Inter- and intra-individual variation in earprints

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CHAPTER 10

EARPRINTS IN FORENSIC INVESTIGATIONS

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Abstract

This manuscript aims to provide an overview of the theoretical and practical issues surrounding the use of earprints in forensic research. In part 1 we provide a limited account of the history of earprints in forensic investigations and their use as evidence in court. Criticism of the use of earprints for individualization is addressed and fundamental questions that require further attention are summarized. In part 2 we summarize the results of various studies that we have performed on earprint variation.

10.1 The use of earprints as forensic evidence

Earprints have been used in forensic investigations since the mid nineteen sixties. Hirschi (1970a,b) was among the first to recognize the value of earprints for person identification when in 1965 two earmarks were among the traces found at the scene of a burglary in Bienne, Switzerland. Later that year, two men were arrested while breaking into another house. Tool mark evidence provided a link between the two cases of burglary. Earprints of the two arrested men were taken in order to compare these with the marks that were recovered at the site in Bienne. While reference prints of one of the two men differed from the crime scene marks, prints of the other man showed a striking resemblance with the crime scene marks. Hirschi then became convinced that this man had been involved in the Bienne burglary.

In the years to follow, several reports of person identification using earprints recovered at crime scenes followed (Dubois, 1988; Hammer, 1986; Kennerley, 1998a,b; Van der Lugt, 1998; Pasescu and Tanislav, 1997). Earmarks offered leads during forensic investigations. Judges in the Netherlands used them as a tool to pry confessions from a defendant (Egan, 1999). It was reported that in Rotterdam earmarks were recovered in about 15% of the committed burglaries (European Communities, 2000; Cor van der Lugt[31], *personal communication*). From that it was estimated that in the Netherlands alone, earmark evidence could be used in approximately 50.000 cases of burglary per year (European Communities, 2000). According to Kees Slottje[32] (*personal communication*), who has investigated up to 135 burglaries involving earprint evidence per year in the Leiden district[33], the extrapolation overestimated the total number of cases. In the Netherlands, earprints are most commonly found in cases of daytime burglary in blocks of flats with doorways. Both this type of dwelling and the phenomenon of daytime burglary occur more commonly in the larger cities. Earprint evidence is therefore more frequently found in the western (urbanized) part of the Netherlands. Both Van der Lugt and Slottje emphasized the practical utility of earprints for interlinking various cases.

[31] Scene-of-crime Officer, Police Academy of the Netherlands.

[32] Scene-of-crime Officer, region Holland Central (Leiden environs).

[33] This was about 7% of the total investigated burglaries that year in this region.

In the United Kingdom, Kennerley (1998a) encountered over a hundred crime cases involving latent earprints between early 1996 and September 1998. The majority of these cases concerned burglaries, but Kennerley also referred to cases of murder and rape. He mentioned that in about forty of the burglary cases the earprints had been individualized. He continued that almost all of these cases were successfully prosecuted without challenge. Indeed, earprints were becoming steadily more important in the United Kingdom, where, according to Champod et al. (2001), they had gained a status as identification evidence that was becoming comparable to that of fingerprints.

Criticism

Meanwhile, there was increasing criticism of the use of earprints as evidence in court on the grounds that the process of individualization was considered to be subjective (e.g., Champod et al., 2001; Egan, 1999; Moenssens, 1999b). Indeed, formal protocols for collecting earprints have not yet been implemented and there are no methods for analysing earprints that have been generally accepted by the scientific community. In 1999, a conviction obtained on the basis of earprint evidence was reversed in the United States (Morgan, 2000). But the use of earprints became more controversial when in January of 2004 in the United Kingdom charges against Mark Dallagher – accused of murdering an elderly woman and convicted in 1998 on the basis of earprint evidence – were formally dropped when it was found that his DNA did not match the DNA that was later recovered from the original earmark. Moenssens (2004b) referred to these events to illustrate “the superiority of DNA analysis over most other forensic methods of individualization” and argued that the DNA evidence proved that Mark Dallagher could not have made the recovered earmark. However, the possibility that the DNA evidence was contaminated may also be considered since the print was lifted by officers not intending to perform a DNA analysis – therefore not taking precautions to prevent contamination – and were using equipment which could have been contaminated from previous cases. Kieckhoefer et al. (2005) pointed out that the original mark had been stored for years on a non-sterile surface.

Advantages and limitations

It is important to distinguish between the legal and the scientific conclusions that may be drawn from the Dallagher case. It is also important to distinguish between specific conclusions about this case and general conclusions about advantages and limitations of earprint and DNA or other types of biometric evidence. Nowadays there is less chance that DNA evidence will be contaminated than in 1998, when the murder for which Dallagher was initially convicted took place, because scene-of-crime officers will take greater care to prevent contamination when collecting DNA evidence.

Obviously, DNA evidence is very reliable in cases where sufficient quantities of bodily substances can be recovered and linked to a perpetrator. However, the strengths of DNA evidence can be over-emphasized. In the Netherlands it was suggested that scene-of-crime officers should only collect DNA and fingerprint evidence (Vermaas, 2003) but we would argue that it is best to keep all options towards solving a crime open. Not all types of evidence will be equally valuable – or present – in all cases of crime. DNA, for instance, has the disadvantage that it may be relatively easily planted on the crime scene to frame an innocent person. In contrast, earprints are almost tamper-proof. A print is usually created when someone is intentionally listing at a door or window. This may decisively place the listener at the crime scene. Planting earprints from innocent people at a crime scene is relatively difficult as – unlike fingerprints – they are difficult to obtain without the consent of the donor for the purpose of creating duplicates. They are furthermore not so easily left by an innocent passer-by.

Earprints have various limitations. Firstly, the study of earprints as a quantitative and rigorous discipline is immature and standard tools and methods for analysing earprints are only now becoming available. Secondly, an earmark is usually left in a publicly-accessible area before any crime is committed (e.g., on the *outside* of a building before a break-in). Furthermore, no accurate indication of the time of its formation may usually be inferred. In the case of Mark Dallagher, it was reported that the window from which the earmarks were recovered had been cleaned three or four weeks before the murder took place (Crown, 2002). Thus all that the presence of his earprint could have proved was that Dallagher listened at the house of the murdered woman within the three to four weeks period leading up to the murder. This may be considered suspicious but without additional evidence the presence of his earprint would not be enough ground for a conviction for murder[34].

Fundamental questions

Bearing in mind the limitations of earprint evidence, let us now consider what is needed for earprints to be accepted as evidence in court. What fundamental questions need to be addressed before we can use earprints for individualization with confidence? What should 'a sound corpus of scientific data on earprint individualization' consist of? A frequently quoted definition for the process of individualization was provided by Tuthill (1994): *"The individualization of an impression is established by finding agreement of corresponding individual characteristics of such number and significance as to preclude the possibility (or probability) of their having occurred by mere coincidence, and establishing that there are no differences that cannot be accounted for"*[35]. In the formerly mentioned pioneer case of Hirschi (1970a,b), one of the two arrested men was readily dismissed, as differences between his earprint and the crime scene mark were judged to be too great to occur in prints of a single ear. For the earprint of the other man, five striking similarities were described. This process appears to follow Tuthill's definition. However, when examined carefully the definition of individualization given above is unsatisfactory and raises fundamental questions.

Firstly, when can corresponding individual characteristics be said to *agree*? Not even characteristics in two prints from the same ear will ever be identical. Judging agreement in practice means judging the degree of similarity between the various characteristics and since degrees of similarity usually vary continuously the term *agreement* is difficult to define objectively. Next, when is the degree of similarity of such significance as to preclude the possibility (or probability) of it having occurred by mere coincidence? We may even ask whether it is ever possible to *preclude* the possibility that agreements occur by coincidence: the concept of *precluding* a probability is unusual. We may further ask whether ruling out coincidence is relevant to individualization. It is known, for example, that the earprints of monozygotic (identical) twins usually share numerous characteristics that are valuable for

[34] Earprint evidence had initially been corroborated by a statement of an informant who had shared a cell with Dallagher after the latter had been arrested for another burglary. The informant had stated that Dallagher had revealed information about the killing that was not in the public domain (Crown, 2002).

[35] Tuthill adapted Huber's principle of identification (Huber, 1959-60).

individualization (Meijerman et al., 2006). The reason for this is genetic and one may safely rule out the role of coincidence in causing the agreement without coming any closer to addressing issues of individual identity. And finally, when are differences sufficiently small or insignificant as to claim that we can account for them, or – rephrased – when are differences too great to pass of as intra-individual variation? Evidently, when subjected to closer scrutiny, the definition provided by Tuthill (1994) is flawed and has limited use in practice where unbiased standardized methods are required.

Hirschi (1970a,b), perceiving a number of hurdles to be addressed before individualizing body traces, initially compared the mark with reference prints from around twenty different persons. He found that no two prints were alike. He further recognized the need for the mark to be of sufficient quality, with sufficient details offering clues for individualization. The number of similarities mentioned in his report (five) appears to be too limited to draw strong conclusions regarding individualization[36]. In theory, though, this would depend on the frequency of occurrence of described details in the prints of an entire population. A limited sample of prints of twenty people would, however, not have sufficed for conclusions regarding rareness.

This brings forward a next – more practical – question to be addressed. Prints of how many individuals does one need to examine before one can be satisfied that earprints offer sufficient inter-individual variation for individualization? Moenssens (1999a) reckoned at least 10.000. He later stated that other scientists had considered a database comprising prints of this many individuals to be unworkable as a basis for comparison, involving an effort that would be too time consuming in a practical sense (Moenssens, 2000). Alberink and Hoogstrate (2002) also addressed the question what could be considered a representative sample of the total population. They proposed that for each of the three countries involved in the FearID research project 700 randomly selected individuals should be included, as well as 100 blood-relatives.

The issue of 'uniqueness'

Hirschi attempted to make the concept of uniquely traceable earprints plausible by

[36] The illustrated reference print and crime scene mark, however, provided more clues for individualization than were summarized by Hirschi.

quoting a number of authors asserting the value of the human *ear* for person identification. Egan (1999), Moenssens (1999a) and Champod et al. (2001) emphasized the flaws of this leap in reasoning from ears to earprints. Assuming that ears may be uniquely distinguished, it would not automatically follow that this is the case for earprints as well. A high variability between ears does not necessarily imply that a high variability is expressed in earprints. The external ear is a malleable, three-dimensional entity, while the earprint is merely a two-dimensional representation of the parts that came into contact with the listening surface. The appearance of different prints from a single ear may furthermore vary depending on a number of variables, of which pressure distortion was most frequently examined (Dubois, 1988; Hammer and Neubert, 1989; Neubert, 1985; Saddler, 1996; Sholl et al., 2004). Ear variability, therefore, does not equal earprint variability. Consequently, answers in the affirmative to the question whether ears are unique – inevitably philosophical in nature – do not justify a claim of 'unique' earprints.

Asking whether ear*prints* are unique does not describe our research question either because even two prints from a single ear will not be identical. Instead, we may ask if earprints are uniquely associated with the ear that created them. We should, however, keep in mind that this cannot result in absolute certainties. Studies will include merely a sample of the population. Eventually, reliable quantitative methods for comparing large samples of earprints will become available. Progress is being made in this direction. The statistics of these samples could be used to put lower limits on the degree of genetic randomness that characterizes earprints, and to estimate the likelihood that two earprints were created by the same ear. The reader is referred to the field of iris recognition, where methods of encoding the patterns on irises are powerful enough to allow such an approach (Daugman, 2003). Note that earprints probably show more intra-individual variation than iris images and are more difficult to analyse using automatic pattern-recognition techniques.

Expressing an opinion on identity

In the past there has been a tendency to express opinions on identity based on earprints in absolute terms, but there is now a growing consensus that this should be avoided in favour of using probabilistic statements. These developments mirror similar developments in the field of dactyloscopy, e.g., Champod and Evett (2001) and Broeders (2003). Until now, fingerprints are either considered a certain 'match' or they are not. Stoney (1991) described this as a leap of faith: when more and more corresponding features are found between two patterns, scientist and lay persons alike become subjectively certain that the pattern could not possibly be duplicated by chance.

Earprint advocates have approached individualization in a similar manner, starting with Hirschi (1970a,b). He concluded that, providing the prints were of good quality, *definite* conclusions regarding identity could be made when several similar prints, or prints of both the left and right ear, were found. Van der Lugt (2001) initially agreed as he wrote: "A positive opinion can be given when the examiner is certain beyond a reasonable doubt that the trace matches with the reference standards. Enough class and individual characteristics are present to lead to his/her conclusion". No directions were, however, provided as to what could be considered a match', and therefore the obvious bias inherent in observer subjectivity would be introduced. Since this publication, Van der Lugt has revised his opinion and refrains from claiming definite matches (*personal communication*). Others (e.g., Kennerley, 1998a; Pasescu and Tanislav, 1997) have avoided the term 'positive identification'. They used expressions such as 'high probability' and 'unlikely to have been made by any other source' to indicate evidential value, but the way of arriving at such an opinion remained equally subjective.

Champod et al. (2001) offered a more objective approach to determining evidential value. They proposed to express the weight of evidence as a function of the likelihood ratio, where the numerator is the probability of the observed degree of correspondence between a crime scene mark and a suspect's print, taking into account intra-individual variability. The denominator is the probability of the observed degree of correspondence, taking into account inter-individual variability. This approach would direct the examiner to express conclusions in terms of the degree of support for intra-individual variation versus inter-individual variation. Hence they would use a formulation such as 'the evidence provides strong support for the proposition that X left the earmark', rather than 'X probably made the mark'. This approach allows us to reformulate an earlier posed fundamental question. The phrase 'when is the degree of similarity of such significance as to rule out the possibility of it having occurred by coincidence' may be replaced with 'when do we consider the likelihood for two prints originating from the same ear sufficiently high as to allow an opinion of individualization'.

The subsequent question of whether we may rule out the possibility of seemingly indistinguishable prints being made by different ears may further be answered negative. We may not, but we could accept the leap of faith and consider two prints ‘a match’ when the likelihood is above a certain threshold. We, however, do not need to, as we may present a statistic in court. This statistic would need to be accompanied with an explanation of how this statistic may be set into the context of the other evidence (Champod et al., 2001).

10.2 Towards a more scientific basis for earprint use

The evidential value of earprints is determined by both inter- and intra-individual variation. For an earprint to have evidential value in a forensic setting it needs to posses a feature, or set of features, for which the intra-individual rate of occurrence is high and the inter-individual rate of occurrence is low. In order to strengthen the scientific basis for earprint individualization we must understand more about how to select and use earprint features and know more about the factors that determine the range of intra-individual variation. Ideally, we would then be able to determine the limits to intra-individual variation. It would answer the remaining fundamental question that was posed, i.e., ‘when are differences sufficiently small or insignificant as to claim we can account for them’.

The realization of earprint evidence

What are the factors that may generate variation in different prints from a single ear? Figure 10.1 shows the entire procedure leading up to the realization of earprint evidence, from the moment the ear is in contact with the listening surface, via lifting and securing the latent print, to scanning and storing the digitised print for the purpose of automated matching. This process of creating earprint evidence can be described in terms of a flow of information. The ear, as well as areas of the head that may get imprinted, contain a full set of information that is assumed to be donor-specific. As information is passed from the ear to an earprint it is transformed, censored and augmented by various processes. If individualization is to be possible, enough donor-specific information must survive the entire process to arrive at the earprint.

The aim is to use donor-specific information that is contained in the earprint to map the print back to the ear from which it originated. This cannot be done directly and the only practical option is to compare a print of unknown origin to a print of known origin (i.e., a suspect's earprint or an identified print in a database). Herein lies one of the biggest challenges for using earprints for individualization. It is impossible to repeat the process outlined in Figure 10.1 exactly, even under controlled conditions. Some degree of intra-individual variation in earprint appearance is therefore unavoidable.

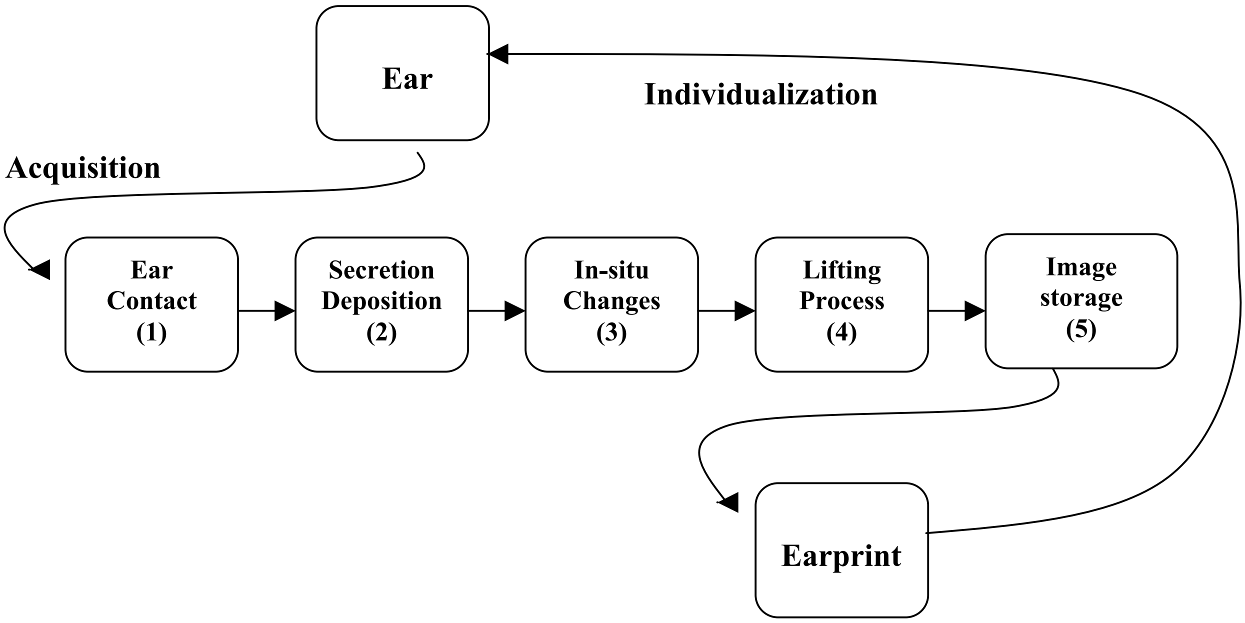

Figure 10.1 *A schematic overview of procedure leading up to the realization of earprint evidence.* Steps 1 to 5 transform, censor and augment the information contained in an ear as an earprint is formed and collected. The goal of individualization is to uniquely associate an earprint with a real ear.

In the worst circumstances, any of the steps in the process can prevent donor-specific information reaching the (stored) earprint making it impossible to trace the print back to an ear with confidence. In the following sections we explore potential sources of variation at the various stages of the process. The sources of variation identified should be considered when determining the effects of intra-individual variation i.e., when compiling a reference or research database.

Ear contact: applied force during listening

A potentially important source of intra-individual variation in earprints appeared to be variation in the force that is applied by the ear to the surface during listening (Hammer and Neubert, 1989; Neubert, 1985; Saddler, 1996). During preliminary studies into applied force while listening we noted that intra-individual variation in applied force was comparatively small as compared with the inter-individual variation (Meijerman et al., 2004c, 2005b). This was confirmed by Kieckhoefer et al. (2005). We hypothesized that applied force may possibly reflect a balance between the aim to create a seal with the ear on the surface to optimize hearing, and the inclination to minimize discomfort to the ear or cheek. The individual anatomy of one's ear would then play a key part in determining both the amount of force needed to create a reasonable seal, and the amount of force that would cause discomfort to the listener. Force applied by the ear to the surface during multiple attempts of listening would thus fall within certain individual limits. We would therefore advise that, if possible, reference prints of suspects are taken after actual efforts of listening.

To explore the limits of a person's functional force range, i.e., the force that is applied by the ear during the act of listening[37], we have tried to predict possible grounds for changes in applied force. We experimented by varying the level of ambient noise while recording the force that was applied during listening. No significant effect from the level of ambient noise on applied force was observed (Meijerman et al., 2005b). Listening to either sound or silence did also not appear to significantly affect applied force (Meijerman et al., 2005c). We did, however, notice a significant effect from chances in the level of the target sound. When the sound level was reduced in between listening efforts, it evoked a reaction of listeners to increase applied force (Meijerman et al., 2005b). In addition, we observed that listeners generally applied less force during their first listening effort. We assumed that – unfamiliar with the procedure – our subjects were more cautious during first listening efforts.

Ear contact: duration of listening

How long a donor listens at a surface affects the appearance of the retrieved earprint.

[37] Händel (1933) pointed out that sometimes earprints are found which are not made while listening at a surface, but while hiding away. These prints may be made using a force outside the functional range, and may therefore be distorted compared with other prints of the same ear.

We have explored the effect of the listening duration on earprints by using the size and the intensity (i.e., grey values of pixels) of the imprinted area to calculate a print-mass. We found that print-mass significantly increased with length of listening (Meijerman et al., 2004a). Kieckhoefer et al. (2005) showed that fidgeting of the ear during listening increased the amount of imprinted surface.

Another effect of increased listening time may be a higher chance of smudging due to a sliding of the ear across the surface. During a preliminary study into the effect of listening time on earprints it was observed that some blurring of features generally occurred after 20 to 25 seconds of listening, although it was usually not so marked as to distort minutiae to the extent that it was expected to affect individualization (De Conti et al., 2003). Smudging in earprints may, however, occur. It may, however, be easily recognized. If smudging is too severe, one might consider dismissing the print.

Ear contact: quality of listening surface

The quality of the surface from which prints are recovered may affect the level of detail to be retrieved in a print. Hence it may affect the evidential value of a recovered mark. Saddler (1996) observed that, for instance, brushstrokes on the paint greatly reduced skin detail in a mark that was lifted from a painted wooden door. Smooth, non-porous surfaces such as glass and metal appeared to offer the greatest potential for the recovery of prints that are rich in detail. Varnished wood may also provide good-quality prints, particularly when the paint is not old and porous. Prints recovered from synthetic materials appeared to be of lesser quality (Cor van der Lugt, Francesca De Conti[38], *personal communications*).

Secretion deposition

We may visualize the ear as a rubber stamp, the earprint being a two-dimensional reproduction of the parts that touched a surface. Oils and waxes that are naturally present on the ear may be imagined to serve as ink on the stamp. The amount of these secretions present on the ear may vary depending on outside temperature, and whether the ear was recently cleaned or not. More or less secretions available for printing could in theory influence the dimensions and/or intensity of the imprinted area. In turn, this might affect the area in which

[38] Junior Scientist, University of Padova, Italy.

characteristics can be found, or the visibility of such details. We therefore continued our explorations into intra-individual variation by comparing the print-mass retrieved from prints collected before and after an ear was cleaned but found no evidence for a significant decrease in the mass of prints created by cleaned ears (Meijerman et al., 2005a). This, however, provides no guarantee that the imprinted details are of equal quality and investigations into the stability of characteristic features (i.e., valuable for individualization) in prints of recently cleaned ears are ongoing.

In-situ changes

In cases of burglary, even day-time burglary, a search for evidence will usually not start until the following day. In between deposition and securing, weathering or – less likely – cleansing may affect the latent print. It may furthermore be possible that secondary imprints of ears, cheeks, palms or fingers are superimposed on the principal print. These events might affect the extent to which details may be recovered.

The lifting process

Discrepancies between different prints of a single ear may also occur as a result of variation in the quality of the material that was used to lift and secure the latent prints. The FearID research team found that Black Gel Lifters were particularly good for preserving details. These prints offered more clues for individualization than prints secured using adhesive and acetate sheets (De Conti et al., 2002). The Inkless Impression Kit (IIK), making use of chemically treated paper that reacts with a coater that has to be applied to the ear in advance, was also tested. IIK initially promised to offer a cheap and quick method to create reference prints of suspects as IIK prints offered a good recovery of details. IIK was, however, dismissed when it was found that, mostly due to variation in the distribution of the applied coater, obtained prints sometimes deviated greatly from natural 'functional' earprints (Van der Lugt, *personal communication*; Meijerman, 2002).

Image storage

Storing the physical medium onto which a print has been lifted is the most reliable way of preserving all the information retrieved from a crime scene or donor. However, this means of storage is limited and earprints are often digitised using scanners. Digital prints can be copied easily to reduce the risk of loss, accessed and shared easily, and analysed quantitatively using image processing techniques. The digitisation of a print involves sampling the information contained on the lifting medium and results in the loss of some information. Therefore the digitisation parameters, such as the spatial resolution and the colour depth, need to be taken into account when comparing prints. Digital image formats that involve image compression are not appropriate because they can introduce spurious image details. A spatial resolution of 600 dots per inch and a colour depth of 8 bits per pixel were found to give acceptable image quality for the FearID project.

The ear: morphological changes

We discussed the various stages that affect the flow of donor-specific information from the ear to the (digitised) earprint. One more factor has to be taken into account when comparing a query print with prints that have been in a database for some time: morphological changes of the ear. When a stamp changes, so will its imprints and we know that the external ear does not remain unchanged throughout life. Imhofer (1906) pointed out that wrinkling of the skin of an older person may change the appearance of furrows that were characteristic in an earlier stage of life. Also, new creases and furrows may appear. Quelprud (1936) believed that the auricular tubercle, or Darwinian tubercle, increases in size with age in the male ear, but decreases in size in the female ear. Hajniš (1969) quoted Borovanský et al. (1960) when stating that the earlobe becomes more hairy with age. Wissner (1970), finally, assumed that the orientation of the crus of helix and the crus anterior anthelicis changes with age. All of these changes can affect the appearance of an earprint.

The external ear furthermore increases in size with age (Asai et al., 1996; Gualdi-Russo, 1998; Hajniš, 1969; Heathcote, 1995; Ito et al., 2001; Quelprud, 1935). To evaluate the extent to which anatomical features appearing in earprints may vary with time, we performed a cross-sectional anthropometric study of the external ear (Meijerman et al., 2004b). We explored the effect of age on ear length, earlobe length and ear width. It was found that all three dimensions significantly increased with age. Estimated length and width increments of the external ear during the various stages of life differed significantly between the sexes. The difference seemed particularly obvious for width expansion.

Earlobe expansion appeared to exceed the expansion of the remainder of the ear, and therefore the imprint of the lobe will probably be less stable over time. We found no evidence for acceleration in the lengthening of the earlobe after a certain age, as was assumed in literature (Iannarelli, 1989; Van der Lugt, 2001). The predicted cartilage expansion (i.e., ear lengthening minus lobe lengthening) appeared to be greatest during early adulthood, particularly in males. Therefore, if results from our cross-sectional study provided an accurate reflection of ear expansion, updating prints in a database after a number of years, if the opportunity arises, may be particularly recommended for relatively young offenders.

In addition to the natural aging process, accidents involving the external ear may also affect its appearance. Scars may develop as a result of injury, and in extreme cases, part of the outer ear may be lost or acquire a deformity called 'cauliflower ear' caused by an auricular hematoma. Frostbite may also result in deformities of the ear. More common, however, are deliberately inflicted changes, such as a piercing of the earlobe and/or helix rim. In addition to acquiring a hole, piercing of the earlobe may lead to permanent stretching of the earlobe as a result of wearing heavy earrings. Provided they are not too extreme, however, such changes usually will not blur the other characteristics of the ear, and once recognized, make the ears positively more distinguishable from others. Abbas and Rutty (2005) pointed out that the position of a hole or void indicating the presence of a piercing may aid the individualization of an earprint.

Intra-individual variability of earprints

When exploring the limits of intra-individual variation, all mentioned sources of variation have to be taken into account. Unfortunately, no golden rule may be provided here to distinguish between inter- and intra-individual variation. With respect to applied force, for instance, it was found that equal variation in applied force did not necessarily lead to equal intra-individual variation in the prints. For some ears, small changes in force appeared to have a relatively great effect on the prints, while for other ears relatively large changes in force seemed to have little effect on the appearance of the prints (Meijerman et al., 2004c, 2005b). Prints of the same ear may further be affected by a change in pressure distribution (Kieckhoefer et al., 2005; Meijerman et al., 2004c, 2005b).

Describing and documenting the characteristics of intra-individual variation can provide useful information for assessing the evidential value of earprints or designing robust algorithms. However, at present there is no practical substitute for a specialist who has studied a large quantity of prints. In the future, statistical techniques for modelling variations in images may help encapsulate and transfer knowledge about inter- and intra-individual variation but these methods are not yet properly tested. A start in this direction has been made by using Active Appearance Models (Cootes et al., 1998) to model inter-individual variations in the gross anatomical appearance of a sample of earprints during the FearID project. In order for an expert, or an algorithm, to learn about inter- and intra-individual variations a suitable sample is required. Such a sample needs to incorporate multiple prints from each of the included ears. If required, it would be possible to influence the amount of intra-individual variation in a sample by exploiting the experience gained about the factors that affect the appearance of a print. For example, applied listening force appears to be generally lower during a first listening effort. A loud target source during this attempt, or a relatively short duration of ear-surface contact, will increase the chance of yielding a print with a relatively low print-mass.

A practical question that now arises is the number of prints from each ear one should study. How many prints suffice to get a proper idea of what can be accepted as intra-individual variation? The FearID team decided on three prints per ear (i.e., six per person) as a basis for comparison, as the need to study prints of a great number of ears had to be taken into account as well. An amount of three prints from each ear involved an effort that could be accomplished within the available project time of three years. One may of course increase this number when obtaining reference prints of the ear of a given suspect. This may broaden insight in the variability of prints of that particular ear. In the past, acquiring information on the magnitude of variation in prints of a given ear was done by purposely exercising ‘soft’, ‘medium’ and ‘hard’ force to the surface (Van der Lugt, 2001). Moenssens (2004b) stated: “By the proper application of different degrees of pressure in taking ear impressions, one may likely produce partial latent ear images of different persons that are indistinguishable and appear to provide a sought-after match”. He has a point that when this procedure is followed, it does bias the statistics. However, it is the amount, position, combination and scarcity of available details that determine the outcome of individualization. Pressure distortion, caused by artificially varying applied force, may influence shape, size and intensity of imprinted features to an extent that will not exist in functional listening prints. It could possibly reduce the amount of individualizing details to be recovered. There is, however, no reason to assume that individualizing characteristics in prints will start to resemble one another so much that the calculated likelihood ratio will become high enough to assume a match. For example, no amount of pressure variation will allow a characteristic pattern of creases or a distinctive notch to be duplicated.

Evidential value

Inherent to the need for sufficient specific detail is the fact that some ears will simply not produce prints that can offer high evidential value. Such prints may still be useful in forensic investigations, as they may be used to exclude a potential suspect, or raise attention to others. According to Moenssens (2004a), it was testified in court that investigated suspects whose ears appeared to match crime scene marks were found to have genuine and corroborated alibis. If we rely on the assumption that all potential detail was taken into account, these prints would be examples of prints that lack a great detail of individualizing characteristics. Few individualizing characteristics would not result in a high likelihood ratio for a match between prints. Consequently, such prints would possess a relatively low evidential value.

An important issue that can diminish the evidential value of earprints is that of subjectivity. Even when automatic systems are used to analyse forensic data human experts are required to make the final judgement about individualization. On the issue of subjectivity in fingerprint individualization, Stoney *(*1991) commented: “The modern image processing techniques used to classify fingerprints may provide an illusion of complete objectivity, yet only a list of most likely matches from a database are provided, and the expert will have to compare and make conclusions”. This would be the case for earprint individualization as well. Some level of subjectivity would therefore have to be accepted. If the option to calculate the match probability for any combination of two prints were provided, the expert would, however, have an objective means to support his opinion. Seemingly ‘perfect matches’ containing few individualizing features, might then be presented in context of their reduced evidential value.

Automatic classification

A number of initiatives towards a (semi) automated classification of earprints have been undertaken. Valvoda (1999, quoted from Champod et al., 2001) presented image-processing algorithms to extract features from the anthelix area. More recently, Rutty et al. (2005) presented their concept of a 'computerised earprint identification system'. Rutty et al. made use of a database containing 800 prints of 800 different ears. Their research therefore did not allow the possibility to verify if selected parameters offered, besides a high inter-individual variability, also a sufficiently small intra-individual variability. In line with Ingleby et al. (2000), Rutty et al. (2005) proposed to calculate centroids of imprinted areas, the pattern formed by these centroids offering clues for individualization. In both studies, it was assumed that the effect of pressure would be overcome by the use of centroids. However, as we pointed out in Meijerman et al. (2004c), the imprints of morphological structures do not only narrow or widen due to a chance in applied force. Features may change position in relation to each other as well. Still, the proof of concept paper by Rutty et al. may serve as a useful starting point for further investigations.

The FearID team has also strived at designing an automatic classification system for earprints. A number of approaches have been explored, but of particular interest is an algorithm used to study the variation in the earprints of identical twins (Meijerman et al., 2006). This algorithm automatically detects and describes salient regions in an earprint. The appearance and constellation of the described regions in a query print may then be compared with that in all other prints of a collection. The number of matching regions can be used to express the level of similarity between any two prints. The result is a ranking list, or 'hit-list', for potential matches and could provide a tool for recovering matching earprints from a large database. In the current implementation the number of similar regions found between two prints is an indicator of the evidential value of a print match: the higher the number of matching regions, the higher the evidential value of the match.

Automatic classification will be based on a subset of features that preferably display limited intra-individual variation and large inter-individual variation (Champod, 2002). A problem encountered with having to base a classification on a set of classifiable features is that, inevitably, some information that may be observed by the human eye – and processed by the brain – is ignored. In addition, it is very difficult to design algorithms that make proper use of appropriate prior knowledge. For example, to enable the algorithms to recognize unusual features and give them extra weight in the way that an expert may notice telltale scars or patterns in pre-auricular creases. All such information should be used. As Coppock (2004) stated: “It is short-sighted to think that complexity and our lack of ability to define such events should prevent such processes from being used in an accurate manner for individualization”. To Champod (2002), the difficulty of classifying certain characteristics as to be able to use them statistically is not a problem. He states that even a limited view on reality may be quantified probabilistically. A statistical assessment based on a model that underestimates the true discriminative power of (in this case fingerprint-) features may still be safely used in court. We feel that it is of paramount importance that not only the forensic community is made aware of the consequences of a probabilistic view. This view has been generally accepted for DNA evidence. When dealing with other types of evidence, however, the prosecution or judges all too often do not accept, or misinterpret, statements that do not reflect absolute certainty (Slottje, *personal communication*).

Expertise

As long as an earprint expert is necessary to form a final opinion on individualization and present the evidence in court, he will remain the last – potentially weak – link in the chain of events leading to the individualization of an earprint. What makes an expert? It may be obvious that the expert will need to have analysed multiple prints of a great number of ears. He will need to have familiarized himself with both inter- and intra-individual variability of gross anatomical features and individualizing details. To facilitate a broader use of earprints, knowledge on individualizing characteristics should be disseminated. Individualizing characteristics do not need to consist exclusively of characteristics that are described to be useful for (semi)-automated classification systems. Focus should be far more on the extent of intra-individual variation than has been done in the past. Details contributing to individualization have been described in Giacon et al. (2005), Meijerman et al. (2006), Van der Lugt (2001) and chapter 8 of this volume. Examples are the combination of notches and angles in the margins of imprinted features, the presence and position of moles, folds and wrinkles, and to some extent the variation in intensity, i.e., presence and position of pressure points and lacunas.

As statements on individualization cannot be made with certitude, experts should be trained to acknowledge this when expressing their opinions. Their opinions should further reflect the degree of similarity between features in prints in the context of their discriminating power. Ideally, opinions will be corroborated by objectively calculated match likelihoods obtained from validated automatic classification systems and large representative samples.

When using earprints as (additional) incriminating evidence in court, it becomes of paramount importance that credentials of the expert presenting (or evaluating) the evidence are scrutinized. Therefore we wholeheartedly agree with, for instance, Champod et al. (2001) in the call for a proficiency practise test. The application of a blind test in which candidates are subjected to a great variety of earprints, including prints offering low evidential value, may gain earprints, and earprint experts, a full-fledged status and acceptance in the forensic community. It may provide a starting point for earprints to be judged for their true merits.

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- *Prints that do not offer high evidential value are still useful in forensic investigations, as they may be used to exclude potential suspects, or raise attention to others.*
- *An opinion on the individualization of an earprint should be expressed using a probabilistic statement and not in absolute terms.*
- *Both the forensic investigators and the judiciary should be aware of the consequences of a probabilistic view on individualization, and of the terminology involved.*