Forensic Science International 206 (2011) 12–18

Contents lists available at ScienceDirect

Forensic Science International

journal homepage: www.elsevier.com/locate/forsciint

Review article

Uniqueness in the forensic identification sciences—Fact or fiction?

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ARTICLE INFO

Article history:
Received 24 March 2010
Received in revised form 30 July 2010
Accepted 4 August 2010
Available online 15 September 2010

Keywords:
Forensic science
Uniqueness
Individualisation
Fingerprint
Forensic odontology
Toolmark

ABSTRACT

Fingerprint analysts, firearms and toolmark examiners, and forensic odontologists often rely on the uniqueness proposition in order to support their theory of identification. However, much of the literature claiming to have proven uniqueness in the forensic identification sciences is methodologically weak, and suffers flaws that negate any such conclusion being drawn. The finding of uniqueness in any study appears to be an overstatement of the significance of its results, and in several instances, this claim is made despite contrary data being presented. The mathematical and philosophical viewpoint regarding this topic is that obtaining definitive proof of uniqueness is considered impossible by modern scientific methods. More importantly, there appears to be no logical reason to pursue such research, as commentators have established that uniqueness is not the essential requirement for forming forensic conclusions. The courts have also accepted this in several recent cases in the United States, and have dismissed the concept of uniqueness as irrelevant to the more fundamental question of the reliability of the forensic analysis.

Contents

1. Introduction

Recently, the assumption of uniqueness for any particular forensic feature has come under fire from several sources, the most prominent being the 2009 National Academy of Sciences report [1], which concluded that 'in most forensic science disciplines, no studies have been conducted of large populations to establish the uniqueness of marks or features'. Perhaps more importantly, it also stressed that the reliability of such disciplines could not be demonstrated by reference to uniqueness. Such criticism had previously been voiced by other academics, who not only question the so-called 'proof' of individuality posited by forensic practitioners, but the absurdity of claiming such an unprovable notion [2–5].

Most of the studies attempting to prove the uniqueness of a particular forensic feature suffer flaws that render their conclusion questionable. Acknowledging this, proponents of the uniqueness concept have argued that no one study ever proves any scientific

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doi:10.1016/j.forsciint.2010.08.004

matter beyond doubt, and that evidence for uniqueness is duly affirmed through the acquisition of knowledge via several sources. This position fails to realise that convincing evidence cannot be derived in this manner when the sources themselves are not merely flawed, as all studies inevitably are, but doubtful. The sources cited as contributing towards the evidence for uniqueness include the anecdotal and experiential, biological, and mathematical, yet all of these approaches suffer disadvantages that result in little faith being able to be afforded to their conclusions.

2. The evidence for uniqueness

2.1. Anecdotal evidence and experience

Fingerprint examiners, odontologists, handwriting experts, firearms and toolmark experts, have all at some stage argued that uniqueness exists because as yet, in the history of their discipline, no two objects have been found to have an exact duplicate. The claims of 'never observing an identical match' may be true, but they rely on the assumption that every examiner remembers the details of every object ever examined, and, even if only subconsciously, they have then 'compared' all of the objects they happened to examine with one another. Such a proposition is highly dubious, and relies on claims and observations that have neither been recorded nor compiled in a systematic manner [2]. More importantly, attempts to affirm the uniqueness proposition using anecdotes and experience rest on pure inductive reasoning. Several authors have cited induction as being inappropriate for application in forensic science research, noting that 'science' arising from pure inductivism gave us the practices of bloodletting and phrenology [6]. Modern scientific and philosophical thinking favours the hypothetico-deductive model and attempts have been made to design frameworks that apply this method to forensic individualisation [7]. As an approach to the verification of scientific knowledge, pure induction fell out of favour during the epoch of Sir Francis Bacon in the 16th century.

The work of Hume demonstrated that there could never be any certainty in induction, even for those inductions that have never been disproved by the occurrence of a contrary [8]. This is because induction necessarily invokes a positivistic approach, where the theory rests on the assumption that the future will resemble the past—but there is no logical reason to assume this [9]. Accumulation of positive instances simply cannot lead to a conclusion of certainty.

Nonetheless, one such argument for the 'proof' of uniqueness using observational experience follows the line of 'I have observed n number of samples, and none of them are the same. Therefore, I can assume that no sample will ever be the same as any other.' Evidence from a relatively small sample of human beings gives us no reason at all for doubting the existence of an identical set of fingerprints (for example) somewhere in the world. Additionally, there is no mechanism which *prevents* the occurrence of two people sharing the same fingerprint, no 'check and balance' to ensure that once one fingerprint pattern has manifested itself in human friction ridge skin it will never appear again [9], as is true for any forensic characteristic.

Experience fails to advance the uniqueness argument to any significant degree even in significantly smaller populations than that of the entire world [5]. Even in modest population sizes, there is a high probability that potential matches would be missed in conducting a random comparison exercise, which is constrained by limited ability of humans to carry out the many millions of comparisons necessary to ensure that each sample was examined and compared with every other.

Intuitively, the likelihood of observing a *duplicate* characteristic, when such a characteristic is noted to be rare, is often thought to be even smaller. However, the probability of observing an event, after it has already been seen once, is always greater than the probability of seeing it when it has not been seen before [10]. For example, if a particular fingerprint has *never* been seen before, then we should only assume an upper bound match probability of 4.41×10^{-10}, according to the $3/n$ rule [11,12]. The probability of observing the same trait *again* in the world population, now that it has actually observed once, is 0.842—or nearly 85%.[1] This is counter-intuitive to most people. It is easy to conclude that when the probability of observing a particular characteristic is low, the likelihood that a second person would share that characteristic would be even lower, however to do so falls into an intuitive fallacy not supported by the mathematical analysis.

2.2. Knowledge about the process of formation

Fingerprint examiners often argue that because friction ridge formation is induced by the stresses and strains experienced by the foetus *in utero*, which are random and infinite, it is likely that they subsequently produce a random, infinite variety of friction ridge patterns [13]. Such reasoning begs the question rather than answering it, as it provides no better grounds for assuming the causal process itself is infinitely variable. Additionally, there is no logical reason why the same effect cannot be caused by different processes [9]. To make such a claim regarding the variety of forces acting upon friction ridge skin *in utero*, it would be imagined that some form of study should be conducted in order to assess the scope of variation in such variables as pressure, fluid dynamics, skin tension, temperature and so on, before concluding that such variables are infinite, or even extremely large [2]. It is not apparent that such a study has been conducted.

A similar argument occurs in forensic odontology. It is well known that the spatial arrangement of the dentition is partly influenced by local environment factors, such as the natural forces exerted by the oral musculature, and other external forces such as oral habits; tongue thrusting and thumb sucking, for example [14]. There is no logical reason to assume that because these forces remain largely unquantified in terms of their scope and their relative influence on the position of the teeth that they are infinite, and that this invariably means that the arrangement of the teeth is also infinite. Without studies demonstrating the magnitude and variety of forces acting on the dentition, assuming they are unique is pure conjecture.

2.3. Research

Propositions for the individuality of the frontal sinus initially relied upon observational studies from as early as 1935 [15]. The fundamental barrier to the acceptance of the uniqueness proposition by this research is the small sample size—in many instances, the sample involved less than 100 people [16,17]. Similarly, an early study in forensic odontology only used five pairs of twins [18], and a more recent study used only 33 maxillary casts and 49 mandibular casts from a total of 50 individuals [19].

Just when n is large enough to allow extrapolation to a population N is a matter of debate, yet mathematicians and statisticians have developed generally accepted tools to assist with this decision. The calculation of sample size is based on a statistical equation that will depend on how certain one wants to be that the induction would hold true. This is also known as the confidence

[1] The probability of not observing a particular trait in a given population can be given by $P(x = 0) = (1 - p)^n$, where p is the probability of any one person having the trait and n is the size of the population. The probability of observing one instance of the trait in a population is $P(x = 1) = np(1 - p)^{n-1}$, and the probability of observing more than one instance is $P(x \geq 1) = 1 - (1 - p)^n$. Therefore:

$$P(x > 1 | x \geq 1) = \frac{1 - (1 - p)^n - np(1 - p)^{n-1}}{1 - (1 - p)^n} = P(x|x)$$

level, and is a well-known concept in scientific studies. However, this statistical tool was developed for determining sample sizes for surveys, and is not applicable for pure observational research when the likelihood of observing an outcome is rare. This statistical model only works when positive instances occur routinely in the sample. Evidence from any random sample of human beings does not necessarily give us reason to believe that a particular characteristic is unique [9], and in fact, other authors have already noted that conclusions of identity cannot be based on pure probabilistic models unless unrealistic assumptions are made [20]. A truly random sample of a large number of human beings may indicate that none of them have the same mother; but we know that to conclude that not one person on the Earth shares the same mother defies common sense.

Researchers can abrogate this issue to some extent by relying on statistical modelling of *combinations* of traits that are known to exist in a population, providing sufficient variation in these traits exist. This is the basis for statistical analysis of DNA frequencies in the population, and a similar approach has been attempted in areas such as fingerprints and forensic odontology. One of the main concerns with the application of this technique to forensic characteristics is that the derivation of the probability that a particular trait will occur is often questionable. Many early studies simply assumed base-rate probabilities without attempting to verify the frequency of the trait in the population. Galton's work [21] is often lauded in the fingerprint community as proof of the individuality of the fingerprints. Scholars criticised this claim from as early as 1930 [22–26], because in deriving his final 'probability' that no two people on Earth would share the same fingerprint characteristics, Galton simply estimated the frequency of particular ridge details in the population. He made no attempt to experimentally verify these assumed frequencies.

Similarly, assuming that the probability of each particular trait occurring is *equal* in an individual, a flaw occurring in other uniqueness studies of the dentition [27], fingerprints [25,28,29] and toolmarks [30,31] does not represent reality. The major failing of these studies is that the authors do not attempt to verify their model assumptions with that of data derived from the population. It is therefore impossible to ascertain to what degree their model represents the true distribution of such traits in the real world. What such studies do represent is the number of *possibilities* of different forensic characteristics, but not the *probability* of any one of these appearing in the population.

The use of population data to model the frequency distribution of forensic traits allows a genuine probability to be calculated, but even this still fails to alleviate doubt regarding the conclusion that any particular characteristic is unique. One fundamental concern in any data derived from a survey is the risk that the samples are not truly random or representative of the target population. Representation of the entire world is a very difficult goal to achieve in a finite sample whose size is always limited by human endeavours.

Another concern regarding the use of population data is that regarding the particular distribution model used to assess it. The most valid studies for characterising the existence of physical characteristics in the population rely on generative models, where the distribution of traits is 'learned' by a computer program from a known data set. This should then be verified against a second data set, and accurate probabilities can then be calculated from this verified distribution model. This is one critique of the 50-K fingerprint study designed to address the uniqueness of fingerprints for a now infamous court case [32,33]. The authors of the 50-K study simply assumed that the distribution of data they obtained was binomial and based their calculations on this assumption, without actually analysing the frequency data. Other studies have also assumed that distribution of the trait is random, and have modelled probability estimates based on this distribution [27,34–36]. This assumption was proven false for fingerprints in the late 1980s [37], and is easily refuted for the arrangement of teeth by the results of any population oral health study [38–41]. This assumption of a random distribution has been recognised as contributing to significant overstatements regarding uniqueness [42].

Another more pervasive concern with probability models is that they all rely on the assumption that each individual trait is independent of any other, thus allowing use of the product rule to calculate the likelihood that two or more of the features would occur in combination. Some studies simply assume independence, such as the earlier fingerprint studies. Several frontal sinus studies have invoked product rule derivations in concluding that they are indeed unique [43], despite the existence of data indicating that such traits are highly correlated [44]. Other studies in the forensic literature recognise the existence of the problem, but suggest inadequate or arbitrary ways of dealing with it [45].

Even in DNA analysis, it is accepted that complete independence of alleles is unlikely, however, studies have allowed the best-estimation of a constant q that is incorporated into the calculation of the random match probability for DNA samples in order to compensate for this fact [46]. While this is not a perfect solution, it goes at least part-way to ensuring a more realistic probability estimate. At this stage, the influence of dependence remains largely unstudied, and thus unquantified, for most other forensic markers.

3. The 'quantification' of uniqueness

Regardless of the method used to arrive at the probability of a particular forensic trait existing, extrapolation to uniqueness from these results still involves a 'leap of faith' [47]. This is because the probability of the same series of markers appearing more than once in the population should technically be zero in order for a trait to be considered truly unique [5]. This is impossible to derive using probability formulae, as it necessarily involves use of multiplication, based on frequencies of the individual characteristics occurring in the population. The probability of observing such a characteristic either alone or in combination with others is always *greater* than zero, which implies that there is always the probability that a duplicate exists, no matter how small. The leap of faith occurs when the practitioner 'rounds down' this probability to zero and then claims uniqueness.

Even arriving at a very *low* probability of encountering a match via statistical modelling does not 'prove' anything. It is a common fallacy that people assume when the probability of sharing a characteristic is given as less than 1 in 6.8 billion, the approximate population of the Earth, then this proves that no one else on the Earth could possibly have the same characteristic. In other words, uniqueness is proven when $P(x|x) \leq 1.47 \times 10^{-10}$. The fallaciousness of this reasoning is exemplified by the familiar 'birthday problem', where in a room of only 23 people, the probability that two people in a room share the same birthday is actually greater than 50%. For a room of 99 people, the probability exceeds 99%, or 0.99. Even though the number of possible birthdays exceeds the number of people in the room by a factor of three, there is almost a 100% chance that someone in the room will share the same birthday [48].

Some have argued that it is safe to assume uniqueness only when the probability of encountering a duplicate characteristic exceeds the reciprocal of the population by several orders of magnitude [4,49]. This appears contrary to the uniqueness concept, as by its own definition, uniqueness implies that there will *never* be a repetition of the same arrangement of friction ridge skin, dentition, toolmark patterns and so on. In other words, the possible number of combinations must be infinite. One should consider the total number of people ever to have lived on the Earth, in addition to the number of people yet to be born, in order to assert that a particular characteristic is truly unique [9]. Implying that

these former and yet to be born persons need not be considered in the equation would also imply that 'uniqueness' only holds for a certain population size. The reasoning that 'uniqueness is true only for numbers less than 10^x, but not for greater than 10^y' makes no sense; as noted before, there is no 'check and balance' that ensures that no repetition occurs below a certain number. Even if the claim of uniqueness is justifiable when the match probability is infinitesimally smaller than the reciprocal of the population, one can still be sceptical of such claims, because it is so difficult to establish that the models used to arrive at such probabilities are realistic or accurate [11].

4. The logic and interpretation of uniqueness studies

Several studies often cited as 'proving' the uniqueness of a forensic marker actually make no such claim. Rather, the proponents have themselves inferred a uniqueness proposition, based on misinterpretation of the study's results or conclusions. Authors of forensic odontology literature frequently cite an identical twin study [18] that concludes that identical twins do not have the same anterior dental arrangements. This may be the case. However, the inference from this study that the dentition is unique may represent the interpretation of the reader rather than the authors. The original authors themselves do not make such an explicit claim, limiting themselves to the conclusion that 'even so-called identical twins are not identical'. Similarly, a more recent study on the similarity of twin fingerprints [50] does not draw any conclusions regarding uniqueness, only on the similarity of twins versus non-twins.

Assuming the results of twin studies allow us to draw conclusions regarding uniqueness misrepresents the purpose of twin studies. Twin studies are useful for determining the heritability of traits by using controls where the genetic influence is supposedly the same, and therefore any observable differences between monozygotic twins can reasonably be assumed to be due to other factors. If the trait were solely determined by genetics, and assuming equal gene expression, the twins should exhibit exactly the same characteristics. The only logical conclusion that can be drawn from the results of monozygotic twin studies that demonstrate that twins do not share identical forensic traits is that the trait itself is not solely determined by genetic factors.

Twin studies can give us information regarding the variation present in any forensic feature in populations who are genetically identical. Such information may provide us with evidence that twins may have *more similar* forensic features than non-twins. This might also provide clues as to the relative influence of genetic versus other factors in the development of forensic features, but this information cannot logically lead us to the conclusion that the feature is way unique, it can only lead us to a statement regarding the amount of similarity between twins and non-twins. To draw any conclusions regarding uniqueness represents a failure of logical argument [2,5]. More recent twin studies reach sensible conclusions based on this fundamental limitation, but in doing so, end up *not* being about uniqueness.

Studies of consecutively fired bullets and cartridge cases suffer a similar logical limitation. Firearms examiners claim to rely on the premise that no two gun barrels will leave the same mark on a fired bullet or cartridge casein order to support their identification [51]. This proposition arises from studies of consecutively rifled barrels that demonstrate differences in either the markings transferred to a bullet [52], or on the internal barrel surface itself [53]. It is assumed that markings from consecutively manufactured or rifled barrels are more likely to be similar than those from random guns. This, in turn, rests on the prior assumption that the possibility of two non-consecutively manufactured barrels sharing the same pattern is zero. The fact that consecutively rifled or manufactured barrels do not leave identical marks on bullets or cartridges is useful for advancing the argument that 'examiners can distinguish between bullets fired from two guns that were consecutively manufactured', but this does not directly address the concern that another gun could possibly have left the same pattern of marks. The fact that two consecutively manufactured barrels do not share the same characteristics does not necessarily address the possibility of a random match. Therefore, such studies also fail to provide evidence of uniqueness, as such a conclusion cannot *logically* be drawn from the data obtained in the study.

Ironically, several studies attempting to quantify the individuality of forensic features such as the frontal sinuses [54] and fingerprints [3,55] provide more evidence to the contrary. These studies have demonstrated that images from the same source may display greater variation than that seen in images taken from different sources, using a particular method of quantification. This degree of overlap in the similarity between images from the same and different sources suggests that the trait is *not* quantifiably unique, at least using the methodologies used in these studies, or that the quantification method itself is fundamentally flawed.

5. Uniqueness as a cultural ideology

The concept of 'uniqueness' has more the qualities of a cultural meme than a scientific fact [56], a term used to described a 'unit of cultural transmission'; a piece of 'thought' transmitted from person to person [57,58]. In this context, one explanation for the origin of the related tenet 'nature's infinite variation' was its support for the existence of God [59,60]. To deny nature's infinite variation was to deny God's infinity—a claim that would have been considered nothing short of heresy. Fingerprints have been held as a paradigm of uniqueness since the early 20th century, and have even been used as 'proof' of claims of forensic uniqueness such as that of fingernails merely by anatomical association [61,62]. The high esteem of fingerprints is reflected in the modern terminology DNA 'fingerprinting'. Few realise that this belief in the uniqueness of fingerprints, first suggested in the late 19th century, represents a continuation of a particular notion that fitted the appropriate cultural ideology of the time, and through social and cultural forces has come to be accepted by subsequent generations—it is not necessarily the result of robust scientific evidence [22].

20th century philosophers and sociologists have also posited that there is a fundamental human desire to see oneself as unique, stemming from a primitive emotional need [63]. Humans have a fundamentally strong desire to *want* to believe in uniqueness, even in the absence of definitive proof. Moenssens has stated that the belief in the individuality of forensic traits rests on what he terms the 'Snowflake Syndrome' [64]. Demonstrating another instance of the cultural meme, snowflakes are often singled out as the paradigm of uniqueness. Most people believe that no two snowflakes are alike because of the enormously large number of possible ways to arrange the approximately 10^{15} molecules in the average snowflake, which by contrast, dwarfs the number of snowflakes predicted to have ever existed [65]. But to say that such arrangements are mathematically possible should not imply that they are physically possible. Almost certainly some arrangements simply could never exist, due to the restrictive nature of inter-molecular interaction in solid crystals. Additionally, similar arrangements would undoubtedly be perceived as exactly the same arrangement at the observer level [3]. In fact, two snowflakes that *were* visually identical were found in 1988 by a researcher who was documenting snowflakes for the National Center for Atmospheric Research, exploding the myth [66–68]. Despite the fact that there is more persuasive evidence to the contrary, the concept that no two snowflakes could be identical appears to persist amongst the general population.

6. Uniqueness is largely irrelevant to forensic practice

There is virtually no argument that at least on some level, everything is 'unique'. More recently, attempts at proving uniqueness in the forensic sciences have taken advantage of modern technology such as computers and imaging devices, and then use complex mathematical models in order to calculate the probability of random match [19,69]. Such data have little practical significance when the real-life forensic analysis is not carried out in the same way. The fact that an imaging device and computer is able to distinguish between similar dentitions, or fingerprints, bears no relevance to the day-to-day comparisons that are done largely by the human eye. This was demonstrated in a recent study of dentitions that were considered physically unique, but failed to be reliably distinguishable when compared using the resultant marks made by the models on cadaver skin [70]. The fact that the dentitions could be considered unique, even as a concept limited to the finite population available to the researchers, becomes irrelevant when considering the task required of the odontologist.

Some experiments regarding the uniqueness of fingerprints have used duplicate images in order to set a 'match' score. Fingerprint examiners do not declare matches on the basis of comparison of the *same images*, they do so from *different images* taken from the *same finger*. Examiners already widely acknowledge that no two fingerprints from the same finger will ever be the same, and thus the comparison of duplicate prints in order to ascertain the definition of a 'match' is unrealistic, and unfairly biases the results in favour of the hypothesis that all fingerprints are indeed unique [3,71].

Uniqueness is also irrelevant regarding the fundamental question of identification, and hence irrelevant to the forensic practitioner. The uniqueness proposition is simply a justification to 'round up' from an unspecified level of uncertainty to being 100% certain. Others, via different epistemic paths, have considered pursuit of the implications of uniqueness to its logical end, and have also reached a similar conclusion that uniqueness is not the basis for individualisation [2,7,56,72]. Uniqueness is invoked as a necessary assumption for the '100% certainty' behind forensic conclusions of a 'match', but this is absurd, as the very process by which a match is declared *must* result in some degree of discrepancy as a direct result of the uniqueness proposition that 'no two objects are ever the same'. Requiring an exact match would set an unattainable standard in forensic science, and would be contrary to the uniqueness proposition that everything is so. Therefore, conclusions regarding identity of source result from the relevant 'agreement' between source and object properties, and can only ever lead to a probabilistic conclusions—there is a point at which the number of matching characteristics can only make it *more likely than not* that the tool was the source of the mark [73]. The stronger the match between an object and its impression, the *more likely* it is derived from that object.

7. Uniqueness is largely irrelevant to the legal system

The condition of uniqueness is also largely irrelevant to the fundamental questions posed by the legal system [2]. The question of whether a particular forensic assay is accurate is far more important than that of uniqueness. Consider an example where the random match probability for any particular forensic feature is calculated to be 1.0×10^{-12}. Under several authors' propositions, we may be justified in deciding that this particular feature is unique. However, it also becomes apparent that the error rate for matching this particular feature, dependent on such things as the quality of the sample, the prowess of the practitioner and so on, might be 0.1%. In other words, the result is wrong about 1 out of every 1000 times. The issue of 'uniqueness' in the context of a remote possibility of a match becomes largely irrelevant, because even if the person's fingerprint *is* unique, the probability that the practitioner has falsely matched the print is a billion times larger, and arguably has far more relevance to the assessment of the evidence.

Many practitioners choose to use the term 'individualisation' rather than 'uniqueness', in recognition of the fact that uniqueness is unproven, however, individualisation can only occur without the underlying assumption of uniqueness when the source is part of a known, finite set. The term 'individualisation' necessarily encompasses the uniqueness proposition in most forensic work because the forensic examiner has no way of knowing whether the source is part of a finite set or not. The inclusion (or exclusion) of potential sources from the set can only be assessed by considering other forms of evidence, and this task is properly carried out by the trier of fact—not the forensic practitioner [4,47,72]. The forensic examiner should therefore not use terms such as 'unique' or even 'individualisation', as they are not issues the forensic practitioners should concern themselves with; these are issues for the judge and jury. To claim that a fingerprint or bitemark has identified someone 'to the exclusion of all others', or has been 'individualised' to only this person, usurps the jury's role as the rightful assessor of the evidence, and implies that the practitioner may have inappropriately considered other evidence in reaching their conclusion. The forensic expert is there to provide his or her expertise in the interpretation of the forensic evidence only.

Judges have also recognised that uniqueness bears no relation to the ultimate issue of identification. From the prospect of ensuring admission of forensic testimony in court, studies proving the uniqueness of any particular characteristic are unlikely to prove helpful. Gertner J noted in *US v Green* [74]; 'But even assuming that some of these marks are unique to the gun in question, the issue is their significance, how the examiner can distinguish one from another, which to discount and which to focus on, how qualified he is to do so, and how reliable his examination is.' The concept of a gun leaving marks on a bullet 'unique to that particular firearm' was noted, but dismissed as avoiding the fundamental issues.

Kwan's logical analysis of identification theory reveals that identification can never be a certain conclusion, but there exists a threshold, or series of thresholds, at which point the likelihood of identity is proportionately higher or lower [73]. Determination of these thresholds becomes a key issue, and these need to be determined via a series of reasoned, valid experiments. Additionally, the effect of phenomena such as bias, error, variation in examination technique, standards and other considerations will also influence the relative certainty of a conclusion, and these too need to be described and quantified in order to provide the trier of fact with a reasonable estimation of the reliability of any forensic analysis.

8. Conclusion

Philosophers specifically avoid arguing for the falsity of the proposition of uniqueness itself, instead restricting themselves to the argument that the theory, even if it is true, can never be known to be such, and that there is no such reason for believing such a theory, as one could never exist. The dictum of philosophy therefore tells us that uniqueness is not an establishable proposition, and belief in such represents 'a highly dubious snatch of metaphysics ... a philosophical assumption rather than what it is presented as being—a hard headed scientific conclusion' [9]. As Thornton concluded in his original article exploring the possibility of two snowflakes the same existing; 'unlike snowflakes, gun barrels [fingerprints, tools and dentitions] are not made in clouds, and the proof of uniqueness of other objects must be based on yet other grounds' [65].

Studies attempting to provide convincing evidence that any feature or combination of features is unique face insurmountable issues, most of which cannot be overcome using modern-day experimental techniques. Stoney recognised nearly two decades ago that attempting to 'prove' uniqueness using statistics was a 'ridiculous notion' [47], yet research continues to this day. Others have also called for abandonment of terminology such as 'individualisation' for the reasoning described in this paper [75]. For those that have attempted to prove uniqueness, analysis of their methodology fails to allow much faith in their conclusions. Even considering these efforts in combination, the evidence for the individuality of any characteristic remains minimal at best when considering their collective flaws.

These issues become secondary with the realisation that 'uniqueness' is not relevant to the theory or practice of forensic identification, or to the courts, and that 'individualisation' is the task of the judge or jury. The forensic expert's role is not to *individualise* or even to *identify*, based solely on the forensic evidence presented to them—it is to provide the trier of fact with additional probative information, within the bounds of their expertise, that may strengthen or weaken the likelihood of guilt. Experts should not usurp the trier of fact's role by drawing prejudicial and unsupportable conclusions such as 'to the exclusion of all others' or other thinly veiled metaphors for the uniqueness proposition.

Directing forensic research resources towards proving uniqueness has been criticised as diverting resources away from more useful projects [2]. To attempt to prove uniqueness also puts the cart before the horse when more basic issues such as the meaning of the term *match*, the quantification of level of certainty and the standard of practitioner performance—all of which will influence how we actually define the term 'unique'—are yet to be agreed upon. Areas such as fingerprints, odontology, and firearms and toolmark analysis appear to defend the uniqueness proposition largely due to a misunderstanding of what the criticisms of their discipline are. The assumption of uniqueness has been considered an 'excuse' for the lack of research data regarding the true likelihood of any particular trait being considered a match. It is far easier to assume uniqueness than it is to come up with actual quantification of match probabilities [76], and as such, the uniqueness proposition acts as a proxy for serious data collection, misleads the trier of fact into thinking conclusions are more certain than they are, and distracts from the more important issues that contribute to the likelihood of error. The reality is that uniqueness is impossible to prove, and is not anywhere near as relevant as some may claim; mistakes and misidentifications are not made because someone has an identical fingerprint to someone else in the world. They are made because of guesswork, poor performance, lack of standards, bias and observer error. There are few valid reasons to claim uniqueness, or to continue this fruitless search for what remains a philosophical ideal.

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