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Fingerprint Identification and Science: a comparative study of attitudes of criminal justice sector professions

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This thesis is the result of the author’s original research. It has been composed by the author and has not been previously submitted for examination which has led to the award of a degree.

Signed: Date:

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Abbreviations

ACE	Analysis, Comparison and Evaluation
ACE-V	Analysis, Comparison, Evaluation and Verification
AFIS	Automated Fingerprint Identification System
CID	Criminal Investigations Department (of London Metropolitan Police)
CSE	Crime Scene Examiner
DNA	Deoxyribonucleic acid (in reference to usage as a forensic identification tool)
FBI	Federal Bureau of Investigation
IAI	International Association of Identification
ISPI	International Society for Personal Identification
NAS	National Academy of Sciences
NPIA	National Policing Improvements Agency
SPSA	Scottish Police Services Authority
SWGFAST	Scientific working Group on Friction Ridge Analysis, Study and Technology
TWGFAST	Technical Working Group on Friction Ridge Analysis, Study and Technology
UK	United Kingdom
USA	United States of America

Abstract

Fingerprint identification is currently undergoing a high level of scrutiny. A field which has been relatively unquestioned for 100 years suddenly finds itself under a barrage of questions on issues such as bias and error rate in its processes, and statistical probability or absolute certainty in its reported findings, which it has not had to deal with before. Commentary and argument over these issues has been developing steadily over the past ten to fifteen years, culminating currently with the publication of the National Academy of Sciences report on forensic science in 2009 and the ongoing Scottish Fingerprint Inquiry.

It is clear from the available literature that there are a wide range of viewpoints regarding these issues; however the general viewpoint of practitioners may legitimately be different from those who actively publish. There has been no previous work done to gather views on these topics from practitioners, but if fingerprint practice is o change to attempt to solve some of the current issues, it is essential to understand the true views of the profession itself, as well as the opinions of others working closely with the fingerprint profession. This study aims to address this lack of information.

An attitudinal survey of fingerprint practitioners and other forensic professionals was conducted to collate views on current issues around the scientific nature of fingerprint identification. The survey findings were significant at the 1% level. The results have shown areas of commonality and disagreement between different professions, differences in attitude between practitioners in different countries, and considerable confusion and misunderstanding about the nature of science.

1 Introduction

1.1 Fingerprint History

It is unclear when people began to consider friction ridge skin on the surface of the fingers and hands as unique to an individual. Archaeologists have discovered fingerprints on ancient clay and pottery, and in China Emperor Ts-In-She (246-210BC) was the first to use a clay finger seal to seal documents [1]. After this, the Chinese began using finger and hand prints to signify genuine documents or contracts. It is unclear however whether these marks were a way to express personal involvement, or a belief in their identifying nature.

Fingerprints came to the notice of the West through the British Empire. Sir William Herschel worked as a civil servant in India in the late 1800s, and whilst there he observed local people using their fingerprints to sign contracts. He carried out his own studies and was the first to demonstrate the permanence of friction ridges, taking his own fingerprints over a number of years and comparing the results.

Sir Francis Galton, an eminent scientist working in Britain in the late 1800s, became aware of Herschel's work on fingerprints, and corresponded with the civil servant about his study. Galton adopted fingerprints as a reliable means of identification, and wrote several books on the subject. It is likely that his high standing in the scientific community enhanced the perception of fingerprinting in these developmental days.

Sir Edward Henry, another civil servant working in India, became Inspector General of Police for Bengal Province in 1891. Working in the same region that Herschel had been earlier, he also became aware of the use of fingerprints, and after reading Galton's book he began work on developing a fingerprint classification system. In Bengal Province he instructed that prints from all ten fingers of criminals be taken on arrest, and assigned two police officers; Khan Bahadur Azizul Haque and Rai Bahaden Hem Chandra Bose to work on the problem of classifying and filing the obtained fingerprints. They eventually developed a suitable system that was adopted in India in 1897.

At the time of these developments, it became clear that there was a problem in Britain with the identification of repeat offenders. An anthropometric system called Bertillonage, which used measurements of various parts of the body, was adopted, but failed to solve the problems. In 1900 a new review was commissioned and Lord Belper led a committee which looked at the issue. It heard from various experts of the time including Sir Edward Henry, and concluded that a fingerprint system of identification, using Henry's method to classify the fingerprint forms, should be adopted. Henry was recalled from India and appointed Assistant Commissioner of the Metropolitan Police in charge of CID. In 1901 the first Fingerprint Bureau in the UK was formed at Scotland Yard, under the control of Sir Henry. The fingerprint system brought in at this time is essentially the same as the one used today to identify repeat offenders; taking a set of ten fingerprints at the time of arrest, and comparing these with those already on file. Henry's system of classification was used in bureaux in the UK until it was superceded by computer searching systems, being used as late as 1991. Presently, fingerprint forms are filed by reference number, rather than Henry's system of classification based the patterns on the fingers.

The first person credited with suggesting the use of fingerprints to identify individuals at scenes of crime by comparing fingerprints left behind at the scene was a Scottish missionary and doctor, Henry Faulds. Like Herschel and Henry he also observed fingerprints being used in the East, when he travelled as a missionary to Japan. However his ideas were not as well received as Herschel and Henry, and when he offered in 1888 to set up a Fingerprint Bureau at New Scotland Yard his offer was turned down. It is not known why Faulds' ideas were dismissed at the time; it has been suggested that he did not move in the right circles of Victorian society [2], but also that Faulds was simply rather an aggressive and eccentric character [3]. Although he was the first to suggest using fingerprints to identify individuals at scenes of crime, Faulds grew out of favour with the new method of identification. He wrote several papers and books claiming that the power of fingerprints was being exaggerated by the police who had now adopted it as a powerful tool for identification, and that the development of fingerprint identification required ‘cautious common sense’ which he felt was not being applied [4]. It is interesting to note that he expressed many of the concerns that are now hampering the fingerprint profession today.

Fingerprints began to be used in criminal cases in the late 1800s. The first fingerprint evidence used was in Argentina in a murder case in 1894, the first example of fingerprint evidence in the UK was in London in 1902, and it was first used in a UK murder trial in 1905. These British cases were the beginnings of fingerprint evidence being accepted as competent evidence by the courts in the UK; that is, evidence which can be accepted on its own merits and does not need to be corroborated by any other evidence. It was not long before palm, foot and toe prints were also being accepted in UK courts.

The development of fingerprints as a system of identification of criminals, and later as a way of identifying perpetrators through marks left at scenes of crime, was essentially conducted by police and non-scientists [5]. Although early developments were by scientists such as Galton, it quickly became the domain of law enforcement. While fingerprint identification was the domain of the police, the biological development of the friction ridge skin was an area of interest to several biologists and anatomists, and key researchers in this area were Inez Whipple, Harris Hawthorn Wilder, Harold Cummins, and Alfred Hale, all working in the first half of the twentieth century.

1.2 Current fingerprint practice

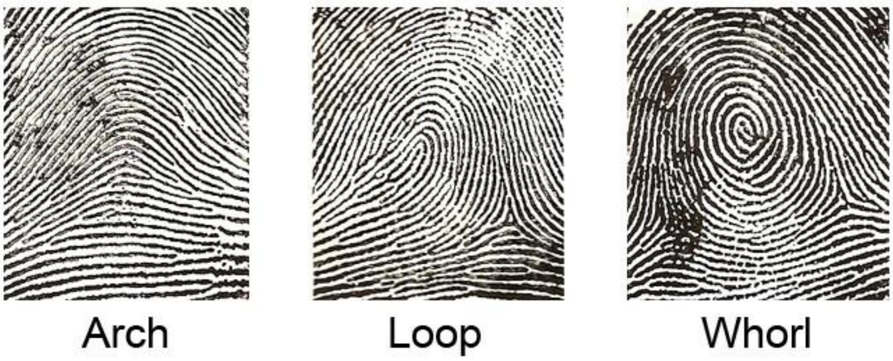
In the current criminal justice system fingerprints are essentially used in two ways. When an individual is arrested a set of their fingerprints are taken. These are then checked against a computer database of all known criminals to search for a match, preventing false names and misinformation from disabling the system.

Their second function is the one for which they are better known. Fingerprints left behind at the scene of a crime can be recovered, and these chance impressions, known as marks, can then be compared against the collection of known fingerprints taken from criminals. This comparison can begin either with a suggestion of a suspect from the police and a comparison between the recovered mark and a fingerprint form, or with a search of the mark against the entire database of forms, using a computer system. In the UK the system is Ident 1, and in North America it is AFIS (Automated Fingerprint Identification System). Fingerprints can also be used in other ways: to identify a dead body through either a computer database search or comparison against fingerprints recovered from the dead person's possessions; to link a person to an item of property; to establish the identity of an amnesia victim.

A fingerprint is an impression of the pattern of ridged skin found on the finger which is left behind when a surface is touched. However the word 'fingerprint' is a general term which can be used to describe prints left by fingers, palms, or toes or soles of the feet; these are the areas of the body which have friction ridge skin. The word 'fingerprint' can also be transposed to mean the ridged skin on the finger itself as well as the print left behind by the finger. This mixed use of the word is the source of some of the issues around uniqueness which will be discussed later.

Friction ridge skin is made up of a series of ridges and furrows which flow across the surface. The friction ridges do not flow in even lines, but form patterns. The ridges on the fingertips, the area most people associate with fingerprinting, flow to form 3 general pattern types: arches, loops and whorls.

Illustration 1: fingerprint pattern types.

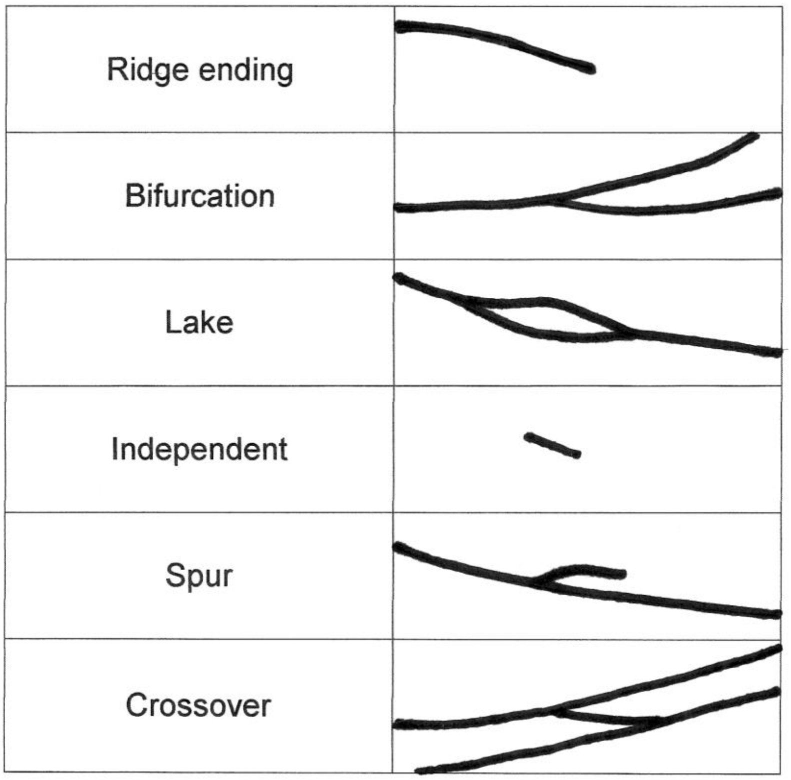


[6]

The ridges on the palms form less striking patterns, but will take on general characteristics for different areas of the palm. For example the area at the base of the fingers is likely to contain several triangulating areas of ridged skin, known as deltas. The large fleshy area on the side of the palm under the little finger is the most likely to contain patterns such as loops or whorls, but more frequently is simply an area of straight flowing ridges.

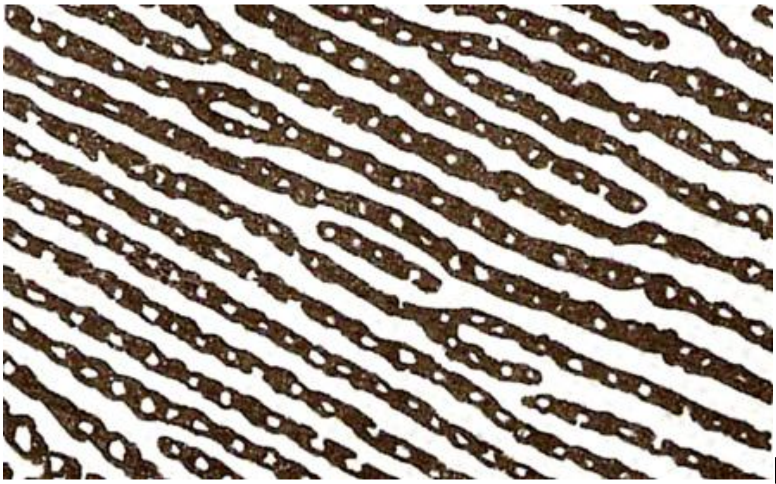
Looking at the ridges themselves, they do not flow evenly and uniformly, like lines in a ploughed field. Instead they bend and curve, stop and start, join together and split apart. The two most basic features of the ridges themselves are a ridge ending, where a ridge comes to a stop, and a bifurcation, where a ridge splits in two. These are known as ridge characteristics, or minutiae, and are the backbone of fingerprint identification. There are other specific features, shown in the illustration below, which are combinations of ridge endings and bifurcations.

Illustration 2: fingerprint ridge characteristics.



Until recently, these features were the main concern of the fingerprint examiner. They would look for pattern and ridge flow, and then more closely at the individual characteristics. However it is now more readily acknowledged that friction ridges have other features which can be used to identify. The ridges themselves are not smooth, instead they have uneven edges, which can become thinner or more bulbous at points along their length. The ridges also contain sweat pores, and these pores can be visible as a tiny dot on the ridge. The development of the use of these features was suggested in the early development of fingerprints, by Edmund Locard, but more recently and more completely by the Canadian fingerprint examiner David Ashbaugh who coined the term ‘ridgeology’, and also the words ‘edgeoscopy’ and ‘poroscopy’ to describe the analysis of these particular features [1].

Illustration 3: ridge pores and edge shapes.


[7]

These features are always present on the ridges of the skin themselves, but do not always present themselves on fingerprints, be they marks from a scene of crime or a print on a fingerprint form. Some individuals may have thicker ridges, and more prominent pores, and therefore these are more likely to transfer, but even that does not mean that the information will be visible on a print. This is a central issue when considering the current issues within fingerprints; a mark left at a crime scene does not fully represent the pattern of ridges found on the finger.

The other factor to take into consideration regarding ridge edge shapes and pore location is that these can be affected by dirt and other contamination even more so than ridge characteristics. A ridge may have a bulbous section, but a tiny amount of dirt, or excess developing powder, can give the appearance of a bulbous section although one is not present. As a result these features can only be used on very clear areas of print.

These three areas together can be categorised as the three levels of detail: 1^{st} level being the pattern type and ridge flow, 2^{nd} level being the ridge characteristics, and 3^{rd} level being the pores and ridge edge shapes. As well as these characteristics fingerprint examiners will also use creases and scars to aid in the identification process.

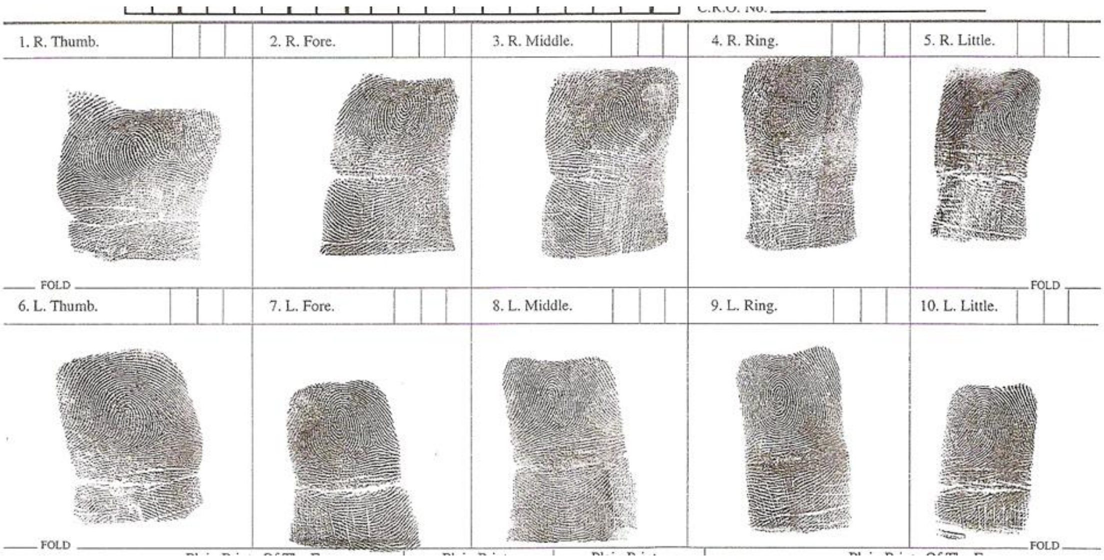
It is claimed the distribution and layout of these various features make an individual's fingerprints essentially unique [8]. The position of the ridges and ridge features is put in place during foetal development, and once their position is set within the dermal layer of the skin, it will remain unchanged throughout a person's life, unless the skin is deeply damaged by disease or penetrating injury. The pattern type corresponds strongly with the development and shape of fleshy pads called volar pads on the finger tips [9]. These pads develop as the hand is forming in the womb, and their size and position can be affected in two ways; genetic or hereditary effects, and physical forces acting on the developing foetus caused by disease or natural intrauterine pressures [1].

As the ridges form they take the path of least resistance over the topography of the surface, and so a high volar pad will result in a whorl pattern, a low volar pad in an arch pattern, and an off-centre pad a loop pattern. The development of the pattern type is also affected by the timing of the various stages of development, and bone morphology [9]. Due to the genetic influences, it is possible for family members to have similar pattern types, and because of the limited variety it is also possible for two unrelated persons to have similar pattern types. For this reason the fingerprint pattern type is an aid to identification, but it is not an individualising feature in itself.

The layout of the ridges themselves is also affected by genetics; but less so than the development of the pattern. Cells will group together to form ridge units, each one containing a sweat duct and pore. These ridge units will then fuse together to form the friction ridges, interacting to form breaks in the ridges and branching apart to form bifurcations. The process which governs this stage of ridge formation is unknown [9]. Due to the number of cells which make up the friction ridges, and the large number of genetic and physical variables which can influence their formation, there are a vast number of combinations possible in even a small area of friction ridge skin. There have been studies into the formation of these characteristics, or minutae, for clinical use. Studies have shown correlation in number of minutae between monozygotic twins, and also differences in quantity of minutae between males and females. There has also been correlations shown between finger and pattern type. These results show that there is a hereditary trait within the ridge formation [9], but the essentially random nature of the minutae formation and placement, combined with the wide variation possible, results in a unique layout of ridges. The wide variety is described by Champod et al [9]: 'ridge units may vary in shape, size, alignment, and whether they fuse to the next ridge unit or not. For example, some units are thinner than others, some have bulges on one side, and some misalign with the next ridge unit or fail to develop to maturity.' This understanding has come from studies of foetal development and the histology of the skin, conducted by biologists and anatomists throughout the 20th century. These studies mean that the uniqueness of fingerprints does not depend on the phrase 'nature never repeats', but has been demonstrated by scientific study [9].

Fingerprints can be left by chance, or they can be taken in a controlled manner, and fingerprint examiners will deal with both types of print. The fingerprint form is the result of a controlled method of taking fingerprints used by the police. Traditionally, the finger would be coated in ink and then rolled across paper, from nail edge to nail edge, capturing the largest possible area of ridged skin. Currently in the United Kingdom the ink and paper method is being phased out and replaced by an electronic means of capturing fingerprints called Livescan. This process involves rolling the fingers on a computer scanning device, and the ridge detail is captured electronically. Both of the above methods, when carried out correctly, will capture a large area of ridge detail for each finger, and therefore contain a vast amount of information.

Illustration 4: fingerprints on a fingerprint form.



This is not often the case when a fingerprint is left by chance. Whenever a person touches a surface there is a chance that a fingerprint will be left. The likelihood of a print being left will vary, being dependent on the surface which has been touched and how receptive it is to retaining the mark, on the substance the mark is left in, and on the individual donor. The most common means of leaving a fingerprint by chance is in sweat. The pores on the friction ridges are constantly exuding sweat, and when a surface is touched the sweat is left behind in the pattern of the ridges. Generally this type of fingerprint is practically invisible to the naked eye, and so these are often known as latent prints, from the Latin *latere*, meaning to lie hidden [9]. The fingerprint must therefore be treated in some way to make it visible. The most common means of recovering a fingerprint from a smooth, non-porous surface is by brushing on a fine powder and then lifting the resulting powdered mark using adhesive tape. The tape is then fixed to a transparent acetate sheet; the resulting item is called a ‘lift’. There are many other chemical processes which can be used to recover fingerprints, their use is often dependent on the type of surface on which the fingerprint has been left. Fingerprints can also be left by chance in a visible medium; in a liquid such as paint or blood, or a malleable substance such as putty. In these cases they would be recovered by photographic means.

Illustration 6: fingerprint left by chance on an object.

[10]

1.3 The fingerprint comparison process

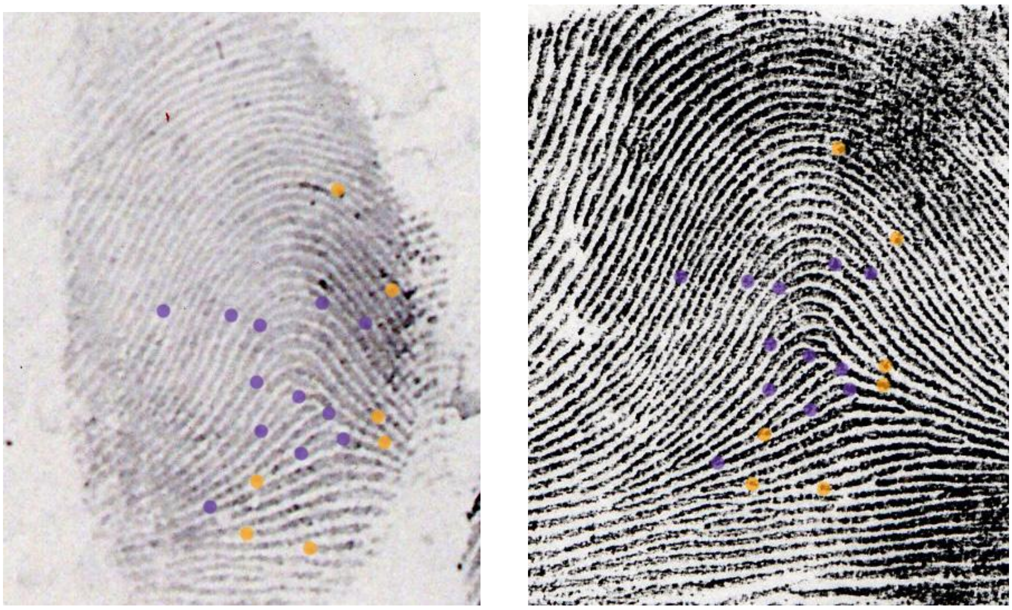
The comparison process for fingerprints is now generally referred to by the acronym ACE-V. This terminology was adopted in the UK in the 1990s, and originated in North America where it was first coined by David Ashbaugh, a Canadian fingerprint examiner [1]. ACE-V is an acronym which stands for Analysis, Comparison, Evaluation and Verification. Although this terminology was established relatively recently the method itself is not a new development, indeed it is generally accepted that this is the method by which fingerprint examiners have always carried out their work. ACE-V is simply a way to describe the process.

Table 1: Description of the ACE-V comparison process.

Name	Description
Analysis	The unknown mark is studied in detail. The examiner will look at the surface the mark has been left on, the substance it has been left in and the development medium. They will analyse the mark, looking at pattern type, ridge flow, scars and creases, and make a determination of possible digits it could be. Looking more closely, they will look for ridge features and clarity in smaller details such as pores and ridge edge shapes. If there is a low level of information contained within the mark it will be deemed *insufficient*; not enough detail is present to make an identification.
Comparison	The unknown mark is compared against a known fingerprint. The examiner looks for features in agreement, with none in disagreement unless there is an explanation for such disagreement.
Evaluation	The similarities found are weighed up in the examiner's mind, and a conclusion regarding identity is reached.
Verification	If the mark is identified, the process is then carried out from the beginning by another examiner.

These images demonstrate a sequence of features found in agreement on the unknown mark (on the left) and the known print (on the right). The yellow dots show ridge endings, the purple dots bifurcations.

Illustration 7: the fingerprint comparison process.



The process I have outlined above is the generally prescribed method for carrying out a fingerprint comparison [1] [9] [11]. However it is a very general description, in distinct phases, and I do not feel it is necessarily an accurate description of what a fingerprint examiner does on a case by case basis. I will return to this topic later when discussing the current concerns around fingerprint identification.

1.4 Current issues in fingerprint practice

After enjoying nearly 100 years of use by, and respect from, the courts as a dependable type of identification evidence, fingerprint practice now finds itself in an unrequested and undesirable spotlight. For most of the 20th century fingerprint examiners carried out their work, gave their conclusions to the court, and were a respected part of the criminal justice system. They had complete faith in their system, and the Law had complete faith in them, and they quietly and solidly got on with their job. But developments in the fingerprint field, and forensic science, in the final decades of the 20th century have brought about major changes, and the attitude towards fingerprint evidence has changed. Where once a fingerprint identification was accepted as just that, now fingerprint examiners are being asked to explain themselves: how did you reach that conclusion? How can you make that claim? Why are fingerprints unique? Can you give your conclusion as a probability? How can you say with certainty that is an identification? Is fingerprint identification a science? Should it be more scientific? What is its error rate? What do you base your conclusions on?

There is nothing wrong with these questions, and any logical, practical profession should be able to answer them but, since its development at the turn of the century, fingerprints has not had any cause to look deeply at itself. A fingerprint identification was a fingerprint identification, the fingerprint expert came to that conclusion, what else was there to explain? Individuals were trained, not as scientists, but as technicians, as individuals skilled in a particular discipline, able to carry out a highly skilled job. They were not trained to question concepts such as uniqueness or certainty, but to simply accept it as known fact. Now they were being asked to think like scientists, to speak like scientists, and to consider ideas that many had never encountered before such as statistics and probability. Disconcertingly, the general reaction of the fingerprint community was not to try to find answers to some or all of these questions, but instead to refuse that such answers were necessary. These issues began in two areas; the advent of DNA evidence, and the move towards a non-numeric system.

As fingerprint identification was developed there was always felt to be a need for a minimum number of points which were required to make an identification. Different jurisdictions had, and indeed have, different numerical thresholds:

Table 2 : examples of numerical thresholds by country.

Country	Points criterion
Italy	16-17
Germany, Sweden, Holland, Switzerland	8-12
UK (pre-2001)	16
South Africa	7
Belgium, Finland, Israel, Poland, Ireland, Greece, Portugal, Romania, Slovenia, Spain, Turkey, Japan	12

[9]

As evidence for court began to move away from technical to scientific evidence, this issue was reassessed. There was no definitive minimum number of points which could be given to ensure an identification. Also, ridge characteristics were not the only things being used to make an identification; other features such as ridge flow, pattern, scars, creases, and pores were also used, and these were not taken into consideration with a numeric standard. In a move to become more scientific, it was decided by the International Association for Identificaion (IAI) that there should no longer be a minimum points standard, as ‘no valid basis exists for requiring that a pre-determined minimum number of friction ridge characteristics must be present in two impressions in order to establish a positive identification’ [12]. This decision was reached in 1973, some time before the adoption of a complete non-numeric system in any jurisdiction. Despite this, many jurisdictions have continued with a numeric system, although the number of areas is becoming less.

DNA was introduced as a forensic identification tool in the 1980s, and was described as ‘DNA fingerprinting’ in an effort to connect it with what was considered the ‘gold standard’ of evidence at the time: fingerprints. It was not received without question; lawyers and judges were dubious of its ability and reliability, and posed critical questions of the new field in areas such as lab application and procedures, and probability calculations in reference to population genetics [13]. In these early stages DNA did not have all the answers to these criticisms, but scientists in the field carried out further studies and research and tightened their procedures, in order to answer the criticisms and concerns of the Judiciary. As a result DNA is now a familiar tool in the court room, and may even have replaced fingerprint as the evidence gold standard due to its rigorous scientific background.

It was not long after the acceptance of DNA as a method of forensic identification that questions began to be asked about other forensic sciences. DNA had presented itself as a science in court, with qualified and experienced scientists testifying and a wealth of scientific study to back up the findings and methodology. The standards that DNA had to meet in order to be accepted had laid down criteria for admissibility, and these were then put to other areas of forensic science, which were found to be lacking. In comparison to the development of DNA, most other forensic sciences have little serious scientific study behind them, and some, like fingerprint identification, were developed in the policing rather than academic arena, leaving them on less sure scientific ground. DNA could explain exactly where its probabilities for its results came from, while other forensic sciences were using a verbal scale without any scientific basis. DNA explained why it gave probabilities, and why is was not exact; fingerprint practitioners did not have a solid, scientific reasoning behind their ability to be absolutely certain about their identifications. DNA had provoked questions about its methods, statistical calculations, laboratory protocols and proficiency [13], and it had developed answers. When these same questions were put to the fingerprint profession they had no answers, and more surprisingly, they did not appear to rush to find them. Despite this, the fingerprint profession, particularly in the USA, was striving to be seen as a science, and this left it open to criticism.

Lawyers, academics, scientists and journalists began to take a closer look at fingerprint identification and its processes and procedures, and generally they were not impressed by what they found. Some examples of the criticism which began to be directed towards fingerprints are as follows:

‘bad science’ [14]

‘house with no foundation’ [15]

‘could the credibility of fingerprint identification actually crumble?’ [13]

‘the criteria for absolute identification in fingerprint work are subjective and ill-defined’ [16]

‘the myth that there is a “science of fingerprints” will thus be exposed for what it really is: an unfounded creation of law enforcement fingerprint examiners’ [17]

‘based on intuition, the examiner thinks he knows where to draw the line, but the question remains: what is the justification for such a judgement?’ [18]

‘defiant world of fingerprint experts’ [19]

Unlike DNA, as these criticisms began to appear, the fingerprint profession did not act. There was no push for research, indeed the IAI made no move to change its 1980 statement: ‘any member, officer or certified latent print examiner who provides oral or written reports, or gives testimony of possible, probable or likely friction ridge identification shall be deemed to be engaged in conduct unbecoming such member, officer or certified latent print examiner […] and charges may be brought about […] If such a member be a certified latent print examiner, his conduct and status shall be reconsidered’ [20]. Rather than conduct further research into their field, fingerprint examiners fell back on the dogma they had been taught – that no one, past, present or future, could share the same fingerprints with someone else. Therefore fingerprint identification could conclude that no one else on Earth could have left that fingerprint. In over 100 years no one had been found to share the same fingerprint features. Fingerprints were infallible.

Unfortunately this was an untenable position, which was demonstrated when errors in fingerprint identifications began to be found. Some of these were discovered through connected DNA evidence, others by disagreement between examiners. In the USA some fingerprint examiners were found to be faking results [13]. In the case of the Madrid bombing in 2004, senior Federal Bureau of Investigation (FBI) fingerprint examiners were found to have misidentified a fingerprint. In Scotland the McKie case in 1997 has caused similar controversy, although it is a more unusual example as the fingerprint examiners involved have not admitted to making a mistake. Both police employees and independent examiners have identified a fingerprint to a police officer, Shirley McKie, and yet other police employees and independent examiners have said it is not an identification. This has resulted in an undecided identification, and despite over 10 years of the most intense scrutiny ever given to a fingerprint comparison, it remains an unresolved issue: how can different examiners disagree, and even after discussion and demonstration, still disagree, if fingerprint identification is infallible?

These are just two examples of a larger number of discovered misidentifications and concerns. These have culminated in 2009, with the publication of the National

Academy of Sciences (NAS) report into Forensic Science in the USA [21], which is highly critical of pattern identification fields including fingerprint identification, and with the McKie Inquiry in Scotland, which may be the most in-depth analysis of the fingerprint profession yet carried out. Both of these investigations clearly show that there are many issues, both in fingerprint practice and forensic science as a whole, which still need to be resolved. The NAS report states that with the exception of nuclear DNA, no forensic method has been rigorously shown to be able to individualise a piece of evidence to a person [21].

The fingerprint profession still appears to essentially be in denial of what needs done. Some examiners do not feel there are any issues which need to be solved ('I, for one, have no desire for scientists to resolve 'vexing questions' which I do not consider exist' a statement made by John Berry [22]), others attempt to explain these issues with what is currently in place [23] [24]. But there are a small number of people beginning to work towards discovering answers to these questions, looking into issues such as probability, bias and the reliability of the methods used.

I would now like to look in more detail at some of these issues and how they relate to fingerprint examination, but before I do this I would like to begin with a general discussion of science. Many of these issues can be traced back to a central argument: is fingerprint identification a science? Questions of reliability, uniqueness, error rate and certainty in fingerprint evidence all incorporate views on whether the field is a science. As a result statements are made by many, but frequently without a reasoned opinion of what science is. I would like to begin this section by outlining the general arguments involved in attempting to define science, and then continue by taking these general discussions and considering them in the context of the specific field of fingerprints.

1.5 What is Science?

The scientific status of fingerprint analysis provokes forceful arguments. In my opinion the reason for this lies in the status given to science. Rightly or wrongly, at the present time, science is thought of as 'the ultimate form of objective and rational inquiry' [25]. A layman may state a fact, but if the same fact is stated by a scientist, it will carry extra weight. Stating something has been 'scientifically proven' gives it the appearance of reliability, dependability, even certainty. The general perception is that scientists are learned, respected, use a recognised methodology, and that their conclusions are sound. To be able to say a pursuit is a science, or scientific, will then bestow on to that pursuit these preconceptions.

The benefits of asserting your field is a science have resulted in a polarised struggle between those who wish to verify the probative strength, reliability and utility of fingerprint identification with the power of science, and those who feel that the scientific claims are not genuine or valid and therefore argue that it is clearly not a science. (It should be noted however that the debate is not as straightforward as these opposed positions suggest; there are fingerprint practitioners who claim their profession is absolutely a science, and there are those who claim it absolutely is not). This has been particularly hotly debated in the USA, where the courts have attempted to define what constitutes science. This still has not resolved the issue with regards to fingerprint identification, and indeed forensic science as a whole. The existence of a 'criteria list' for science as provided by the American law courts have led to claims that fingerprint practice meets all criteria, and other claims that it meets none.
A large proportion of those writing about the scientific nature of forensic science fields such as fingerprints make no attempt to discuss the nature of science, or to define it. On the rare occasion a definition is given, it does not seem to encompass the issue; 'science must be falsifiable in order to be separate from religion' [26]; 'for those of you who ought to be reminded the definition of science is an orderly body of knowledge with principles that are clearly enunciated' [27]. Both of these definitions demonstrate either very basic reading on the issue or a crude understanding of one of the most commonly quoted recent thinkers on the philosophy of science. These statements are acceptable for basic general knowledge, but not for published discussion and opinion, particularly when the issue is of scientific reliability, validity or admissibility. Both statements have counter-arguments.

The general population is very familiar with the word 'science'. It is commonly used in society, it is a staple of the school curriculum, we feel like we know what science is. But to define science, it's nature and it's defining characteristics, may well be impossible: 'it is highly unlikely that any simple-minded, one or two sentence definition of science will yield a plausible demarcation criterion that we can use to label and condemn as pseudoscientific those theories (and their advocates) that fail to meet the standards of good science' [28]. The study of the nature of science, is known as Philosophy of Science, and for over a century has found no conclusive answer. The average individual may believe that the concept of science and it's distinctive characteristics can be easily known, but it is not possible to neatly separate science from non-science. The concept of 'science' is not as easily definable as, for example, the concept 'triangle' [29].

The concept of science has evolved over time. Areas such as astrology and phrenology are now known to be superstition, when once they were considered scientific. Medawar described two different views of science as the romantic and the rational; one involving imaginative insight, the other the evidence of the senses. 'Is science an imaginative and exploratory activity, where the scientist is using his brain to take part in an intellectual adventure? …. Or is it a critical and analytical activity, where the scientist is someone who does not make an opinion without weighing up evidence?' [30]. The notions of 'romantic' and 'rational' appear opposing, but both these views appear to fit different aspects of what we might consider science to be. However the current view of science leans more towards the latter description: a critical and analytical activity, one where empirical evidence is gathered and assessed using objective methodologies before conclusions are reached. This is what gives science its epistemic authority, but I feel it is wrong to dismiss the first part of Medawar's description; the imaginative and exploratory aspect of science is also a key part of its makeup.

I have sought to establish that a simple definition of science is in all likelihood not something which can be achieved. But although there can be no straightforward definition, there are still essential features that are a part of science. There are also ‘myths’ of science; features which are often claimed to be key features of science but which in fact are common misconceptions.

The most pervasive myth about science is that it provides absolute proof. There is a general public perception that science provides proof. In fact all science is tentative; as evidence is gathered about a theory it can give support and validation to that theory, but it cannot prove it as true [31]. This misconception may rise from a confusion between deduction and induction. Medawar defines deduction as arguing from the general to the particular, and induction as arguing from the particular to the general [32]. It is not possible to make observations of particular instances of an event and then definitively conclude that a particular event will happen every time without fail. This is described as naïve inductivism; the idea that a large number of observations of an event, with no contradictions, leads to a universal generalisation [25]. The only time a definitive conclusion can be reached is by using deduction, and the conclusion of a deductive argument can only be true if each of the premises are true. In the case of fingerprint identification, the uniqueness of a fingerprint is not a truth, it is an assumption, albeit a strong one.

It is often stated that what generally occurs in forensic science is deduction, with the assumption being that providing the premise is valid, the deduction will be valid [33]. The key issue is the general premise however, and whether it is actually valid or simply an assumption. In the case of fingerprint practice, the unique nature of fingerprints left behind is an assumption, therefore the process cannot be deduction; instead it is an example of naïve inductivism.

Evett states that in deductive logic there are only 2 states – certainly true or certainly false, and for this reason he is clear that inductive inference is the central activity of science; concerning propositions which have varying amounts of certainty. In his view both deduction and induction are used in forensic science, but the deductive inferences tend to be trivial [34]. Scientific theories are not facts; they are probabilistic statements, and as such have a range from highly improbable to highly probable. Therefore scientific conclusions cannot be given as facts, they must be given with a degree of probability. This can lead to the question ‘how can we know anything?’; everything we take to be true could be proved wrong tomorrow. Science is about understanding the degree of uncertainty involved, determining the potential error, to allow us to know how likely it might be that a theory might be disproved tomorrow.

Karl Popper, a philosopher of science, created a good analogy for this: ‘The empiricial basis of objective science has thus nothing ‘absolute’ about it. Science does not rest upon solid bedrock. The bold structure of its theories rises, as it were above a swamp. It is like a building erected on piles. The piles are driven down from above into the swamp, but not down into any natural or ‘given’ base; and if we stop driving the piles deeper, it is not because we have reached firm ground. We simply stop when we are satisfied that the piles are firm enough to carry the structure, at least for the time being.’ [35].

The idea of ‘Scientific Method’ is, like science, an accepted concept by many, but which in reality is much less concrete. There are those who state the scientific method is the cornerstone of science, that it is what makes science what it is: ‘it is the scientific method that will provide the truth’ [33], ‘all scientific disciplines share at least one commonality, they all utilize the scientific method’ [26]. There are others who say it does not exist, it is just a convenient idea to enhance the perception of science and scientists: most philosophers of Science, including Popper, deny the existence of any simple ‘scientific method’ [36]. It is claimed that it is comprehensible to every college student [5], but also that most scientists receive no tuition in it [32], and generally speaking someone with a science degree ‘has not had a single college lecture on precisely how the scientific method works’ [33]. On becoming a professional scientist, it is claimed on the one hand that scientists analyse what they actually do and then formulate rules and methods [5], but also that scientists ‘cannot describe the process they use reliably’ [32] and scientists do not ‘study the implementation of the scientific method’ [33].

It is in keeping with the image of scientists as industrious, intellectual, objective, rational people that there must be a method that they use that allows them this objectivity, and aids them as they seek knowledge. Medawar states the general public feel that science is a hugely prosperous and successful enterprise, and this is because it is the outcome of applying a sure and powerful method of discovery and proof to the investigation of natural phenomena – The Scientific Method [30]. Clearly this is a strong and appealing idea; McComas feels this is among the most pervasive myths of science [31]. Of course it can be argued that just because scientists do not consciously follow a methodology this does not mean that one does not exist; perhaps they follow it subconsciously [32]. This could be through their training; the process is not learned as an overall 'method', but a way of thinking and working is instilled as part of their training and as a result it becomes second nature; an engrained process that can be difficult to describe in words.

Science has been very successful, so there is a need to understand why this is so, and this leads to a need to understand the process. A general description of the scientific method is that it is 'a way of observing, and then thinking about, and finally solving problems in an objective, systematic fashion' [5] but this gives no indication of what 'the way' actually is. More in-depth descriptions show the scientific method as a series of steps.

McComas lists them as: Define the problem, Gather information, Form a hypothesis, Make relevant observations, Test the hypothesis, Form conclusions, Report results [31].

Acree describes it as Observation, Hypothesis, Literature Review, Experiment, Conclusion, Peer Review [26].

In relation to criminalistics, Tuthill describes it as Analysis, Comparison and Evaluation. [5]

I believe that, like quick and easy definitions of science, the idea of a simple scientific method that all scientists use is incorrect. When ideas of this Method are distilled down, and combined with more general ideas of what scientists do, the result is essentially an extension of common sense and logical thinking.

Recent models of science view it as a logical, objective field. However scientists are not only critical, sceptical individuals; they can also be a discoverer, a pioneer, an innovator [32]. At first glance these seem to be opposing views, and yet both are descriptive of what a scientist might be like. They must be ‘freely imaginative and yet sceptical, creative and yet a critic’ [30]. Medawar argues that these are two stages in scientific thought, but they do not occur in a sequence, but rather work in ‘rapid reciprocation’ [30]. He defines this as a hypothetico-deductive method, a process alternating between imaginative and critical thought, taking a view and then experimenting to find out if it is correct [32]. However the process is not a regimented, linear process. William Whewell, the 18th century English scientist, described scientific reasoning as a constant interaction between hypotheses and the resulting logical expectations: ‘there is a restless to and fro motion of thought, the formulation and rejection of hypotheses, until we arrive at a hypothesis which, to the best of our prevailing knowledge, will satisfactorily meet the case.’ It could be described as a dialogue between the possible and the actual [32]. So perhaps there is nothing distinctively scientific about this process – Medawar describes it as a scientific context for a more general idea: feedback [32].

Another myth of science is that science and scientists are completely objective; objectivity is regarded as a hallmark that distinguishes genuine science from pseudoscience [37]. Objectivity itself also has differing definitions. One definition is that a subjective outcome is the product of a sentient mind, and an objective outcome is the mechanical outcome of an immutable algorithm [38]. Following these definitions, it would be impossible for anything involving human thought or interaction to be truly objective.
Another definition, described by Seigel et al as an ‘everyday-language definition’ [38] is that an objective view is uninfluenced by emotions or personal prejudices; based on observable phenomena; presented factually. Similarly, subjective means proceeding from or taking place in a person’s mind rather than the external world; particular to a given person. These definitions allow a level of human interaction in both subjectivity and objectivity, and so therefore are more applicable to human

endeavour, but they are quite different from the first definitions, in which objectivity was defined as truly mechanical, repeatable, and uninfluenced. It would seem that there are different concepts of objectivity and subjectivity, and different conclusions on the nature of a process will be reached dependent on which definitions are applied.

The essential difference between objectivity and subjectivity is bias, and this is the reason why science strives for objectivity, and why there is a desire to be seen as objective; to be free from bias. Information gained from a mechanical system is one extreme, but not feasible in a human context. It is not possible to be completely objective, just as it is not possible to be completely free from bias. Scientific disciplines endeavour to be as free from bias as possible, using techniques such as blind and double blind testing, and peer review.

Objectivity is the goal, but this does not mean that subjectivity is always negative. Expert opinion is subjective; it is based on training, skill and experience of the individual, and this is not irrelevant or unworthy simply because it is not objective. Medicine is a good example of a combination of objective science and subjective interpretation; the subjective aspects of medicine are not a negative aspect but an important part of the field. However there can be a negative side to subjectivity. Just as in everyday life we can be affected by our judgement, beliefs and preferences when making decisions, science is not exempt from this occurrence. Robert AJ Matthews has chronicled in some detail instances where claims have been dismissed on the subjective judgement of peers, only to be later vindicated. One such example is the concept of continental drift; an idea dismissed as ‘fairy tale’ until it was vindicated, 50 years after its proposal [37].

The idea of science as truly objective appears to have come from the early concepts of science, where discoveries were thought to be made through objective, unbiased observation, the evidence of the senses [32]. However this view has now evolved, and, in the physical sciences, it is now well-established that the observer has an influence on what is being observed [39].

Different types of bias can affect individuals. They can be influenced by the results of those who have gone before, which may create an expectation of what result will be achieved. And example of this is the discovery of 'N-Rays'. N-Rays do not exist, but a large number of scientists were deluded into seeing them, because they had been informed they were there [5]. This instance demonstrates that science is not always as objective as it is portrayed to be. Individuals can also be affected by extraneous information which could influence them subconsciously, or they may come to see something believed to be meaningful in vague data. All of these issues affect forensic science, and I will discuss them further later.

This problem of the subjectivity of human perception can be described as the theory-laden nature of observation, as discussed by philosopher of science Thomas Kuhn. Observations are not simply collected as untainted facts to be explained. They are always guided by theory, which 'not only tells us what to look for, but how to look for it as well' [40]. Prior knowledge can unconsciously affect what is being perceived; facts can either be not seen, or deemed unimportant [31]. We all are taught how to observe, and in some fields of work observation, and being taught how to observe and interpret certain things, are key; a radiologist viewing an X-ray, a fingerprint examiner looking at a crime scene mark. We learn how to observe, and then we have certain expectations about what we will observe in certain situations. Science has become aware of these biases and the subjective nature of observation, and has developed controls, and blind and double-blind trials to try to counter the effects of bias. They do not view conducting experiments featuring controls, or blind trials, as an affront to their professionalism, it is accepted that bias is unconscious and extremely difficult to control, and the best response is to remove it as much as possible, rather than just attempt to view the work dispassionately.

Science is not these common misconceptions: pure objectivity, absolute proof, the scientific method. However there are some general concepts which do describe the ethos of science. Science is not just an accumulation of knowledge, as already discussed, but its aim is to develop and add to the body of tried and tested knowledge

[40], and to enlarge human understanding [30]. As well as attempting to find knowledge, science also tries to explain; it is a process by which knowledge is obtained and interpreted. Science also does not take things at face value; it has a culture of ‘organised scepticism’ [40] which encourages individuals to question traditional beliefs. Scientists are encouraged to look for contrary evidence, and consider its meaning, and this way of thinking and dealing with information marks science out from other types of thinking. The methods used to accumulate this knowledge are ideally use instruments that use standard definitions and scales, with processes others can follow, to ensure an objective a result as possible. This then means that the results obtained are testable. A second individual should be able to learn how an experiment was done, repeat the experiment, and reach the same result. Science should also involve predictability. Claims made by science should lead to predictions, and these predictions can then be tested to add evidence to confirming or refuting the theory, and test the claims made by that theory. For example, science allows us to postulate that we could fire a rocket to the moon. We can predict that using certain calculations the rocket will land on the moon, even in a particular place on the moon’s surface. This prediction, these calculations, and the science behind them, can then be tested by attempting to carry this out – its success is a demonstration of the strength of the theories. Science is also keenly interested in and aware of error. Like bias, error is always possible, and it is important to document all possible errors and attempt to minimise the chance of error occurring. This can be error from a number of sources; from equipment and calibration error to human error. Science is uncertain. It cannot prove anything absolutely, and so works on levels of uncertainty; levels of probability. For the most part, nothing can be proved beyond any doubt, because it is not possible to observe every instance of something, or every possible effect of something. And finally, good science depends on honesty, an attitude of professional integrity [29].

These ideas are quite abstract; there is no simple way to distill them down into a simple sentence or two, and they also do not draw any straightforward division between what is science and what is not. Some areas are clearly science. In general terms, there is no argument that Chemistry and Physics are science, and that Law and

Politics are not. Different reasoning is used in Law than is found in Physics. However there is a large grey area in between, where it can be difficult to conclusively say what is science and what is not.

So if science is difficult to describe, perhaps it is simpler to define what is not science. Unfortunately this is no more straightforward. The philosopher Paul Thagard attempted to define pseudoscience by describing it as a theory which has been less progressive than alternative theories over a period of time, and one which faces many unsolved problems, but the community of practitioners using the theory makes little attempt to develop it towards a solution to these problems, and is selective in considering confirmations and disconfirmations [28]. This proposes a concept which could help to identify pseudo- or non-science. Rather than constantly developing and modifying their theories to account for new problems, testing claims and looking for statistical correlations, practitioners in non-science are often content to rest their beliefs on superficial analogies [28]. But this does not mean there is a lack of complexity, statistics or scientific language in pseudoscience; indeed, because of the authority that science is seen to have in current society pseudoscience can often present itself as highly complex, riddled with ad-hoc hypotheses [28]. Scientific language is not enough to make a field a science, but it may be enough to fool a layperson into believing it is scientific.

Philosopher Karl Popper put forward the concept of falsification as a defining factor of science. Popper's theories are prevalent in forensic science debates because they were frequently referenced, and incorporated, in the US Supreme Court's definition of science, which I shall discuss later. Popper determined that in order for a theory to be scientific it had to be falsifiable; it had to be able to be proved false. His view was that it was quite possible, when trying to prove a theory, to only look for confirming instances; overlooking or not even considering factors which could refute the theory. Popper's conclusion was that the only thing a scientist could do with certainty was to find something to be false [30], therefore attempting to falsify a theory must be a key part of science. In his view scientists should not be committed to their theories, but remain sceptical and critical. Popper viewed 'refutation by observation and experiment as the hallmark of genuine science' [28]. This view has been widely accepted, both as what scientists do and also good scientific practice [40], and it was one of the definitions of science used by the US Courts to determine admissibility. But this view has also been criticised; there are claims in science which are not testable, for example atomism and field theory, but which are scientific because they give rise to theories which are testable. The final concern is one which is expanded upon by Kuhn. A theory can be testable, and so falsifiable, but results which could falsify the theory can be explained away or ignored.

Thomas Kuhn, physicist and historian of science, followed Popper. Popper saw Science as a rational, logical activity, one which was constantly changing as theories were postulated, tested, and dismissed if they were proved false. However Kuhn concluded that Science was rigid, rarely changing unless the weight of evidence becomes too great, and dependent on cultural and social factors. This was a radical point of view, as the idea of culture having an influence on what was science called into question the rationality of science.

Kuhn suggested that every science works within a paradigm. Essentially the paradigm is the research tradition in a particular field, a way of thinking and working within an established framework of theories, ideas and methods [40]. Most science is 'normal science', carried out within this established paradigm. Kuhn describes this as 'puzzle-solving' science [25]. Therefore most science is conservative – scientists do not question the fundamentals of their field. There is a logical reason for this however; if scientists were constantly questioning the fundamental aspects of their science, no progression would ever be made.

Working within these paradigms results in a concept of scientific community. The community has its own norms, policies and patterns of behaviour [40] and scientists work within this community.

Although generally this concept is valid it does result in another trait. Educated, trained and working within their paradigm, scientists become very committed to their theories. Kuhn felt that an instance of falsification would be explained away, rather than cause scientists to question their theory [25]. However not all discrepancies can be explained away. They may accumulate to a point where they can no longer be ignored, or one instance may prove too significant to simply amend a theory to accommodate it. This can result in the paradigm becoming unstable and lead to a crisis; a rare event in science. When it happens scientists can show their least objective side. They can be so devoted to their theory/paradigm that they will do almost anything to try and retain it, perhaps even by distorting scientific data, using poor reasoning and bad arguments, even using institutional power to stifle dissent [25].

Scientists may become insecure, and begin to hold philosophical disputes about the nature of their science [40]. Kuhn likened a scientist switching from one paradigm to another to a religious conversion, it can be such a huge change in way of thinking and working [40], and he described this as a paradigm shift; a total shift in understanding and direction, a radical rethink [25]. Newcomers are the most likely to change, as they are more likely to speculate about alternatives to the fundamental ideas which may explain anomalous results. Differing opinions and challenges to scientific paradigms often come from people working in different areas, who therefore have a different outlook or overview [40].

Kuhn also felt there was a cultural aspect to science. He argued that much of science depends on the values and views of the scientists, and that psychological and sociological factors affect whether scientists choose to adopt or reject a particular theory [25]. The idea of paradigm can provide direction for research, or it can stifle investigation. It can encourage a search to explain an anomalous result which can lead to further knowledge, but it can also prevent new ideas, which are seen as too different from the traditional thinking, from being accepted [31]. This bias against new ideas can be found in academia, but can be even more difficult for those scientists working in a field outwith an academic environment to gain a hearing. Here there is even less scope for questioning background assumptions, because generally this is science carried out for an employer, who may not want to consider that there could be underlying issues. This is work being carried out at ‘normal science’ level, essentially puzzle-solving, and so to question the background assumptions behind these puzzles can be very difficult [25].

Scientists must be trained in their field, and often must be trained to be able to make specific types of observations, particularly when using electronic devices; from Ground Penetrating Radar to an X-Ray. An individual trained in these areas will ‘see’ and understand much more about what is shown than a layperson. But there will always be an underlying possibility of unconscious bias, of seeing what you want or expect to see. So it is possible for the gathering of observational evidence to be biased by the presuppositions of the observers, even in a scientific context [25].

These views show that science cannot be held up as perfectly logical, rational and objective at all times. But these concepts of paradigm shift and scientific revolution are not everyday occurrences. Much of science is of the ‘puzzle solving’ variety that Kuhn describes; not because science is not seeing the conflicts in their work, but because these conflicts are not regular occurrences. A general theory is not adopted until it is robust and there is a good quantity of evidence to support it, and equally a good quantity of evidence will then be needed to disprove it.

Kuhn, and those like him, are thought of as controversial because they blur the divisions between knowledge and belief. If, as he argues, science, and therefore knowledge, is shaped by social and cultural forces, how do we know what is genuine knowledge and what is belief? [40]. It seems clear that there is a difference between knowledge and belief; knowledge gained through science is different than knowledge gained through reading a religious text. Kuhn’s ideas demonstrate that science is not as pure and objective as it is often thought to be, and create awareness of the limitations of science.

The views of Popper and Kuhn appear to be conflicting, as do many of the debates around the definition of science. I feel it is important to accept that reality may fall on the middle ground – as I have already discussed there is no easy answer to this question; science might not be as open-minded as Popper thinks it is, but it is also not as closed-minded as Kuhn thinks it is [28].

1.6 Science and the Law

There have been two attempts by the legal system to define science; both in the United States. The first in the decision of US District Court Judge William R Overton in the case McLean v. Arkansas Board of Education (1982), a case relating to the teaching of Creationism as a Science.

1. It is guided by natural law
2. It has to be explanatory by reference to natural law
3. It is testable against the empirical world
4. Its conclusions are tentative
5. It is falsifiable [36]

The second was as a result of the case of Daubert v. Merrell Dow Pharmaceuticals Inc. 509 US. 579 (1993) and was a result of the perceived need to 'gatekeep' expert evidence. In this case the US Supreme Court laid down a series of questions which the judge in a case could use to help decide whether an area was a science. They did note however that the criteria were not strict; a field did not have to meet all criteria:

1. Whether the expert's technique or theory can be or has been tested
2. Whether the technique or theory has been subject to peer review publication
3. The known or potential rate of error of the technique or theory when applied
4. The existence and maintenance of standards and controls
5. Whether the technique or theory has been generally accepted in the scientific community [41].

These criteria have led to Daubert hearings in the USA, which are used to determine admissibility of evidence.

The general definition of forensic science is science as it pertains to the law. This phrase in itself highlights a potential problem, and one which has come to the fore as science has become more crucial and definitions like the ones above are arrived at. Science and law are very different areas.

Like the general public, the Courts appear to share the view that 'scientific' means 'reliable'. They have looked to science to provide conclusive evidence; something which science cannot do. Science and the Law have very different goals. Those conducting science are searching for a comprehensive understanding, and this develops through a collective process involving many scientists, with its ultimate validity being the test of time. A trial seeks to resolve a focussed legal dispute in a finite period of time [36]. They also differ in terms of consideration of evidence; scientists weigh all evidence without formally distinguishing the admissible from the inadmissible, and they are inclined towards letting new ideas be presented and debated [36]. This is not the case in a legal setting; admissibility is crucial, and generally a field must be established before being allowed to be presented in court.

Attempting to describe the nature of science is a difficult if not impossible proposition. To attempt this challenge, and also to reach a definition which would be of use in a court of law, is possibly even more difficult. And it would seem that the US Supreme Court realised this. In their ruling in the case Kumho Tire v Carmichael (1999) they retreated from the attempted philosophy of science of Daubert. Rather than focussing on whether or not a field was 'scientific', they chose to refocus the issue on whether or not the field was 'reliable'[42]. This is the more important issue, not whether something can be definitively described as science or not.

I would now like to progress and address some of the issues raised above in the context of fingerprint identification and the current issues within the field.

1.7 Fingerprint Identification as Science

The argument that fingerprint practice is a science is probably the most polarised debate in the fingerprint profession. I believe this is the case not because those taking part in the debate are fully informed of all of the subtleties of the argument, but because of the value placed on a field which describes itself as 'science', and also because of the devotion to a traditional view of the discipline by most of those who work within it. This notion of the weight given to science is encapsulated in a sentence from an online article: 'Not all people believe, however, that fingerprint identification is a science and therefore should not be used as a means to identify or individualise' [43]. This illustrates the view that, in order to be accepted, fingerprint practice must be considered a science; if it is not a science then it should not be used. This is a misconception. Another demonstration of the value placed on science is in the USA. In1995 the Technical Working Group on Friction Ridge Analysis, Study and Technology, TWGFAST, was formed. In 1999 the FBI renamed all of the working groups as ‘scientific’ rather than ‘technical’, and the group became SWGFAST [44]. The work it carried out did not change, only its title; in fact SWGFAST is currently described on its own website, www.swgfast.org, as well as other publications, as having been created in 1995 although this is clearly not the case [45]. The debate around fingerprint analysis is not so much a debate as a series of statements from one side of the argument or the other. Below are some examples of such statements:

‘It is obvious that fingerprint identification surpasses the criteria for being a true science’ [26]

The IAI ‘supports and promotes the continued and proper application of the science of friction ridge skin identification’ [46]

‘Fingerprinting is an established science’ [47]

‘Friction ridge identification, or the science of fingerprints’ [48]

‘Friction ridge identification is a bone fide science which is over one hundred years old’ [49]

‘We know today that friction ridge identification is an applied science’ [43]

‘fingerprint identification falls into a category we call applied science’ [24]

‘you say fingerprint examination is a science because it is!’ [50]

Reading only these statements, one would assume there is a definitive view from the fingerprint community, that the field is a science, and there is no dispute. However from the other side we have opposing, but no less concrete, statements:

‘fingerprint work is a ‘Discipline’ or a ‘Trade’; admittedly supported by science… it is most definitely not a ‘Science’. [22]

‘We, however, do not conduct science!’ [51]

‘a vote for science is a vote to exclude fingerprint expert opinions’[52]

‘the myth that there is a “science of fingerprints” will thus be exposed for what it really is: an unfounded creation of law enforcement fingerprint examiners’ [17]

Comments come from both experienced fingerprint practitioners and vociferous legal critics of fingerprints. And there are also those who seem to be certain, and yet change their minds:

‘Skilled examiners of fingerprint evidence agree that the process of comparing latent prints of unknown origin with inked impressions of known origin is an ‘art’, rather than a science’ [53]

‘today, friction ridge individuality may be said to be a mature science’ [54]

Both of the above statements are from experienced fingerprint examiner and professor, Andre Moenssens.

Ashbaugh, a vocal proponent of fingerprint science, may have unwittingly found the truth when describing the science of fingerprints: ‘The scientific basis is a biology issue. The knowledge learned about the friction skin, can be applied to the identification process’ [49] Fingerprint examination has its basis in various sciences. But this base of sound scientific principles [24] does not make something a science.

I believe this confusion over the definition of fingerprint identification as a science arises in part from the historical development of the field. The development of fingerprints began in a scientific manner; individuals like Herschel and Galton began the field with their own observations and experiments. However once this field was discovered to have an application to identify individuals who had committed crimes it was quickly taken over by police practitioners. The purely scientific questioning and investigation died away, taken over by the practical use of the field by technicians from police backgrounds. This move from scientific to police-driven development is demonstrated by the creation and development of organisational bodies in the field in the USA. In the early 1900s there were two bodies: the International Association for Identification (IAI), which was composed mainly of identification bureau heads and technicians working in police offices, and the International Society for Personal Identification (ISPI), which was a forum for those interested in the more philosophical and scientific questions about fingerprints [55]. As the IAI grew in strength, the ISPI dwindled, and was almost non-existent by the 1920s. From this point, the debates about fingerprints focussed less on the fundamental premises of the field, and more on practice-based issues such as competence [13]. Fingerprint evidence was more widely used, and the courts came to trust it as an established field. However this security did not come with an underlying base of scientific evidence, instead ‘it was based on anecdote, experience, and nineteenth century statistics’ [13]. Critics have highlighted this lack of focus on the fundamentals in the early stages of the development of fingerprint examination is a criticised area. Some argue that police investigators invented the field, and did not develop any basic knowledge to support their claims [56]. This is not accurate, as there is considerable research into the development and uniqueness of formation of friction ridge skin, however this research was not carried out by individuals connected to fingerprints; in fact those working within the field do not seem to have acknowledged the strong connection between fingerprint identification and this biological research fully until David Ashbaugh wrote in detail about it [1].

It was not until 1973 and the IAI ruling that there was no valid basis for a numeric standard [12] that fundamental questions seem to have been considered. It is likely this was a result of the acceptance of fingerprints by the legal profession. Fingerprint identification was never required to validate itself by the courts, instead it was essentially accepted as it was presented. The courts have proved a powerful ally for the fingerprint profession, and have endowed the field with considerable rhetorical power that has only recently begun to weaken.

The IAI ruling in 1973 signalled another separation with the profession; essentially a split between the United States of America (USA) and the United Kingdom (UK). Despite the IAI ruling, the UK kept its numeric standard, and its technician-style certainty. In the USA the profession continued to prefer to portray itself as scientific, whilst also maintaining certain conclusions. This new enthusiasm for science did not appear to result in a new eagerness to carry out research into the underlying principles of fingerprint identification. Rather than in-depth study into what makes a field a science, and how fingerprints could be better understood and used, there has instead been a rush to claim to be science, and a misunderstanding of what constitutes a science. In an effort to make fingerprints fit the concept of science, some examiners have gone to the extremes of claiming that the assertion ‘nothing is absolute in science' is a myth, basing this conclusion on arguments such as 'gravity is absolute (infallible)', and that no two snowflakes are alike [57]. Falsifiability has been mentioned in Daubert hearings and so is a more widely known concept of science, but one examiner attempts to circumvent this by claiming that 'falsifiability should not be applied to an observation or applied science like Fingerprints' [57]. His reasoning is that the philosophical notion of falsifiability does not translate very effectively to every idea or science, therefore it is easier to choose not to apply it. Clearly the easier route is not always the most appropriate, and these fallacious comments do nothing to help the cause of the embattled fingerprint profession.

Naivety and misunderstanding has also led to claims such as 'Fingerprint identification shares many things in common with mathematics', 'very few forms of scientific evidence could be better described as objective than the identification of a latent print by a skilled examiner' and 'fingerprints …. Is just as scientifically valid and reliable as any other science and, indeed, more accurate than many' [58]. These illogical comments demonstrate one end of the spectrum of assertions made by fingerprint examiners that their field is a science, claims made without any evidence. They are by no means held by every fingerprint examiner, but they do reflect views held by some working examiners and demonstrate the strength of belief in the fingerprint process, and also the lack of wider knowledge surrounding what might be required to be thought of as science. There is a tendency to use specious arguments to try to affirm what most examiners believe is the truth; few within the profession have the will or desire to investigate further.

It is disconcerting that those conducting vociferous arguments on the scientific nature of fingerprint identification, or indeed other areas of forensic science, feel that science can be defined in a simple sentence, or indeed does not need to be defined at all because we are all familiar with it. The field of philosophy of science demonstrates that the nature of science is too complex to be able to make black or white statements about the scientific status of many fields. It is also pertinent to question the relevance of this argument at all; although science clearly has a level of epistemic authority, it is also clear that forensic science, and fingerprint analysis, do not conform to rigorous descriptions of the nature of science. This does not mean that these fields are not without significant utility however; the misconception in these discussions is that a field has to be scientific in order to have value. Rather than continuing an irresolvable argument it would be more valuable for the fingerprint profession, and forensic science, to ask questions of their field and seek more knowledge. In the process this research may provide evidence to rebut some of the criticisms raised at the field.

1.8 ACE-V as 'the Scientific Method'

The ACE-V process as outlined previously is described by many fingerprint examiners as a scientific process, or scientific methodology [49] [59] [60]. It is championed as a demonstration of the science of fingerprints, because "the scientific method" is followed. There is already a weakness in this argument; there is disagreement about the existence of an accepted scientific method, and disagreement about whether the adoption of such a method makes a field a scientific.

There are those who prefer to break the process down into two parts: ACE, the identification or evaluation process, and ACE-V, the 'complete scientific methodology' [11] [24]. The fingerprint profession suggests verification is the key factor which makes this scientific method – a stage which does not appear to conform with the general descriptions of scientific method. A recent FBI article on the fingerprint process gave another stage to the scientific method: 'confirm the process and conclusion through repetition by others' [45]. This is an opportunity for the findings to be confirmed or refuted and has been linked to Popper's concept of falsification; a opportunity for the findings to be falsified [61]. However terminology such as 'repetition' and 'replication' as used in the FBI article, and the name 'Verification' describe the opposite. Verification seeks to confirm, falsification seeks to refute. This does not mean verification is not necessary; it is a valuable stage of the process, but to claim this stage is equal to falsifiability, and therefore makes fingerprint analysis a science is to overstate its weight.

The desire to involve more a scientific descriptive style has been taken further by Pat Wertheim who offered a change of description from the three step process as documented by Ashbaugh to a five step process. Offered as a 'counterpoint', Wertheim suggests five stages: *examination of the unknown, formulation of a hypothesis, experimentation, formulation of a conclusion,* and *testing the conclusion* [24]. This appears to be a very scientific description and echoes the description of scientific method given previously. Wertheim describes that before even looking at the known print the examiner has a hypothesis, a conception of what the conclusion will be. Even more surprisingly, he suggests 'the hypothesis is always that the latent print was made by the same person as the inked print' [24]. Aside from serious concerns around issues of bias, this does not seem to genuinely reflect the process of fingerprint comparison which I feel is based on having an 'open mind'. The *formation of a conclusion* Wertheim suggests is when a tentative conclusion is reached. This has been described as playing 'directly into the scientific method' [62], but it appears to be taking a concept found in science and attempting to apply it to fingerprint identification with little understanding of what the concept actually means. The final stage he described as *testing the conclusion*, is when the tentative conclusion is progressed to one of absolute certainty, thereby removing any doubt. The illogical nature of this description of the process suggests that is may have been constructed precisely to develop an image of science, rather than to try to accurately describe the fingerprint examination process. Perhaps more concerning is the recurrence of some of these assertions in a recent FBI article reviewing the fingerprint process, which states the examiner sets out to falsify the hypothesis that the mark and print were made by the same person [45]. This is a worrying approach from such a major institution.

This image of a systematic process implies objectivity, but it is clear the fingerprint process is subjective. Kasey Wertheim has described the ACE-V process as both 'completely objective' [23], but also objective 'with the exception of a portion of the evaluation phase' [63]. This is an example of the illogical arguments used by some of the fingerprint community to attempt to strengthen their field but which in fact weakens it. Wertheim Jr. also states that because an identification will be checked to ensure two examiners will reach the same conclusion, this ‘[speaks] for the overall objectivity of the entire examination process’ [23]. Fingerprint examiners describe part of the evaluation phase as subjective because it involves the ability of the examiner [23]. However, it seems self-evident that all stages will involve the ability of the examiner, and therefore by this argument, all stages are somewhat subjective. This misconception arises from a confusion of the meaning of subjective and objective. Ashbaugh states that the opinion of identification is subjective, but that friction ridge comparisons must always be objective in nature [1]. In his view, the opinion of identification is subjective because it involves the ability of the examiner, but the comparison process is objective because one should not set out with a mindset to prove a match. The first statement defines subjectivity as involving human ability, skill and opinion and objectivity as output of a machine. The second statement suggests subjectivity is only present if an examiner carries out a comparison assuming they will make an identification; assuming that the individual is guilty. It is the first statement which uses the concept of subjectivity correctly; if people are involved then a process must have a subjective element. If however they have an expected outcome, this is not subjectivity but bias.

This confusion is further demonstrated by another quote in a document prepared to advise US examiners on dealing with Daubert-driven questions. The determination of sufficiency is described as being made ‘based on an objective analysis and comparison…. which is naturally affected by knowledge, training, skills and experience of that examiner’ [50]. There is a determination to be objective, but also to maintain the importance of the examiner in the process. Deciding on sufficiency is clearly subjective. Wertheim Jr attempts to circumvent this by claiming that the determination that the print is ‘of value’ happens before ACE-V, and ‘therefore does not affect the objectivity of the methodology’ [63]. The fact that part of the definition of the Analysis phase is to determine the quantity and quality of detail present, in other words to determine sufficiency, does not deter the author from making this statement. The point is then taken even further; it is possible, once Analysis has taken place and a comparison made, that the mark might be made insufficient or ‘no value’. This would appear to be subjectivity at the Comparison stage, but Wertheim states ‘in that situation the print would not be identified anyway, and the methodology would still remain objective’ [63]. This comment suggests the methodology is only used in identifications. It is shocking the lengths that some examiners seem comfortable to go to in an effort to make fingerprints ‘fit’ with an image they would like it to have.

This issue has arisen in part due to the perceived objectivity of DNA and scientific evidence, and also as a result of the move away from a numeric standard to a non-numeric system. The numeric standard could be viewed as objective; a number was reached, and it was always the same number. The perception of the examiner still came into play in perceiving the characteristics, but the decision of identification appeared clear-cut. In continental Europe, where numeric standards are still used, an Interpol report states that ‘a firm, common reliable and proved standard’ is better than a conclusion which is ‘just an opinion’. This document provides an insight into the perceived advantages of a numeric standard, stating it ‘serves as a linking pin to the common, historical and safe domain of knowledge and experience’, and that it carefully defines what is sufficient. [64]. This is the illusion of objectivity; a standard to which all fingerprint examiners could refer when reaching a conclusion of identification.

The arguments used to claim that fingerprint identification is a science suggest that some of the profession are in danger of engaging in sophistry. Judge Posner has written that descriptions of techniques used can be ‘affectations of mathematical rigour, by use of intimidating jargon, by suppressing doubts, and by concealing the personal, judgemental factor in the evaluation of experimental, statistical or observational results’ [36]. In my opinion those authors who use scientific language whilst avoiding description of certain aspects of fingerprint practice, as Wertheim does in my example above, are sophists. This argument has been observed by others; Cole comments that the fingerprint profession have adopted jargon to make their field seem more scientific [65], and even Ashbaugh admits that the word ridgeology was adopted to get peoples attention [1].

As the profession strived for a scientific approach, it became clear that there was no scientific basis for a numeric standard. Adhering to this standard appeared to reduce the credibility of the profession [13] and so a non-numeric system was adopted. The ‘security blanket’ [54] of a numeric standard had been removed, and all that was left was the concept of ‘science’. When the non-numeric system was first established, it was stated by the IAI that there was no valid (later changed to scientific) requirement for a particular number of characteristics in common [27], but did not provide guidance, or suggest required research, to ascertain what might be required to conclude identity. This lack of information left examiners with nothing but their own experience and opinion when just a short while before there was a perceived objective standard, a clear number to reach. This led to confusion, and examiner John Thornton said that there were now no standards ‘that you can find particularly helpful if you’re faced with a miserable smeared partial distorted bloody print’ [27].

The new standard was ‘science’, and this led to claims of objectivity and the adoption of ACE-V as the process used by fingerprint examiners. This description was useful to explain the general process used to compare fingerprints, but it does not offer the sort of guidance Thornton and others were looking for. The question “How much does it take to individualise?” is answered by Ashbaugh with ‘Friction ridge identification is based on the agreement of friction ridge formations in sequence, having a sufficient volume of unique details to individualise. All friction ridge formations are evaluated in the aggregate based on a quantitative-qualitative friction ridge analysis formula’ [49]. This statement may have the required scientific feel, but it does not describe how an examiner decides how much is enough, and it does not offer any help to an examiner who may be unsure. Despite the claims that ACE-V ‘breaks down into phases exactly what every latent print examiner actually does when comparing two prints’ [23] and that ‘a specific and structured protocol has been established to ensure the methodology of friction ridge identification is fully objective and unbiased’ [49] in truth the ACE-V process is simply a general description of the comparison process, rather than an objective methodology which provides a road map of how to carry out an examination and reach a conclusion.

Fingerprint examination is not wholly objective, but nor is DNA analysis, or science. Acknowledging this will show that it is not possible to fully document, step by step, how an identification is made. The claim that ACE-V is a valid scientific methodology and a full description of the identification process allowed Haber and Haber to write a scathing criticism of the process, cataloguing the ways in which it had not been tested to be valid, and the many reasons why it is not even able to be tested as such in its current form [66].
There needs to be more transparency [41], and I believe this transparency will come when the fingerprint profession recognises the reality of fingerprint practice, rather than the idealism presented by certain proponents of the profession.

What is needed is a better understanding of the inferential process [41] by studying how fingerprint examiners reach their conclusions. This means collecting information on how fingerprint examiners actually work, rather than analysing what is assumed to be their working practices. To attain greater transparency fingerprint examiners need to admit the subjective nature of their conclusions. The fingerprint analysis process cannot be described by a step by step process. By describing the process in stages much of the genuine method of comparison is ignored. To say that the unknown fingerprint is first looked at (Analysis), then compared to a known print (Comparison) and then a conclusion reached (Evaluation) is an obvious statement; there is no other logical way it could be done. But this does not show how a comparison is made, and it is an error to attempt to define the comparison process in a similar stage by stage manner. The process is much more free-flowing and organic than this. It is my opinion that Whewell's description of a 'restless to and fro motion of thought' [32] is much more accurate. The examiner will cycle back and forward between the unknown and known fingerprints. They may consider certain aspects, move on, but later return and reconsider them. A fingerprint may be considered insufficient at the start of the process, or much later on, after comparison.

The fingerprint profession appears to wish to be more scientific, but perhaps it could make more progress by attempting to be more logical, rational and transparent. This would allow it to develop a genuine understanding of fingerprint practice, and therefore become more adept at explaining the process of identification [67], rather than trying to conform to simplified notions of what constitutes science. This understanding does not just mean being able to explain for court purposes, but gaining in-depth knowledge for a fuller understanding. As fingerprint examination was developed in a criminal justice context, with a goal of presenting court evidence, this has led to a mindset which looks for explanations which will suit the court system, rather than logical explanations which are investigated irrespective of the court process. This is demonstrated by a quote from John Thornton, discussing numeric standards in fingerprints; ‘going to court is like licking honey from a razor blade. If you can get away with it, it’s real sweet. If you can’t, then it’s going to hurt’ [27]. The goal should not be ‘getting away with it’, or even simply generating results which you avoid discussing. The goal should be logically sound conclusions [64], presented clearly in the court room.

1.9 Absolute certainty and wishful thinking

Fingerprinting is synonymous with absolute specificity and absolute identification [68]. This type of reporting is not required by the courts, but a rule which has been laid down by fingerprint examiners [5]. When fingerprint findings were first reported as evidence in the early 20th century they were presented as fact. An article in Fingerprint Magazine in 1919 described fingerprint identification as certain because ‘the fingerprint expert has only facts to consider; he reports simply what he finds’; a handwriting expert gives only an opinion, the Bertillon system is open to error, but fingerprint identification is fact [69]. In 1927 another text described that fingerprint evidence could not be contradicted by another expert because ‘the print is from the person’ unlike handwriting analysis which was ‘merely the opinion of a person who has made a study of detecting similarities’ [17]. This type of testimony was not questioned, perhaps because it was exactly the type of evidence that the legal system had hoped science would be able to provide [70]. It was authoritative, precise, straightforward. As a consequence a definitive conclusion became the expected result of a fingerprint analysis. An absolute conclusion has a lot of power. Any suggestion of reducing this to a probability is unpopular with some working in the fingerprint profession, as it can be viewed as weakening the status of fingerprint evidence.

This approach was unproblematic at a time when the courts desired definitive evidence and the fingerprint profession was happy to supply it, but with forensic evidence now coming under considered scrutiny this position is becoming untenable. The descriptions of infallible fingerprint practice were not left behind in the early part of the 20th century; a chapter in the publication *Advances in Fingerprint Technology* (2000) states 'Because fingerprint science is objective and exact, conclusions reached by fingerprint experts are absolute and final' [71].

The focus on science brought about by Daubert hearings in the USA has lead to a development of scientific awareness, and an understanding that uncertainty is a key part of science. A field which reports its conclusions with absolute certainty attracts scrutiny [65]. Fingerprint practice has not been able to stand up to this scrutiny. DNA evidence has highlighted that no forensic procedure can lead to a categorical identification [72], because there is no logical basis for such a conclusion. Some of the fingerprint profession have adopted a slight shift in terminology to try to escape this issue. Where previously the conclusion of absolute certainty was claimed as fact, fingerprint examiners are now described as 'stating their conclusions as a matter of opinion' [46]. It is 'the opinion of individualisation …. In the opinion of the forensic identification specialist' [1]. However this opinion can only be given when the examiner is 100% certain of an identification, and also certain that any other examiner would reach the same conclusion. No opinion is given on any mark which cannot be conclusively identified, and this maintains the impression of factual evidence reporting. There is no possible or probable or likely, only yes or no or too little information to give any conclusion (insufficient).

By removing any probabilistic interpretation, and without any statistical data, it is left to the judgement of the fingerprint examiner to decide whether there is enough information present to identify. Fingerprint examiners claim to be able to determine this, indeed some continue to claim they can infallibly determine this [70], but this is logically not possible. Conclusions are based on experience, but the examiner cannot remember the minute details of all the prints they have looked at in the past and use this knowledge to judge the print they are studying at that particular moment. The judgement of identity is based on intuition [18], and has been described as a 'leap of faith' [68]. No data has been gathered and no base rate probabilities calculated to assist fingerprint examiners in making their decisions [56], it is simply a subjective judgement. The lack of objective information means there is no guide for the examiner other than their own experience, and discussion with colleagues. Haber and Haber point out that even this experience base can be flawed, as there is no access to 'ground truth' [66], meaning in case work there is no way to be sure of the correct answer because the absolute truth could only be known if the individual was seen leaving the identified fingerprint. As a result there is no way to know whether the case work conclusions reached previously, and used as a knowledge base, were correct. To claim absolute certainty, the examiner must form a view of the entire world, when they have only examined a fraction. This cannot result in a conclusion of absolute certainty.

Despite these issues the fingerprint profession still reports its findings as 100% conclusive. They may have discarded the numeric standard because there is no scientific basis for it [73], but they seem reluctant to discard absolute identification, even although it also has no scientific basis. Unfortunately, as with objectivity, some examiners attempt to argue that fingerprints can be both. Acree writes 'relatively few areas of science can claim that their paradigm is based on absolute certainty. Fingerprint science has that luxury…… [teachers and professors] have instilled in all of us that nothing can be an absolute certainty in this world …. In the case of fingerprint ridge identification it looks as if they were wrong' [26].
However these statements should not imply that this is the view of the fingerprint profession as a whole. Currently, fingerprint examiners take an opinion of 'beyond reasonable doubt' and turn it into 'a totally positive and absolute identification' [5]. But recognition is growing that results might be being overstated [74], and there is a small but growing interest within the profession in a probabilistic approach to fingerprint evidence.

1.10 Awareness of error

The practice of giving conclusions of absolute certainty has led to the assertion that fingerprint evidence is infallible, and this is still commonly found in the views of fingerprint examiners [22] [58] [57]. Writers on fingerprint practice routinely emphasised that fingerprint identification could not be erroneous [70] and the FBI has long stated that fingerprints are infallible [75]. As a result, for many years the courts were conditioned to the fact that a fingerprint examiner, when stating their conclusions, cannot be in error [76]. This claim of infallibility has led to an assertion that the error rate for fingerprints is zero. Despite this claim being 'virtually nonsensical' [77], it is a claim which continues to be made. Stephen Meagher, an FBI expert, testified in a US Federal case in 2002 that the error rate was very low, or even zero. In support of this, he stated that he had never heard of a fingerprint error, and that in his 35 years at the FBI no examiner had ever made an erroneous identification in court [66]. To suggest the error rate is zero for a profession, on the basis of personal experience, is foolhardy to say the least. There is no documented information for any Fingerprint Department (or Mr Meagher's for that matter), and there is the added unknown that simply obtaining a conviction does not validate the identification [18]. The assertion is further undermined given the errors which have been discovered in the supposedly definitive conclusions of fingerprint analysis.

Until recently there had been no studies on the error rate of fingerprint examination. If the error rate was very high, a large number of errors would have been uncovered. Whilst this is probably true, the assumption that the rate is not 'very high' does not then lead to it being 'zero'.

There is a general assertion that verification, though not carried out blind, identifies most errors [66]. Proficiency testing is also often cited as proof that examiners are tested to maintain a level of competence, further reducing the chance of error. However the release of data showing the results of proficiency tests taken by fingerprint examiners in the USA demonstrates that the assertion of infallibility is false, and also that proficiency tests do not uphold the assertion of a very low error rate. Some of these results were presented in the article by Lyn and Ralph Haber [78]:

Table 3 : results of competency testing showing numbers of errors.

Year of test	Number taking test	% giving all correct answers	% making one or more erroneous IDs	% making one or more missed ID
1995	156	44	20	37
1996	184	16	3	80
1997	204	61	6	28
1998	219	58	6	35
1999	228	62	5	33
2000	278	91	4	5
2001	296	80	3	18
2001	120	80	2	18

It is self-evident from these results that the error rate is not zero. The result which attracted the most attention is the 1995 test, in which 20% of examiners made a misidentification. Interestingly, in this test the fingerprints from twins were used; a mark from one twin and a set of prints from the other [79]. This was the most frequently misidentified. Although the fingerprint profession likes to stress the uniqueness of prints by remarking that DNA is identical in twins, it would appear that a large number of fingerprint examiners could not tell the difference between a mark left by one twin, and the print of the other. It demonstrates that prints can be very similar, and that a 'near miss' or 'look alike' being wrongly identified is possible.

These data, in particular the test from 1995, caused alarm in the fingerprint profession, and appeared to provide evidence for those critics who claimed fingerprint practice was unreliable. Grieve demanded 'positive action' from the fingerprint community after the 1995 results [18], but it is not known what specific action, if any, was taken as a result.

There have been more recent studies into the accuracy of fingerprint examiners, which has provided less concerning results. A study by Wertheim, Langenburg and Moenssens demonstrated an error rate for misidentifications of 0.034%. This figure is considerably smaller than that obtained from the proficiency test results. The study also looked at verification, and found no errors in their results for this process. [80].

A concern with using these results as a measure of error rate is that the errors documented may relate to the way the study was conducted; this may affect both the high and low error results above. All of the studies analysing error rate have limitations, and they may not represent all aspects of fingerprint practice; in all the above studies the examiners were aware they were being tested.

Cole has conducted research into instances of error in casework of latent fingerprint identification [81]. In his paper he lists all known fingerprint misidentifications which have arisen out of unintentional misattributions. He lists 22 cases, the first in 1920, but the majority from the mid-1980s to the present day. The majority are for serious crimes such as rape and murder, and more than half (12) involved more than one examiner reaching a conclusion of identity. Also, more than half (13) were not discovered through the normal course of justice [81]. One in particular garnered more publicity and notoriety due to its international significance: the misidentification of Brandon Mayfield in the Madrid bombing case.

After the Madrid terrorist bombing in March 2004, the Federal Bureau of Investigation (FBI) claimed to have identified a fingerprint to an Oregon man, Brandon Mayfield. The identification was made by three senior fingerprint examiners, but when the FBI passed this information to the Spanish authorities they were surprised to find the Spanish experts did not agree with the identification. FBI examiners travelled to Spain to demonstrate the identification, but the Spanish examiners still disagreed with their findings. The case proceeded through the court system, and the identification was verified by an independent examiner in the USA, before the Spanish experts identified a second individual, an Algerian. On viewing

this information, the FBI accepted that it was the Spanish experts who were in fact right [82].
This case demonstrates a number of flaws in the arguments put forward by the fingerprint profession. The original identification was made by three senior examiners at the FBI, and an independent examiner, before being acknowledged as a misidentification. This was not an error by one incompetent individual, and shows the verification process is not sufficient to catch all errors; even the adversarial court system is not sufficient. There are several bias-related issues shown, and highlighted in the FBI report into the misidentification [82]. The committee which reviewed the case noted these issues, but concluded that the error was due to failure in the application of the ACE-V methodology. Rather than use the opportunity to address the issues which their own review had uncovered, the committee chose to take an over simplistic view and as a result preserve the general fingerprint process, protecting it from any blame. Whilst it is true it is not possible to lay all the blame on the process - human errors were clearly made – application of the ACE-V method as it is described would not have prevented the errors which occurred.

An example of one of the biases commented on by the committee is: ‘once the mind-set occurred with the initial examiner, the subsequent examinations were tainted’ and ‘to disagree was not an expected response’. The issue here seems to be the general mind-set of the fingerprint profession, rather than a level of adherence to ACE-V. The belief in absolutely certain conclusions, discernible uniqueness and ‘expert’ status seem to have been the ingredients in creating this error. This suggests a cultural problem; it will take a dramatic shift in to prevent this type of error occurring again as these concepts are deeply embedded in the professional culture. This incident has not prevented claims of infallibility, even from one of the examiners involved in the case, Agent Massey, who said after the case ‘I will preach fingerprints till I die, they’re infallible.’ [75]

Despite the recent writings and evidence on this issue, Mr Meagher’s view has not changed; he testified in Maryland v Bryan Rose (2007) [83] that there is ‘no error rate’ in ACE-V as it is ‘an infallible methodology’ [84]. The reason he seems to feel able to make this assertion is the adaptation that the fingerprint profession has made in order to be able to maintain this claim: a separation of error into two types.

It is logical to distinguish between different types of error; for example in fingerprints there are what is known as Type I errors, that is false positive errors, and Type II errors, that is false negative errors. However fingerprint practice has developed a different division; between practitioner error and methodological error. Using this rationale, the fingerprint profession claims that any error which occurs is an error made by the practitioner, therefore the methodology has an error rate of zero [11] [85]. As long as the methodology is correctly applied, there will be no error [86]. This has led to some unusual statements such as, given the fact that any two prints were either made by the same source or were not, 'There is no probability associated with that fact. Therefore, the science allows for only one correct answer, and unless the examiner makes a mistake, it WILL be the correct answer. That is what I mean when I say the error rate for the science of fingerprints IS zero' [87]. Examiners are advised to 'drive home the point that the error rate of the methodology is zero' [50], and given examples such as pilot error causing a plane crash does not invalidate the scientific principles of flight [87]. The use of this example is illogical, as just as pilot error does not invalidate flight, so fingerprint errors do not invalidate the whole fingerprint process. The inherent flaw in this line of thinking is clear. Given the subjective nature of fingerprint examination, and the key part of the process the examiner occupies, it is impossible to separate the examiner from the methodology. Without the examiner there would be no methodology. As Zabell puts it, 'in latent print examination people *are* the process' [18].

The practice of assigning error solely to the practitioner has supported a culture of blame within fingerprint practice: asserting that any mistake is due to the incompetence of the examiner avoids any deeper analysis into the cause of error. 'Errors occurred due to a lack of professionalism shown by the practitioners involved' [88]; 'errors that occur are therefore lapses on the part of individual examiners' [15]; 'misidentifications … resulted in the removal of incompetent, negligent or fraudulent individuals' [89] 'a misidentification …. is an unforgivable error for which there can be no justification' [54]. Those who have committed the 'most feared error' [9] are often dismissed, or decertified [5]. The problem here, as demonstrated in the Mayfield case, is that these apparently incompetent examiners showed no signs of being incompetent prior to making a misidentification. In the Mayfield case, all of the examiners had considerable FBI identification experience, and were highly regarded. Rather than admit that a mistake could arise through disagreement over a difficult mark, the IAI prefers to conclude misconduct on the part of the examiner [90]. Again, given the subjective nature of the examination process, it is irrational to suggest that an honest mistake is not possible. Rather than laying the blame on the examiner, the problem which caused the error should be identified, and research undertaken to identify risks that are faced by all examiners when confronted with difficult interpretation of evidence [9]. This may not be a quick solution, but it will help to identify the root cause and therefore strength the fingerprint field [9].

1.11 Issues of uniqueness

The concept of uniqueness is key to fingerprint identification. When arguing the case for the reliability, validity, and scientific basis of the discipline, much is made of the uniqueness of friction ridge skin. This uniqueness of formation has been established through the study of the development of friction ridge skin by embryologists and biologists, and is agreed to form unique arrangements on individual's hands and feet. In the USA judicial notice was given to the permanence and uniqueness of fingerprints in the case US v Mitchell (1999)[91] after a Daubert hearing [9]. However biological research is not the only evidence of uniqueness given by the fingerprint profession. They also use the tenet 'Nature never repeats'. This is attributed to the Belgian statistician Quetelet, although there is some uncertainty over whether he actually made this claim [72]. This notion was popular around the time fingerprints came into use, when jurors looked at their fingertips and 'seemed to see nature speaking directly' [70]. This concept had cultural plausibility at that time, and its acceptance has resulted in it becoming ingrained in general thought. There is something appealing about the concept; as Thornton says 'it has a nice ring to it' [5], like the idea of the uniqueness of snowflakes. A tautological argument such as ‘all objects in the universe are unique’ [5] is then used to claim that friction ridge skin is unique on every level [23]. There are also claims that, because everything in Nature is unique, there is no need to prove the uniqueness of fingerprints because it is known [92].

The infinite variety of friction ridge skin is a point often stressed by fingerprint examiners; is it described as going to the core of comparative examinations [93]. It is seen as one of the key premises of friction ridge identification: ‘friction ridge patterns and the details in small areas of friction ridges are unique and never repeated’ [1]. To the fingerprint profession, because all things are unique there is no requirement to define how much is required for uniqueness – every part is unique. This concept is epitomised by a quote from Pat Wertheim:

‘The fact is that human friction ridge skin is unique. One empirical way of grasping this concept is to start with the premise that the friction ridge skin on a whole fingertip is unique. That is to say, no two people now living, or who ever have lived, or who ever will live, can have exactly the same minute details across the whole surface of a fingertip. If that fact is accepted, then one must accept that, if a fingertip were cut in half, each half would still be unique; half of unique must still be unique. Slice again the remaining half a finger, and still there is uniqueness; one-fourth of unique is still unique. At no point in the division process does some small fraction of uniqueness cease to be unique.’ [24]

This argument of the uniqueness of one ridge, or one pore, or one ridge edge shape, is irrelevant. The essence of fingerprint examination does not rest on the uniqueness of the friction skin; a fingerprint examiner never (or only extremely rarely) examines the actual skin of the finger. What is examined is a transfer of that information, a print, either taken intentionally or left accidentally, and developed with a medium. Fingerprint examiners know this, because none would make an identification on the basis of one ridge feature, one pore, or one ridge edge shape in common [9]. Wertheim Sr. does acknowledge this, stating that at some point our ability to discern the uniqueness he describes will falter, but he does also comment that if the skin is unique, then ‘we must agree’ that every recovered mark must also be unique [24].

Arguing the legitimacy and accuracy of fingerprint identification using the uniqueness of friction ridge skin is like arguing the legitimacy and accuracy of eyewitness testimony because of the uniqueness of the human form [18]. This only addresses the variability of the source [9]. The key issue is one of fidelity. How well has the information transferred from the skin, and how much detail is shown? Examiners acknowledge the issue of clarity by placing importance on the quality and quantity of information shown on the mark. The combination of these two aspects has led to the strange phrase 'sufficient uniqueness' [1]. How much uniqueness is there? Is enough uniqueness shown? Which is more unique? [89] Or even 'the fingerprint is unique, and made even more so by the addition of a scar' [1]. Something is either unique, or it is not. It cannot be more, or less unique.

This notion of Nature's uniqueness has led to more unusual evidence being presented in court; that of ear prints, and lip prints [75]. If, as the fingerprint profession likes to argue, everything in Nature is unique, there should be no problem with this type of evidence for identification. Yet it is far less accepted; such claims are questioned. What is instinctively wrong about the uniqueness argument for lip prints, should also be instinctively wrong about the uniqueness argument for fingerprints. More is required than the claim of uniqueness of source.

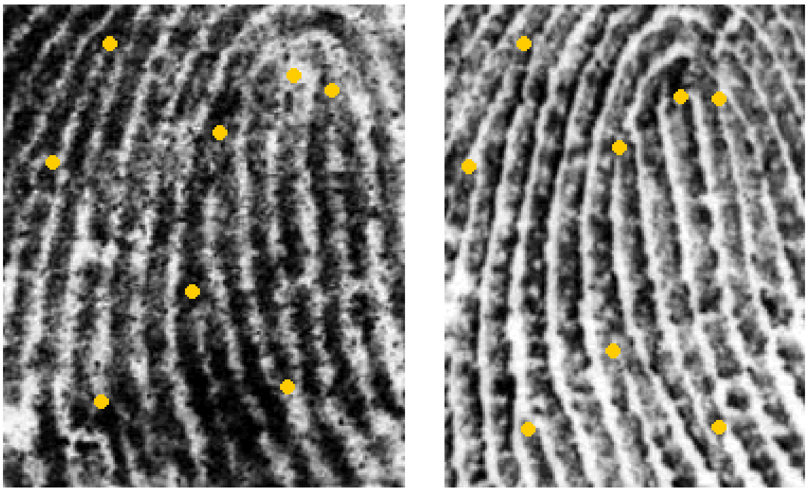
This assertion of uniqueness is then carried through into a second assumption, of identification – the assertion that every trace can be related to a unique source [72]. Whilst it is obvious to state that one particular finger left a particular mark, the ability to identify the individual is dependent on the quality and quantity of information left behind, not on the fact that the source skin is unique. It is not the skin which is being compared, it is the mark, and the appearance of this mark depends not only on the source skin, but also on the surface, the medium it is left in, the pressure, the duration of contact, distortion, and the development medium employed. There has been little research on how these factors affect the appearance of ridge detail [9]. Critics realise that a mark is a much smaller, smudged copy of the detail found on friction ridge skin [18], yet fingerprint examiners continue to refer to the fact that human friction ridge skin is unique [58]. The knowledge that even the ridge edge shapes are unique is irrelevant if it is not known how clearly this uniqueness is transferred, and how its appearance may be affected by different factors. Ashbaugh did note this issue, commenting that many of the minute details that make friction ridge skin unique do not survive the transition from ridge to print [1], but rather than collect data on the frequency variations in areas of print, and the transfer of detail, the profession has generally fallen back on the assumption of discernible uniqueness [94]. Words such as ‘sufficiency’, ‘uniqueness’, ‘infinite variety’ and ‘partial’ are often used, but with no empirical information about how partial a mark can be before it can no longer be identified, and how much information is sufficient. The general statement is that it depends on the mark itself, which is an acknowledgement of importance of the clarity of information present, but also appears to be used as a way to avoid the issue of data gathering. Because the friction ridge skin itself is described as unique, and containing infinite variety, it is claimed there is therefore no way to study or document this because of the infinite number of variations [24].

I feel this confusion between skin and mark stems from confusion over the word ‘fingerprint’. As I said previously, it can be used to mean the print left behind, and also the skin of the finger itself. When the judge in US v Mitchell (1999) [91] took judicial notice of the uniqueness of fingerprints, this was referring to the friction ridge skin. The uniqueness gathered from biological research also refers to the friction ridge skin. Because the word ‘fingerprint’ is sometimes used to describe these patterns of the friction ridge skin on the finger, as well as the mark left behind, it can therefore be misconstrued that the print left behind is unique. I think this affects both examiners and critics, and requires acknowledgement and clarity. Much is written by examiners extolling the uniqueness of friction ridge skin, but this effort needs to be shifted to the prints which are left behind by the friction ridge skin, and research done to assess how to judge uniqueness from these marks. This has been noted by a committee reviewing the scientific basis for friction ridge comparisons, who stated that tests to prove the ‘uniqueness of a whole print does not provide any gain in the fundamentals of the science of friction ridge examinations. It shifts resources away from addressing more pertinent questions …. The uniqueness issue of interest is not that a fingerprint in its entirety is unique … The critical issue is the minimum number of objective features in a latent print necessary to render an identification with confidence [95].

This distinction is not often recognised by fingerprint examiners, whose use of the notion of uniqueness has been used to suggest there is no point in pursuing a statistical approach: ‘Statistical inclusion declares an inability to differentiate, and implies than those formations existing below the threshold of quantity have a shared commonality, a shared sameness. This approach, in essence, refutes biological differentiation as a natural and consistent occurrence and strongly suggests that a significant part of any fingertip is not actually unique’ [44]. This comment from David Grieve highlights the confusion between the skin on the fingertip and a print left on a surface. To suggest a threshold below which marks will have shared commonality does not refute the uniqueness of biological entities, but rather the ability to perceive this uniqueness in a copy.

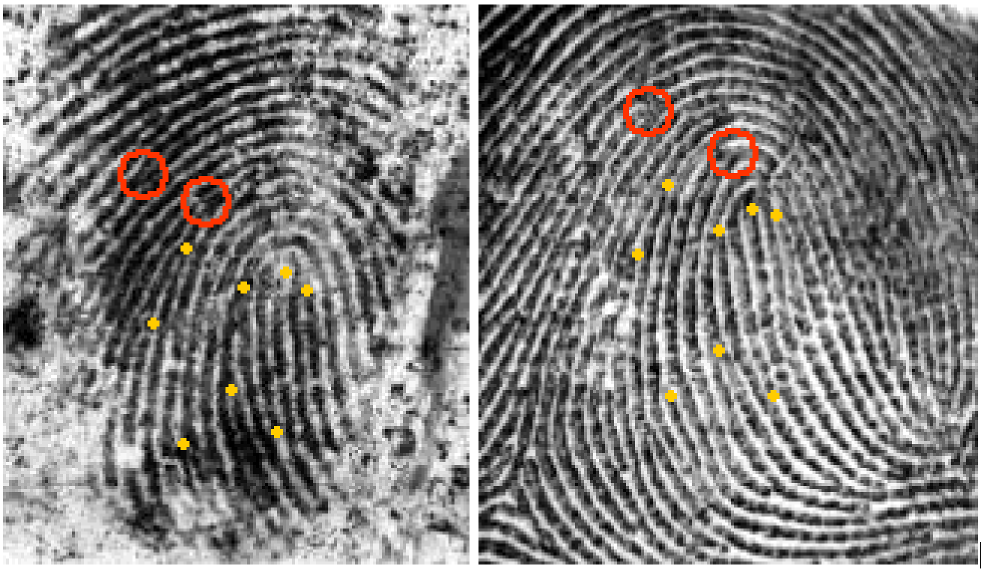
This fallback to biological uniqueness also allows many to claim that there is never any commonality between different fingerprints; ‘no two fingers have been found that are anywhere near identical’ [27], and, more extreme; ‘those who state… that they have found two different fingerprints which shared a certain number of points in common commit more than a violation of a fundamental tenet of nature and, by default, the fingerprint science. Such statements reveal an uninformed allegiance to dogma as well as a resounding rejection of all science’ [44]. Again these comments confuse the skin with the print. Those who state they have found a fingerprint with points in common are stating just that; they are not claiming the skin itself on those two fingers is exactly alike. All examiners have seen such prints, but not many like to admit this. This web example shows two prints, the left a scene of crime mark, the right a print from a fingerprint form, with 8 points in common:

Illustration 7: Two fingerprints with 8 points in common.



This may appear to be an identification, until a larger area of the prints are shown:

Illustration 8: The same two fingerprints, showing areas of dissimilarity.



[96]

The red circles highlight some of the discrepancies. Without research on the likelihood of finding such prints it is not possible to know how likely these comparisons are, and indeed whether a print showing only 8 or 10 features is indeed identified, or just a “look alike”. An Interpol report on fingerprint identification comments that there are fingerprints from different origins that show unexpected levels of similarity, and that there is a ‘real danger for false conclusions’ [64]. There needs to be further acknowledgement of the existence of such similarities, in order to create awareness and encourage further study. An adherence to the mantra of the uniqueness of friction ridge skin will be of no assistance to the field in the future.

1.12 The impact of ability

One of the recurrent features found in any description of fingerprint examination is the application of the examiner's knowledge, experience and ability [97] [1]; it has been described as the most important element in the process [98]. The examiner should be 'trained in why all areas of friction ridge skin are unique' [98], and which details on the friction ridges may be used to identify [1]. The value of each feature is determined by its rarity, judged by taking into account it's direction, how it relates to other features, and it's position within the pattern [64]. However, no authoritative research has been done in this area [99], therefore the judgement is purely a subjective one, the feel for which can only come from practice. It is suggested that the required knowledge can only come from an extensive number of comparisons of borderline or 'look alike' prints [64], but how it can be ensured that all examiners receive this experience is unclear. Different examiners will have had different personal experiences of near-misses [18].

Ashbaugh states that determining the level of detail required depends on the capability of the expert, and this threshold will fluctuate within parameters. These parameters are apparently set by the general population of fingerprint examiners through peer review [1]. However, with no empirical evidence regarding levels of detail required; it is not possible to determine the correct level of detail for identification. This presents a conundrum: 'consider a mark of dubious and contentious quality yet one which has been identified by an examiner. This person may be judged by his peers as an excellent fingerprint officer in identifying a very bad mark but somebody else may take the other road and opt for caution judging by their own experience of courts – and marks. Who would be considered the most competent – the one who said yes to a poor mark or the one who would urge caution because of doubt?' [67]. With no way to know ground truth, there is nothing to calibrate against, and no way to know who is the better. In these situations experience often wins out. But is more experience always better? Wertheim states 20 years experience could be 20 years, or 1 year repeated 20 times, depending on the examiner [97]. Evett describes a study into identification of human hairs where experience level was also measured. He states there was an association between experience and performance: the less experienced participants performed better [34]. To only learn from personal experience means we do not know whether we are building a knowledge base or an ignorance base. In other scientific fields experiments would be carried out, to check whether interpretations are concurrent with reality [100], and this is the case to a certain extent in other forensic sciences; for example in fire investigation experiments are undertaken to replicate observed results to test theories [56]. Evett states 'I do not believe that our claims of experience count for much unless we can show that our knowledge is subject to repeated testing under controlled conditions' [100]. Ashbaugh also states that 'experience is only bone fide when it is gained from a position of knowledge' [49], but the knowledge he suggests is that of the development of friction ridge skin, rather than objective, experimental knowledge of required sufficiency or genuine distortion. Intuitive judgements from experience may seem to provide the right conclusions, but do not always prove to be the best predictive tool [18]. In the USA, Judge Letts in the case US v. Parks (1991) commented on this issue by remarking to the fingerprint examiner 'You don't have any standards. It's just an ipse dixit. "This is unique, it's very unusual" "How do you know it's unusual?" "Because I never saw it before" [13].

1.13 Statistics and a probabilistic approach

The fingerprint community has generally attempted to avoid the use of statistics and probabilistic models to assign a weight to the evidence. The adoption of a numeric standard meant there was no perceived need to look at this issue in any more depth. This reticence to consider a probabilistic approach was not the case at the beginnings of fingerprint identification. Two of the forefathers of the discipline, Galton and Henry, put forward statistical methods for evaluating the strength of fingerprint identifications.

Following Galton and Henry there were other attempts to address fingerprint identification from a statistical standpoint by Balthazard (1911) [101], Roxburgh (1933) [102], Amy (1948) [103] and Osterburg (1974) [104] who was interested in determining the 'unusualness' of features, but these gained little attention in a profession which was by this point solidly accepted by the Criminal Justice community and working to numerical standards. Kingston (1964) was the first to attempt to propose a model which took into account the varying quantity of minutiae in different areas of the print [9]. Recently there has been a revived interest in a probabilistic approach, which has developed since the widening adoption of a non-numeric system of fingerprint identification, and the introduction of DNA evidence.

DNA evidence brought a scientific field with a huge accumulation of data into the forensic arena, and its widespread adoption introduced the courts, and the lay public, to evidence presented as a calculation of probability. This was evidence presented with apparent mathematical precision, and calculable error rates [89]. The presentation of DNA evidence has increased the general understanding of such models, and has also sparked critical comment of other forensic evidence, including fingerprint identification [72]. As the fingerprint profession endeavoured to be seen as scientific and moved away from unjustified points-based standards, this new knowledge about statistical evidence has posed questions; what is an identification based on? Why does fingerprint analysis not have a statistical model?

Currently, the fingerprint profession is of the view that fingerprint evidence should only be stated as an absolute conclusion [64], and any discussion about a probabilistic approach has, until very recently, been rejected on principle by virtually all fingerprint examiners. There are three general reasons given by practitioners for not using a probabilistic approach:

1. the individuality of friction ridge skin does not allow it – the skin is unique, and a probabilistic statement would imply the possibility of duplication. Most fingerprint examiners do not believe there is the possibility of duplication, and so do not see a need for a probabilistic approach. However this ignores the essential issue in fingerprint examination; the difference between the skin

and the mark which is left behind, and the ability of the examiner to discern this uniqueness from a mark containing limited information.

2. as yet there is no dedicated tool to assess match probabilities.
   Although there is no ideal model in existence as yet, this should not preclude their investigation, and the use of imperfect models to gain more information on the weight of the evidence.
3. the adoption of a probabilistic approach would weaken fingerprint evidence.
   At present the profession generally seems to believe that the strength of fingerprint evidence is in its absolute conclusions. To remove this certainty would weaken its findings. It is clear from other types of evidence, in particular DNA evidence, that this would not be the case. This is a cultural view rather than a genuine one [9].

A probabilistic model could also provide evidence when there is insufficient information to reach a definitive conclusion. At present this type of evidence is dismissed by the fingerprint community, who feel the examiner should only report definitive findings rather than probable ones [64]. One of the defining figures of forensic science, Edmund Locard, suggested giving probable identifications when one could not be certain. Despite Locard's standing as a scientist and researcher, Moenssens has stated 'his suggestion should be totally rejected', saying that 'there should be no evidence whatsoever of a probable identification' [99]. It is claimed that a system which gives both certain and probable conclusions 'does not serve anyone' [64] although it seems clear that, in a case where the suspect has only whorl patterns and the marks at the scene are all loops, disclosing this information may be of value. These views only seem to be held by the fingerprint community, with others stating that there is no reason in 'logic or law' why a probable conclusion should not be given [105]. Simply because there is no certainty, does not mean the evidence should be ignored [9], it is not the role of the fingerprint examiner to decide the value of a piece of evidence, but to present the weight of evidence as they have found it, and leave decisions of value to the courts [5].

Currently it is claimed that examiners should give no opinion on the weight of the evidence, for example in the case of currently insufficient marks, because they have no statistical tools to do so and therefore would only be expressing their ‘feeling’ [64]. This is an irrational argument, because this is exactly how fingerprint examiners currently go about their work. The conclusion of absolute certainty is essentially a ‘feeling’, based on personal judgement, ability and experience. By continually stressing the impact of judgement, experience and ability on the fingerprint examination process, practitioners are in effect acknowledging the subjective probability estimation that is required.

At present there are no tested probability models, or statistical data, to objectively assist in decisions of identity. Conclusions are based on observation, the examiners intuition and assumptions gained through experience, training, and ability. Using this a conclusion of identity is reached; a belief that although only some of the information is visible, any further recording of the print would also have matched [50]. However there is no way to ascertain the reliability of such a judgement, as the examiner’s experience is only gained through casework. Previous conclusions will have been made regarding identity or difference, but there is no way to know that these conclusions are always correct; experience is gained through casework where the right answer is not known. Examiners might agree that a small number of features is sufficient, but they may be wrong – no research has been done with known examples, the ‘ground truth’ is not known in case work [66].

By reaching an absolute conclusion the examiner is concluding they have found enough features in common between mark and print to eliminate all other donors in the world, when they cannot possibly have viewed more than a small subsample [9]. This type of judgement is illogical, and therefore open to question and criticism. As an example, suppose the examiner is wrong to conclude that they have found enough features in common to declare identity, and instead there is a 1 in 1 million chance that another print could share the same features. An individual would not be able to distinguish between these two situations using only knowledge and experience, because the world would essentially look the same; people do not usually see events that only happen once in a million instances [18]. It is in this kind of judgement that statistical information can inform, and a probabilistic estimate can provide validation for what is currently a very subjective judgement.

The crux of the issue the concept of ‘sufficient agreement’; how much is needed to reach a conclusion of identity. At present probabilistic models are being researched to provide more objective information from which to draw conclusions. Current models being formulated use Bayes Theorem to calculate likelihood ratios for this probability – the ratio of the likelihood of a match to the suspect, over the likelihood of a random match [106]. Applying this type of model to a fingerprint identification may be hard for some in the fingerprint profession to accept, because it requires the consideration of features matching more than one individual, and this concept is not readily acknowledged. The engrained view is one of absolute certainty, and absolute identification, and this view will have to alter in order for a probabilistic model to be adopted. This alteration of view may be initiated by the legal system. The current confidence in absolute conclusions has persevered because of support and acceptance by the courts; were this support to shift to a probabilistic approach, the fingerprint profession would have to change its practices.

The current research into probabilistic models has arisen from the understanding that the evaluation of forensic evidence is inductive, rather than deductive. Various research studies have been carried out in this area, including Meuwly et al [107], who state it is necessary to revisit the methodology used for human identification in forensics, and Pankanti, Prabhakar and Jain who have studied the individuality of fingerprints, approaching the issue from the standpoint of biometric analysis rather than criminal justice [108].
In the specific area of crime scene mark comparison, studies by the Forensic Science Service in the UK in conjunction with the University of Lausanne [109] have used computer modelling to calculate likelihood ratios for corresponding minutiae on mark and print, and their research has indicated extreme selectivity even at limited configurations of minutiae. Their studies suggest that in some instances even 3 corresponding minutiae can be evidentially valuable, and that match probabilities of 1 in a billion can be obtained, even without consideration of pattern or ridge count

[41], [109]. It should be noted however that these results were obtained with a relatively small dataset. Further validation studies will show whether the strength of these results is replicated over a larger population.
A criticism of statistical models from fingerprint examiners is often that the calculations do not take into account anything other than ridge characteristics. Current research being undertaken by Champod et al and funded by National Institute of Justice is working to develop a model which takes into account ridge count between characteristics, as well as the placement of the characteristics themselves. Current data using a dataset of 12000 images and using 7, 10 and 13 corresponding minutiae has resulted in strong match probabilities [110].

It is seems clear that the future of fingerprint comparison will consist at least in part of a probabilistic analysis of the evidence. Current research suggests that leaving behind absolute certainty and adopting a statistical approach will add a powerful extra dimension to fingerprint evidence, rather than weaken it. To be able to demonstrate the strength of identification evidence from a logical rather than purely subjective experiential level can only benefit the profession.

1.14 Perception, bias and subjectivity

The fingerprint profession has always strived to present factual, objective evidence. As I have already explained however, these notions of fact and objectivity cannot be supported. The ACE-V process is inherently subjective, and due to the nature of inference results can never be ‘fact’. Another factor which prevents true objectivity has recently been brought to the fore: an aspect of cognitive reasoning called confirmation bias.

Confirmation bias has been known to cognitive scientists for many years, and has been established by decades of rigorous behavioural experiments [111], and has become perhaps the best known type of inferential error [112]. Confirmation bias can be defined as ‘the tendency to confirm an initial theory or preconception and avoid disconfirming information’ [111]. It is not reflective of a malicious desire to choose one outcome over another [111], rather it is an unconscious characteristic of our way of thinking. As a result confirmation bias will have an effect on all human endeavours to a greater or lesser degree, and will affect the reliability of almost any form of expertise to some extent [113].

The human eye is not a camera; what we see is immediately processed by our brain, and it is here that it is affected by subconscious cognitive processes. ‘Observation is not at all a bare apprehension of pure sense content, but rather an active process in which we anticipate, interpret, and structure in advance what is to be seen. There are, indeed, things right in front of our eyes which we fail to ‘see’, and things we see through expectation when given only the faintest clues. ‘We even see what is not there at all, as any proofreader knows.’ [114]
This unconscious interpretation of what we see can be affected by many different influences, including past experiences, motivation, personality and ability [115]. The biggest issue with this subconscious information processing is that we are not aware it is taking place. This means it can be hard to tell whether we are genuinely observing true features, or being influenced by our preconceptions [112].

One feature of confirmation bias, the avoidance of disconfirming information, was realised many years ago by Francis Bacon who commented that ‘it is the peculiar and perpetual error of the human understanding to be more moved and excited by affirmatives than negatives’ [116]. This concept is why falsification was an important facet of science to Popper; one’s mind can be drawn to the positive, so it is important to always look for aspects which could disprove the findings or theory. As science has become more aware of the effects of bias most fields have attempted to develop methods to minimise its effects. Concepts such as ‘double-blind’ and ‘placebo’ are now well-known, and were developed to try to minimise the effects of subconscious bias [113].

Forensic science is one of the few fields which has not adopted stringent measures to prevent bias [113]. This was highlighted in the recent National Academy of Sciences report in the USA, which stated that ‘much more must be done to understand the sources of bias', and that 'the forensic science disciplines are just beginning to become aware of contextual bias and the dangers it poses' [21]. Forensic scientists have no less need than any other scientist to be aware of the issues of bias and determine methods to reduce their effects; they work in interpretive fields, and are therefore are heavily dependent on cognitive processes. Paul L Kirk commented that physical evidence cannot be wrong, error can only be in its interpretation [117]. It is interesting to note that this argument is echoed by fingerprint examiners who wish to split error into different types, however this was not the meaning intended by Kirk. Currently fingerprints, and often forensic science as a whole, gives the impression that it is 'infallible, scientifically proven, undeniable truth' [111]. As a result it is given a lot of evidential weight, but mistakes can happen, particularly when those involved in criminal justice, from police officers to forensic scientists, do not receive any training on cognitive issues [111]. Currently few if any forensic textbooks mention bias issues [113]. Confirmation bias affects all individuals; to not know about or acknowledge its effect is to invite errors. An awareness of the inherent bias allows for an adoption of procedures to control its effects, and so is essential [118]. Unfortunately the current lack of specific research in this area, and the reticence of fingerprint examiners to acknowledge the issue, means that its impact is unknown. Being affected by bias does not weaken an individuals' expertise as all people are open to these effects. These are not the errors of incompetent individuals; confirmation bias 'can lead competent and honest forensic scientists, using well-validated techniques, to offer sincere conclusions that are, nevertheless, distorted and inaccurate' [113]. Fingerprint practice, with its history of 'infallibility' and findings of fact, has been slower than other areas of forensic science to acknowledge that confirmation bias is an issue. This is concerning, as I feel there are two major areas of fingerprints which can be strongly affected by confirmation bias. The first is during the ACE-V process, and the second is in the underpinning beliefs of the profession.

The concept of confirmation bias in the comparison process of fingerprint identification can take various forms:

- being unconsciously affected by extraneous information, such as police case information;
- being affected by the known conclusions of others about the mark in question;
- explaining away discrepancies because of a subjective confidence in the identification;
- being led by the known print to find features in the unknown, and poor quality, mark.

All of these are aspects of confirmation bias. The one most often discussed in fingerprints is the first example: being influenced by extraneous case information. Other areas are more critical as they can affect every comparison carried out.
The example of the effect of case information may be the most prevalent because it was the topic of the first study investigating confirmation bias in fingerprint practice. It was carried out by Dror, et al [119] and was published in 2005. The study examined the effect of case information on the identification process, and concluded that the participants had been affected. However the study did not use fingerprint examiners but university students as its subjects.

A further study was conducted by Dror and Charlton, in which they used fingerprint examiners as their subjects [119]. Only 5 examiners were involved in this study; they were shown a mark which they had previously identified and were told this was the mark from the Madrid bombing case; a known and highly publicised misidentification. Four of the five experts changed their conclusions. Although this could be seen as strong evidence to suggest that fingerprint examiners are open to confirmation bias in the form of contextual information, this example is far removed from everyday casework. In the fingerprint profession, it is apparent that 'the very worst thing' any examiner can do it make a misidentification [120]. When presented with these marks, even if features were found in common, it is likely that the examiners would be more likely to err on the side of caution given the commonly known facts about the Madrid case. This is an extreme example of bias from contextual information, and not easily transposed into everyday casework. It does however pose some interesting questions regarding queried misidentifications, the most obvious being the marks in the McKie case in Scotland. Due to the highly-publicised information surrounding these marks, the study would suggest it is impossible to reach an objective conclusion of identity or non-identity. Those who did feel there were features in common may have concluded it was insufficient, or not stated their views for fear of being ostracised.

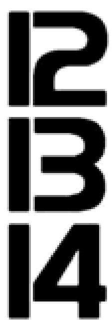
Dror and Charlton progressed their research with a third study, using more realistic information, such as the suspect had confessed to the crime (to suggest guilt), or the suspect was in police custody at the time of the crime (to suggest innocence) to study the effects of extraneous information [121]. Again, fingerprint examiners were used as subjects, and again it was a low number of participants, in this case six. Out of 48 comparisons, the fingerprint examiners changed from their original conclusions in 6 instances. 4 of these instances (out of 24) were when they were provided with contextual information. These results are more concerning, as they more closely replicate normal case work, and Dror and Charlton feel that the changes in opinion were a result of contextual information: 'Our data demonstrate that fingerprint experts were vulnerable to biasing information […] Thus contextual information does not need to be extreme and unique to influence experts in their fingerprint examination and judgement' [121]. However I feel there are aspects of the study which make it difficult to reach any wider conclusions.
The extraneous information, though realistic, was not equal in its effect. To say a suspect was in police custody at the time of the crime would suggest it could not be his print. The information that the suspect had been arrested for the crime would not have the same strength of evidence for the opposite conclusion; the prints could still belong to someone else even if the suspect was guilty. There is also a strong effect given by the object the mark was recovered from; a weapon used in the crime, or a door in public use? This information was not given in the study.

Given the variety of possible ways in which a fingerprint examiner may be affected – by past knowledge, current emotional state, and/or expectations to facilitate perception and judgement [111] – which have not yet been studied, it is not clear whether the change in opinion (almost entirely recorded on comparisons of difficult marks) was due entirely to the contextual information, or some other variable.

The Dror/Charlton research in this area is the most publicised, but there have been other studies investigating the influence of confirmation bias through contextual information. A study by Kersholt into shoemark examiners found no indication of bias in its results [122]. Another study on fingerprints, using forensic students trained in fingerprint identification, showed no bias at the analysis stage, even when presented with a known print to compare against, and concluded that this demonstrated ‘robustness at the analysis phase’ [123].

Other influences of confirmation bias are harder to quantify. They include circular reasoning (looking for features from the known print in the unknown mark), disregarding discrepancies by explaining them away, and incorrect verification of results [123]. These involve subconscious cognitive processes which affect all humans, but which the fingerprint profession appears reluctant to accept. The images below demonstrate visual confirmation bias. Look at the image below:

Now look at the same image with other visual information around it:



Your mind will now see the original image as the number 13, regardless of what you saw it as before. But this can be altered with different visual information:

Your mind will now perceive the image as the letter B, because of the surrounding context.

[124]

This type of observational bias has been described as ‘the tendency to resolve ambiguous stimuli in a manner consistent with expectations’ [125]. As fingerprints found at scenes of crime are often of poorer quality, this bias may have an effect. It has been suggested that the lower the quality of the mark, and therefore the more difficult the task, the more subjective the analysis will be, and therefore more vulnerable to these types of observational bias [123]. Despite this possibility the fingerprint profession has yet to fully acknowledge this and train their examiners to be wary of its effects. While there is no way to eliminate this type of bias one must be aware of the way the brain processes data in order to be able to interpret it correctly.

The possibility that an examiner looking at a poor quality mark could subconsciously convince themselves that any discrepancies are a result of ‘distortion’. It would appear that this was one of the causes of the FBI misidentification in the Mayfield case, despite the examiners working on the case being highly qualified with many years of experience.

David Ashbaugh states ‘to protect from errors, parameters or protocol must be established which are designed to combat the brain’s tendencies to form opinions on little data and allow us to see what we expect to see’ [49]. This an accurate description of the current situation, but Ashbaugh feels the fingerprint profession has already ‘developed and follows a structured protocol to ensure forensic comparisons are objective and free from bias or shortcuts’ [49]. His implication is that the protocol of ACE-V is sufficient to avoid any errors caused by confirmation bias. As I outlined previously, ACE-V is essentially a description of a very general process, and has little specific instruction on how to avoid issues of unconscious bias. There is a possible solution for one type of observational confirmation bias, namely circular reasoning or reading from the print to the mark. Removing the known and studying the unknown separately can assist, but judgement can still be affected by what has been seen previously. However, observations could be tested by giving the unknown mark to another analyst, without giving them the benefit of seeing the known print. If the feature(s) can be seen by the second examiner then these features can be used. If they cannot be seen without the assistance of the known, then there is a serious question over the objectivity and reliability of the comparison [126].

The Verification stage is not sufficient protection against bias influencing a conclusion. Unless this process is carried out completely blind (ie. the verifying examiner does not know what has been identified, or even if the case is an identification), this stage is open to confirmation bias. Once a mark has been labelled as an identification it may be difficult to view it as if it may not be. This problem of verification of findings also occurs in science, when investigating new theories such as cold fusion, polywater or N-Rays. These examples show that simply having others check a result does not guarantee lack of error if there is an expectation of a particular result.

One aspect of a fingerprint examiner’s work can help to lessen the effects of bias. Accountability for conclusions can reduce the effects of bias, and the cost of the error has been shown to increase accuracy in judgement. It does not however eliminate the effect of bias entirely [111].

1.15 The role of bias in preventing progress

I would like to go on to discuss the other aspect of bias in fingerprint practice; that which involves the underpinning beliefs of the fingerprint profession, their use of subjective probabilities, and their perceived unwillingness to consider new ideas.

The characteristics of fingerprint identification which have already been discussed: uniqueness, 100% certainty, infallibility; were adopted by the fingerprint community over 100 years ago. They were a product of their Victorian age, and accepted as truth. They have rarely been questioned by those working in the field, and in fact until recently have rarely been questioned by anyone. They were believed to be facts, they appeared to work for those who used them, so there was no need to investigate them any further. This is described as a type of confirmation bias by Nickerson, who commented that the lay scientist seems to look only until a plausible explanation is found that can be linked to the outcome through theory. This then generates a vicious circle – the subjective ease of the explanation encourages confidence, and the confidence makes the lay scientists stop searching once the explanation has been found, thus avoiding discoveries of alternative explanations and investigation of complexities from shaking the lay scientist's confidence [112]. He describes this as a conditional reference frame: the focal hypothesis (in this case the premises of fingerprint identification) are assumed to be true. This assumption then affects the way the problem is perceived and how relevant evidence is interpreted. 'A certain inertia sets in, which makes it more difficult to consider alternative hypotheses impartially' [112]. The premises of fingerprint identification are instilled very early on in an individual's career, and currently little or no training is given in 'alternative ideas' such as probability and the possibility of confirmation bias. It has been shown that once an individual has taken a position on an issue, they will then move to a position of attempting to defend or justify that position, and less readily accept alternatives. It has also been shown that, when assessing information received, the information acquired early in the process is likely to carry more weight [112]. Many fingerprint examiners have worked in their profession for several years. The training they received was that the premises of fingerprint identification were fact, and in practicing their work these premises have solidified in their mind as they will see many positive instances to confirm their beliefs. As a result there is a great reluctance among many to consider alternative options.

An example of attitude towards new ideas can be found in the response of Martin Leadbetter, recent Chairman of the Fingerprint Society, to the published study by Dror and Charlton into confirmation bias:

'*any* fingerprint examiner who comes to a decision on identification and is swayed either way in that decision making process under the influence of stories and gory images is either totally incapable of performing the noble tasks expected of him/her or is so immature he/she should seek employment in Disneyland.'

'In all my 40 years service in fingerprints I can categorically state that I never knew of any examiner changing his or her decision because the crime was nasty or unimportant or had been swayed by a gruesome photograph.'

'Personally I believe that this sort of reporting unnecessarily damages the true state of fingerprint identification.'

'And I do find it rather unsavoury that those within our own ranks, who ought to know better and are aware just how reliable the fingerprint system is, continue to provide fuel for those within the media and Press who seem to relish attacking what is the most valuable tool in the investigating officer's armoury' [127].

Dror and Charlton responded to these comments, stating they reflected 'a defensive, unscientific and unprofessional approach' [128]. A very experienced fingerprint examiner described those from a fingerprint background who wished to carry out research as people who 'ought to know better'. Studies like those of Dror and Charlton are the only way to learn about current issues through research, and when this research is done by those within the fingerprint profession it is more likely to reflect the actual working practices of fingerprint examiners. Mr Leadbetter used a familiar argument to dismiss the concept of confirmation bias by claiming that he has never known any examiner to be affected in such a way. This is one of the key factors of confirmation bias; it is something which will affect everyone to a certain extent, and it is a subconscious effect. One would not be aware one was being biased in this way. Dror and Charlton refer to this as an epistemic claim, reflecting his personal knowledge, rather than an ontological claim, reflecting what actually exists [128]. Much of the basis of fingerprint practice rests on similar accumulated personal knowledge.

This aspect of accumulated personal knowledge is the second confirmation bias-led concern about the field of fingerprints in general. The adoption of a “non-numeric system” has left the decision of identification as a subjective judgement by the fingerprint examiner. This is a judgement based on their training, experience and ability [97]. Whilst in many cases this may not be an issue, little research has been conducted on the effect of subjective judgements on fingerprint comparisons. The combination of marks of poorer quality (therefore more difficult to interpret) and the lack of acknowledgement of bias as a factor, means that the lack of any empirical information can become a concern.

Humans believe that they are a good judge of their knowledge. This has been shown to be true in everyday situations, but the human mind is not well-suited to determining ‘the truth or falsity of hypotheses’ [112]. It has been shown that the ability to process and compare patterns is something which humans are generally very good at [33], and this skill is clearly put to good use in fingerprint examination. However because there is no frequency data on fingerprint features, examiners must intuit, and rely on ‘experience’, so subjectively determine the ‘uniqueness’ of a given group of features. This is calculating subjective probabilities, and is something humans are generally quite poor at [33]. Evett comments that due to a lack of empirical knowledge, forensic scientists are expected to develop the ability to evaluate uncertain situations ‘by some mysterious process of osmosis leading to what we call “experience”’[100].
Fingerprint examiners are assumed to be able to judge the ‘uniqueness’ of a group of features through accumulated experience. But how can a value be placed on this experience? How can one know what the examiner has taken from their experience, or indeed what they have experienced in comparison to another examiner?

With no data to consider, this judgement of how much is sufficient is left to intuition, instincts and experience [125]. This appears to be a satisfactory state of affairs for most fingerprint examiners [1] [45] [59] however, research into cognitive processing and confirmation bias has shown:

- In general, people tend to express a higher degree of confidence than is justified by the accuracy of their performance
- Overconfidence can result from scientists overlooking specific sources of uncertainty
- Once an opinion is formed it can be very resistant to change, even in the face of compelling evidence [112]
- Expectations lead us to conclude more readily that we have perceived one thing rather than another
- This effect is reinforced when we later try to remember what we perceived
- We are more likely to notice and recall positives than negatives [113]

All of the above points could subconsciously affect the mental calculation of subjective probabilities if there is no empirical data to compare to. A fingerprint examiner cannot recall every comparison they have carried out, and equally could not recall every time they have observed a particular pattern or ridge feature. As we are more likely to recall positives than negatives, it seems possible that examiners are more likely to recall the prevalence of 'making an identification' than the prevalence of finding features in common only for it to prove to not be an identification. Without keeping a record of these instances it is unlikely that the mind will be able to recall the frequency of these events, because the event it is seeking for is an identification. Evett felt that claims of experience cannot count for very much unless the knowledge gained from it can be subjected to testing in controlled circumstances. Currently, in forensic science, experience is gathered from examining a large number of events, but these are not representative of the world at large [100]. We need to be able to demonstrate that what we observe is relevant to the world in general, and is a true reflection of the 'bigger picture'. It is not possible to gain a full, accurate understanding simply from observing a small instance at a time, and hoping to store it in one's memory. These effects of confirmation bias and cognitive processing are one of the reasons the science uses a statistical approach.

From these examples of confirmation bias it should not follow that fingerprint identification is weak or unreliable. These traits are found in all humans to a greater or lesser degree, and it is impossible to reduce their effect to zero. The biggest advance which could be made by the fingerprint profession would be to recognise the existence of these effects; if an individual is aware of these issues they can be more cautious about their conclusions, and be more open to opinions which differ from their own [112]. Simply following the ACE-V process is not enough, because one can follow the ACE-V process and still reach the wrong conclusion if one is not aware of the possibilities of bias. Possible ways to lessen bias would be to make more use of note-taking to document what is seen as it is seen, although it is difficult to truly document the thought process during a comparison. The area of note-taking is one where there appears to be jurisdictional differences, and it may be possible to research and compare different areas to determine the most successful method.

Subjectivity is not something to be avoided or belittled, experience is a key part of knowledge accumulation and being able to learn from our previous experiences is crucial in many areas of life. Our cognitive system allows us to tune in to perceive some things and ignore others [113], and this is an important skill. What is crucial is an understanding of how the processes of our mind can affect our perceptions. Risinger has suggested that this change may already be slowly occurring in forensic science, with development of more scientific, rather than simply technical, fields. As more trained scientists move into the field, an awareness of the chance and effects of bias should grow [113].

1.16 Different examiners, same conclusions

Currently, the fingerprint profession state that two competent examiners who correctly follow the ACE-V methodology will arrive at the same conclusion [50] [98] [1]. Fingerprint methodology not only expects consistency, but demands it [60].

Given the arguments I have outlined above on the general description of process, the subjective nature of reaching conclusions and the lack of any statistical data, this assertion is problematic. No two examiners will have exactly the same ‘training and experience’ [1]; as Wertheim points out, inherent ability also plays a part in competence . It is accepted that scientists may reach different conclusions regarding the same data [129]. Whether the fingerprint profession is striving to be more scientific or just learning from science and adopt logical processes, to maintain not only the assertion of absolute certainty from subjective judgement, but also a certainty that any other examiner would reach the same conclusion (which has been described as drawing subjective conclusions about other people’s subjective conclusions [56]), is not plausible.

The FBI unwittingly added to the statistics on disagreements over identifications during the case US v Mitchell in 1999 [91]. The defendant chose to challenge the accuracy of the fingerprint evidence, and in an attempt to demonstrate the scientific certainty of the identification process, the FBI sent the two identified marks, along with the defendant’s fingerprint form, to 53 different law enforcement agencies in the US. The aim was to demonstrate the unanimity of opinion between fingerprint examiners. 39 agencies returned the prints to the FBI, and 9 of them found that either one or both of the marks did not match the prints of the defendant. Unfortunately for the FBI, their experiment showed that there was no ‘certainty’ to the conclusion of identity, and that every examiner does not necessarily reach the same conclusion [78]. A further, perhaps more worrying aspect of this incident was the response of the FBI to their results. Rather than investigating to discover the reasons for 9 of the agencies to report the marks as negative, they instead sent the marks back to them, plus enlargements contained in plastic sleeves marked with red dots to show characteristics, and asking ‘please test your prior conclusions against these enlarged photographs with the marked characteristics’ [19]. Unsurprisingly in such a situation, the 9 agencies then reached a conclusion of identity. In retrospect, this seems disconcertingly similar to the events of the Mayfield case.

It may be that as the Mayfield case is a good example of fingerprint error being exposed to the world, the McKie case may prove to be a good example of differences of opinion between experts. The Chief Constable of Northern Constabulary, Ian Latimer, is quoted as saying ‘Fingerprint evidence is based on expert opinion …. it would appear that differences of opinion in this particular case also exist in the wider fingerprint community’ [130]. To fingerprint examiners this appears to highlight a concern, as all fingerprint examiners should reach the same conclusions [130], but perhaps this is just another example of an attempt to cling to an outdated way of thinking. Fingerprint evidence is not fact, therefore it is possible that two examiners may differ in their conclusions. It does not make logical sense to stress the importance of the examiner in the identification process and acknowledge the importance of factors such as innate ability, talent, training, experience and daily variables [97] and at the same time claim that all examiners will reach the same conclusions, as the fingerprint profession currently does.

2 Research aims

It is clear from the available literature that there are a wide range of viewpoints regarding these issues. However the views expressed in published literature may not be an accurate reflection of the opinion of the general fingerprint profession; those working in the fingerprint profession do not frequently publish articles, and the general viewpoint may legitimately be different from those who actively publish. By conducting a survey of fingerprint practitioners and other forensic professionals the extent to which the published views are held by practitioners can be investigated.

A short survey was distributed in paper form and also in web form to allow distribution internationally. The aim of the survey was to investigate several key questions by gathering opinions on the following areas:

- to what extent is fingerprint identification considered to be a science?
- are fingerprint identifications considered to provide100% certain results?
- what are the views regarding a probabilistic approach, and whether one should be adopted in fingerprint identification?

The survey also covered a number of other issues including science, reliability, error rate and subjectivity across a selection of forensic fields to see how fingerprints is viewed when compared with other areas such as DNA and footwear analysis by the various target groups.

The questions addressed are as follows:

- To what extent do fingerprint experts consider fingerprint identification to be a science? Are such views uniformly distributed or do certain countries espouse them more than others? Does this view differ between professions?
- Is there any relationship between the view that fingerprint identification is a science and the length of service of the individual?
- To what extent do fingerprint examiners believe their profession to be error free, and is this view held in some countries more than others?
- Do fingerprint examiners feel their profession and work is objective, and how does this view relate to their opinions of other forensic fields?

- To what extent are fingerprint examiners opposed to a statistical approach, and how does this view vary between professions?
- Is there any relationship between the level of education gained by an individual and their views on the issues of fingerprint identification as science, and the view that a probabilistic approach to fingerprint identification is possible and of value?
- To what extent do fingerprint examiners believe fingerprint identification provides 100% certain results? Does this view differ from that of other criminal justice professions?

3 Methodology

Choice of survey

A survey was compiled to gather the views of those working in criminal justice on the topics covered in the research questions. A survey can be defined as 'collection of quantified data from a population for purposes of description or to identify covariation between variables that may point to causal relationships or predictive patterns of influence' [131]. This method was chosen as it was the best way to reach the relevant population and professions; distributing it online it also allowed quick responses internationally. It was an efficient method of collecting data on the views of criminal justice personnel across the world, and was the most practical given the issues of geography and economy to collect a structured set of data. The target population are very familiar with a survey format, and if the subject material is of interest and relevance to them they may be quick to respond. Surveys can also be anonymous, which can encourage participation.

Other methods of data collection were not as suitable for this research as a survey. Analysing existing data was not possible as no existing data was available. An in-depth case study of attitudes in a particular field or area would only have considered one small area, most likely one or two offices or departments, and therefore it would not have been appropriate to infer from the data gathered views which might be held by the profession or region as a whole.

Content analysis of other written work was generally carried out as described in the introduction, however few criminal justice personnel publish their views on these issues and therefore such analysis would not reflect the views of the profession. Structured Interviews would have gleaned more in-depth answers to the research questions, but are difficult to analyse and also would have resulted in a much more restrictive sample size as cost and distance would have played a large role. This may also have affected the individuals who assisted with the research, as it may only be more enthusiastic individuals who would be prepared to take part in an interview.

An argument against conducting a survey for this type of data is that the specific nature of the questions can limit the possible responses. The issues being dealt with by the survey are fairly expansive so short, simple questions may constrain the answers which individuals can give. The results of this survey cannot be described as a complete view of these issues from the professions questioned, but can provide an overview of general opinions held, and so guide further, more in-depth study.

General format of survey

The length of the survey was limited to two sides of A4 paper to ensure that when distributing a paper copy the length of the survey was not off-putting. Given the scale of this research it was also important not to collect information on too many different areas which could not be practically analysed in the time available. A copy of the survey can be found in Appendix A.

A paragraph was placed at the top of the survey explaining the reasons the survey was being carried out, and requesting participation with the research. Although this research was funded by both the University of Strathclyde and the Scottish Police Services Authority (SPSA) it was decided to only place the logo of the university at the head of the survey. Due to ongoing repercussions from the McKie fingerprint case in Scotland there is resentment towards SPSA in some areas, so the SPSA logo was omitted to ensure it did not influence participation. A short paragraph was also placed at the end of the survey, thanking the individual for their assistance and providing an email contact address should they wish to raise any questions.

Selection and format of questions

The questions were formatted to provide either nominal or ordinal data. The first 6 questions were demographic in nature, and grouped and titled as such. They covered general information which was then used to analyse the research-specific questions which followed. Individuals were asked their age (as an age bracket), their gender, their profession, how much experience they had, their years service in that field, the

country in which they work and their level of education. These questions allowed a grouping of individuals for comparison.
The groupings for age in question 1 were determined by general assumptions for likely age groups employed in criminal justice. They were counter-balanced by question 4 which asked how much experience the individual had in their field. This allowed analysis on the basis of a definite answer of years experience, rather than the assumption that the younger the individual the fewer years experience they would have. A wider range of options were given for groupings of years experience as this may have a great effect on the views of an individual as training in different fields is likely to have evolved considerably over time.
The choice of professions in question 3 were determined by assessing the main professional groups in criminal justice and forensic science who would be targeted by the study. The legal profession was divided into three categories (solicitor, barrister/advocate, judge) as it was felt these groups could have quite different views. Had the response been too low the categories could have been grouped together to provide a general response from the legal profession. Unfortunately the responses from the legal profession were so low that no analysis could be conducted on this group.

It was felt an anonymous questionnaire would be the most successful. Individuals can be reticent to give their opinion if they may later be shown to have made the 'wrong' choice. As some of the topics could be viewed as quite controversial in the fingerprint profession (such as probability and science) asking individuals to identify themselves may have led to a low response rate. Identifying information was not a requirement of the research, nor was the identification of a particular city or department, so this information was not asked for in the survey.

Questions 7 to 14 comprised the research specific section of the survey. The first three questions were nominal in nature (agree/disagree/unsure responses). Questions 10 – 14 were Likert scale questions; question 10 asked the individual to rate the value of a statistical approach to fingerprints, and questions 11-14 asked the individual to provide a rating for rating specific questions against different forensic fields.

All of the research questions were constructed with some basic tenets in mind. It was important to design the questions to ensure all the respondents understood the questions in the same way. The survey was about fingerprint identification, and questions were asked of fingerprint examiners, but they were also asked of other professions, for example police personnel, and academics, who may not be familiar with fingerprint terminology.

The questions were all constructed as closed questions. Although open questions provide the opportunity for respondents to give specific personal opinions, give unanticipated responses and therefore are more likely to convey the detailed views of the respondent [132] they are much more difficult to analyse and draw conclusions from. The aim of the survey was to be a basic investigation into the opinions of the criminal justice professions on fingerprint analysis, so for this reason a closed question style was chosen. To allow individuals the opportunity to put their own personal views forward a comments box was placed at the end of the survey. This was used by a proportion of the respondents to give a range of comments.

Dillman gives a list of simple criteria to be considered when constructing survey questions:

- Use simple words.
- Do not be vague.
- Keep it short.
- Be specific (but not too specific).
- Do not talk down to respondents.
- Avoid bias.
- Avoid objectionable questions.
- Avoid hypothetical questions. [133]

All of these criteria were considered when compiling the questions.

The first three questions of the research questions section (7,8 and 9) were formulated as short statements to which the respondent is asked to agree or disagree. They cover the three main areas of interest of the study: is fingerprint identification a science? Does it provide 100% certain identification? Is a statistical approach possible? These three questions could also be combined to analyse the view of individuals on the nature of science; a science does not provide 100% certain answers, and a statistical approach of some kind should be possible.

Question 10 asked the respondent to rate the value of a statistical approach. This was included because it elaborates on the preceding question. It may be that a statistical approach is possible, but those who are of this view may vary on whether they feel such an approach would be useful.

The final set of questions (11-14) was constructed using a Likert Scale and respondents were asked to rate four different evidential types in different contexts. The four types of evidence were DNA analysis, fingerprint examination, footwear examination and eyewitness testimony. Choosing four different evidence types allowed the responses given by individuals on fingerprint analysis to be compared against their views of other evidence types. This was particularly relevant when examining views of objectivity or subjectivity of a field, as this judgement will depend on the individual's views of objectivity and subjectivity. DNA analysis was included as it is the current 'standard' in forensic science, and much of the discussion of the science of fingerprint identification and probabilistic analysis has come from the growing use of DNA in the courtroom. Of the four evidence types, DNA is generally viewed as the most scientific, and perhaps the most objective. Footwear examination was included because it is, in essence, very similar to fingerprint examination. An unknown mark is compared with a known source, and a judgement reached on identification. Eyewitness testimony was included as it contrasts strongly with DNA analysis. Eyewitness testimony is clearly unscientific, and clearly wholly subjective.

In these questions the phrase ‘fingerprint identification’ was not used as it was important to stress that what should be considered was the whole ACE-V process, whether identified, unidentified or insufficient, rather than labelling the evidence type as identification only.

The topics covered by these questions were reliability, the scientific nature of the evidence types, the error rate, and the level of objectivity or subjectivity found in each type. These topics were chosen as the answers relate specifically to the research aims of the study. They also are more appropriately served by questions which allow a wider range of answers than a simple ‘agree/disagree’ option.

A Likert scale was chosen to allow some flexibility in answer options rather than two extremes and an area of middle ground. This allows a more precise answer to be given. A scale of 7 was not chosen because this may have provided too much flexibility on topics that the respondents may not be well-versed in. Most individuals working in forensic fields will be very familiar with their own discipline, but may not have much knowledge of how another discipline functions. Providing seven options may have resulted in less accuracy due to too much choice.

The order of the questions was determined using the structure suggested by Fink: ‘objective questions come before subjective ones; move from the most familiar to the least’ [134]. Using this as a basis the demographic questions were placed at the start, the more basic ‘agree/disagree’ questions followed, the most complex Likert scale questions, before a free text comment box concluded the survey.

Distribution of the survey

Once the survey was compiled it was tested on two groups; staff in the Centre for Forensic Science at the University of Strathclyde, and a small number of fingerprint examiners working at the Glasgow Fingerprint Unit, SPSA. Feedback was received from the participants and implemented to ensure the questions were clear and gathering the required information.

The survey was distributed as a self-administered questionnaire. The initial distribution of the survey was in paper form. It was distributed to every fingerprint examiner working in the Glasgow Fingerprint Unit, handed out at a Glasgow forensics CPD lecture, and distributed to the Glasgow Scenes of Crime Unit. Completed surveys were returned personally or through departmental internal mail. The survey was also distributed at the Forensic Science Society's Annual Conference at Wyboston, England in October 2008. It was distributed by hand to conference attendees, and a pack of surveys was also fixed next to a poster presentation for the research project which was on display. Completed surveys were returned personally, or placed in a receptacle next to the poster display.

The survey was then distributed using the internet, as the view from different countries was a key area of interest. The survey was constructed as a webpage and hosted on an independent website. The style of the survey layout was kept as similar as possible to the paper version. A copy of the online survey can be viewed in Appendix B.

Once the web version was completed a link was distributed to all heads of fingerprint departments in Scotland, to all Scientific Support Managers in England and Wales, to divisional police areas in Glasgow and to staff at NPIA. The link was also displayed in the members area of the Fingerprint Society website, in the monthly bulletin for IAI members, on the www.clpex.com and www.onin.com discussion forums for fingerprint professionals. Along with the website link a paragraph of text was also given explaining the reason for the survey, and asking individuals to forward the link on to any other colleagues who may wish to help with the research.

Distributing the survey on the internet in this manner allowed a much wider range of individuals to be contacted, and allowed a random sample to be gathered. It is possible that there may have been some cases where the link was forwarded from one individual to other link-minded individuals, but due to the range of online locations of the questionnaire this should not have impacted too strongly on the results. The area where this factor could have the most effect is in countries with a low number of responses, ie. less than 5. Distributing the survey online also allowed responses to be gathered very quickly (delivery of a completed survey to an email account was instantaneous) and may have resulted in a larger response; an online survey may be viewed as quick to do, and therefore done immediately, whereas a paper or postal survey may be put to one side to be dealt with later, and forgotten. The online method does not allow a non-response rate to be gathered, because it is not known how many individuals may have viewed the web link but chosen not to visit, or who may have visited the survey page but chosen not to complete it.

Results were collected from paper and online sources from October 2008 to March 2009. At intervals over this period the results were entered into a Microsoft Excel spreadsheet to gather the data. Once all of the results had been gathered the data was then coded to provide a format which could be analysed using a computer package.

Analysis methods

Analysing the data was carried out first by constructing basic tables displaying information relevant to the research questions. Bivariate crosstabulation was then used to analyse the responses of more than one question combined using pivot tables. To obtain these tables both Microsoft Excel 2003 and SPSS 17.0 were used.

Various methods of statistical analysis were used to study the results and determine possible significance of the findings.

To analyse results presented in 2 columns (generally ‘agree’ or ‘disagree’ answers) a chi-squared (x^2) analysis was used. This test is appropriate for categorical data which consists of relatively small numbers. Conducting this test investigated the significance of differences between the responses of various groups or classes (for example professions or countries) to a question by comparing the different classes to test whether all contain the same proportion of values. In order to conduct this analysis the ‘unsure’ responses were disregarded. The decision was made to compare the definitive responses from each group. This was carried out in each analysis where x^2 analysis was used to ensure consistency. Another option considered was to group the ‘unsure’ responses with the ‘disagree’ responses. This was rejected as the individuals who responded to the survey and answered ‘unsure’ chose this answer rather than the definitive ‘disagree’ answer, and it is not possible to know the reasons for this. To assume their ‘unsure’ answer would fall in the ‘disagree’ category is too large an assumption.

In one table of results a value of ‘0’ was obtained in one cell, and a x^2 analysis cannot be carried out on such a result. In this case the results were broken down and analysed as a 2 x 2 table using Fisher’s Exact Test. This test is similar to x^2 in that it compares observed frequencies, however it allows for a result of ‘0’.

The results for questions 11-14 which used Likert scales required a different method of analysis. The Kruskal Wallis H test is a nonparametric test of one-way analysis of variance and was used to analyse the overall difference between 2 or more independent samples, for example professions, or evidential types. This test determines the mean of the samples and compares distributional differences of results. This was used to provide a general determination of whether there was any uniformity in opinion.

To obtain a more specific analysis of this type, comparing 2 independent groups, the Mann-Whitney U Test was used. This test analyses results in a similar way to the Kruskal Wallis H Test, by testing equality of means, but is applied to 2 independent samples and so was used to conduct specific comparisons between two different groups, such as professions or evidence types.

All of these statistical methods were used to provide a level of significant difference. This result then determined whether the null hypothesis in each case could be rejected. As this study analysed results from a small sample of the entire criminal justice population, and due to the methods of analysis, the results which were obtained are not a definitive answer to the research questions. Rather they provide a starting point from which to make further inferences about the likely nature of the questions being researched [135].

The next section will present the results of the analysis of the data gathered, and this will be followed by a discussion of the possible wider meaning and explanation of the findings.

4 Results and Discussion

This results section begins with an overview of the responses received, broken down by the main demographic areas of profession, country, age group, education and experience level.
Following this are the results of the questions posed in the research aims. These will each be discussed separately, before a final general discussion which will comment on the general outcomes.

Overview

A total of 448 completed surveys were received. These were across 8 different profession categories.

Table 4: responses by profession:

Profession	Total
Fingerprint examiner	182
Forensic Scientist	87
Crime Scene Examiner	83
Police	42
Academic	31
Law	4
Other	11
Lab Technician	8
Grand Total	448

Individuals from a wide range of countries responded to the survey, but there was not a high response from all countries, so countries within Europe, countries within Africa, North America, Australasia and Asia have been grouped together to provide statistically measurable results (see Appendix C for complete country results).

Table 5: responses by country group:

Country	Total
Scotland	155
England + Wales	81
Continental Europe	61
North America	106
Australasia	22
Africa	16
Asia	4
Middle East	1
(blank)	2
Grand Total	448

Table 6: spread of responses by profession in each of the geographical areas.

	Profession								
Country	Finger prints	Forensic Scientists	CSE	Police	Academic	Law	Other	Lab tech	Grand Total
Scotland	30	35	40	27	17	1	5	0	155
England + Wales	29	29	8	0	8	1	3	3	81
Continental Europe	31	16	2	5	2	1	2	2	61
North America	66	5	24	6	2	0	1	2	106
Australasia	21	0	1	0	0	0	0	0	22
Africa	3	1	6	3	1	1	0	1	16
Asia	1	1	0	1	1	0	0	0	4
Middle East	1	0	0	0	0	0	0	0	1
Grand Total	182	87	81	42	31	4	11	8	446

Table 7: responses by education level:

Education	Total
High School	93
College	18
Undergraduate	164
Postgraduate	160
Diploma	10
(blank)	3
Grand Total	448

Table 8: responses by experience:

Experience	Total
Less than 3 years	36
3 – 5 years	49
6 – 10 years	95
11 – 20 years	119
21 – 30 years	89
More than 30 years	49
(blank)	11
Grand Total	448

Table 9: responses by age bracket:

Age	Total
Less than 3 years	59
3 – 5 years	147
6 – 10 years	141
11 – 20 years	80
21 – 30 years	21
Grand Total	448

The most responses came from fingerprint examiners, which is to be expected given the topic of the survey and the places it was distributed online. However there were also significant response numbers from forensic scientists and scenes of crime examiners.

By country, the most responses came from Scotland; again to be expected as this was the location the research was based. However email and the internet have allowed a substantial quantity of responses to be gathered from England and Wales, continental Europe and North America.

4.1 Research question 1:

a).To what extent do fingerprint experts consider fingerprint identification to be a science?

Table 10: responses to the question 'Is fingerprint identification a science?' according to profession.

	Is Fingerprint Identification a Science?		
Profession	**Yes**	**No**	**Unsure**
Fingerprint examiner	137	22	22
Forensic scientist	52	26	8
Crime Scene examiner	60	16	7
Police	38	4	0
Academic	20	10	1
Law	3	0	1
Other	10	1	0
Lab tech	5	3	0

76% of fingerprint examiners expressed the view that fingerprint identification is a science, with 12% saying it is not and 12% being unsure. This is a strong assertion from the fingerprint profession that fingerprint identification is a science.

The research did not allow for individuals to explain why they held this view, and this may be a topic for further research. It may be a long-held assumption; historical publications on fingerprint practice refer to it as a science including documents from the Home Office in UK in 1940 [6] and the FBI in 1941 [136], as do many newer articles and books [1], [45]. It is possible that as a result, fingerprint examiners have been taught by their peers that fingerprint identification is a science, and combined with a basic view of science gained from early education it is likely that a proportion of those giving this view are doing so unaware of their error. However it is also possible there are those who have researched this area and yet are choosing to avoid the truth, preferring to enhance the perception of fingerprint analysis. This may be done intentionally, engaging in sophistry to trade on the reputation of science [36], or it may be an example of unconscious bias where meanings are misunderstood because the individual's mindset is not to look at the issues logically or critically. Examples of this can be basic; describing fingerprint examinations as experiments [137], and statements such as 'a comparison by a skilled examiner is objective science' [138]. Or they can be more complex; attempting to state that examiners begin the process with a hypothesis – an expected outcome which may be one of identity [24] or one of inconclusion [139] using language such as 'the definition of exclusionary report verbiage and incorporation of the practice into the identification unit ultimately holds the examiners to a higher granularity of conclusions' [140], or attempting to add complexity to the process using scientifically-styled abbreviations such as 'Hs6b: Sufficient Q/Q of dissimilarity (disagreement) of detail does not exist to establish exclusion (INC.) (H0: disagreement exists to establish exclusion)' [141]. A field is not scientific because it uses scientific words to describe its processes.

b).Are such views uniformly distributed or do certain countries espouse them more than others?

Table 11: responses to the question 'Is fingerprint identification a science?' from fingerprint examiners, according to country

	Is Fingerprint Identification a Science?		
Country	**Yes**	**No**	**Unsure**
Scotland	13	11	5
England + Wales	20	4	5
Continental Europe	18	4	9
North America	64	0	3
Australasia	18	2	0
Africa	3	0	0
Asia	1	0	0
Middle East	0	1	0

Given that zero occurred in some of the results, use of chi-squared for analysis was not appropriate and Fishers exact test was used. The 'unsure' responses were disregarded, as were those countries with a very low response rate. Those who answered ‘unsure’ were unable to give a definite answer, and it is those individuals who hold a definite opinion that are of interest. The null hypothesis was that there would be no difference in response by the fingerprint profession in different countries.

Table 12: results of Fishers exact test analysis comparing 2 country group results:

Country A	Country B	P value	Result (1% level)
Scotland	England and Wales	0.060	No significant difference
England and Wales	Continental Europe	1.000	No significant difference
Scotland	North America	0.000	Significant difference
England and Wales	North America	0.004	Significant difference
Australasia	North America	0.054	No significant difference

These results show differences in opinion within the fingerprint profession across different countries. Individuals working in Scotland, England and Wales and continental Europe countries held one view, which contrasted with the view from individuals working in North America and Australasia. Although all countries favoured the answer that fingerprint identification was a science, this opinion was much stronger in North America and Australasia; of the 67 fingerprint examiners who responded to the survey in North America, not one answered that fingerprint identification was not a science. The country which gave the weakest positive answer was Scotland, where ‘yes’ and ‘no’ answers were split 13/11. This was a more spilt response than that from the rest of the UK or continental Europe, but statistically there was no significant difference in the results from these countries.

This may be the result of the type of training given to fingerprint examiners in the different countries. Although fingerprint identification has been referred to as a science since early last century, in North America in the last 10 years there has been a propensity for Daubert hearings on fingerprint evidence, which have attempted to diminish the value of fingerprint evidence by claiming it is not scientific. This has lead to publications on the scientific merits of fingerprint identification, and a push from critics in the USA to confirm fingerprint identification as not a science and so not admissible [17] [52] [56]. As a result this is a much more widely debated issue in

North America, and it is likely that many examiners expect to be questioned on this as part of their court evidence. The suggestion of non-science is combined with the suggestion of non-admissibility and non-validity, so examiners are instructed to counter this with claims of science [50]. In contrast, there is much less legal criticism on this front in Europe (including the UK), therefore there may be less of a perceived need to be seen to be science. In the UK there is no instruction for fingerprint trainees on whether the field is or is not a science [142]. An area of further study may be to see whether this difference in opinion from different countries is also reflected by those working in other professions.

c). Does this view differ between professions?

Table 13: responses to the question ‘Is fingerprint identification a science?’ according to profession:

Profession	Yes	No	Unsure
Fingerprint examiner	137	22	22
Forensic Scientist	52	26	8
Crime Scene Investigator	60	16	7
Police	38	4	0
Academic	20	10	1
Law	3	0	1
Other	10	1	0
Lab technician	5	3	0

A chi-squared analysis was carried out on the results. The results for Law and Other were disregarded as the responses were too low. Unsure responses were also disregarded. The null hypothesis was that there would be no significant difference between the professions.

Table 14: chi squared analysis for all professions for the question ‘Is fingerprint identification a science?’

Comparison	P value	Result (1% level)
Profession (all) – fingerprint identification is a science	0.001	Significant difference

This shows a significant difference in opinion between the different professions, therefore the null hypothesis must be rejected.

By examining the numerical distribution, a chi-sq analysis was conducted on the results to compare various groups of professions:

Table 15: chi squared analyses for groups of professions for the question ‘Is fingerprint identification a science?’

Comparison	P value	Result (1% level)
Profession (Fingerprint examiner, Crime scene examiner, Police) – fingerprint identification is a science	0.192	No significant difference
Profession (Forensic scientist + academic) – fingerprint identification is a science	0.22	No significant difference
Profession (Fingerprint examiner + forensic scientist) – fingerprint identification is a science	0.000	Significant difference

There was no significant difference in the first two sets of analyses (Fingerprint examiner, crime scene examiner, police; and forensic scientist, academic) therefore the null hypothesis cannot be rejected; there appears to be no clear difference of opinion between these professions. There was a significant difference in opinion for the final analysis (fingerprint examiner, forensic scientist) therefore the null hypothesis is rejected; the results suggest the different professions do not hold the same opinion.

The results show that the professions questioned were split into two groups in their opinion of whether fingerprint identification is a science. Fingerprint examiners, crime scene examiners and police personnel generally feel that fingerprint identification is a science (combined average: 75% - 13% - 12%). Forensic scientists and academics, share this view, but less strongly (61% - 31% - 8%).

Although there was a difference in opinion across the different professions, the majority from each profession answered that fingerprint identification was a science. One might expect the prevalence of graduate and post-graduate education found amongst respondents from forensic science and academic professions to result in a different view, however the majority of forensic scientists and academics also answered that fingerprint identification is a science. The views of these professions on fingerprint identification have never been gathered before, so it is not clear why they would hold these views. It may be due to the perception of fingerprint identification among those who do not work in the field; a lack of knowledge about the process of comparison and identification, combined with the literature stating that fingerprint identification is ‘a bone fide science’ [49] and confirmation from bodies such as the IAI [46] and FBI [45] may seem plausible enough for many not to give cause for concern.

4.2 Research question 2:

Is there any relationship between the view that fingerprint identification is a science and the length of service of the individual?

Table 16: responses to the question 'Is fingerprint identification a science?' from fingerprint examiners according to the number of years experience in the role.

Fingerprint Profession	Is Fingerprint Identification a science?		
Years Experience	**Yes**	**No**	**Unsure**
Less than 3 years	8	1	3
3 – 5 years	18	2	3
6 – 10 years	36	7	4
11 – 20 years	36	8	6
21 – 30 years	24	2	3
More than 30 years	15	2	3

A chi-squared analysis was carried out on the results; for statistical analysis the 'unsure' responses were disregarded; the definitive answers were analysed.

The null hypothesis was that there would be no significant difference between different categories of experience.

Table 17: chi squared analysis for the fingerprint profession over years of experience in response to the question 'Is fingerprint identification a science?'

Comparison	P value	Result (1% level)
Fingerprint profession - years experience	0.835	No significant difference

There was no significant difference in the results, therefore the null hypothesis cannot be rejected. The result shows a uniformity of response across all of the experience brackets. This appears to indicate that differences of opinion over fingerprints as science, which do appear to exist, are governed by features other than length of experience.

The research question was proposed due to published views of experienced fingerprint examiners like Berry [22] on the topic of fingerprint identification as science; generally their view is that fingerprint identification is a skill or discipline rather than a science. However there are also those with experience who gave a different view, such as Wertheim Sr [24] and Ashbaugh [1]; their view is that fingerprint identification is a science. Equally there are also some, like Moenssens, who have changed their view over time; from a skill [99] to a science [54]. Some voices within the profession, may state the case strongly that fingerprint identification is not a science, and blame critics such as Cole for pushing this argument [22], however their views do not appear to be held by the profession generally; and the results suggest the view that fingerprint identification is a science is equally strong across all experience levels.

4.3 Research question 3:

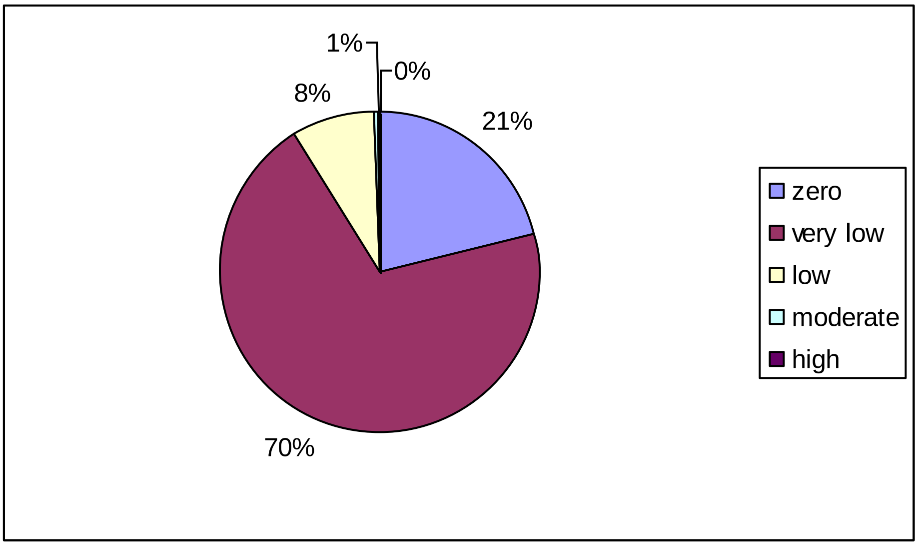
a). To what extent do fingerprint examiners believe their profession to be error free?

Table 18: responses to the question ‘In your opinion what is the error rate of fingerprints?’ according to profession.

	What is the error rate of Fingerprint Examination?				
Profession	**Zero**	**Very low**	**low**	**Moderate**	**high**
Fingerprint examiner	38	127	15	1	0
Forensic scientist	2	47	27	10	0
Crime scene examiner	18	45	13	6	0
Police	3	28	10	1	0
Academic	1	14	10	6	0
Law	0	1	0	2	1
Other	0	7	3	1	0
Lab Technician	2	6	0	0	0

Looking specifically at the results from fingerprint examiners, it is clear there is a significant percentage who have answered that fingerprint examination has a zero error rate.

Figure 1: responses to the question ‘please rate the error rate for fingerprint examination’ in percentages, from the fingerprint profession



21% of fingerprint examiners who responded to the survey answered that fingerprint examination has zero error rate.

Although the view of zero error rate in fingerprint identification was frequently stated 5-10 years ago, both in publications [11] [87] and court testimony from experienced experts such as Leo [143] and Meagher [91], there now appears to be a wider understanding that it is not possible to simply state there is no error when there have been widely publicised mistakes made. In 2008 the IAI acknowledged that fingerprint practice is not free from error [46], and publicised misidentifications have highlighted what can go wrong with the process [18]. For this reason it was unexpected to find as large a percentage of examiners giving the opinion that the error rate was zero. However those claiming an error rate of zero do not appear to represent the general view of the fingerprint community at the present time. Despite the concern at a response of 21% suggesting an error rate of zero, 79% of fingerprint examiners are of the opinion that there is some level of error rate involved in fingerprint identification.

As with the issue of fingerprint identification as science, the issue of determining an error rate has also been misused. Wertheim Jr, stated that one could assume the FBI, over its history, has made ten million correct identifications. As they are now known to have made one error – Mayfield – this gives the FBI an error rate of 1 in 10 million, or 0.0000001% [144]. Examples such as these are either missing the point, that errors may go undetected, or intentionally obfuscating the issue to promote fingerprint practice.

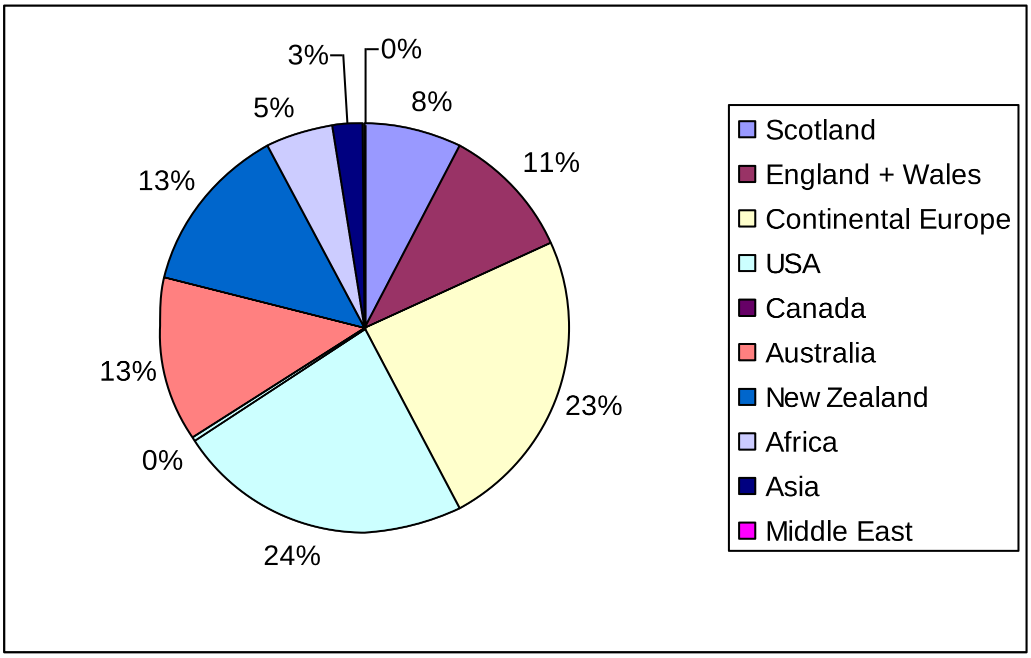
b). does this view differ between examiners working in different countries?

Many documented examples of zero error rate claims have come from the USA. Does a disproportionate number of responses expressing the view that the error rate is zero come from the USA?

Table 19: responses for the question 'In your opinion what is the error rate of fingerprints?' from fingerprint examiners, according to country:

		Error rate of fingerprint identification					
Profession	country	Zero	Very low	Low	Moderate	High	Grand Total
Fingerprint examiner	Scotland	3	24	3	0	0	30
	England + Wales	4	21	3	0	0	28
	Continental Europe	9	18	3	1	0	31
	USA	9	50	5	0	0	64
	Canada		2	0	0	0	2
	Australia	5	6	0	0	0	11
	NZ	5	5	0	0	0	10
	Africa	2	0	1	0	0	3
	Asia	1	0	0	0	0	1
	Middle East	0	1	0	0	0	1

Figure 2: responses to the question 'please rate the error rate for fingerprint examination' in percentages, from the fingerprint profession by country:



This does not show a disproportionate amount coming from the USA; in fact the USA and Continental Europe have approximately the same share of responses stating 'zero error rate'.

Table 20: the three levels of error rate given as answers by the fingerprint profession, according to country and displayed by percentage

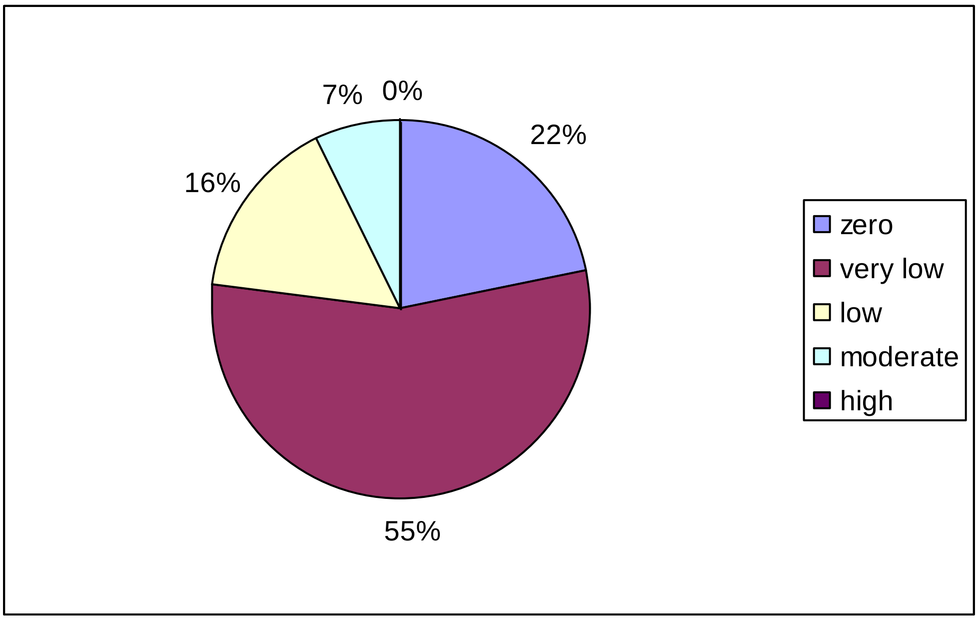
Country	Zero error (%)	Very low error (%)	Low error (%)	Moderate error (%)
Scotland	10	80	10	0
England + Wales	14	75	11	0
Continental Europe	29	58	10	3
USA	14	78	8	0
Canada	0	100	0	0
Australia	45	55	0	0
NZ	50	50	0	0
Africa	67	0	33	0
Asia	100	0	0	0
Middle East	0	100	0	0

Some of these percentages were calculated on the basis of low numbers, so they cannot all be equally compared against one another. These percentages do highlight an unexpected response; for countries with 10 or more respondents (this excludes Canada, Africa, Asia and the Middle East) New Zealand has by far the highest percentage of respondents answering 'zero' for error rate, at 50%, and Australia gives a very similar response of 45%. Continental Europe also gives an unusually high response of 29%. These results contrast sharply with the American result of 15%.

The analysis for the question regarding the error rate of fingerprints showed a strong percentage (21%) of fingerprint examiners who opined that the error rate was zero. Given this view was most frequently expressed in publications and comments from examiners from the USA it might be surmised that many of these responses would come from North America; however the results have shown this is not the case; a large number of examiners who gave this answer came from Australasia, with a significant proportion also coming from Europe. Although the phrase ‘zero error rate’ appears to have begun in America, the term ‘infallible’ has been used about fingerprint analysis almost since its inception [145] and is still used currently both by examiners [88] and a national law enforcement organisation [146]. Some may have recently attempted to claim that ‘infallible’ does not mean without error [57] but it would seem obvious that this is what was meant when this word was used: the meaning of infallible is ‘incapable of error’ [147]. The term was more common when a numeric approach was used, which may have been viewed as a safeguard which led to error-free results. There are still several countries in Europe which use a numeric system, and appear to feel that this does provide a safeguard against error and a level of objectivity [64]. It may be this numeric approach which has resulted in a substantial proponent of European fingerprint examiners answering that the error rate is zero.

Of the professions questioned by the survey, fingerprint examiners gave the highest proportion of answers with the view the rate of error is zero. Examination of the results in table 18 above shows another profession with a high result for zero error rate: crime scene examiners.

Figure 3: responses to the question ‘please rate the error rate for fingerprint examination’ in percentages, from crime scene examiners.



The percentage who answered there was a zero error rate is almost identical to the response from the fingerprint profession (21% and 22% respectively). To compare the responses a Mann-Whitney test was carried out on the results from these two professions. The null hypothesis was that there would be no significant difference between the two professions.

Table 21: Mann-Whitney analysis on responses from fingerprint examiners and crime scene examiners on the error rate of fingerprint identification

Comparison	P value	Result (1% level)
In your opinion what is the error rate of fingerprint examination?	0.091	No significant difference

There was no significant difference in the results, therefore the null hypothesis cannot be rejected.

This result suggests that crime scene examiners have similar views to fingerprint examiners on the error rate of fingerprint identification, to the extent that approximately one fifth are of the opinion the error rate is zero. There has been no other research on the views held by crime scene examiners on fingerprint identification; further research would be required to investigate this apparent similarity in views.

The same Mann-Whitney test was carried out between fingerprint examiners and police personnel, and police personnel and forensic scientists, to determine any other commonality.

Table 22: Mann-Whitney analysis on responses from fingerprint examiners, police and forensic scientists, police on the error rate of fingerprint identification

Comparison	P value	Result (1% level)
In your opinion what is the error rate of fingerprint examination? (fingerprint examiner, police)	0.001	Significant difference
In your opinion what is the error rate of fingerprint examination? (forensic scientists, police)	0.027	No significant difference

This demonstrates that the common viewpoint held by fingerprint examiners and crime scene examiners is not shared by forensic scientists and police personnel, who have a different view. Table 18 shows a very low response from these professions to the answer ‘zero’; the majority of forensic scientists and police personnel gave the answer of ‘very low’. This suggests an understanding of the chance of error inherent in any process.

No research has been conducted on the views of other fields on the error rate of fingerprint identification. The difference of views between crime scene examiners and police personnel is unexpected; one might assume the level of training received on fingerprint identification would be similar for each profession. This is an area which would warrant further study.

4.4 Research question 4:

a). Do fingerprint examiners feel their profession and work is objective?

Table 23: responses to the question 'please rate, in your opinion, the degree of subjectivity or objectivity in fingerprints' according to profession

	How subjective or objective is Fingerprint examination?				
Profession	**Wholly subjective**	**Somewhat subjective**	**Both**	**Somewhat objective**	**Wholly objective**
Fingerprint examiner	6	15	33	66	59
Forensic scientist	7	23	15	32	9
Crime scene examiner	4	6	13	25	28
Police	3	4	2	16	16
Academic	2	4	7	10	6
Law	1	0	2	1	0
Other	0	0	1	6	3
Lab Technician	0	0	2	4	2

Figure 4: responses to the question 'please rate, in your opinion, the degree of subjectivity or objectivity in fingerprints' in percentages, from fingerprint examiners:

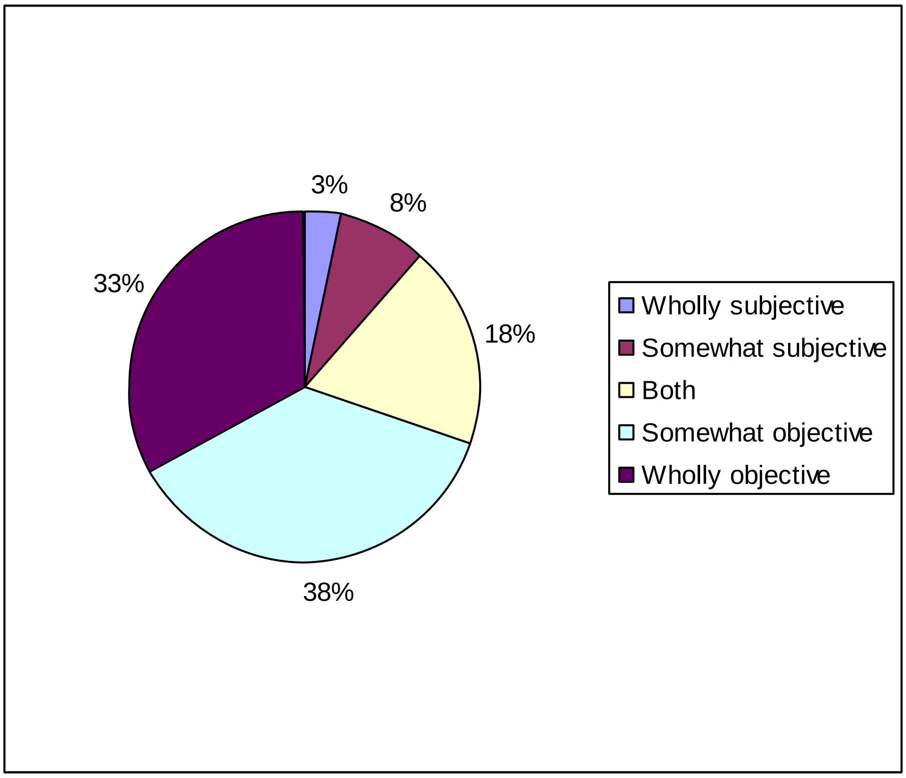


Figure 4 shows that the general opinion of those fingerprint examiners who responded to the survey is that fingerprint examination is objective. A total of 71% of fingerprint examiners expressed the view that fingerprint examination is either wholly or somewhat objective.

Fingerprint analysis has many subjective features, but numerous articles are published stressing the objectivity of the field and the method of analysis [5] [23] [138]. This view was reflected in the results; despite the fact that 'the question of unusualness is of critical significance in the process of individualisation' [148], and determining a level of unusualness is inherently subjective. Despite a recognition by the IAI that fingerprint examiners conclusions are a matter of opinion [46], this is not a view shared by some examiners, shown by statements such as 'a fingerprint examiner's conclusion is not based upon personal opinion, but rather on an evaluation of the detail present using knowledge and skills acquired through training, education and experience' [138].

Given this view from fingerprint examiners, the results shown in table 23 allow a comparison of the views of the different professions. A Kruskal-Wallis analysis was carried out on the results for all professions to assess if there was consensus of opinion.

Table 24: Meaning ranking of responses by profession to the level of subjectivity/objectivity in fingerprint examination

Profession	N	Mean Rank
Fingerprint examiner	179	221.57
Forensic scientist	86	151.38
Crime scene examiner	76	225.07
Police	41	233.94
Academic	29	182.36

Table 25: Kruskal-Wallis analysis of responses by profession to the level of subjectivity/objectivity in fingerprint examination

Comparison	**P value**	**Result (1% level)**
Profession - please rate, in your opinion, the degree of subjectivity or objectivity in fingerprint identification	0.000	Significant difference

This result shows there is a difference in opinion between professions of the subjectivity or objectivity of fingerprint examination.

Looking at the mean rankings, there appears to be a similarity between fingerprint examiners, crime scene examiners and police personnel. A Mann-Whitney analysis was used to compare the results from fingerprint examiners with those from crime scene examiners, and then police personnel.

Table 26: Mann-Whitney analyses of responses by professions to the level of subjectivity/objectivity in fingerprint examination

Comparison	**P value**	**Result (1% level)**
Profession (fingerprint examiner, crime scene examiner) - please rate, in your opinion, the degree of subjectivity or objectivity in fingerprints	0.786	No significant difference
Profession (fingerprint examiner, police) - please rate, in your opinion, the degree of subjectivity or objectivity in fingerprints	0.470	No significant difference
Profession (fingerprint examiner, forensic scientist) - please rate, in your opinion, the degree of subjectivity or objectivity in fingerprints	0.000	Significant difference
Profession (forensic scientist, academic) - please rate, in your opinion, the degree of subjectivity or objectivity in fingerprints	0.191	No significant difference

These results show a commonality of opinion between fingerprint examiners, crime scene examiners and police personnel, who feel that fingerprint examination is generally objective. This differs from the view of forensic scientists and academics, who feel it is neither strongly subjective nor objective.

Figure 5: responses to the question 'please rate the error rate for fingerprint examination' in percentages, from fingerprint examiners, crime scene examiners and police combined.

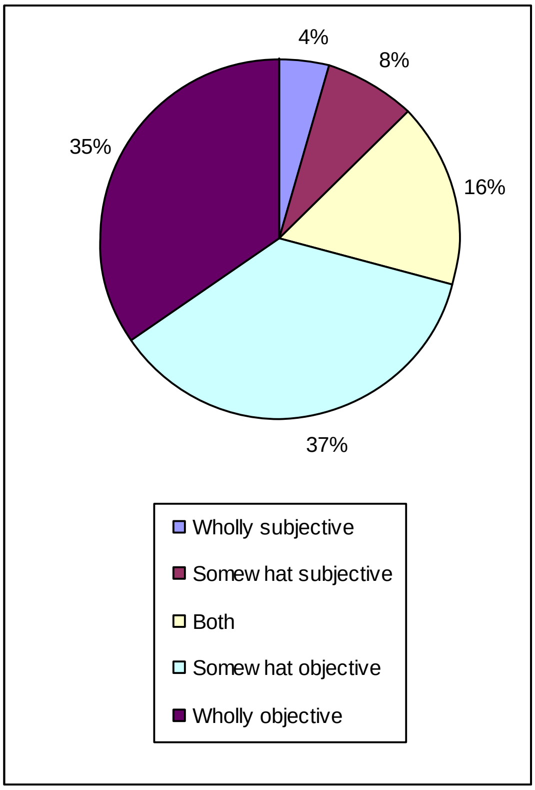
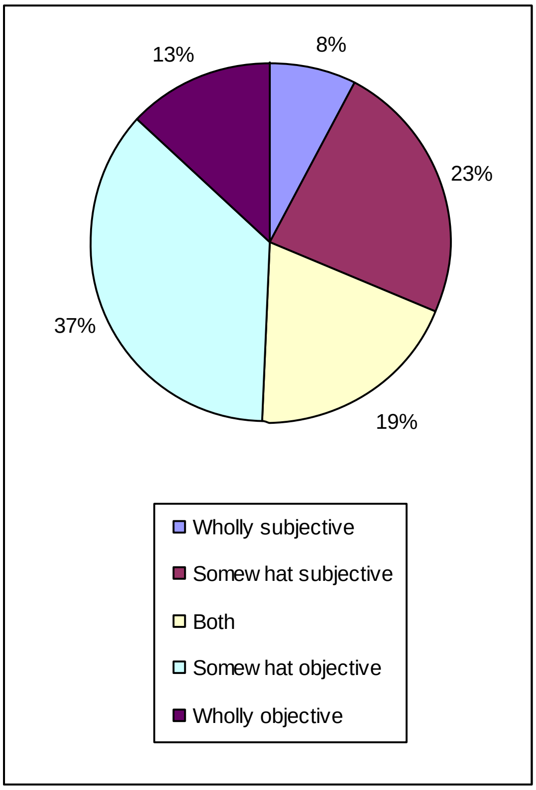


Figure 6: responses to the question 'please rate the error rate for fingerprint examination' in percentages, from forensic scientists and academics combined.



Figures 5 and 6 show this difference in view graphically. Both groups of professions share the same large percentage giving the view of 'somewhat objective' (37%), however the clear differences are to either end of the scale. The fingerprint examiners, crime scene examiners and police personnel have a much stronger view that fingerprint identification is wholly objective (35% to 13%) and the forensic scientists and academics have a much stronger view that fingerprint identification is somewhat subjective (23% to 8%).

b). how does this view relate to their opinions of other forensic fields?

To analyse the level of objectivity fingerprint examiners feel about their profession, the result given by fingerprint examiners on fingerprint examination was compared with their responses on DNA analysis and footwear examination.

Table 27: responses to the question 'please rate, in your opinion, the degree of subjectivity or objectivity' in percentages, from fingerprint examiners:

	How subjective or objective is the field in question?				
Field	**Wholly subjective**	**Somewhat subjective**	**Both**	**Somewhat objective**	**Wholly objective**
Fingerprint examination	6	15	33	66	59
Footwear examination	7	33	57	51	26
DNA analysis	7	5	17	60	87

Figure 7: responses to the question 'please rate, in your opinion, the degree of subjectivity or objectivity in footwear examination' in percentages, from fingerprint examiners:

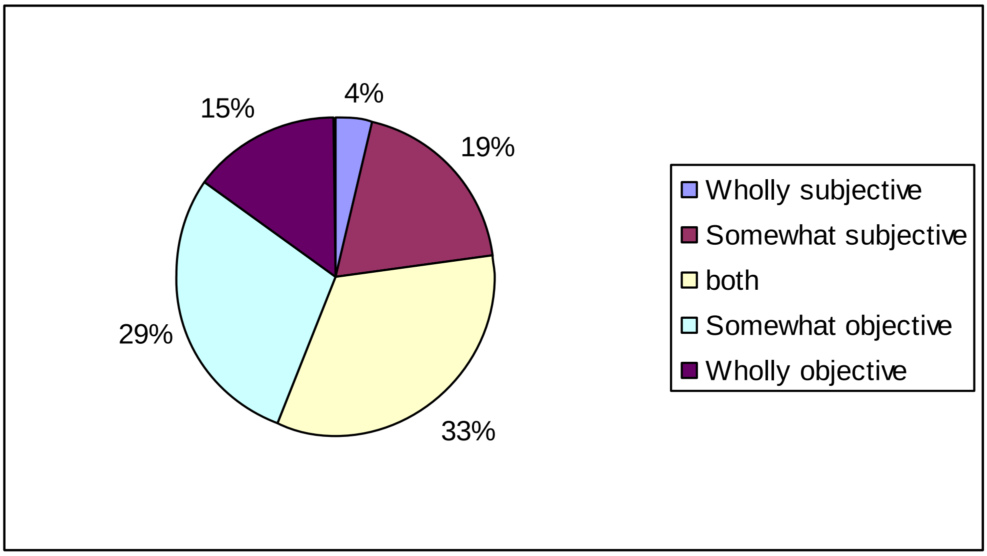
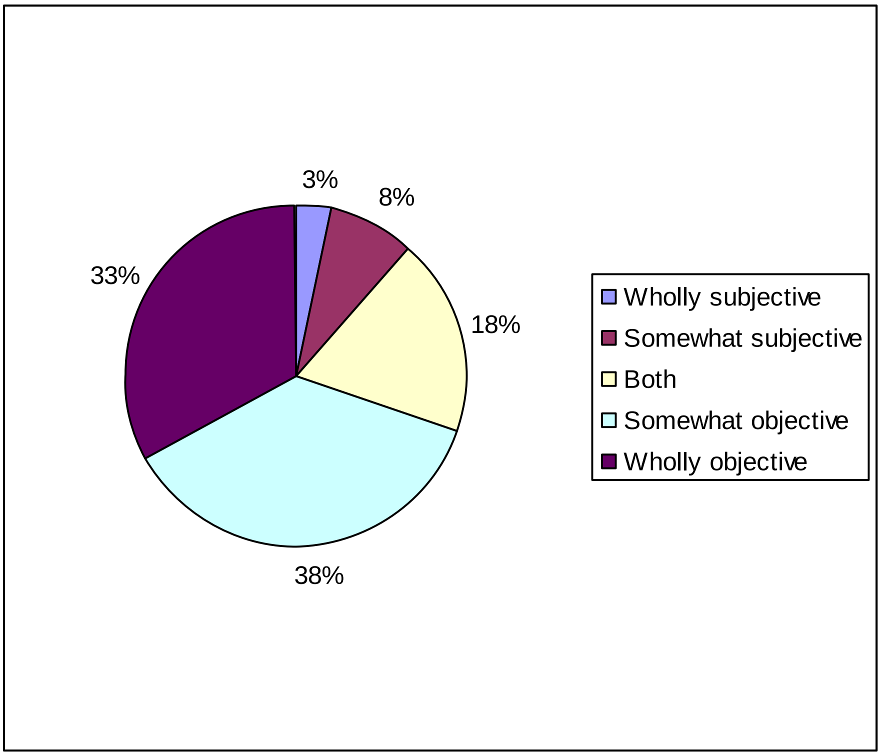


Figure 8: responses to the question 'please rate, in your opinion, the degree of subjectivity or objectivity in fingerprint examination' in percentages, from fingerprint examiners:



A Mann-Whitney analysis was carried out on the responses given by fingerprint professionals on the level of subjectivity involved in fingerprint examination and footwear examination. The null hypothesis was that there would be no difference between the responses.

Table 28: Mann-Whitney analysis of responses of fingerprint profession regarding subjectivity/objectivity of fingerprint and footwear examination fields

Comparison	P value	Result (1% level)
How subjective or objective is the field (fingerprint examination, footwear examination)	0.000	Significant difference

The null hypothesis is rejected; the result shows that the fingerprint examiners questioned view the two fields differently. 71% answered that fingerprint examination was either wholly or somewhat objective, compared to only 44% giving that answer for footwear examination. The method of analysis for both fields is very similar; a comparison of an unknown mark against a known print, with a skilled examiner looking for small details in common, a quantity of which will build up to provide an answer of identification. However the results show that fingerprint examiners do not view their work as similar to that of footwear examination, at least in the aspect of objectivity.

This could suggest that the biological nature of fingerprints somehow provides a feeling of more objectivity, even though the nature of the item being compared, biological or otherwise, has no bearing on the objectiveness of the analysis process. Fingerprint examiners appear to view the development and characteristics of friction ridge skin as highly important to their field; it is seen as the foundation. Ashbaugh states ‘the scientific basis is a biology issue’ [49], while Wertheim Sr. writes ‘fingerprint identification is based on biological uniqueness’ [24]. Cole states that if you ask a fingerprint examiner for scientific proof which demonstrates fingerprint identification is accurate, they are likely to refer to you an embryology text detailing the formation of friction ridge skin [149]. As mentioned in the Introduction, the uniqueness of skin is often transposed on to the mark being compared, and even to indicate an infallible process as stated in court by examiner William Leo: ‘And we profess as fingerprint examiners that the rate of error is zero. And the reason we make that bold statement is because we know based on 100 years of research that everybody’s fingerprints are unique, and in nature it is never going to repeat itself again’ [143]. This desire to attach more meaning to the biological nature of the skin than to the comparison process of two marks may explain why fingerprint examiners perceive their work to be different to that of footwear examiners.

4.5 Research question 5:

a). To what extent are fingerprint examiners opposed to a statistical approach?

Table 29: responses to the question 'Is a statistical approach to fingerprint identification possible?' according to profession

	A statistical approach to fingerprint identification is possible		
Profession	**Yes**	**No**	**Unsure**
Fingerprint examiner	77	51	52
Forensic scientist	63	9	13
Crime scene examiner	43	20	18
Police	28	4	9
Academics	16	4	11
Law	2	1	1
Other	7	0	3
Lab Technician	2	2	4

Table 30: responses to the question of how valuable a statistical approach would be, according to profession

	A statistical approach to fingerprints would be:				
Profession	**Of no value**	**Of some value**	**No different**	**Quite valuable**	**Very valuable**
Fingerprint examiner	25	49	15	29	22
Forensic scientist	2	6	2	24	36
Crime scene examiner	4	18	11	12	15
Police	1	6	2	14	10
Academic	1	5	2	6	11
Law	1	2	1	0	0
Other	0	2	1	3	4
Lab Technician	1	1	2	1	1

Table 31: responses from the fingerprint profession on the value of a statistical approach, in count and percentage

	A statistical approach to fingerprints would be:				
Profession	**Of no value**	**Of some value**	**No different**	**Quite valuable**	**Very valuable**
Fingerprint examiner: count	25	49	15	29	22
Fingerprint examiner: %	18	34	11	21	16

Of the five options, the first choice (‘of no value’) is the only opinion which suggests a negative view towards a statistical approach, and this was only given by 18% of fingerprint examiners. This suggests fingerprint examiners generally feel a statistical approach would be of some value. There was no overall consensus of opinion, with answers spread across the scale.

From table 29 it is clear that there is no strong opinion from the fingerprint community (48%, 28%, 29%); indeed 29% answered ‘unsure’. However, the majority view was that a statistical approach to fingerprint identification is possible. An uncertainty of opinion also apparent from table 30, which shows a spread of answers across all five options.

There is no other research available which has collected data on the views of working fingerprint examiners on a statistical approach to their work, and this research demonstrates a more open view to the adoption of a statistical approach than may have been expected. Published views often show a negative reaction to the idea of a statistical approach. Wertheim Sr stated ‘we refuse to do probability’ at the Scottish Fingerprint Inquiry [150], presumably speaking for the whole fingerprint profession. Bush suggested a fear within the profession that unless a counter argument is made to support current fingerprint practice, the profession ‘could be heading towards conclusions expressed as statements of probability’ [137].
The large number of unsure responses may highlight a lack of knowledge in this area, therefore an inability to make a definite judgement. This could also be seen as a positive response, as a large proportion is currently unsure and therefore delaying judgement until they have more information.

This variation in response is also present in the range of answers given when rating the level of value a statistical approach could bring to fingerprint identification. Only 18% answered that such an approach would be of no value, a figure almost equalled by the 16% who answered that a statistical approach would be very valuable. These answers show that the fingerprint profession is not strongly opposed to the adoption of a statistical approach, but also that there is no clear opinion as to whether such an approach would be valuable. This may be a result of a lack of information amongst the working fingerprint profession about how such a statistical approach would work, and the reasons why it would be of benefit. Until very recently such discussions were most likely found at an academic rather than practitioner level.
These findings suggest the fingerprint profession is more open to the idea of a statistical approach than expected. By inference, the negative views found in print do not appear to be the views of the profession as a whole.

b). Does this view vary with other professions?

The uncertainty in answers given by fingerprint examiners also appears to be present in crime scene examiners, whereas the other professions appear to be give the opinion that a statistical approach is possible.

For the first question, a chi-squared analysis was carried out on the results. The results for law, other and lab technicians were disregarded as the responses were too low. Unsure responses were also disregarded.The null hypothesis was that there would be difference in opinion between the professions.

Table 32: Chi squared analysis by profession on the question ‘Is a statistical approach to fingerprint identification possible?’

Comparison	P value	Result (1% level)
Profession – a statistical approach to fingerprint identification is possible	0.000	Significant difference

This result shows there is a difference in opinion between professions as to whether a statistical approach is possible; the null hypothesis is rejected.

A chi-squared analysis was conducted on specific groups of professions to discover where the difference lay, with the null hypothesis being that there would be no difference between the professions.

Table 33: Chi squared analyses conducted on different profession groups on their responses to the question 'Is a statistical approach to fingerprint identification possible?'

Comparison - Profession – a statistical approach to fingerprint identification is possible	**P value**	**Result (1% level)**
Fingerprint examiner, crime scene examiner, police and academic	0.008	Significant difference
Fingerprint examiner, crime scene examiner and academic	0.17	No significant difference
Forensic scientist and police	1	No significant difference

These results show a significant difference in opinion between the professions, therefore the null hypothesis is rejected. There appears to be a commonality of opinion between forensic scientists and police, who feel that a statistical approach is possible. This differs from the view of fingerprint examiners, crime scene examiners and academics, who feel much less strongly that a statistical approach is possible. To further investigate the views on a statistical approach, a Kruskal-Wallis analysis of the results for the second question, how valuable would a statistical approach be, was carried out. The views of the different professions were compared.

Table 34: Mean ranking of responses to the question 'How valuable would a statistical approach to fingerprint identification be?' by profession

	Profession	N	Mean Rank
How valuable	Fingerprint examiner	140	127.77
	Forensic scientist	70	221.37
	Crime scene examiner	60	157.03
	Police	33	189.09
	Academic	25	196.40

Table 35: Kruskal-Wallis analysis on response by profession to the question 'How valuable would a statistical approach to fingerprint identification be?'

Comparison	P value	Result (1% level)
Profession – how valuable would a statistical approach be?	0.000	Significant difference

There was a significant difference in the results, therefore the null hypothesis is rejected; there is a difference of opinion between the professions on whether a statistical approach would be valuable.

To determine which professions held different views, a Mann-Whitney analysis on pairs of professions was carried out.

Table 36: Mann-Whitney analyses on pairs of professions on responses to the question 'How valuable would a statistical approach to fingerprint identification be?'

Compared professions	P value	Result (1% level)
Fingerprint examiner + crime scene examiner	0.025	No significant difference
Fingerprint examiner + police	0.000	Significant difference
Forensic scientist + police	0.034	No significant difference
Fingerprint examiner + forensic scientist	0.000	Significant difference
Fingerprint examiner + police	0.000	Significant difference
Forensic scientist + academic	0.243	No significant difference

These results show a similar trend as was found in the responses to the question 'is a statistical approach to fingerprint identification possible?'; police, forensic scientists and academics have similar views on value of a statistical approach, and those views differ from those of fingerprint examiners and crime scene examiners. The former group feel that such an approach would be more valuable than the latter. This commonality in response to both of the questions suggests a definite viewpoint on the merits of a statistical approach from the different professions.

There has been no other research gathering the views of different criminal justice professions on the use of a statistical approach to fingerprint identification. There are some published views from the fingerprint profession, as discussed above, but no views from other professions. Forensic scientists use statistical analyses on their own results, and present these in court, so it might be expected that they would be in favour of a statistical approach to fingerprint evidence. The same may apply to academics, who are aware of the uses of statistical analysis and apply these to their own research areas. Fingerprint examiners and crime scene examiners do not currently use any statistical model, and may instead focus on the track record of fingerprint identification to suggest such a model is not required. This view might also be expected from police personnel, however their views are instead bracketed with the forensic scientists and academics to be in favour of a statistical approach. Further research could help understand this viewpoint.

4.6 Research question 6:

a). Is there any relationship between the view that fingerprint identification is a science, and the level of education gained by the individual?

Table 37: responses to the question 'Is Fingerprint identification a science?' according to the level of education completed.

	Is Fingerprint Identification a science?					
Education	**Yes**	**%**	**No**	**%**	**Unsure**	**%**
High school	69	75	16	17	7	8
College	12	67	6	33	0	0
Undergraduate	123	76	23	14	17	10
Postgraduate	111	74	35	23	4	3
Diploma	7	70	2	20	1	10

A chi-squared analysis was carried out on the results; the 'unsure' responses were disregarded.

The null hypothesis was that there would be no significant difference between different levels of education.

Table 38: Chi squared analysis by education for the question 'Is fingerprint identification a science?'

Comparison	P value	Result (1% level)
Education – fingerprint identification is a science	0.276	No significant difference

There was no significant difference in the results, therefore the null hypothesis cannot be rejected. The level of education achieved does not affect the opinion of an individual of whether fingerprint identification is a science.

This result may be unexpected as the assumption could be made that a graduate or post-graduate level education would provide a more critical way of thinking. However the survey did not distinguish between different areas of education, eg. arts or sciences, so it is not possible to assume that those with graduate or postgraduate education would have been educated critical thinking or the nature of science as part of their studies.

b). Is there any relationship between the view that a probabilistic approach to fingerprint identification is possible and of value, and the level of education gained by the individual?

Table 39: responses to the question 'Is a statistical approach to fingerprint identification possible?' according to the level of education completed.

	A statistical approach to fingerprint identification is possible					
Education	**Yes**	**%**	**No**	**%**	**Unsure**	**%**
High school	39	42	29	32	24	26
College	5	28	5	28	8	44
Undergraduate	81	50	34	21	46	29
Postgraduate	106	68	21	13	30	19
Diploma	5	56	2	22	2	22

A chi-squared analysis was carried out on the results; the 'unsure' responses were disregarded. The null hypothesis was that there would be no difference between levels of education regarding the opinion towards a statistical approach.

Table 40: Chi-squared analysis by education in response to the question 'Is a statistical approach to fingerprint identification possible?'

Comparison	P value	Result (1% level)
Education – a statistical approach to fingerprint identification is possible	0.001	Significant difference

This result shows a significant different in results between different levels of education, therefore the null hypothesis is rejected.

To determine where the difference in opinion lay, a chi-sq analysis was carried out on several groups of results.

Table 41: Chi-squared analyses on different groups of education levels in response to the question ‘is a statistical approach to fingerprint identification possible?’

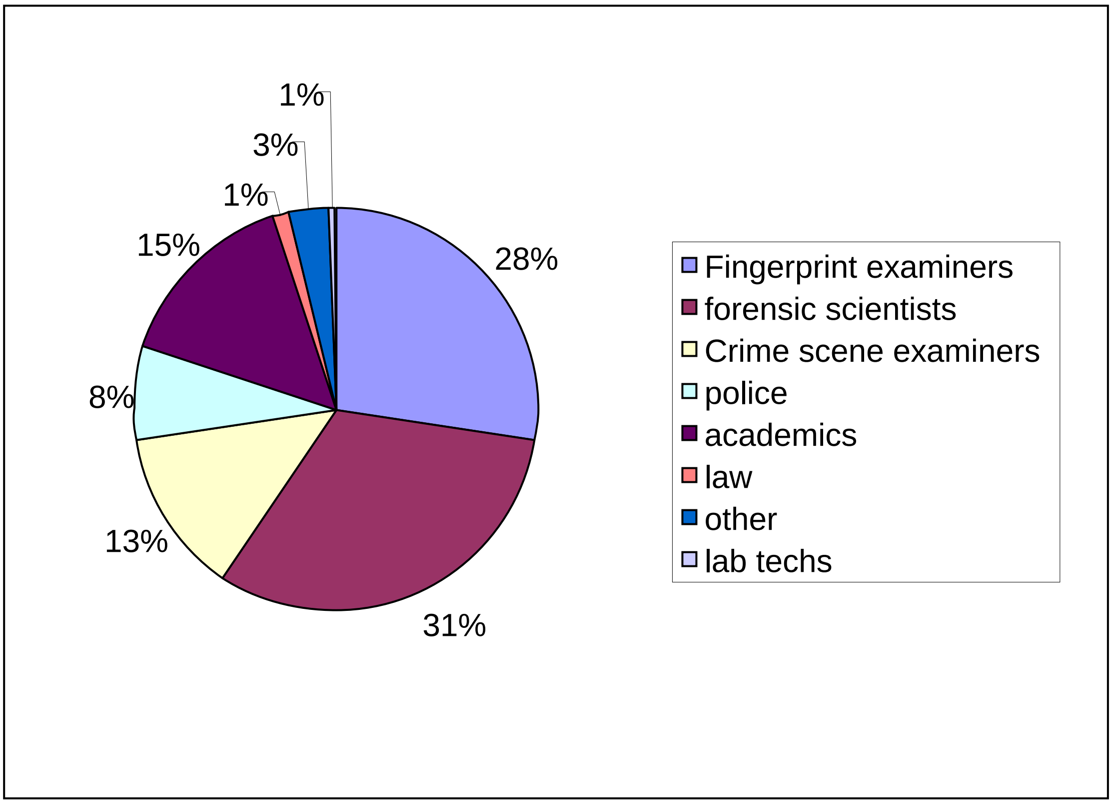
Comparison – Education – a statistical approach to fingerprint identification is possible	**P value**	**Result (5% level)**
High school, college and undergraduate	0.121	No significant difference
High school and post-graduate	0.000	Significant difference
Undergraduate and postgraduate	0.015	Significant difference

The difference of view appears to come from post-graduate level education, this difference is only statistically significant at the 5% level rather than 1%. This result suggests there may be a link to postgraduate education, which may expose an individual to statistical research and arguments, and the view that a statistical approach is possible.

Although there was no significant different of opinion between education levels on the question of fingerprint identification as a science, this has not been the case with opinion on a statistical approach. It may be suggested that individuals completing post-graduate degrees are taught about the use of statistics and for this reason there is a significant difference in response from post graduates in comparison with all other levels of education.

Research question 5, which examined the views of the different professions, showed that for the survey respondents, forensic scientists felt strongly that a statistical approach would be very valuable. This may have influenced the results in this section, as of the groups questioned it is possible a large proportion of those with post-graduate qualifications are forensic scientists. To investigate this possible link it is necessary to analyse the individuals with postgraduate qualifications.

Figure 9: breakdown according to profession of individuals who have postgraduate level education.



This shows there is not a considerable bias towards forensic science in the responses from postgraduates; the postgraduate responses are spread across all professions. The prevalence of a positive view of a statistical approach to fingerprint identification from those with post graduate education cannot be attributed solely to the views of forensic scientists.

4.7 Research question 7:

a). To what extent do fingerprint examiners believe fingerprint identification provides 100% certain results?

Table 42: responses to the question 'Does Fingerprints provide 100% certain identification?' according to profession:

	Fingerprint Identification is 100% certain		
Profession	**Yes**	**No**	**Unsure**
Fingerprint examiner	165	11	5
Forensic scientist	35	34	15
Crime scene examiner	73	10	0
Police	26	15	1
Academic	10	18	3
Law	1	3	0
Other	6	4	1
Lab Technician	6	0	2

These results show a strong opinion from fingerprint examiners that fingerprint identification provides 100% certain results, with 91% of fingerprint examiners answering in the affirmative. This is not unexpected, as this is how almost all fingerprint examiners will report their findings. Their ability to do this whilst other fields do not is seen by some as a matter of pride, as demonstrated by Wertheim Jr: 'we are saying this print matches beyond any doubt, and to the exclusion of every other finger of every other individual on earth. Is this a high order? Sure!! We are latent print examiners!' [62]. More interesting is the 6% of fingerprint examiners who answered 'no'. This is a small figure, but nevertheless in a profession which frames its evidence as either an identification or not an identification, it is an interesting minority.

b). Does this view differ from those of other criminal justice professions?

From table 42, crime scene examiners also appear to hold a strong opinion of 100% certainty. A chi-squared analysis was carried out on the results to compare the

different profesions. The results for Law, Other and Lab Technicians were disregarded. Unsure responses were also disregarded.
The null hypothesis was that there would be no difference in opinion between the professions.

Table 43: Chi-squared analysis by profession for the question 'does fingerprint identification provide 100% certain identification?'

Comparison	P value	Result (1% level)
Profession – fingerprints provide 100% certain identification	0.000	Significant difference

There was a significant difference therefore the null hypothesis is rejected; the results show the different professions do not hold the same opinion. To determine the location of the difference one profession was compared against another, with the null hypothesis that there would be no difference of opinion between the two compared professions.

Table 44: Chi-squared analyses on different pairs of professions for the question 'does fingerprint identification provide 100% certain identification?'

Compared professions	P value	Determination
Fingerprint examiner + Crime scene examiner	0.000	Significant difference
Forensic scientist + Police	0.19	No significant difference
Forensic scientist + academic	0.179	No significant difference
Fingerprint examiner + Forensic scientist	0.000	Significant difference
Fingerprint examiner + Police	0.000	Significant difference

These results show a difference of opinion between fingerprint examiners and all other disciplines. Fingerprint examiners appear to feel very strongly that fingerprint identification provides 100% certain results (91%). All of the other professions analysed feel much less strongly that this is the case, with the biggest difference being the opinion of forensic scientists, who appeared split almost equally between yes and no (42% - 40%).

Fingerprint examiners can view the fact that they report findings as 100% certain, as what gives their profession its strength and reliability. Does this result suggest that those professions who feel it is not 100% certain feel it is less reliable?

Table 45: responses to the question 'please rate the evidential reliability of fingerprint identification, by profession.

	What is the evidential reliability of fingerprint examination?				
profession	Very unreliable	unreliable	reliable	Very reliable	Wholly reliable
Fingerprint examiner	1	1	4	65	110
Forensic scientist	0	0	18	57	11
Crime scene examiner	0	0	10	31	41
Police	0	1	4	21	16
Academic	0	1	13	11	5
Law	1	0	2	0	1
Other	0	0	3	6	2
Lab Technician	0	0	1	2	5
Grand Total	2	3	55	193	191

Much of the writing on fingerprint identification states that the conclusions reached are absolute and final [71]. The survey results suggest that the most entrenched views on 100% certainty are found within the fingerprint profession, and that they feel particularly strongly that fingerprint analysis does provide this type of conclusion. The development of DNA evidence, which has set an implicit example of a scientific forensic identification field [72], has increased the awareness that the establishment of a positive identification is an opinion [106] and that identity of source is not absolute and can only be inferred [107]. In the 2003 case US v. Patrick L Crisp dissenting Judge Michael commented that fingerprint identification may be seen as reliable because testimony is not given unless the examiner is certain of a match, and that this may be the reason the technique was accepted so quickly by the courts. However he stated that 'professions of absolute certainty seem out of place in today's courtroom' [151].

The above results demonstrate the view that the reliability of fingerprint analysis is not reliant on absolute conclusions; all professions feel fingerprint examination is reliable to some degree; the majority feel it is either very or wholly reliable. This may indicate that the belief held by some fingerprint examiners that the strength of the field comes from providing 100% certain identifications is incorrect; indeed in the case of forensic scientists, 40% gave the view that fingerprint identification could not provide 100% certain results, but 79% were of the opinion that fingerprint examination is either very or wholly reliable. Moving away from categorical conclusions will not weaken the profession; instead it would be remaining with absolute certainty, and continuing to try to defend obscure dogma [152] which will weaken the fingerprint profession.

4.8 General discussion of results

The survey has gathered strong evidential data as the findings have shown significant difference measured at the 1% level. There was also a higher than anticipated level of response, which resulted in substantial numbers from professionals in several different countries and different fields which allowed comparison and analysis of the views of different groups.

The issues raised by the survey are all key issues to fingerprint practice at the present time. Commentary and argument over these issues has been developing steadily over the past ten to fifteen years, driven by the publication of Ashbaugh's book on Ridgeology [1] and the issue of fingerprint reliability being debated in a legal context in the USA [17] [52], and culminating currently with the publication of the National Academy of Sciences report on forensic science in 2009 [21] and the ongoing Scottish Fingerprint Inquiry. Issues such as science, probability and bias can no longer be avoided, and this study has attempted to gather some basic data on the views held by those working in the fingerprint profession, as well as those in other criminal justice areas. There has been no previous research conducted to gather views on these topics from practitioners, but if fingerprint practice is to change to attempt to solve some of the current issues, it is essential to understand the views of the profession itself, as well as the opinions of others working closely with the fingerprint profession.

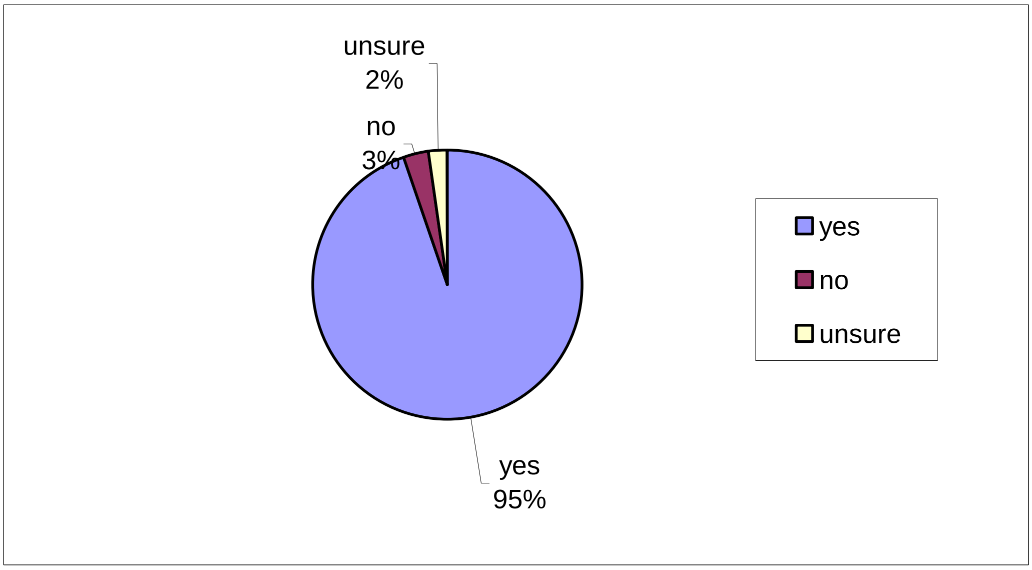
The survey gathered opinion on specific topics, from which inferences can be drawn on the views of different groups. The data also allows a more in-depth view to be gathered by combining the responses to several different questions. There are two areas which I would like to discuss in more detail; the first examines the opinions of fingerprint examiners and their view of science. From the results, the majority of individuals expressed the view that fingerprint identification is a science, and this was particularly true of the fingerprint profession. In the literature there are contradictions within the writing of some fingerprint examiners, with individuals giving the opinion for example that fingerprint identification is a science but also that it can provide 100% certain answers [1] [24]. The survey provided an opportunity to find out whether this is a common view by analysing those results given by individuals who answered that fingerprint identification was a science, and then looking within those answers at the responses to questions on 100% certainty, error rate and statistical interpretation.

'Fingerprint science' and 100% certainty:

Table 46: responses from the fingerprint profession for the question 'does fingerprint identification provide 100% certain results?' according to their answers to the question 'is fingerprint identification a science?'

	Fingerprint identification provides 100% certain results			
Fingerprint Identification is a science	**yes**	**no**	**unsure**	**Grand Total**
Yes	129	4	3	136
No	18	4		22
Unsure	18	2	2	22

Figure 10: responses to the question ‘does fingerprint identification provide 100% certain results?’ as a percentage, from individuals who also have the view that fingerprint identification is a science.



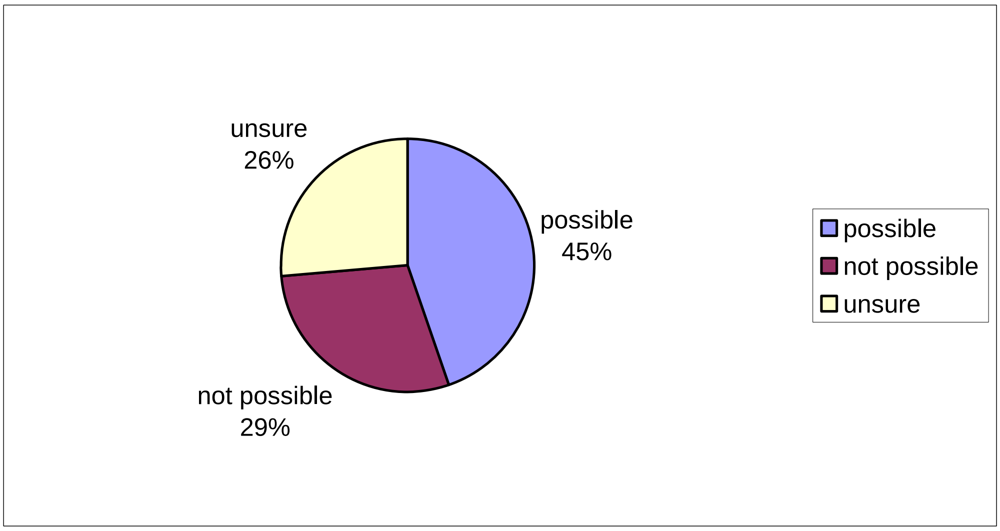
95% of those working in Fingerprints who think it is a science, also think it gives 100% certain results.

‘Fingerprint science’ and a statistical approach:

Table 47: responses from the fingerprint profession to the question ‘is a statistical approach to fingerprint identification possible?’, according to their answers to the question ‘is fingerprint identification a science?’.

	A statistical approach to fingerprint identification is possible			
Fingerprint Identification is a science	**Yes**	**No**	**unsure**	**Grand Total**
Yes	61	39	36	136
No	7	4	10	21
Unsure	9	8	5	22

Figure 11: responses to the question 'is a statistical approach to fingerprint identification possible?' in percentages, from individuals who also have the view that fingerprint identification is a science.



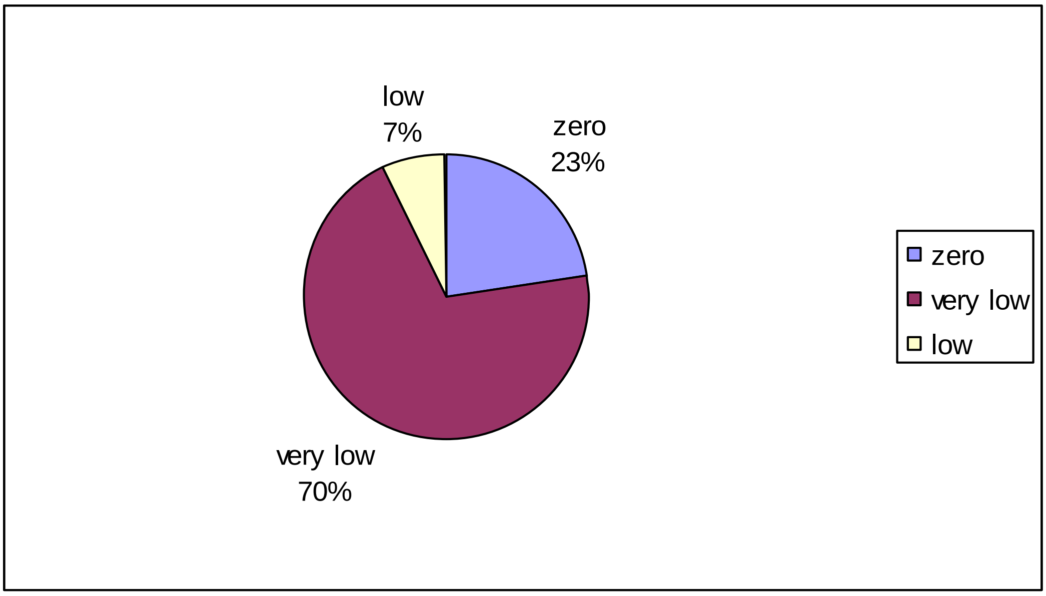
Of those fingerprint professionals who say Fingerprints is a science, 29% think a statistical approach to fingerprint examination is not possible.

'Fingerprint science' and error rate:

Table 48: responses from the fingerprint profession for the question 'please rate the error rate for fingerprint examination', according to their answers to the question 'is fingerprint identification a science?'.

	Error rate of fingerprint identification				
Fingerprint identification is a science	zero	Very low	low	Moderate	Grand Total
Yes	31	95	10	0	136
No	6	13	2	1	22
Unsure	1	18	3	0	22

Figure 12: responses to the question 'please rate the error rate for fingerprint examination' in percentages, from individuals who also have the view that fingerprint identification is a science.



Of those working in the fingerprint profession who answered that Fingerprints was a science, 23% answered the error rate was zero.

These results show a clear confusion among some examiners about the nature of science, and what it can provide. The areas of error rate, statistical approach and 100% certainty encapsulate the fundamental aspects of science; its acceptance of uncertainty and its aim to measure this uncertainty in any activity.

A large proportion (95%) of fingerprint examiners who said fingerprint identification was a science also said it provided 100% certain results. A substantial proportion (23%) also said it had an error rate of zero, and that a statistical approach was not possible (29%). This is clearly an error in both logic and knowledge; the holding of these mutually exclusive views demonstrates that some make this claim of science without realising the genuine nature of science or scientific methodology. This could suggest a lack of knowledge when making the claim that fingerprint identification is a science, but also suggests an unawareness of this lack of knowledge. Examining the answers to questions on a statistical approach, a substantial number of fingerprint examiners answered ‘unsure’, and acknowledgement of a lack of knowledge. However in answer to the question of whether fingerprint identification is a science, very few were unsure, 76% felt able to answer in the affirmative. While some fingerprint examiners may feel they need to know more about statistical models to be able to reach a conclusion, most feel educated enough about science to be able to give a definite answer, and for many this answer is in error. McComas highlights that the teaching of science is often lacking; that textbooks can provide an inaccurate view of science and its nature, and that more education on the strengths and limitations of science is required [31]. This may be the cause of perceived knowledge in this case. It may also explain the issue highlighted by Grieve, who described ‘one of the strangest instances of irony ever to befall either fingerprints or logic’ being that those who maintain fingerprint identification is a science, openly show signs of disdain for anyone who advocates a scientific approach’ [153].

Examining the results from the fingerprint profession overall, the study has provided some outcomes which were expected given the evidence from publications: fingerprint identification is considered by most to be a science, it is generally considered to be objective, and there is a strong view of absolute certainty in conclusions.

It has also provides some unanticipated outcomes: although fingerprint identification has been stated as being ‘error free’, the expectation was to find only a very small number of examiners who gave this response to the survey question. For one fifth (21%) of fingerprint examiners to answer that fingerprint identification has an error rate of zero was unexpected, and concerning. A high proportion of this response was from Australasia and continental Europe, which was also unexpected as most published comments regarding zero error rate are found in commentary from North America.

Although the strength of response to zero error rate was a concern, there was a more optimistic than expected conclusion from the questions on a statistical approach. A mainly negative response to this question was expected, however the majority (48%) opined that a statistical approach to fingerprint identification was possible. Although approximately one quarter (28%) were of the view that a statistical approach was not possible, a similar percentage were unsure, which suggests a current lack of knowledge on the plausibility of such a method, and also suggests a willingness to hold judgement until more information is known. This suggests an open-minded approach which is often not attributed to the fingerprint profession.

Professional differences

The second area for which the study has provided a general view is the difference of opinion between the various criminal justice professions.

In the responses to several questions there was a grouping in opinion between the professions. Generally, fingerprint examiners and crime scene examiners showed no significant differences in their opinions (this was seen in the questions 'is fingerprint identification a science?', 'what is the error rate of fingerprint examination', 'how objective or subjective is fingerprint examination', 'is a statistical approach possible?' and 'how valuable would a statistical approach be?'). There was only one area where fingerprint examiners and crime scene examiners held different views; the issue of 100% certainty in fingerprint identification. Always differing from the views of fingerprint examiners and crime scene examiners were the responses from forensic scientists; a significant difference was measured for all analysed questions.

The professions of police personnel and academics were less consistently grouped. Academics were generally grouped with forensic scientists (the only question where this was not the case was 'is a statistical approach to fingerprint identification possible?'). One might expect that police personnel would group with the fingerprint examiners and crime scene examiners, considering similarities between these professional fields. However although this was the case with some questions ('is fingerprint identification a science?', 'how objective or subjective is fingerprint examination?') it was not consistent; There was s significant difference in response to the questions 'what is the error rate of fingerprint examination?', 'is a statistical approach to fingerprint identification possible?' and 'how valuable would a statistical approach be?' from police personnel in comparison to that of fingerprint examiners and crime scene examiners; instead police personnel shared a view on these questions with forensic scientists.

Table 49: professional groupings by response to research questions:

Question	Group 1	Group 2
Is fingerprint identification a science?	Fingerprint examiners, CSE, police personnel	Forensic scientists, academics
What is the error rate of fingerprint examination?	Fingerprint examiners, CSE	Forensic scientists, police personnel
How subjective or objective is fingerprint examination?	Fingerprint examiners, CSE, police personnel	Forensic scientists, academics
Is a statistical approach to fingerprint identification possible?	Fingerprint examiners, CSE, academics	Forensic scientists, police personnel, academics
What value would a statistical approach have?	Fingerprint examiners, CSE	Forensic scientists, police personnel, academics
Does fingerprint identification provide 100% certain results?	Fingerprint examiners	Forensic scientists, police personnel, CSE, academics

The difference between opinions of fingerprint examiners and those of forensic scientists, a difference which is maintained over all the questions above, may be due to a different style of training, and a different approach to working methods and conclusions.

The similarity of responses between fingerprint examiners and crime scene examiners may be linked to a history in some countries of dual-role officers, who conducted both crime scene investigation and fingerprint analysis. This may still be found in some jurisdictions. However, despite the similarity of views in most areas, crime scene examiners do not share the confidence in fingerprint identification providing 100% certain results which is held by fingerprint examiners. The strength of feeling on this issue from fingerprint examiners is not replicated by any other profession; 91% of fingerprint examiners answered ‘yes’ to this question. Forensic scientists provided a very different view, split almost equally between yes and no (42% - 40%).

Police personnel share the same opinion as fingerprint examiners and crime scene examiners with regards to the questions on science and objectivity, but have different views on questions regarding the use of a statistical approach. It would be expected that forensic scientists would be more open to the concept of a statistical approach, but it is surprising to find a similar level of openness in police personnel, particularly as this openness is not replicated in crime scene examiners. It may be that police personnel, seeing the apparent strength of DNA evidence in the court system, are of the view that the adoption of such an approach would also be of value to fingerprint analysis.

There is no previous research gathering data on the views of any criminal justice profession on fingerprint identification, and there is little or no published opinion from crime scene examiners, police or forensic scientists on fingerprint practice. Further research could investigate the similarities and differences discovered in this study.

4.9 Methodological issues

When considering the success of the survey and the findings, aspects of the survey which may have affected responses must also be considered. The responses from academics may be the hardest to define as a wide group of people may have responded to the survey with this answer. It may apply to professors and lecturers, but could also refer to undergraduate or post graduate students, or retired police personnel from any field who now consider themselves as academics. The question for this section asked ‘please indicate what best describes your occupation/experience’, which does leave the possibility of those with many years experience in a forensic field classifying themselves as an academic rather than an individual in an academic field. Therefore it is not possible to assign the ‘academic’ responses to a group such as ‘university staff’ or ‘university students’. Any future survey looking at this area could delineate between student and staff, and could also specify if individuals are now retired from a forensic field they should select the field in which they are most experienced.

An area of particular interest had been that of the legal profession; much of the negative published work has come from the legal profession in the USA. However legal professionals appeared reticent to complete the survey with some professional bodies refusing to circulate the survey and others simply not replying. This may be due a concern that the survey could give an overall view from the legal profession in particular countries, which may have been a cause for concern depending on the results.

One area of questioning involved assigning a level of subjectivity or objectivity to particular fields. The results suggest there may be a level of error in the responses, created by confusion over what these two words mean: one individual commented ‘I don't know what 'subjective and objective ' means’ in the text comments box at the end of the survey. When the results were analysed there appeared to be a small percentage who gave the opposite response to what might be expected; for example ‘completely objective’ to eyewitness testimony (4%), and ‘completely subjective’ to DNA analysis (3%).

Use of language in the phrasing of questions appears to have given some fingerprint examiners a means of avoiding the question. In the text comments several individuals commented on the phrase ‘fingerprint examination’ being used rather than ‘fingerprint identification’ or ‘fingerprint analysis’. Two examples of comments given are:

“Do not like terminology fingerprint examination, fingerprint identification would have implied more.”

“My interpretation of Fingerprint Examination is the process of finding fingerprint at crimes scenes and subsequent examination in Bureaux not the identification process and have answered these questions with that in mind.”

The phrase ‘fingerprint identification’ was not used for reasons already explained in the Methodology section, however perhaps the word analysis would have avoided this issue.

The general terminology of some of the questions could leave room for interpretation and again comments have shown this to be the case. The question asking for opinions on the statement ‘fingerprints provide 100% certain identification’ seems to have been interpreted by some to mean it ‘can’ provide certain identification, as opposed to it ‘does’ provide certain identification. One example of a comment highlighting this was “It would depend on the quality of the print both in size and visibility. In general I would agree that if it was a "perfect" print then identification could be 100% however if it were not (as in recent high profile cases) then it would not.” It is impossible to know how individuals viewed this this question when answering; the question could have been improved by the phrasing ‘fingerprints will always provide 100% certain identification’. There may also have been some confusion over what was meant by a ‘statistical approach’ as stated in questions 9 and 10; an assumption was made that individuals would understand this referred to a probabilistic evaluation of a fingerprint comparison, but this may not have always been the case.

Conclusions

When considering the issues covered in this research, it is interesting to consider some examples given by Evett to differentiate between scientific and unscientific expertise.

Table 50: Unscientific expertise as described by Evett:

Mystique	"when you've been doing the job as long as I have…."
Intuition	"I rely on my gut feeling…."
complacency	"I've done thousands of cases and I've never been shown to be wrong…"
entrenchment	"It's stood the test of time…"

Table 51: Scientific expertise as described by Evett:

study and debate	"what are our fundamental principles?"
continuous improvement	"why do I do it this way? Is there a better way?"
self-analysis	"why do I think this?"
Calibration	"am I as good as I think I am?

[100]

On the basis of the above discussion, the fingerprint profession is still occupying the 'unscientific' area; the example phrases given by Evett can be frequently heard in discussion or conclusion about fingerprint evidence by fingerprint examiners.

These views are slowly beginning to shift, with individuals within the fingerprint profession beginning to ask the questions Evett outlines above as consistent with scientific expertise. However it does still appear that many of these questions are being raised by those outside the profession, rather than those working within it. For fingerprint practice to advance it is important that these issues be raised by those within, rather than only being proclaimed by those outside the field.

The results from the research showed a general consensus across all professions surveyed that fingerprint identification is a science. Although the strength of this view varied across the professions all were more likely to answer that it was a science. Although the biological basis of friction ridge skin is scientific, fingerprint practice is not. Rather than accumulating knowledge through empirical research, the main collection of knowledge used by fingerprint examiners is accumulated through their own experience, 'common sense' explanations and through oral tradition from one examiner to another [21]. This is not scientific, and those views stating fingerprint identification is a science are misplaced or uninformed.

Fingerprint analysis has developed over a century, in a criminal justice environment, and so was never subjected, as for example DNA analysis has been, to the type of stringent scientific scrutiny. Researching the limitations and foundations of the field has never been a top priority [21], and even now the recent NAS report of 2009 states that 'little rigorous scientific research has been done to validate the basic premises and techniques in a number of forensic science disciplines' [21].

My view is that, as it functions currently, fingerprint identification does not conform to any adequate description of science. But this statement alone does not mean that fingerprint practice has less utility, and should be dismissed. There are aspects that the fingerprint profession could learn from the philosophy of science debate, and it could adapt and adopt some of the features of science to strengthen itself and become a logically and rationally stronger field. The current practices of absolute conclusions, no probabilistic assessment of results, no knowledge of error rate and little acknowledgement of bias are outdated practices which need to be improved. However an important issue which seems seldom to be raised is whether the question of fingerprint identification being truly a science is relevant. It is not the key issue; it may be a question that has no definitive answer. What matters is the utility of fingerprint analysis, and for this its strengths and weaknesses must be fully understood, its processes must transparent to outsiders; with this it will be as robust against attack as it can be; currently it is not.

The study of the nature of science can be considered more academic than practical, but it can educate about ways of reasoning, and can show how the epistemological view of science has evolved over time. An awareness of the arguments of the nature of science demonstrates differences in deduction and induction, which show that current fingerprint practice is an example of naïve inductivism, and therefore cannot be conclusively certain about its findings. It demonstrates that there is no such thing as a simple definition of science, and so fingerprint practice should not be striving to fit an unrealistic model of the world to be able to claim it is therefore a science. Issues raised by Kuhn and others show that being 'science' is not necessarily better, only perceptually so. One aspect of the philosophy of science which does appear to strongly relate to fingerprint practice, and echo the current problems, is Kuhn's paradigm model. His descriptions of a field working within a paradigm; a set of rules and behaviours, accurately depicts the fingerprint profession. The current paradigm, of absolute identification, is strong. Criticisms are rejected and explained away; there is a dogmatic belief in the current system. But questions have arisen, which cannot be easily explained away, and these questions have accumulated.

In the past, fingerprint identification was readily accepted by the courts. No questions were asked of the validity of the field [56], and defence lawyers did not challenge fingerprint experts with difficult questions [13]. This acceptance led to a situation where there was an almost blind faith in fingerprint evidence [9]. The system obviously worked [70], examiners were trained in the facts of fingerprint identification; it was a well-respected field within the criminal justice system. Unfortunately, this complacency has led to the situation the profession finds itself in at the present time; several major issues are currently present in fingerprint practice and have been raised by strong critical voices. They have argued that the field may not be as reliable as previously thought and have brought to the fore issues such as validity and reliability [66], awareness of error [78], issues of bias [121], concern over illogical tenets [86] and the appearance of faith rather than science [56]. On the whole these claims have been well-argued, and as a result are now in the public domain and cannot be refuted with simple statements such as:

'the science is well constructed with principles, standards, techniques, methods, rules and, importantly, results that are reproducible' [137]

'very few forms of scientific evidence could be better described as objective than the identification of a latent print by a skilled examiner' [138]

'I believe with all of my heart and mind that no two fingerprints or other areas of friction ridge skin are alike' [59]

Challenges to fingerprint identification 'are not due to a failure within the science, but are due to success' [49]

'a fingerprint examination conducted by a competent expert represents no void or absence of knowledge about the details under examination' [137]

According to Ashbaugh, fingerprint identification currently rests on 3 premises:

1. Friction ridges develop on the fetus in their definitive form before birth
2. Friction ridges are persistent throughout life except for permanent scarring
3. Friction ridge patterns and the details in small areas of friction ridges are unique and never repeated. [1]

A critical inspection of these three premises gives a clear indication of the current deficiency in fingerprint practice. The first two are scientific, based on biological studies of the development of the fetus and of skin. Fingerprint identification would not be possible without these first two premises, but these form only a small part of the underlying knowledge required for fingerprint identification. The third premise as highlighted by Ashbaugh is much less specific; he mentions 'small areas' without defining what this is. Even this is not fully appropriate to fingerprint identification however, because it is not the friction ridge skin that is being examined The crux of the matter is whether a mark left behind by the touch of friction ridge skin is unique, and this cannot be easily defined as quality and clarity can vary greatly.

Cooley gives a different phrasing of 3 premises which he feels the fingerprint profession rests on:

1. The source is unique
2. The source leaves an equally unique impression behind

3. Methods of observation and inference used are adequate to link back to a one and only source [154]

These premises are a more all-encompassing view of fingerprint practice, but also highlight the areas of weakness. The first premise is an echo of Ashbaugh's first two premises, regarding the uniqueness of the friction ridge skin. Cooley's second two are key to fingerprint identification, but currently based on little or no empirical evidence.

There is a need to appreciate the difference between the argument for uniqueness of friction ridge skin, and the transference of this quality of uniqueness to a mark left behind at a crime scene. The unique and permanent nature of friction ridge skin is just one aspect of fingerprint analysis; the key is whether 'one can determine with adequate reliability that the finger that left an imperfect impression at a crime scene is the same finger that left an impression (with different imperfections) in a file of fingerprints' [21]. Friction ridge skin may be accepted to be unique, but this does not mean fingerprints – in the sense of an impression left behind by a finger – are unique. Furthermore it does not mean that uniqueness is reliably discernable.

One of the strongest opinions given in the survey results was the view of the fingerprint profession on the 100% certainty of its findings; 91% of fingerprint examiners gave this answer. Regardless of whether fingerprint identification is a science, logic dictates that it cannot provide 100% certain answers as the examiner has not looked at every fingerprint when conducting a comparison. It is also the case that no human being is 100% perfect in practice. The conclusion of identity is a subjective one, based, as the fingerprint profession freely admits, on levels of knowledge, training and experience [49], and therefore cannot be absolute. It must be opinion, and Evett states 'opinion of identity is still no more than opinion and two different experts looking at the same comparison might differ as to whether or not there is sufficient identity to be inferred' [34]. An extreme example of this is the outcome of the McKie case in Scotland where there are many different opinions on one mark. The fingerprint profession must accept that the subjective nature of the comparison process will involve uncertainty, and therefore the idea of identification must be replaced with a probabilistic association [21]. Fingerprint examiners currently use a personal subjective probability method, which should be at the very least augmented by a scientific model.

The link between adopting a statistical model and moving away from absolute certainty appears to be an area of issue for fingerprint examiners according to the survey results. There appears to be relative openness to the idea of probability shown in the results; however there is a clear strength of feeling shown that fingerprint identification is 100% certain. In order to adopt a probabilistic model there must be an acceptance that fingerprint identification cannot be 100% certain, and this may be the largest hurdle to overcome.

It is now acknowledged by the fingerprint profession that there is no scientific, moral or logical reason for a points standard for identification [88]. This standard was imposed by the fingerprint profession, there was no logical reason for it. This argument should now be applied to the issue of 100% certainty. This stance is also illogical, entirely arbitrary and imposed by the profession rather than from any scientific principle [34].

The NAS report published in 2009 documented areas of fingerprint practice which are currently determined solely by personal experience, and research into uniqueness is ‘greatly needed’ [21]. However, because of the perception of infallibility and strength the field has developed over many years of acceptance, practitioners appear to be afraid to engage in research, in the mistaken belief that this will be a sign of weakness in the profession[54]. This opinion has not been helped by claims of some critics, such as Cole, who suggest the field has nothing to gain and everything to lose from validation studies [155]. This statement is only true if one considers giving up the ability to give absolute findings, or discovering flaws in particular processes, as a loss. Maintaining the position of absolute certainty means maintaining an illogical position, and replacing it with an improved process through validation studies would strength the profession against criticism; and there can be no loss in replacing a process which is flawed with one which is improved. The profession has been very slow to respond to the criticisms that have arisen through Daubert hearings in the

USA [77]. They have not been an ‘eager partner’ [77] in research to strengthen their claims; indeed Dr Itiel Dror, a leading researcher in cognitive bias and fingerprint evidence, has said ‘scholars are used to scholarly debate, but in this dispute, the practitioners simply don’t respond’ [155].

Unfortunately this fear of criticism has led to some practitioners making illogical, fallacious comments, attempting to dismiss the issues. The concepts raised by Popper are dismissed because ‘Popper was a philosopher, not a bench scientist’ [57]; rather than discussion and debate there is the reiteration of out-dated dogma and dire warnings about the collapse of the system [153]; Weise describes when, as a new fingerprint examiner in the US, she asked about the meaning of sufficiency, and was told ‘maybe I was just being “argumentative”, or that I “obviously” did not believe in the science. I was told, on more than one occasion, that if I believe in the science then I would know what “enough” was and I would just “let it go” ’ [59]. Some choose to criticise those undertaking research, claiming they have not worked in the field: in response to reasoned criticism from Professor David Faigman, examiner Steve Scarborough wrote ‘it is all well and good to have abstract theoretical discussions by inexperienced and remotely detached laymen about these issues, it is a whole different world than that understood by the comparative discipline experts who are immersed in day to day practical examinations. Perhaps Mr Faigman should remain “safe” within the “confines of academia” instead of lashing out at those who valiantly brave the real world’ [93]. Obtuse comments such as these only highlight the arrogant attitude of some working within the fingerprint profession. As Stuart Kind found in laboratory forensic science in the 1960s, in many laboratories and departments conducting fingerprint examination, research may still viewed with suspicion as a waste of time [156].

The paradigm shift which is beginning in fingerprint practice is not of Coperinican scale, and therefore perhaps not a true paradigm shift as Kuhn describes, but in terms of the fingerprint profession it is a radical shift in thinking and approach. To the fingerprint profession the shift from the infallible, absolute identification model which is currently used, to an opinion-based, probabilistic model is huge; this would be a fundamental change in fingerprint practice, a deep-seated change in way of thinking. The essential working processes would remain the same, but the knowledge behind them, and the conclusions made, would be dramatically different for a profession which has changed little since its inception at the start of the 20th century.

It is clear that more research is needed; fingerprint identification has been described as a wasteland of non-research [85]. The Department Of Justice in the USA has admitted that required studies have not yet been carried out [17], and some fingerprint examiners have also commented that little research has been done, and more is required [54] [60] [17]. Forensic Science research is most commonly on technical developments, but there is a growing appreciation that what is required is research into the fundamental issues. This was being suggested by Kirk in 1963 [5], by Evett in 1993 [100], and now by the NAS report in 2009 [21].

Fingerprint examiners have traditionally come from the police ranks, or as non-university graduates. There was never a perceived need for graduate learning; on-the-job training from fingerprint examiners was seen as the way to learn about the profession. As a result, fingerprint examiners have always been told that their profession is based on fact, with little training on the culture of science, openness and issues such as error and bias [79]. There has also been little academic interest in the field; which some examiners have blamed for the lack of progress in the field [48]. However I would argue that whilst there is a need for more academic research, the fingerprint profession itself has shown that this research also needs to come from within the fingerprint community, to avoid criticism that those undertaking research have never 'done' the work [89]. Fingerprint examiners naturally have a wealth of knowledge about how their profession actually works, and are aware of its value. But there must be a move within fingerprint departments and law enforcement laboratories to appreciate research is an important area, because through research one can strengthen and grow the field of fingerprint examination.

In 1982 Robert Olsen published a paper entitled 'Cult of the Mediocre' [157]. In it he suggested there was a trend towards mediocrity within the fingerprint profession; an acceptance that the career of a fingerprint examiner should begin as a layman, with training and education progress to novice, and with experience progress to an expert, and then the process stops. He suggested there should be further stages; through research and continuing education to progress to be a professional and then a scholar. He felt there should be encouragement to progress beyond competence to excellence, and that this would come from independent research, conference and seminar attendance. Unfortunately it would seem that, for some time at least, the profession did indeed condemn itself to the Cult of the Mediocre [157], but perhaps there are the signs of a shift beginning to occur.

Opinions are slowly changing. It is no longer possible for fingerprint professionals to make statements such as ‘during the last 100 years’ … ‘the fingerprint system of identification has maintained its infallible status’[158] because the legal profession in America, when presented with evidence of this infallible status, are reaching the conclusion that the fingerprint analysis procedure is ‘a subjective, untested, unverifiable identification procedure that purports to be infallible’ [84]. This pressure from the legal profession may be what is required to force the fingerprint profession to reconsider its practices and processes. ‘Science must be open to change, no matter how confident one feels at present’ [29]. This statement could equally be true of any logical, rational pursuit, and therefore is relevant to fingerprint practice whether science or not. It is clear that fingerprint identification has value, and certainly has a place in the criminal justice environment. However this environment is very different from the one in which fingerprint identification began at the turn of the 20th century, and the paradigm shift on which fingerprints is currently embarking is required if the profession wishes to maintain its acceptance and utility. Developing rigorous protocols for analysis, and conducting rigorous research and evaluation [21] and in turn training fingerprint practitioners on key issues and research will strengthen the profession and in turn help it defend itself from those who seek to criticise or diminish its value. Progression towards an environment of openness, transparency and research will ensure it holds its place as a key part of criminal justice.

7 Further research

The survey yielded a higher response than expected and so has provided a large quantity of data. This data could be further analysed to study the findings reported in more depth, and to draw further conclusions.

For further studies: the analysis carried out has highlighted possible connections in opinion between fingerprint examiners and crime scene examiners which could be further investigated. The opinion of police personnel, which both agrees and differs with that of fingerprint examiners and crime scene examiners, could also be further studied. A quantifiable response from the legal profession was not obtained for this survey, but as much of forensic evidence is driven by the demands of the courts it would be interesting to study the views of the legal profession. The answers given by the fingerprint profession have provided an insight into their views, but this could be expanded upon with a survey which allowed freer answers, or interviews to allow more expansive answers. Further study could be carried out on the opinion of fingerprint examiners towards a statistical approach to investigate the reasons for the wide range of responses and to discover how much knowledge there is within the profession on the value and use of probabilistic methods. The issue of bias was not investigated in this survey but is an area where study may provide an insight into the opinions of both fingerprint examiners and other professions on the effect this may have on fingerprint analysis.

The Introduction section of this research provided an overview of published work on various areas of fingerprint identification. To allow a more direct study between the answers given by respondents to the survey and views expressed in publication, a meta-analysis could be conducted on recent literature to determine the general viewpoints given by fingerprint professionals in print. This could be compared with the responses given in this study.

The literature shows a confusion between the uniqueness of friction ridge skin and the uniqueness of a mark left behind by chance. The survey determined that many - a substantial majority in the case of fingerprint examiners - have the opinion that fingerprint identification can give 100% certain results. This may be a result of the perception of uniqueness of skin, and the transference of this uniqueness to the mark, but as this was not investigated by the survey it is not possible to know. A further study could investigate this area more specifically to determine whether the view of 100% certainty is a result of the uniqueness of friction ridge skin.

This view of uniqueness of skin may also have an effect on the difference highlighted in the study held by fingerprint examiners when considering fingerprint examination and footwear examination. The general nature of the survey did not allow any in-depth analysis of why these views are held; a specific study on this area would investigate these findings further and attempt to discover why fingerprint examiners have such a different perception of their profession in comparison with that of footwear examiners. A study could investigate where the particular differences in view are, and also examine the views of footwear examiners on fingerprint analysis.

It can be inferred from the study results that the majority working in the questioned professions believe fingerprint identification to be a science. Further study could investigate why this is so, and also whether this was deemed an important or even crucial factor.

This study investigated the views of those working in criminal justice on fingerprint practice. Although there was a option to choose 'other' in the profession field, distribution was targeted at criminal justice professionals. Another area for investigation would be to look specifically at those not working in the criminal justice arena. The general public make up juries in criminal trials, however gathering the views of jury members is extremely difficult. A survey gathering the views of the general public on fingerprint practice would give an indication of the views on those with no educated knowledge of fingerprint practice or forensic science but who could be chosen to pass judgement on such evidence.

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Appendix A : Survey – printed version.

I am a postgraduate student at the University of Strathclyde, studying at the Centre for Forensic Science. My area of research is fingerprint identification; in particular the issues surrounding the rationality, objectivity and science of fingerprints. As part of my thesis I am gathering the opinions of various groups regarding these issues, and it would assist me greatly if you could complete the survey below. It should only take a few minutes of your time, and I also welcome any comments you would like to make. The survey is totally anonymous.
Thank you.

University of Strathclyde Glasgow

<u>Demographics:</u>

1. Please state your age:

Under 30 30-40 41-50 51-60 over 60

2. Please state your gender:

M ❑
F ❑

3. Please indicate what best describes your occupation/experience:

Fingerprints	Forensic Science	Crime Scene Examiner	Crime lab technician
Police	Solicitor	Barrister/Advocate	Judge
Academic	None of these	(please go to Q5)	

4. Please circle how many years experience (including training) you have in your current field:

Less than 3 3-5 6-10 11-20 21-30 over 30

5. Please circle the country in which you work:

Scotland	England/Wales	N Ireland	S Ireland	France	Germany
Switzerland	Holland	Italy	Spain	Other European	Russia
USA	Canada	S America	Australia	New Zealand	Asia

Other (please state) ________________________________

6. What is the highest level of formal education you have completed?

High school (approx. 11-18 yrs of age) ❑
University – undergraduate ❑
University – postgraduate ❑
Other (please state) .... ❑

<u>Research questions</u>
<u>Please express your opinions regarding the statements below:</u>

7. Fingerprint identification is a science
agree / disagree / unsure

8. Fingerprints provide 100% certain identification
agree / disagree / unsure

9. A statistical interpretation of fingerprints is possible
agree / disagree / unsure
If you disagree, please proceed to Q11.

10. A statistical approach to fingerprints would be:

Of no value	of some value	no different	quite valuable	very valuable
1	2	3	4	5

11. Please rate the following in terms of reliability:

	very unreliable	unreliable	reliable	very reliable	wholly reliable
DNA analysis	1	2	3	4	5
Fingerprint examination	1	2	3	4	5
Footwear examination	1	2	3	4	5
Eyewitness testimony	1	2	3	4	5

12. Please rate how scientific the following activities are:

	unscientific		neither		wholly scientific
DNA analysis	1	2	3	4	5
Fingerprint examination	1	2	3	4	5
Footwear examination	1	2	3	4	5
Eyewitness testimony	1	2	3	4	5

13. In your opinion what is the error rate in the following:

	zero	very low	low	moderate	high
DNA analysis	1	2	3	4	5
Fingerprint examination	1	2	3	4	5
Footwear	1	2	3	4	5

examination					
Eyewitness testimony	1	2	3	4	5

14. Please rate how subjective or objective individuals dealing with the following are:

	Completely subjective		Neither subjective or objective		Completely objective
DNA analysis	1	2	3	4	5
Fingerprint examination	1	2	3	4	5
Footwear examination	1	2	3	4	5
Eyewitness testimony	1	2	3	4	5

If you would like to make any comments please do so:

Thank you for your valuable participation.
Isobel Hamilton
I.hamilton@strath.ac.uk

Appendix B : Survey – online version.

I am a postgraduate student at the University of Strathclyde, studying at the Centre for Forensic Science. My area of research is fingerprint identification; in particular the issues surrounding the rationality, objectivity and science of fingerprints. As part of my thesis I am gathering the opinions of various groups regarding these issues, and it would assist me greatly if you could complete the survey below. It should only take a few minutes of your time, and I also welcome any comments you would like to make. The survey is totally anonymous.
Thank you.

University of Strathclyde Glasgow

Demographics

1. Please state your age:

○ under 30 ○ 30-40 ○ 41-50
○ 51-60 ○ over 60

2. Please state your gender:

○ M ○ F

3. Please indicate what best describes your occupation/experience:

○ Fingerprints ○ Forensic Science ○ Crime Scene Examiner
○ Crime lab technician ○ Police ○ Solicitor
○ Barrister/Advocate ○ Judge ○ Academic
○ None of these (please go to Q5)

4. Please indicate how many years experience (including training) you have in your current field:

○ Less than 3 ○ 3-5 ○ 6-10
○ 11-20 ○ 21-30 ○ over 30

5. Please select the main country in which you work:

☐ Scotland ☐ England/Wales ☐ N Ireland
☐ S Ireland ☐ France ☐ Germany
☐ Switzerland ☐ Holland ☐ Italy
☐ Spain ☐ Other European ☐ Russia
☐ USA ☐ Canada ☐ S America
☐ Australia ☐ New Zealand ☐ Asia

Other (please state) ________

6. What is the highest level of formal education you have completed?

○ High school (approx. 11-18 yrs old) ○ University – undergraduate
○ University – postgraduate Other (please state) ________

Research questions

Please express your opinions regarding the statements below:

7. Fingerprint identification is a science

○ agree ○ disagree ○ unsure

8. Fingerprints provide 100% certain identification

○ agree ○ disagree ○ unsure

9. A statistical interpretation of fingerprints is possible

○ agree ○ disagree ○ unsure

If you disagree, please proceed to Q11.

10. A statistical approach to fingerprints would be:

Of no value	of some value	no different	quite valuable	very valuable
○	○	○	○	○

11. Please rate the following in terms of evidential reliability:

	very unreliable	unreliable	reliable	very reliable	wholly reliable
DNA analysis	○	○	○	○	○
Fingerprint examination	○	○	○	○	○
Footwear examination	○	○	○	○	○
Eyewitness testimony	○	○	○	○	○

12. Please rate how scientific the following activities are:

	unscientific		neither		scientific
DNA analysis	○	○	○	○	○
Fingerprint examination	○	○	○	○	○
Footwear examination	○	○	○	○	○
Eyewitness testimony	○	○	○	○	○

13. In your opinion what is the error rate in the following:

	zero	very low	low	moderate	high
DNA analysis	○	○	○	○	○
Fingerprint examination	○	○	○	○	○
Footwear examination	○	○	○	○	○
Eyewitness testimony	○	○	○	○	○

14. Please rate, in your opinion, the degree of subjectivity or objectivity in the following activities:

	completely subjective		neither		completely objective
DNA analysis	○	○	○	○	○
Fingerprint examination	○	○	○	○	○
Footwear examination	○	○	○	○	○
Eyewitness testimony	○	○	○	○	○

If you would like to make any comments please do so:

____

submit

Thank you for your valuable participation.

Isobel Hamilton
i.hamilton@strath.ac.uk

Appendix C : complete results by country.

Country	Total
Asia	3
Australia	11
Belgium	3
Canada	5
Cyprus	1
Denmark	1
England + Wales	81
Estonia	1
Finland	1
France	2
Germany	6
Greece	1
Holland	12
Hungary	2
India	1
Isle of Man	1
Israel	1
Italy	2
Macedonia	1
New Zealand	11
other European country	3
Portugal	4
Romania	1
South Africa	15
Republic of Ireland	3
Scotland	155
Slovakia	3
Slovenia	4
Sweden	3
Switzerland	7
USA	101
Zimbabwe	1