helix	Posterior Part of Helix	Antihelix	Tragus	Anti-tragus	Lobule	Knob of Darwin
Proportion (%)	83.3	73.0	44.9	96.2	59.3	72.4	27.1	0.8

Figure 2: *Outline of the processing developed by Valvoda*

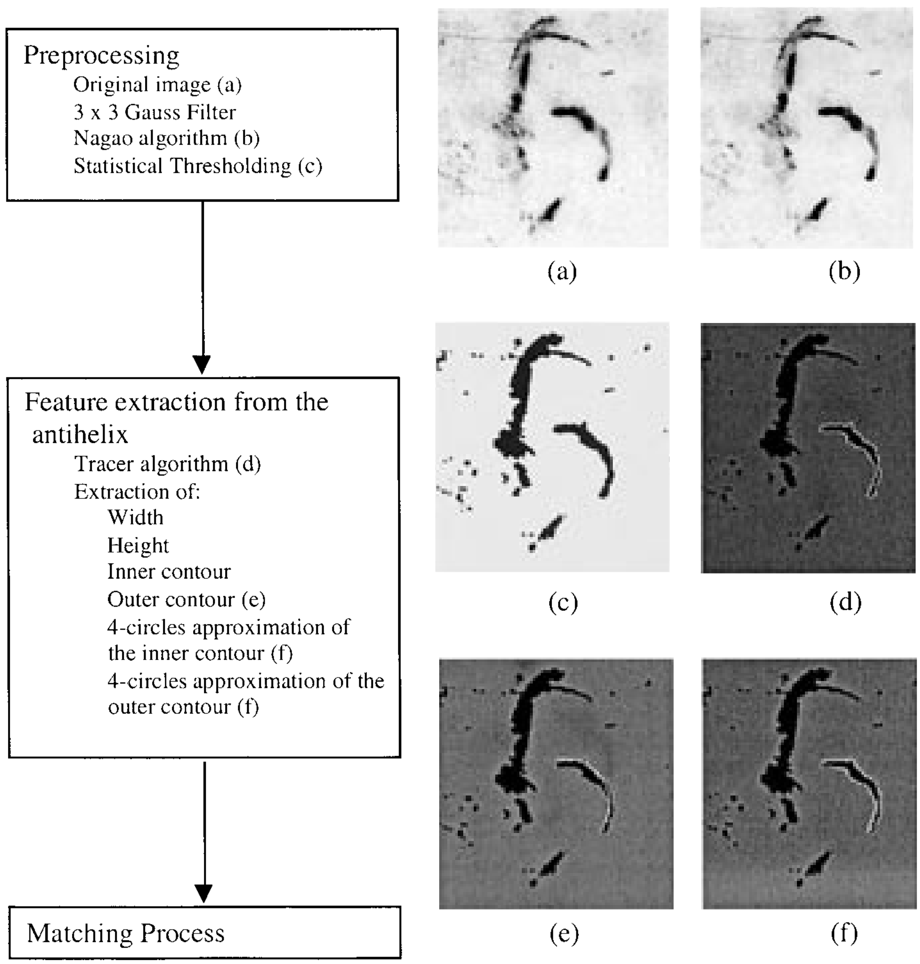

FIG. 2—*Outline of the processing developed by Valvoda.*

TABLE 2—*Output from the computation using Valvoda's algorithms.*

				ROI SIZE		UPPER LEFT POINT		LOWER LEFT POINT		INNER CIRCLE			OUTER CIRCLE		
FILE	IND	SIDE	PRESS	WIDTH	HEIGHT	ULPX	ULPY	LLPX	LLPY	ICX	ICY	ICR	OCX	OCY	OCR
Original.tif	1	right	3	69	82	0	0	47	80	-30	71	77.82	16	44	47.17

FOUR-CIRCLE APPROXIMATION OF THE INNER CONTOUR											
IC4C1X	IC4C1Y	IC4C1R	IC4C2X	IC4C2Y	IC4C2R	IC4C3X	IC4C3Y	IC4C3R	IC4C4X	IC4C4Y	IC4C4R
9	3	9.96	73	-37	76.12	22	55	30.70	92	75	45.68

FOUR-CIRCLE APPROXIMATION OF THE OUTER CONTOUR											
OC4C1X	OC4C1Y	OC4C1R	OC4C2X	OC4C2Y	OC4C2R	OC4C3X	OC4C3Y	OC4C3R	OC4C4X	OC4C4Y	OC4C4R
50	64	15.93	-2	53	66.37	75	-22	46.87	15	81	82.73

Where C stands for the proposition that the ear mark has been left by the person X that provides the print P, and $\bar{C}$ stands for the proposition that the ear mark has been left by another unknown ear.

The distance d is an algorithmic measure of the distance between the two sets of measurements (one set from the recovered mark(s) and one set from the known prints). Depending on the metric used, d can be a single number (such as an Euclidean distance), a vector or even a matrix, which summarizes the distance between the two sets of measures.

The probability density function for the numerator, addressing the within source variance, is obtained by computing the various distances between marks left by X and the reference print P. A schematic representation of the computation is given in Fig. 3 (restricted here for illustration purposes to one dimension).

The probability density function for the denominator, addressing the between source variance, is obtained by computing the distances between M and a collection of prints from a sample of individuals as outlined in Fig. 4.

In biometrics, these distributions are named "genuine" and "impost" or distributions (81). The likelihood ratio is obtained by the ratio the densities observed at the distance d between the unknown mark M and the known print P as illustrated in Fig. 5.

As soon as an efficient match algorithm is designed, then the design of a database becomes realistic. It will provide an essential intelligence tool allowing marks to marks comparison and marks to known prints comparisons.

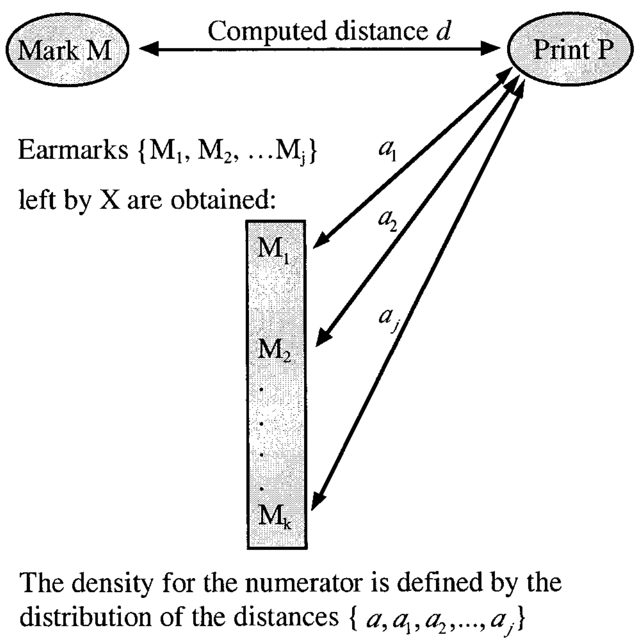

FIG. 3—*Computation scheme for the numerator.*

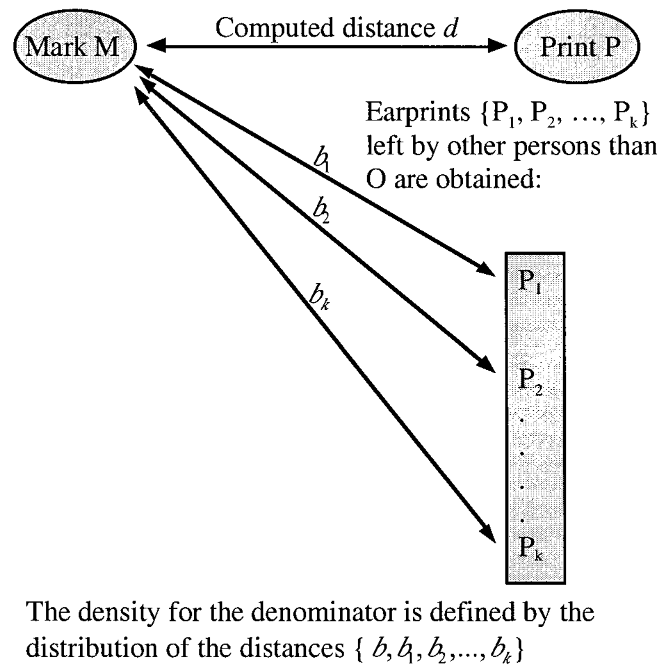

FIG. 4—*Computation scheme for the denominator.*

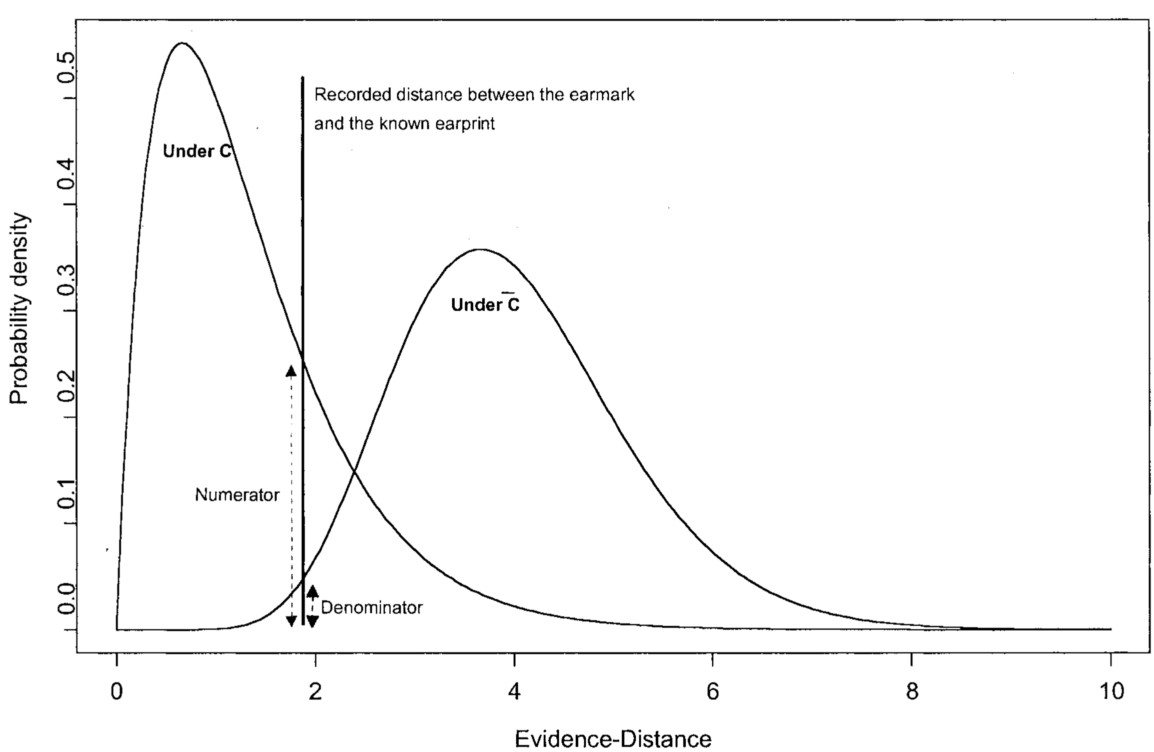

FIG. 5—*Computation of this likelihood ratio.*

Another aspect that may need further research is the collection of the reference prints. Its necessity follows three observations:

- the time to take reference sample from both ears from one individual is appreciable, about 30 min;
- the methods currently used reveal elements of the modus operandi. In the long run, it may lead to a reduction of recovered marks;
- the variability for a given individual of the prints obtained with various pressures is important and has been shown to be larger than the variability of the marks given by an individual in series of burglaries.

3D acquisition technologies available today could offer a rapid and noninvasive way of recording the morphology of the ears. Through an adequate pressure model, it should be possible to extract from the 3D image all potential marks (2D) that could be left. The natural extension is then the development of a matching algorithm, but now dealing only with marks and 3D images.

Proficiency Assessment

There is another strand of development that would complement systematic research studies: it follows from the recognition of the extraordinary power of the human eye-brain combination. It is highly desirable that this power be fostered and developed in a structured and disciplined environment. This may be achieved by a large-scale program of collaborative studies and proficiency tests. We are particularly impressed by the initiatives that are being implemented in the handwriting comparison field by Found and his co-workers (83 and related references), which are based on large proficiency testing programs for validating individual examiners (84–85).

The principle that Found espouses—and which we fully support—is that we should move to a culture where the forensic scientist convinces the court of his/her expertise, not by referring to years of service or thousands of comparisons completed, but by presenting a detailed portfolio that records his/her proficiency in a long series of independently conducted proficiency tests. Such validation programs are currently being implemented in Australia and New Zealand to qualify handwriting examiners, and we see them as a model for calibrating the judgments of scientists who carry out comparisons in the earprints field.

Conclusions

Nowadays only a few experts are active in earprints. Positive identifications are provided based on earmark to earprint comparison. However, the scientific literature that could underpin such identification is poor and most opinions expressed are based on the sole and unique experience of some experts.

There appears a fairly widespread view that a scientific approach necessarily reduces a comparison to an objective result. Obviously DNA probability based evidence has promoted such a view (82). Certainly we expect a judgment to be objective in the sense of being based on the evidence alone and independent of prejudice toward either prosecution or defense view. That aside, it is inevitable that there will be an element of subjectivity in all scientific opinions: indeed, if there were not, then they would not be opinions! Even in the field of DNA profiling, where the weight of evidence is presented numerically, the statistic is based in part on scientific judgment with regard to the validity and robustness of the assumptions that are inherent in the calculation that has been made. Nevertheless, subjectivity cannot be unfettered. It should be exercised within a sound professional framework founded on a sound corpus of scientific data: high standards of quality management; proficiency testing; performance monitoring; and blind testing. Overall, the pursuit should demonstrate its robustness through international programs of collaborative study.[12] Given such professional structures and a corpus of knowledge acquired through high-quality research, earprint identification could move towards a legitimate claim for the status of a scientific pursuit.

Through this paper, we have inquired into the corpus of scientific knowledge pertaining to earmarks identification. It appears that scientific research has been done, but it has mainly been devoted to the study of the variability of ear morphology based on the examination of ear photographs. The limitations of such studies are obvious when we attempt to apply these data to the assessment of mark to print comparisons for the following reasons:

- Numerous morphological features are not discernible (or cannot be classified) on earmarks. Moreover, most classification criteria remain highly subjective.
- It is not feasible to carry out many measurements on earmarks.
- The within-source variability of features and measurements has not been fully investigated (taking into account the process of leaving and recovering a mark).
- The same applies to the assessment between source variability. It is expected that the distinguishability of earmarks from different persons will be much lower than what is observed on ear photographs.

Attempts have been made to set up studies aiming at comparing earprints from different persons. All studies led to the conclusion that "no match" was found among prints coming from different persons. Apart from the fact that the concept of "match" is never defined, these studies suffer from a major methodological bias because the examiner involved knew beforehand that the prints being compared originated from two distinct sources. Finally, very few studies have been devoted to the assessment of the effects of pressure and orientation on earprints or earmarks.

Acknowledgments

We would like to thank the police forces and identification bureaux of Geneva, Vaud, and Neuchâtel for the support they gave to us during this review. Special thanks are addressed to Mr. Laurent Canel, to Mr. Michel Burkhalter and to Mr. Hans Aebersold, earprints specialists in these three bureaus for their fruitful discussions.

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[12] We are aware that John Kennerly initiated a collaborative study among European practitioners. However, the results have not been rendered public.

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