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Fingerprinting: A Study in Cognitive Bias and its Effects on Latent Fingerprint Analysis

Jessica Kern
Long Island University, jessica.kern@my.liu.edu

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Jessica Kern

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Forensic Science Department

Pasquale Buffolino

Pasquale Buffolino, Ph.D.

Francis T. Harten

Francis T. Harten

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Abstract

The forensic science world contains a variety of disciplines that cover a wide range of sciences, from chemistry to physics to biology. Today, DNA is considered to be the "gold-standard" of forensics, due to the amount of information that can be collected. However, fingerprinting used to be the pinnacle of forensic science before DNA because of the uniqueness of each print and their unchanging nature. The different patterns, along with the smaller ridge details, allow examiners to categorize and differentiate between two similar fingerprints, using the standard method of ACE-V, adopted by all fingerprint examiners. Experts had believed that fingerprints were infallible and therefore could always be relied upon when used in court. This changed when the practice came under scrutiny due to various cases in which errors occurred within the fingerprint method. The process of fingerprinting is a subjective process that leaves room for potential bias to affect the examiner. The biases that can affect fingerprint examiners can be both conscious and subconscious, making them difficult to avoid. Cognitive neuroscientist Dr. Itiel Dror explains that bias is a part of the human experience and cannot be prevented, only lessened. In addition, there are many other shortcomings within the fingerprinting method that have been studied to determine how and why they occur. Through these studies, various solutions, including a blind-verification method, have been developed to solve these issues. The cases of the Madrid Bombing and Shirley McKie are two prime examples of the mistakes that can be made when bias is allowed to interfere.

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Introduction

Forensic science is used worldwide as a means of solving crimes and proving or disproving the guilt of a person. It is a discipline that has been practiced for hundreds of years. Its development has led to more advanced and reliable methods that have become valuable to law enforcement and the court system. Fingerprints have always been known for their unique characteristics that allow for an almost infallible form of identification. The various patterns of loops, arches, and whorls, along with the smaller and more detailed minutiae, adorn each print. It is through a thorough examination of these characteristics that an examiner can identify or exclude a suspect from a criminal investigation. The ACE-V process, a 4-step method that is followed by all examiners, creates a unified approach to the analysis. These steps are performed sequentially and individually, without circling back for additional information. The final step of verification is an invaluable part of any forensic analysis, as it requires a second examiner to perform their own analysis to validate the initial conclusion. Ideally, this step would be performed blind, where the second examiner knows neither the initial decision nor whether one was made. A non-blind verification would be open to potential bias and influences. Bias is an unavoidable aspect of the human experience. Cognitive bias, an unconscious effect, and motivational bias, a conscious effect, are two types of bias that affect nearly every fingerprint examiner. While often difficult to detect, measures have been put in place to lessen and possibly prevent bias from influencing the decisions of examiners. Dr. Itiel Dror, a cognitive neuroscientist, initiated this development with his own study, pioneering the forensic world into stepping back and re-evaluating the fingerprint process. Through these studies, several solutions have been found, some of which have already been implemented. These solutions include blind-verification, working in a linear fashion, establishing an error rate, removing crime laboratories from law enforcement jurisdiction, and adding psychology to the training of fingerprint examiners. Unfortunately, bias has affected not only low-profile cases, but high-profile cases as well. Two cases, one more infamous than the other, became known world-wide for their misidentifications. The case of Shirley McKie was an incident where McKie was accused of having been within a crime scene when she clearly stated she had been nowhere near it. The second case, and possibly the most famous for a fingerprint misidentification, is the Madrid Bombing case. This act of terrorism spurred the FBI into an urgent search for the source of a fingerprint found in connection with the bombing. In both of these cases, an innocent person was charged with a crime they did not commit. Fingerprinting, which had once been considered the gold-standard, was being put under scrutiny for its errors.

Chapter 1.1: Fingerprint Patterns and the ACE-V Process

It has been known that fingerprints possess an exceptional characteristic that sets them apart from other aspects of forensic science. Each fingerprint found on a human's fingers and toes are unique. Looking closely, one can detect small ridges and lines covering the surface pads of our fingers. Even without the use of magnification, it is plain to see that there are different basic patterns that can be found, however, under a microscope a much larger variety can be seen. The variability of fingerprint patterns is so vast that a classification system was created in order to distinguish one pattern from another (Ashbaugh, 1999). Three main categories of level 1 detail were created in order to help with the classification: arches, loops, and whorls. The most common of these three prints is the loop, followed by whorls, and then arches. In addition, these patterns can have subcategories (N. Kaushal, P. Kaushal, 2011). These patterns will have one or more features as a result of the various ridge flows: cores, the center of a pattern; and deltas, where the ridge path flows in three different directions. Arches can be tented, with a sharper point, or plain, with the ridges entering from one side of the finger, moving in an arch pattern, and exiting the opposite side. There are no deltas present in an arch and the core is often difficult to discern. Whorls have the largest variation, including simple whorls, central pocket loops, double loops, and accidental whorls. These patterns move in a circular direction with the core in the center and have at least two deltas. Loops do not have much variety, but are either directed towards the little finger, known as an ulnar loop, or towards the thumb, known as a radial loop. The ridges in this pattern enter from one side, curve around the core, and exit the same side that they entered. Loops will have one delta, located on the opposite side from where the ridges entered and exited (Daluz, H. M., 2015). These patterns play an important role in examination of fingerprints for forensic purposes for many reasons. Firstly, they provide a means of orientation when examining the pattern. Having the print oriented correctly allows the examiner to position the print in such a way that certain areas will be recognizable when comparing to a known print. The known print will also have to be oriented correctly for any comparison to take place. Secondly, knowing the pattern of the print can allow an examiner to exclude other prints of different patterns, effectively increasing the chance of finding a match, which is also known as an individualization (Kaushal, 2011).

During a criminal investigation, there are multiple types of fingerprints that can be discovered. Surfaces, as well as the manner of contact, can determine which of these types will be revealed. The main types are latent, patent, and plastic prints. Latent is often the most common print found at crime scenes. These are not visible nor are they able to be photographed without various chemical techniques. Human skin contains sweat glands and produces oils that transfer to a surface in the pattern of a fingerprint when contact is made. These prints can be found virtually anywhere and vary in degree of quality, depending on the circumstances by which they were transferred (Crime scene chemistry: fingerprint analysis., 2016). In forensic fingerprint analysis, these are the unknown prints that are from an unknown source. Careful lifting, or the removal of a latent print from a surface onto an adhesive strip, and recording is important because these prints are evidence that can potentially prove or disprove the innocence of a person. The second type of fingerprint, patent prints, are visible without needing to be processed by chemical means. These can be photographed at the scene and are often recorded in a "visible medium" such as paint or blood. The touching of this medium and then a separate surface will produce a patent fingerprint. Even though these prints are able to be seen, some chemical techniques and processing may be needed in order to increase their quality. The third main type of fingerprint is plastic prints. Like patent prints, these are also visible and can be photographed easily. They result from contact with soft substances such as clay or wax. The pressure of the finger creates a mold of the ridge detail and preserves it. (Daluz, H. M., 2015). In addition to these three types of fingerprints, there is a fourth that is used for every forensic fingerprint analysis. A known print, or exemplar print, is a print from a known source that is not found at the crime scene. These are often collected by police to use in criminal investigations. The prints of a suspect are recorded on a fingerprint card to be used to compare to any unknown prints found (Kaushal, 2011). Quality is also important for these prints because a comparison will need to be made between any unknown prints found and those that were collected by police. The better the quality, the easier the comparison will be.

Chapter 1.2: Fingerprint Patterns and the ACE-V Process

The most important part of a fingerprint in criminal investigation is the friction ridges found on the surface of the skin. These ridges are raised portions of the skin that allow us to grip objects with ease and are what creates the various fingerprint patterns of arches, loops, and whorls (Daluz, H. M., 2015). The formation of these ridges begins in early fetal development, where swellings appear on the fingertips and palms, as well as the feet. These swellings, called volar pads, vary in size and shape. During the 11th or 12th week of gestation, the volar pads will begin to deflate, forming the beginnings of friction ridges. The first ridges to form are primary ridges, which are the raised areas on the surface of the finger. Secondary ridge formation follows, creating the furrows that separate the raised ridges. The random stresses of the volar pads on the surface of the skin will affect the variability in the flow of the friction ridges. For this reason, no two fingerprints are alike, even in identical twins. Despite having the same DNA, identical twins will always have unique fingerprints caused by the random volar pad sizes and shapes occurring during gestation (Ashbaugh, 2005).

As the surface of the skin grows and expands, the friction ridges begin to differentiate and individualize. This is a random process and is affected by numerous biological and environmental factors such as the locations of gaps in the ridge sequence, volar pad location, and the growth of the skin itself. Due to these factors, primary ridges may differ in length, pattern, and distance from each other, creating unique patterns and designs that are unlike any other fingerprint. It is for this reason that fingerprints are an excellent form of identification in criminal investigation (Ashbaugh, 2005). It is also important to note that these ridges “remain constant throughout a person’s lifetime,” as dead skin cells are replaced by new ones from the bottom layer of the epidermis. The cells will always be replaced in the same way, keeping the ridge formations permanent. However, the friction ridges can be affected by scarring resulting from injury or mutilation. This will alter the fingerprint overall, but will add to the uniqueness of the individual (Kaushal, 2011).

Moving beyond the level 1 detail of fingerprint pattern types, the friction ridges give rise to unique formations and details. The sometimes-subtle differences between fingerprints gives each print its uniqueness. These differences, known as level 2 detail, are called minutiae, the individual characteristics and details of a fingerprint. These are the features that a fingerprint analyst will examine and compare between known and unknown prints. Ridges can deviate in shape and size from each other due to random growth. The most common minutiae details are bifurcations, ending ridges, islands or dots, and short ridges. As the friction ridges form, they can branch out from each other forming a bifurcation, or a separation of one friction ridge into two. These result from the expansion of friction ridges surfaces as the newly forming branch is pulled away from the main one. Ending ridges may also be present in a fingerprint. These are normal ridges that come to a sudden end. Other types of minutiae include islands or dots, which are isolated ridges. These can range in length, but are always disconnected from surrounding ridges. Due to the varying length, these features can also be called short ridges, with an ending ridge on each side (Ashbaugh, 1999). The placement of each feature on the print as well as their relative distance between each ridge event is random and unique. No two fingerprints will have the same ridge features in the same locations. As had been stated before, these ridge features cannot change and will remain the same as the skin regrows. Alteration can occur due to injuries and scarring can change the way a fingerprint may look, however slightly. It is these small details that a fingerprint examiner will look for in order to make a match between two fingerprints. The last category of detail, level 3, can also be used in identification if present. This refers to the general location of pores, ridge thickness or thinness, and the small shapes on the ridge. Any sort of random damage or misalignment in the growth of the ridge is considered to be level 3 detail (Ashbaugh, 1999).

Chapter 1.3: Fingerprint Patterns and the ACE-V Process

For any experiments, or in this case examinations, to be accepted in the scientific community, there must be a common method that is followed by all who would conduct the analysis. The scientific method is a basic procedure by which all experiments follow. It begins with determining the problem that needs to be solved, followed by a proposed solution. The experiment itself is the process by which a scientist goes about testing the solution to see if a result can be achieved and a conclusion made. What makes this method important to use is its ability to be replicated by other scientists who would like to see if they can achieve the same results. Repeatability is necessary for the experiment to be considered acceptable. This is especially important as scientific practices and procedures change throughout the years to give rise to new and improved methods. These new methods must still require a standard basis that is accepted by the scientific community. For a fingerprint examiner to conduct an examination on a set of fingerprints, they must follow a certain methodology that all fingerprint analysts follow. This scientific method is known as ACE-V, or Analysis, Comparison, Evaluation, and Verification. Each part of this four-step method is essential for a complete and thorough examination. This method is an evaluation of the level 1 and level 2 details found within a fingerprint and uses a series of "subjective assessments" in the selection of usable fingerprint regions (President's Council of Advisors of Science and Technology, 2016). Not only is it used to identify a fingerprint source, it also allows for the exclusion of an individual as the source. Despite there being many misgivings about the way a fingerprint analysis is performed, this method is considered to be the standard that all examiners follow, giving the practice legitimacy in the scientific community. In this way the comparison process for fingerprints can become the standard that is followed by all examiners (Daluz, H. M., 2015). As with any scientific method, it is important that this method is able to be repeated in the same manner by separate analysts to elicit the same conclusions.

The first phase of the ACE-V process is the analysis. Similar to the scientific method, this stage consists of observation of the unknown and known prints separately (first the unknown and then the known), and gathering as much information as possible. The "quantity and quality of information present" is observed and recorded (Kaushal, 2011). The overall features are looked at to determine if the print is suitable for comparison. Distortion must be considered as a factor that could potentially alter the fingerprint. The more distortion, the less likely the print will be suitable for comparison. Exemplars, or known prints, will normally have minimal to no distortion (Ashbaugh, 2005). A fingerprint examiner may choose to not use a certain print if the clarity is too low and the distortion too high. If the print is decided to be suitable for comparison to a known print, the examiner will then determine the pattern type as an arch, loop, or whorl for the purposes of excluding any non-matching prints. Shape and overall ridge flow is examined and recorded for the unknown and known prints (Daluz, H. M., 2015). If there is a similarity in this level 1 detail between the unknown and known prints, then the examiner will move on to the next stage of the method. The more skilled and experienced an examiner is, the shorter the time it takes to make this decision. Knowing the overall shape and ridge flow pattern of a print and being able to rule out known prints that do not match is a skill that comes with practice. It must be stressed that this phase of ACE-V is subjective. Due to distortion and a lack of clarity, two examiners may disagree on whether a fingerprint is suitable for comparison and experience may play into the decisions of analysts.

The second phase of the ACE-V process is the comparison. This takes the unknown print and the similar known print and looks more closely at the details in each. The prints are looked at side by side under a magnifying loop or on a computer screen. The unknown print is placed to the left of the known print and is to be examined first. The idea behind this is that most people are familiar with reading from left to right and so the unknown print should be seen first to avoid any potential bias (Daluz, H. M., 2015). Beginning with a focal point chosen by the examiner, an examiner will look at the level 1 detail to see if the shape and flow matches between the known and unknown. Those that match will be examined further and those that do not will be excluded. Level 2 detail is examined next. Examiners will make note of the various ridge characteristics and events on the unknown print using pins or other markings to keep track of their locations. Once these events are found on the unknown print, the examiner will move to the known print to see if the same minutiae can be found. Each of the events found must be compared to the known print. At the same time, level 3 detail will also be assessed if it can be seen. The visibility of this detail will depend on the clarity and quality of the unknown print. Due to pressure or distortion, pores and ridge thickness or thinness may be hard or impossible to discern (Kaushal, 2011). The two prints being compared must be in agreement before an examiner can determine them to be a match. Spatial relationship between ridge events is important to note because two prints may have the same two ridge events in seemingly the same places. For example, one print may have two bifurcations separated by four ridges, and another print may also have two bifurcations, but separated by six ridges. This would indicate that although the two prints may appear to be similar, they are actually two different fingerprints. The relative position of ridge events must also be noted. This means that a ridge event must also be looked at as where it is found compared to a nearby ridge event (Ashbaugh, 2005). The number of points of similarity that must be found between two fingerprints is determined by the examiner. If he or she feels that there is enough similarity that a decision can be made, then the evaluation phase can begin.

Once a sufficient number of ridge events have been found and compared, the examiner can then move on to the next phase in the ACE-V process. An evaluation of the compared prints must be made. There are three possible conclusions that an examiner can reach. The first is an identification or an individualization. This conclusion means that the unknown print and the known print came from the same source and there is enough matching detail to support this decision. The opinion of the examiner must be confident that the data presented on the print cannot be repeated in another fingerprint (Ashbaugh, 2005). The second conclusion that can be made is an exclusion. This will occur when there are dissimilarities between the prints being compared and there is not enough evidence to support the decision that the prints are from the same source. Some comparisons may show that the prints share similar points and an examiner may be inclined to deem the prints a match. However, because of the increasingly large amount of variability in fingerprint patterns and ridge flow, two fingerprints may share similar characteristics and not come from the same source. One must look at what is dissimilar to reach an exclusion. Even one unidentical point of minutiae may be enough, regardless of how many other similar points there may be (Daluz, H. M., 2015). The third conclusion that can be reached in the evaluation phase is an inconclusive decision. This occurs when the examiner can neither reach an individualization nor an exclusion decision. There are various reasons that could lead to such an end. The latent and known prints may be in agreement with some characteristics, but there might not be enough for an examiner to be fully confident in coming to a decision. At times, the latent print may not have sufficient details present to compare and so may seem to match to multiple known prints (Ashbaugh, 1999). The print therefore cannot be an individualization nor an exclusion and must be deemed inconclusive.

Most sciences have a way of checking data to ensure the highest accuracy of results, often in the form of peer-review. This is a way of double-checking the results of an experiment or, in this case, an examination (Daluz, H. M., 2015). The final stage of the ACE-V process is a very important part of the analysis, although it is not always implemented as part of the normal analysis. The verification phase is the last step before the fingerprint examination comes to a close. It is technically not part of the examination process because it comes after the examiner has made a decision (Kaushal, 2011). The purpose of the verification step is to serve as a form of peer-review. Another examiner will perform a separate ACE-V analysis in full. Each step must be done as if it was the first time performing this examination, including checking the clarity and quality of the print to see if it is suitable for comparison (Ashbaugh, 2005). When finished, the results of both examinations will be compared to see if the same decision was achieved, the second of which will either support or refute that of the first. This method of verification is essential to prevent mistakes. Mistakes can result in a guilty person going free or an innocent person going to jail (Daluz, H. M., 2015). These mistakes can often be the result of bias, where outside information or knowing the result of the initial exam can influence the decision of the second examiner (President's Council of Advisors of Science and Technology, 2016). The process of verification must be performed in a certain way to ensure that the examiner will not be influenced by the previously made decisions. The method used to enforce this is called blind-verification. Used by multiple laboratories including the Federal Bureau of Investigation, this type of peer-review prevents the second examiner from not only knowing the result of the first examination, but also knowing if that examiner reached a conclusion. No information at all from the first exam is provided to the second examiner. In this way, the second examiner is acting as if it was the first time that print was being examined (Kaushal, 2011). This fully blind-verification is the ideal setting in which a fingerprint analysis should take place, however this is not always the case. Some laboratories perform a semi-blind verification, where the second examiner knows the first came to a decision, but is unaware of what that decision is. While this is not the ideal setting for a fingerprint analysis, this process still does the job of preventing bias from interfering. All humans are subject to bias, so having a verification stage allows for this bias to be lessened if not eradicated. Because the comparison stage is objective, each examiner must be able to see what the other has seen and then form their own opinion. In the event that two examiners disagree on the results of their analyses, a third examiner can be brought in to carry out another verification (Ashbaush, 1999).

Chapter 2.1: Fingerprint History and Important Court Cases

Having a historical background is not always seen as important as knowing and understanding scientific concepts and methods and being able to apply them. Yet, for any science to grow and improve, one must know how it came to be and how it can continue to change. Forensic science is no different. The many disciplines within forensics each have a notable history and development, as well as multiple uses. Fingerprinting, most likely the most well-known discipline of forensics other than DNA, has an extensive history that is essential to its advancement. The knowledge of fingerprints has been around for thousands of years and not necessarily for use with the law, however they were most often associated with identification of people. Modern fingerprinting, meaning how it is used today, is seen as being connected to criminal investigations, but it was not always used in this way. Some of the first evidence recorded of fingerprints were accidental impressions found on clay pottery unearthed in China, most likely resulting from the process of sculpting the pots. In the Middle East, more intentional fingerprint markings were found on pottery as well. These markings are thought to have been used as a way to discern a specific artist's work from another's (Daluz, H. M., 2015). Other evidence like stone or wood carvings and drawings on parchment or cave walls also show that humans knew of and acknowledged the presence of friction ridges on the tips of the fingers. These drawings would depict spirals or other circular lines located on the fingertips. In terms of identification, in ancient China, fingerprints and handprints were often used rather than personal signatures to sign documents, or used in addition with signatures to reinforce their identity. It is believed that the diplomats sending these letters knew of the uniqueness of fingerprints and therefore knew that anyone who tried to replicate or forge these documents would be unable to succeed (Ashbaugh, 1999). Due to the exchange of fingerprints on letters, a record keeping system was developed. This record keeping of fingerprints in China evolved to be included in criminal investigations, along with hand and finger measurements (Daluz, H. M., 2015).

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The fingerprinting method did not come about all in one day or by one person alone. It was developed over a number of years, changing and growing into what it has become today. There were a number of people who saw the advantages fingerprints held over other forms of identification and saw fit to install it as the main method. In addition, these people aided in the creation of a system of classification and the use of the method in criminal investigations. Many of these people performed their own studies and conducted their own research, compiling information to be used and studied by future researchers.

The first of these individuals is Sir William J. Herschel, a British citizen born in 1833. He is credited as the "first European to recognize the uniqueness of fingerprints" (Daluz, H. M., 2015). Herschel's discovery of fingerprints happened in India where he became a member of the Civil Service. During a contract where he supplied road building materials, he noticed that inked prints of the fingers and hands were being placed beside signatures on some of the paperwork. Those papers that included these prints seemed to be more respected and accepted by those who received them. Through this, and a collection of fingerprints from friends and family, Herschel was able to recognize that there is a uniqueness among fingerprints that allows for a more authentic document. Later, in Nuddea in 1860, he encouraged the use of fingerprints to prevent frauds such as fake checks and false impersonations. He had established the practice of taking the fingerprints of those receiving their pensions as a way to prevent imposters from collecting the money. In 1877 he was appointed to Magistrate and Collector where he oversaw the criminal courts and the prison, among other things. In each area he controlled, Herschel implemented the use of fingerprints. He also attempted to have the practice expanded in other areas of the courts, but was ultimately denied. In addition to trying to have fingerprinting become the accepted method, he also performed his own experiment to test if the friction ridges changed over time. He printed himself multiple times throughout his life and compared the cards each time to see if any change had occurred. He saw none. Herschel's letter published in *Nature*, an academic journal published by a scientific publishing company, claimed that his previously written letter, called the "Hooghly Letter," was proof that he was the first to use fingerprints as a means of identification (Ashbaugh, 1999).

Dr. Henry Faulds, born in 1843 Scotland, was another individual who contributed to the development of the fingerprint method. He is considered to be the "first European to publish an article stating that visible fingerprints, such as bloody, greasy, or sooty fingerprints, may be useful for solving crimes" (Daluz, H. M., 2015). The exact nature or time of his exposure to fingerprints is unknown, but it is calculated to be sometime during his medical work, where he realized that fingerprints are unique. In 1880, he had written a letter to Charles Darwin. Even though his own studies were merely a year old, Faulds understood that the classification of fingerprints is easy because of their unchanging nature over a lifetime. His letter mentions how China fingerprinted their criminals, and Japan and Egypt used a fingernail stamp for the same reason. This information led Faulds to believe that criminals could be caught by simply finding fingerprints at a crime scene. Through his thinking, he associated the use of fingerprints as a tool for solving crime. He published a letter in *Nature* called, "On the Skin—Furrows of the Hand," that stated all his work was based on what had already been done by the Chinese (Ashbaugh, 1999).

Another very prominent figure that aided in fingerprinting is Sir Francis Galton, born in 1822 in the United Kingdom. His book *Finger Prints*, was the first book to be written on fingerprinting and contained all of his work up until that point (Daluz, H. M., 2015). His initial encounter with fingerprints occurred in a letter from his cousin, Charles Darwin. In this letter, Henry Fauld's ideas about fingerprints were discussed. Galton then looked into the fingerprinting method used in China to keep track of criminals. He began to examine several fingerprints he collected, but lost interest. It wasn't until he was asked by the Royal Institute in 1888 to give a lecture that he began to find himself studying fingerprinting. The lecture was to be on the topic of Bertillonage, an anthropometric system of classifying criminals based on physical measurements developed by Alphonse Bertillon. Galton visited Bertillon to observe his work and found that he disliked the system that was being used. He did not think that taking measurements of the body was efficient enough for making identifications. He considered fingerprinting to be a better method. In his lecture, he expanded upon the idea that fingerprints were so unique and individualistic that they would be a better and easier option for identification. Following the presentation of his lecture, Galton began an intensive study on fingerprints and corresponded with William Herschel, who willingly handed over his work. His resulting book emphasized the superiority of fingerprinting over any previously used system of identification (Ashbaugh, 1999).

The last important figure to be discussed is Sir Edward Henry, born in the United Kingdom in 1850, who is credited with "developing the classification system" known as the Henry Classification System used throughout the world (Daluz, H. M., 2015). While working in the Bengal Province in India as the Inspector General of Police, Henry noticed just as William Herschel did that hand and finger prints were being used as a means to sign and authenticate documents. At this time, an anthropometric system and the locations of scars, tattoos, and deformities were being used to classify criminals. Per Henry's request, the left thumbprint was taken from all criminals and added to the anthropometric cards. He also began to correspond with Francis Galton after having read his book. In later years, his conversations with Galton inspired him to begin developing a system of classification for fingerprints, in which they could be recorded, filed away, and retrieved for future use. Upon his return to India, he instructed that all ten fingerprints of each prisoner be added to their anthropometric cards. His team was responsible for creating and setting up the classification system in India. The Indian government reviewed this system and ultimately accepted it as the official identification method, effectively replacing anthropometry. Henry's book, *Classification and Uses of Fingerprints*, also aided in the transition from an anthropometric system to fingerprint identification (Ashbaugh, 1999).

<u>**Chapter 2.3: Fingerprint History and Important Court Cases**</u>

As has been said before, knowing the history of any aspect of science allows one to have a fuller and deeper understand for that discipline. Since becoming a recognized form of identification, fingerprinting has been used to solve crimes and bring criminals to justice by becoming a part of the court system. To understand the usage of fingerprint identification in crime solving, one must understand just how the process came to be associated with the courts. Before 1911, it had been accepted that fingerprints were a method of identification, and that each person's prints were unchanging and unique from the next. Throughout the last one hundred years, fingerprinting has been a part of the court system as evidence used to convict or exonerate an individual. Early in the 20th century, the court case of People v. Jennings (*People v. Jennings, 69 N.Y.2d 103 (1911)*) changed the way fingerprints were used in court. In 1910, an intruder broke into a house where he murdered the father and molested the daughter. In addition to the ballistics evidence that was found, fingerprints were discovered on the outside railing of the house. This was the first case where fingerprint evidence was ruled as admissible in court (Cole, 2004). However, unlike what would be required in future cases, there was no requirement to show that the fingerprint identification method was accurate or reliable. It was only noted that authorities in Britain perceived the method to be accurate. From this point on, fingerprint evidence was established as an acceptable form of identification in criminal law (Stickel, 2016).

Following this case was another incident in which the court began to change the way forensic evidence was to be presented. Frye v. United States (*Frye v. United States, 293 F. 1013 (D.C. Cir 1923)*) was a case in 1923 where James Frye was convicted of second degree murder. Frye had taken a polygraph test where he confessed, but the court did not consider this test to be admissible and therefore did not accept his confession as evidence. Frye v. United States created a need to have a standard by which forensic evidence was processed and examined in order to be considered admissible. In doing so, all forensic evidence was required to adhere to a criteria of case relevance and have a general methodological acceptance in the scientific community. Scientific approaches were added to the court system that would ensure a guilty verdict to a crime that would have previously never been a conviction (Stickel, 2016). Court judges were assigned the task of "gatekeeping." They were the final deciders in what was deemed admissible and what was not, basing their verdicts off of the previously stated criteria (Cole, 2004). This applied to almost all forensic evidence, save fingerprinting. Although some aspects of the fingerprinting process fell under the jurisdiction of the judges, the practice as a whole was seen as its own field, separate from other disciplines. This was because fingerprinting had always been seen as accepted, even from the beginning (Schmidt, 2008).

Many years later in 1993, another case came to court, Daubert v. Merrell Dow Pharmaceuticals (*Daubert v. Merrell Dow Pharms., Inc., 509 U.S. 579 (1993)*). This was a very famous case for the forensic world because it expanded upon the ruling from Frye v. United States. Jason Daubert and several others claimed they had suffered birth defects after their mothers had taken the drug Bendectin during their pregnancies. There were no studies at that time that linked the birth defects to the drug. The plaintiffs tried to provide their own evidence, but since their methods had not yet been approved or reviewed by the scientific community, they could not be accepted by the court. Evidence and its admissibility once again came into question when the court had concerns that the evidence presented in the case had no scientific reliability (Schmidt, 2008). Unreliable evidence posed a danger when used in court, possibly resulting in the conviction of an innocent person or the exoneration of a guilty individual. Thus, the Daubert Standard was created. All evidence presented in court had to follow five general criteria that were added to the Frye Standard: the evidence must be falsifiable, peer reviewed, have an error rate, disclosed techniques, and be generally accepted (Stickel, 2016). The judges were deemed responsible for confirming that the evidence presented is both reliable and relevant to the case. There was a great flexibility that was allowed for each of the forensic disciplines, but each still needed to be proven to be reliable by the scientific community (Cole 2004). The challenges that were presented to fingerprint evidence resulted in an always consistent admission of evidence that was unrestricted. This was because most judges and people have an instinctive tendency to believe that evidence presented by a fingerprint examiner is accurate, even without proof. However, there were several challenges that were presented to show that fingerprint evidence is not as infallible as the experts claimed. Clarity and quality varied greatly, as well as how much of the print was found at a crime scene. The number of matching features that were necessary to declare a match between two prints was different for each examiner. A “one discrepancy rule” caused examiners to declare prints with as simple as one difference an exclusion (Schmidt, 2008). The Daubert factors took these issues into mind and as a result, discovered that fingerprint examinations were “liable” because they lacked a system by which all forensic examinations adhered to. This, however, did not stop fingerprint evidence from being used in court, although it was made aware that the “rigor of scientific discipline” was absent (Stickel, 2016). Daubert, however, did state that peer review was the most common and easiest way to assess scientific validity and reliability. This is important because peer review is reminiscent of the “Verification” step of the ACE-V process, which is now used by all forensic fingerprint examiners (Cole, 2004).

The idea that fingerprint evidence did not fully pass the Daubert Standard was brought up again in 2002 in a case called Eastern District of Pennsylvania in United States v. Llera Plaza (*Eastern District of Pennsylvania in United States v. Llera Plaza, 188 F. Supp. 2d 549 (E.D. Pa. 2002)*). Carlos Ivan Llera Plaza and Wilfredo Martinez Acosta were brought up on murder and drug charges after their fingerprints were found in a car. In this case, the court ruled that the admissibility of fingerprint evidence was to be limited because it did not satisfy the criteria set by the Daubert factors. Due to this ruling, all fingerprint examiners testifying in court were not permitted to give conclusions saying if the unknown prints matched or came from the same source. They could merely testify about the similarities and differences found between them. This was a severe setback for the forensic fingerprint community. However, ten weeks later, in a second hearing for the same case, the trial judge reversed his decision. The ruling of this second hearing stated that although fingerprint identification is not an actual science, it contains scientific roots. This was the reasoning for why it had been limited in the first hearing. The court had been examining the method as if it were a science, which under the standards set by Daubert, would fail to be seen as reliable. Now looking at it as a “technical discipline,” it passed the Daubert factors that it had previously failed (Cole, 2004).

Chapter 3.1: Shortcomings and Experiments of the Latent Fingerprint Analysis

Any aspect of forensic science has its advantages and disadvantages, but there are a few disciplines that are considered to be infallible, merely because people believe it to be. Fingerprinting has always been considered a foolproof way of convicting criminals. The uniqueness of each print as well as their unchanging nature leads people to believe that making an identification is easy and that an examiner cannot be wrong. In a perfect world, this would be true. However, the shortcomings with fingerprinting have been prevalent enough that they have sparked numerous experiments and tests that seek to understand and better the process of comparing fingerprints.

As a result of its admission to the court system as admissible evidence, fingerprinting went relatively unchallenged. No restrictions were placed on the process as it evolved and so fingerprints were always accepted as admissible evidence. Collection of evidence has its shortcomings as well, leading to incorrectly packaged prints. Distortion, smudges, and partial prints can affect how well an examiner can reach a conclusion. The more information that is available to them, the easier it is to compare with known prints. Collection of exemplars can also be an issue as law enforcement personnel may not have had the proper training or understanding to create proper ten-print cards. In matching prints, there is an incredible amount of variability that can affect the outcome of an examiner's decision. The skin's condition at the time of contact, scarring, and movement of the finger over the surface during transfer are all examples of how fingerprint quality can be affected. The quality of the print can be the tipping point between whether or not that print can be accepted and used for comparison. The creation of a computer system such as Next Generation Identification (NGI) or the Integrated Automated Fingerprint Identification System (IAFIS) has been helpful in containing and organizing millions of profiles, including fingerprints, palms, irises, and face scans, but they all have one flaw. They cannot make a match on their own. A human examiner is needed to make the final decision. This leads to the possibility of human error. There are no universal regulations that the computer or examiner must abide by, and so the process becomes very subjective (Stickel, 2016).

One of the biggest issues among fingerprints is how many points are needed to make an identification. The "points" refer to the ridge characteristics that are present on every fingerprint, but in various quantities, sizes, and locations. The observations of these points are what allows an examiner to compare an unknown print with a known print. The average amount of ridge characteristics that a fingerprint can have ranges between 75 and 175. However, not all can be seen within one print. Partial and distorted prints will have much less ridge details as they are not a perfect rendition of the finger. The question that is often asked is, "Is there a minimum number of points which can be used to show identity beyond any possible error?" This essentially means that there needs to be a number of points that when reached in a comparison, guarantees the identity of the print being examined. The purpose of the standard is to create consistency in how many ridge details are necessary for each and every identification. While not all organizations and divisions have a standard by which they adhere to, current standards today range from 6 to 17. Clearly no universal standard exists. The FBI Identification Division states that 12 is enough to satisfy an identification, but experience has shown that fewer can also be enough. The United States has no requirement for any standard to be used in comparison, but other countries have created their own standards that are followed by their own legal systems. As has been stated before, the ridge formations may be obliterated or distorted by the way the print transfers to a surface. Developmental techniques can also alter a print if they are not performed correctly. It has been found that the distribution of ridge characteristics is not uniform throughout the print and varies greatly. This means that two partials of the same print, but of different areas, may contain a different number of ridge details. The creation of a standard, although seen as a possible advantage to the fingerprint process, can have setbacks as well. If a standard were to be set for fingerprint comparison, the question of legibility could come under scrutiny. Since fingerprinting is subjective, one examiner might be able to see more ridge detail than another, leading one examiner to deem a pair of prints a match, and another to deem them a non-match (An Analysis of Standards in Fingerprint Identification, 1972).

Chapter 3.2: Shortcomings and Experiments of the Latent Fingerprint Analysis

As has been mentioned before, the shortcomings of fingerprints have generated numerous studies that seek to find the issues within the practice and understand and improve them so that they may become more scientifically accepted. Seven studies will be looked at. The first four will explore how accurate examiners are in their decisions, if these decisions can be replicated, how an examiner determines sufficiency for individualization, and what factors of a fingerprint affect the examiner's conclusion. The final three are not formal experiments, but will use a semi-structured interview to analyze the analysis process, followed by two matching tests that look at the effects of fingerprint patterns and expertise.

Chapter 3.2.1: Shortcomings and Experiments of the Latent Fingerprint Analysis

In 2011, Bradford, Ulery, R. Hicklin, JoAnn Buscaglia, and Maria Antonia Roberts put together an experiment that looked at the effect of fingerprint quality on the accuracy of examiners. They were looking to see if a level of consensus between examiners could be reached. To do this, the frequency of false positives and false negatives were to be determined and the examiners were to be evaluated at specific points during the analysis and evaluation steps of the ACE-V process. Regarding participants, 169 were chosen, who ranged in organization and training. All were highly experienced, but only 83% were certified latent print examiners. For fingerprint data, there were 356 latents chosen from 165 fingers from 21 people to be used and 484 exemplars. Together 744 latent/exemplar image pairs were created. Of these, 520 were mated (of the same source) and 224 were non-mated (not of the same source). All exemplar prints were chosen specifically to represent those from the FBI's IAFIS. Prints of low and high quality were chosen so it could be studied how difficult latents can affect decisions. Each image pair was examined by an average of 23 examiners (Ulery, Hicklin, Buscaglia, & Roberts, 2011).

The results of the study showed that the true negative rate was greater than the true positive rate, suggesting that individualizations were more difficult than exclusions. Three factors contributed to this. The first was that the amount of information necessary to make an exclusion decision was usually less than what was needed for an individualization decision. This is often because there are less common features that will be found among differing fingerprints. The second factor is that false positives are seen as having worse consequences than false negatives. A false positive is an individualization made based on non-mated pairs. In court, this would mean that an innocent person could be convicted of a crime they did not commit. A false negative is the opposite. It is an exclusion made based on a mated pair. In this case, a guilty person would be let go instead of convicted. The third factor is that mated pairs had a greater proportion of poor quality prints, leading examiners to make more difficult decisions. The six false positives were made by five examiners, no two of which made the same error. Five errors were made on image pairs that were excluded by the majority and one was made on an image pair that a majority deemed inconclusive. The rate of false negatives was higher than the rate of false positives, suggesting that even though an exclusion decision can be made quicker, they are not guaranteed to be correct. 85% of examiners made at least one false negative error. These errors were spread across half of the image pairs and those deemed false negatives had lower qualities and higher distortions. In terms of consensus, there was a general lack of agreement among many of the image pairs. This could be due to the environment of the test, the characteristics of the images, and if the examiners had a tendency to come to certain conclusions. However, 48% of mated pairs and 33% of non-mated pairs had unanimous decisions (Ulery, 2011).

The study concluded that the rates of the false positives and negatives determined are useful information for future research. The skills of each of the examiners, although not measured, appeared to play a part in their decision-making. The study also provides blind verification as a possible solution to decrease the rate of errors. Blind verification is the act of subsequent examiners performing the same ACE-V process on the image pair, without knowing if the pair had already been examined or what the previous examiner concluded (Ulery, 2011).

Chapter 3.2.2: Shortcomings and Experiments of the Latent Fingerprint Analysis

The second experiment that will be discussed is a follow-up study performed again by Bradford, Ulery, R. Hicklin, JoAnn Buscaglia, and Maria Antonia Roberts in 2012. The purpose of this study was to test the same examiners to see if they could achieve the same conclusions as they did in the first experiment. This was done by measuring repeatability (able to get the same conclusion on the same print) and reproducibility (able to get the same conclusion as another examiner on the same print). 72 of the initial 169 participated in this study. Each examiner was given 25 image pairs, all of which they had seen in the previous study, but were not told they were the same prints. Of the 25 image pairs, 9 were non-mated, and 16 were mated. The examiners that had committed a false positive error in the previous study were given the same prints to be reexamined. In total, there were 339 latents (Ulery, Kicklin, Buscaglia, & Roberts, 2012).

The results showed that the repeatability of initial responses was measured to be 89.7%, but when asked to differentiate no value from exclusion decisions, it dropped to 84.6%. After breaking down the numbers, 93% of individualizations, 55% of exclusions, and 85% of no value conclusions were repeated. The reproducibility of individualizations was unanimous on 42% of latents, meaning that all examiners who looked at those prints agreed on the same conclusions. However, there were some decisions that were changed from the previous study. Nearly half of the latents on which there was no unanimous agreement were examined by examiners who concluded a different decision than from the first study. On the 197 latents that had non-unanimous decisions, reproducibility was measured to be 75.2% and repeatability was measured to be 83.3%. This shows that if examiners are not consistent in their own decisions, then it results in disagreement among examiners as a whole. The first test had resulted in six false positives, none of which were repeated or reproduced in this second study. In addition, no new false positives were committed. However, 30.1% of false negatives were repeated and 19.0% were reproduced (Ulery, 2012).

The study concluded that most but not all examiner decisions are highly repeatable and reproducible. This was because the overall patterns of agreement and disagreement tended to be similar, possibly due to similar training or the ACE-V process. Ulery, Hicklin, Buscaglia, and Roberts constructed two questions that emerged during the study: “Why do examiners not always repeat their own decisions?” and “Why do different examiners reach different decisions?” The data of the study helped to answer these questions. Regarding the repeatability of examiner decisions, there is a difference in each examiner’s assessment of the features in a print. One could decide that a certain feature is of more value than another and vice versa for another examiner. The use of those features will affect how an examiner makes his or her decision. Another factor is the interpretation of the quality and quantity of those features. Are they clear enough to make a comparison? Is there enough to use for comparison? The differences in training may have contributed to these factors. Regarding reproducibility of examiner decisions, conclusions may differ depending on which features are present in a print or if the information present within the print is sufficient enough to support the examiner's decision. The study concluded that skill, experience, and the use of technology all play a part in affecting the decisions of examiners and their ability to achieve the same conclusion, either on the same print or on a print examined by another examiner. As did the previous study, this follow-up also concluded that a blind verification step in the examination process would be highly effective in preventing errors from occurring (Ulery, 2012).

Chapter 3.2.3: Shortcomings and Experiments of the Latent Fingerprint Analysis

In 2014, Bradford, Ulery, R. Hicklin, JoAnn Buscaglia, and Maria Antonia Roberts came together again for another study of the fingerprint process. This time they would be looking at the evaluation phase of ACE-V and determining what factors contribute to an examiner's determination of sufficiency for individualization. The number of minutiae used to make their decision would be measured. As has been mentioned before, a universal standard is not used by all latent examiners and so this study would aim to see how each examiner decides when the number of ridge detail found is enough to satisfy a match between prints. The study was performed using a computer software that was a modified version of the FBI's Universal Latent Workstation's Comparison Tool. Each participant needed to complete practice exercises using the software in order to participate. A total of 170 examiners participated, 90% of whom were certified. The fingerprints to be used were selected from current casework at the time. There were 301 latents chosen that formed 320 image pairs, 231 of which were mated and 89 were non-mated. Each examiner was assigned 22 image pairs, 17 mated and 5 non-mated. Each image pair had an average of 12.4 examiners performing their analysis (Ulery, Hicklin, Buscglia, & Roberts, 2014).

The study resulted in an overall strong association of the number of minutiae and the examiners' decisions in their comparisons. Some examiners were noted to have followed a 12-point standard, but seven points appeared to be the most frequent tipping point between exclusions and individualization. Those who found less than seven tended to come to an exclusion decision, while those who found more than seven tended to deem the prints a match. There were, however, 16 individualizations made with less than seven points, but these accounted for 1% of all decisions made. Only one false positive error was made, having 14 matching minutiae marked. This could have been due to clarity, which has a strong influence on an examiner during the analysis phase, when he or she is trying to decide if the print contains enough information to be compared. Clarity, however, was found to have no additional effect after minutiae were found and marked. The study noted that not all examiners found the same number or points of minutiae to be an individualization. There are several factors that contribute to examiners marking different minutiae points. Interpreting whether or not to mark an unclear minutiae point is difficult and often relies solely on the judgement of the examiner. Minutiae close to cores and deltas can be or not be considered sufficient depending on type and location. The extent of the region of interest plays a part because a smaller area may contain less ridge detail than a larger area. Certain ridge features such as dots and incipient ridges can be marked in different ways that may be unfamiliar to other examiners. It was also found that some examiners have a tendency to mark more points than others. The study determined that image pair effects (features and characteristics of the latent print pairs) contributed to 65% of the difficulty in examiner decisions, while 11% was caused by examiner effects, and 24% was residual effects. Overall, the minimum number of minutiae varied greatly (Ulery, 2014).

The study concluded that there were substantial differences in the annotations and marking of minutiae in examiners. A "lack of clear criteria in latent print discipline specifying when and how to mark features may have contributed" to the differences. Since no universal standard has been created, examiners are not always consistent with the number of minutiae they find nor with other examiners. This makes the practice very subjective because each examiner has their own way of determining what minutiae points are important and how many are needed. The individualization decisions of the examiners were closely related to the number of matching points that were marked. Clarity is an influencer that can determine which minutiae points are noticeable and different regions of a print with varying levels of clarity can alter what points are seen. Those area with a higher level of clarity will most likely have more points marked than areas with a lower level of clarity. The study also mentions the possibility that examiners could reach preliminary decisions subconsciously, which would influence their conclusions. An examiner that subconsciously believes a print to an individualization before beginning the examination will most likely deem that print a match, regardless of how many minutiae are found (Ulery, 2014).

Chapter 3.2.4: Shortcomings and Experiments of the Latent Fingerprint Analysis

In 2014, another experiment was done that was similar to the previous experiment. This study also wanted to know how examiners determined a pair of fingerprints to be a match or not. The purpose was to test which specific characteristics would be factors in the ability of fingerprint examiners to determine whether a pair of fingerprints are from the same source or different sources. This was done by measuring examiner performance based off of various image properties and features (Kellman, et al, 2014).

56 fingerprint examiners participated in this study. Their levels of experience ranged from 1 year to 25 years. 1,133 fingerprint images were collected. 5 prints were taken from 103 fingers, all of which were known prints that matched and the 515 known prints would be used for potential non-matches. Of these 1,133 prints, only 200 were selected. A computer system was used to present the chosen prints in pairs in trials. For each trial, 20 prints were presented, half of which were a match and the other half a non-match. Most examiners completed two trials. During these trials, examiners would observe the given print pair and have to determine if the two prints came from the same source. They would also have to answer questions that would test their confidence and assess the difficulty of their decisions. Questions such as, "How difficult is this comparison?" and "How confident are you in your decision?" were answered using numbers 1 through 6, where 1 stood for least confident/difficult and 6 for most confident/difficult. The study was looking to see what features of the print had the most influence on examiner decisions. The image properties focused on were total area (the number of pixels), area ratio (proportion of known print information potentially available), image intensity (dark vs. light), block intensity (uniformly or not uniformly distributed pixels), deviation from expected average intensity (image should be half white and half black), contrast (gamma), block contrast (gamma for smaller areas), ridge sum, and visibility of cores and deltas (Kellman, 2014).

The results of the study showed an overall accuracy of 91%. For matches, there was an 86% accuracy, and 97% accuracy for non-matches. Of all the decisions made, there were 200 total errors, creating an error rate of 9.6%. 118 of the 200 print pairs produced 100% accuracy from all examiners. The study found that six of the nine features focused on were the most important predictors of accuracy. These features were ridge sum, area ratio, visibility of deltas, mean block contrast, interaction between block contrast for latents and known prints, and the deviation from the expected average intensity for both latents and known prints. The visibility of the deltas had a positive effect on how accurate examiners were most likely because they provide a means of orientation. This allows an examiner to position the latent print correctly to match the known print so they may be compared properly. The area ratio had a negative effect because it is believed that a larger area is associated with more difficult comparisons. The more area there is to examine, the harder it will be to evaluate that print and find a match. This could be due to the idea that an examiner might believe that they must find more ridge points within a larger area than a smaller one. The high contrast and clarity of ridges caused an increase in accuracy. Having clearer prints allows the examiner an easier comparison because it lessens the chance of having indistinct ridge formations (Kellman, 2014).

The study determined that an expert's confidence is influenced by their judgement of difficulty for each comparison. If an expert believes the comparison to be difficult, their confidence decreases, and vice versa for a less difficult comparison. The response time among examiners varied greatly, most likely due to their own skill and experience. Overall, the examiners were highly accurate and committed few errors. The study concluded that "physical characteristics derived through image processing methods may be valuable in predicting expert difficulty and error rates for printed pairs" (Kellman, 2014).

Chapter 3.2.5: Shortcomings and Experiments of the Latent Fingerprint Analysis

The final experiment that will be discussed is different from the rest because it is not a formal experiment. The study consists of a semi-structured interview of latent print examiners followed by two matching tests that tested different aspects of the fingerprint analysis process. The purpose of the first part of the study was to interview examiners in order to analyze the common themes of their process in comparison. For this, 12 expert latent fingerprint examiners were chosen, six males and six females. All were fully trained and their experience ranged from two years to 24 years. Within the interview, each examiner was asked a series of questions that encompassed fingerprint characteristics and analysis. They were requested to explain their own specific method of analysis. No reference was made to ACE-V by the interviewer. The results showed a great deal of similarity between all of the examiners. Each referenced the ACE-V process and was able to provide detail explaining each of the stages. They stressed the importance of evaluating the print in the Analysis stage on its own. In the Comparison stage, each examiner noted that focusing on the latent print before considering the exemplar print is important in preventing any prior judgements. For the Evaluation stage, all examiners considered it to be a "reflection" of the Comparison stage. The decision made is based off the work done in the previous stage. Finally, all examiners mentioned and were able to describe a verification stage following the fingerprint analysis. Each examiner describing a similar method of examination without having mentioned it or talked about it beforehand is important to the study because it shows a sense of uniformity among examiners. The ACE-V process has allowed there to be an analogous way of performing an examination on latent fingerprints. The interview also had the examiners describe the various characteristics and features found on fingerprints. Each examiner described the first-level detail and types of patterns that can be found. The directionality of the pattern was stressed to be important as well as locating deltas and cores because this gives the examiner a sense of orientation. The distance between the core and the delta was noted as a good indicator of whether a print matches another. A longer distance means there are more ridges between the two formations. By counting the number of ridges, an examiner can easily eliminate a print from being a match if the numbers are not the same. The second-level detail was described by all examiners. They mentioned the different types of ridge characteristics that are normally looked for, such as ridge endings and bifurcations. Third-level detail was also mentioned by all examiners, which was notable for the study because oftentimes these details are hard to find if they are even present. The examiners reflected on the valuable information scars and creases provide. These make the fingerprint more unique and easily recognizable. The study concluded that there is a high level of consistency and confidence among examiners in their descriptions of the ACE-V process (Stevenage & Pitfield, 2016).

The second part of the study used a fingerprint matching test to measure accuracy and speed of response among examiners, regardless of experience. The ACE-V process would be looked at to see how it was used in this situation. The same 12 examiners from the first part of the study participated. 36 fingerprints were used for this test, each of which were taken multiple times to result in a “good” and “bad” quality print. Each examiner had to complete 72 trials that consisted of a pair of prints, either a “same” trial (where the prints were from the same source) or a “different” trial (where the prints were from different sources). Out of the 864 decisions, there were only two errors, both of which were false negatives. Overall the performance of the examiners was highly accurate. Response times were measured to be faster on the “different” trials than the “same” trials. This is believed to be because the human eye can pick out differences faster than similarities and so it takes longer and more thought for a pair of prints that are the same or similar. The degree of expertise, although not measured, had no effect on the examiners’ responses. Overall, the examiners all utilized the ACE-V process in order to differentiate prints from one another and to make matches (Stevenage, 2016).

The final part of the study utilized the same matching test as the previous part of the study, but added in student participants to test the effect expertise had on the ACE-V process. The same 12 participants from the first and second studies participated once again and would represent the “expert group.” 54 student participants were chosen and separated randomly into two groups, “trained” and “novice.” Beforehand, the students had no prior experience with fingerprint analysis. The “trained” group consisted of 28 students that were taught the ACE-V process and fingerprint characteristics using a PowerPoint comprised of all the information the “expert” group provided in the first part of the study. The “novice” group was given no training and served as a control group. The same procedure from the previous study was followed by all three groups. As expected, the “expert” group performed the best out of the three groups. The “trained” group, even with their training, performed significantly worse than the “expert” group. The “novice” group had the worst performance. As with the previous study, the speed of correct responses was faster for “different” trials than “same” trials. The “expert” group performed the fastest, while the “novice” group performed the slowest. In terms of bias, there were no differences between the “expert” and “trained” groups. However, in the “novice” group, the students had a tendency to say that the prints were the same rather than different. It was concluded that training in the ACE-V process reduces bias and improves discrimination. However, mere knowledge of the process does not constitute expertise (Stevenage, 2016).

Chapter 3.3: Shortcomings and Experiments of the Latent Fingerprint Analysis

The shortcomings of the ACE-V process are not the only problems that fingerprint examiners face. In addition to their examinations, computer systems are also used when an unknown print has no possible known suspects. The Integrated Automated Fingerprint Identification System, known as IAFIS, is the most well-known computer system used for fingerprint identification by the FBI. Originally, its use was simply a means to search for criminal ten-print cards when needed. Currently, it is used to identify suspects of a crime. This is done through latent print searches against local, state, and national fingerprint databases. The development of such a computer system had many advantages because it was more cost-effective than searching by hand, and produced rapid results. In order to perform a search using IAFIS, the unknown print is scanned in to the computer and encoded by the system. This means that the friction ridge minutiae are digitized so the computer can read it easily. A human examiner then selects the pattern type and finger position and other criteria that would help categorize the unknown print and allow future searches to be narrowed down. The search is then launched and the computer brings up a list of candidates that have the closest correlation to the unknown print. The comparison of each candidate to the unknown print is then performed by a human examiner (Kaushal, 2011). This leads into the issue of human error. Since IAFIS can only provide a list of possible candidates, but not differentiate between them, a human examiner must step in to make the comparisons. Each candidate is compared independently with the unknown print to either exclude or individualize (Stickel, 2016). In this way, if a mistake is made, the computer is not to blame, but the examiner. Human error is nearly impossible to avoid. Individuals can be responsible for errors when uploading an unknown print that can affect the system as a whole. Variations in impressions can limit the effectiveness of the system, which in turn can affect the performance of the examiner (Kaushal, 2011). These errors often result from the false sense of security that these computer systems bring. Local and state databases are not as inclusive as national databases and can limit the effectiveness of the system. Many believe that IAFIS and other large databases are always right and that lack of skepticism can extend to the human examiner (Stickel, 2016).

Another system that can provide possible errors is the US-VISIT program. This program is designed to capture terrorists that attempt to enter United States airports through a fingerprint scan. Overall, this system has been 91% accurate, but only when fingerprint conditions are optimal. For lower fingerprint quality, the performance level drops. Stanford Professor Lawrence Wein conducted a study in which he used mathematical models to show how poor fingerprint image quality can affect the accuracy of US-VISIT. Through his research, he concluded that the accuracy of the program drops to as low as 53% when poor quality prints are presented. This poses a potential problem. Wein states, "About five percent of the general public and 10 percent of those on the watch list have bad quality fingerprints due either to genetics or hard labor." He mentions that terrorist organizations could become aware of this and begin using people with naturally or intentionally bad quality fingerprints. Wein's offered solution is to scan 8 to 10 fingers, which he calculates would result in a 95% detection probability. The threshold for poor images would also need to be loosened while the threshold for good images would need to be increased. Overall, this would decrease the chance of any errors from occurring (Rothman, 2005).

Chapter 4.1: Biases in Fingerprint Analysis

One of the most prevalent shortcomings of fingerprint analysis is the human factor. As humans, we are not perfect, nor can we always perform tasks perfectly. While we can control most of our thoughts and actions, there are aspects of the human mind that we cannot control, such as our subconscious, which may bleed into our regular day to day life. Fingerprinting is thought to be an objective science, when actually because of the human element, it is subjective (Russell, 2009). This is due to bias. Cognitive bias is present in every facet of our lives, from the way we think to how we act. No matter how we try to prevent bias from affecting us, we will always be influenced by it. Dr. Itiel Dror, a cognitive neuroscientist, believes this to be true. Dror has studied the effects of bias on fingerprinting and has found that bias can never fully be eradicated because humans are naturally biased. Even with the advanced technology used today, humans are still needed to make the final judgement call in fingerprint analysis. The role of the forensic examiner is "to achieve maximum impartiality, objectivity, and unbiased work" (Dror, 2015). Bias is a normal part of how the mind works and is unavoidable, even in experts. This however causes many problems since "bias distorts the way we perceive and evaluate information." We may be affected by irrelevant information that does not pertain to the current case or may have a predetermined idea about the evidence being examined. Latent prints that are smudged, distorted, or incomplete are at the highest risk for bias, according to Dror. Despite the current studies, the full extent to which bias affects fingerprint analysis is not yet fully known or understood (Russell, 2009).

Cognitive bias is a persistent and constant part of our lives that can affect us in many ways. We often do not realize we are being affected because it is a subconscious occurrence. It is defined as the "ways in which human perceptions and judgements can be shaped by factors other than those relevant to the decision at hand" (President's Council of Advisors of Science and Technology, 2016). Forensic experts are not exempt from such a phenomenon. Criminal cases are filled with biasing information, such as the criminal record of an individual or being pointed towards one suspect over another, that can affect examinations and alter conclusions. As humans, we are easily swayed by information, but at the same time, hold firm beliefs and ideals. This causes us to act in certain ways or make decisions that pertain to those beliefs. The distortions of cognitive bias interfere with the way humans perceive reality, and therefore causes our thinking to have a subjective nature. This subjectivity has been established through many scientific studies. Itiel Dror believes that the reason humans are affected by cognitive bias is because of the human factor: "When we process visual information subjectively, it depends on the context and who we are, what we expect, and a whole variety of basic, well established psychological and cognitive phenomena" (Russell, 2009). Cognitive bias itself is a larger category that contains various other types of biases that are also subconscious. Each of these plays a role in affecting the fingerprint analysis and the conclusions made by fingerprint experts.

Chapter 4.2: Biases in Fingerprint Analysis

Most often in forensic casework, there is a large amount of information that is collected through evidence and investigation. This information can be shared among examiners and investigators in order to help solve the case. The problem with sharing information is that it creates the opportunity for contextual bias to affect examiners in their analyses. Contextual bias occurs subconsciously when "individuals are influenced by irrelevant background information" (President's Council of Advisors of Science and Technology, 2016). This means that any extraneous information given to an examiner can alter their examination and result in an incorrect conclusion. Examiners can be pressured by many different influences such as politics, religion, the economy, terrorism, and the environment. In order for an examiner to perform an analysis objectively, they need to be able to separate themselves from any outside information. For example, knowing the name of a suspect and their past criminal record may cause a fingerprint examiner to unintentionally focus more on that person's print rather than on any others. Any information that is not associated with that examiner's specialty should be avoided. Research in this area is not very extensive nor is it fully acknowledged because expert assessments are considered to be objective, which is not always the case. Fingerprint examination is a subjective assessment because human examiners are making judgement calls and decisions. The studies that have been done show that examiners are influenced more by emotional context when the prints being examined are of low quality and low clarity. On clear prints, this effect is not as prevalent because the images of higher quality are easier to examine and evaluate (Dror, Charlton, & Peron, 2005). A 2005 experiment performed by Itiel Dror showed that when fingerprint examiners are given the same prints, but a different context, their conclusions can be reversed. This study was done by giving five examiners the same prints they had deemed a match five years prior. Each examiner was given the potentially biasing piece of information that the unknown print was the Brandon Mayfield print from the Madrid Train Bombing case. No other aspects of the cases were changed. Three of the five examiners changed their answers to exclusion, one resulted in an inconclusive decision, and one stayed an individualization (Russell, 2009). The study concluded that misleading and irrelevant information can determine the decisions of examiners. The cognitive flaws and limitations occur more often in challenging cases, such as the Madrid Bombing case, because a higher profile case means more pressure to solve it. More thinking, and therefore mental processes, are involved because the answers may not always be clear (Dror, 2005). In another example of contextual bias, pieces of a cut up detonation cord were found in a garbage can outside a suspect's house. This led to an FBI examiner to identify a substance found at the crime scene to be consistent with an explosive. Where the cord was found was irrelevant to the case, but that information was enough to sway the examiner (Giannelli, 2010a). Contextual bias can be very dangerous, especially for experts who need to perform separate examinations, but it is also preventable. By removing any information that might influence an examiner, the biasing effect can be greatly reduced.

Chapter 4.3: Biases in Fingerprint Analysis

Another type of bias that is underneath the category of cognitive bias is confirmation bias. This is another subconscious effect that many examiners may experience under certain circumstances. Our brains are being affected by stimuli constantly, from sounds to light to visuals. In puzzle-solving, some people may not be aware of the answer until a hint is given or someone points them in the right direction. That person may then suddenly see the answer, surprised that they had not known it from the beginning. What is significant about this is that the person solving the puzzle would never have seen the answer if they had not been led to it. In fingerprinting, this is confirmation bias. Many studies have been conducted that test human ability to perceive stimuli and understand why it affects us the way it does. In one study, participants were given picture pairs of individuals' faces and asked to rate the facial resemblance between them. Some pairs, who were not related, were hinted at that they were genetically related, and the participants concluded the faces to have a higher resemblance. On pairs that were related, and the participants were told they were not, a lower rate of facial resemblance was concluded. A second study had participants identify objects through blurry pictures that would gradually become clearer. The blurrier the picture began, the harder it was for the participants to name the object. The study concluded that each participant had created a hypothesis early on about what the object was supposed to be, and even as the picture became clear, they continued to believe in their own hypothesis. The preconceived notions that the participants had developed were subconscious, and they were unable to control how they perceived the object (Kassin, Dror, & Kukucka, 2013). In terms of confirmation bias, these studies showed that stimuli can affect how we make decisions. Defined as, "interpreting information, or looking for new evidence, in a way that conforms to their pre-existing beliefs or assumptions," confirmation bias is a natural and subconscious action (President's Council of Advisors of Science and Technology, 2016). In terms of fingerprint analysis, confirmation bias often affects the comparison stage of the ACE-V process. During this stage, the examiner must examine the unknown and known print individually before comparing them together. The unknown print must always be examined first for the very reason of confirmation bias. Just as in the two studies mentioned before, stimuli can often affect decisions. If an examiner were to analyze the known print first, that examiner could then see minutiae points in the unknown print that are not there. The quality of an unknown is usually much lower than that of a known print and so minutiae points are harder to find and decipher. The points on the known print are often of better quality. Subconsciously, an examiner might begin analyzing the unknown print by looking for points that confirm its similarity with the known print rather than examining it as its own piece of evidence (Gianelli, 2010a). This is dangerous as it can result in false positives. Bias has resulted in an increase in the number of errors and wrongful convictions. Fingerprint examiner judgements are easily affected by the factors that can affect the outcome of print, such as distortion and the surface to which the print was transferred. Itiel Dror concluded that fingerprint expert reliability has a large range due to this bias that causes the practice to be more subjective than objective (Kassin, 2013).

Chapter 4.4: Biases in Fingerprint Analysis

Bias does not always have to have an unconscious effect. Occasionally events occur where a person feels that they have to or want to make a certain decision, simply because they feel that they can. In this type of bias, the person is knowingly being affected and chooses not to follow the procedures that would reduce bias. The most popular view of bias is when, for example, a referee favors one team over the other because he wants them to win the game. Motivational bias fits in this view. It is dangerous because it involves conscious actions that can be prevented, but are not (Giannelli, 2010a). In a study that focused on the problems and effects of motivational bias in fingerprinting, it was found that there are emotional motivating factors that are present in our day to day lives. Five main themes were derived from these factors as being the most motivating. These themes are reward, satisfaction, motivation, fear, and need for closure. Through a series of interviews with participants, the study was able to discern the reasoning behind each of these factors. For reward, participants found their work more rewarding when they worked on higher profile or longer cases because it gave them a sense of accomplishment. Long cases were seen as having a higher difficulty and so the reward for solving a tougher case was more fulfilling. This is different than satisfaction, which the participants described as having pride in their work and their skills. The study found that the participants showed personal interest in solving crimes and catching criminals, which when done through their work, is highly satisfying. Their pride in their skills comes from years of training and experience which has brought them to the level they are current at. Motivation is also a factor because it encompasses the need or want to solve a crime or complete a case. It also involves the want to help others, either their co-workers, or the victims of the crime. Fear is an important theme in motivating factors of the participants because it involves the fear of making mistakes or errors in their examinations. In fingerprinting, a mistake can lead to the wrongful arrest of a person or the exoneration of a guilty party. False negatives and false positives are considered unacceptable because they are the result of an error in the fingerprinting process ACE-V, which is held in high regard as it is the standard that all fingerprint examiners follow. Need for closure is also another very important theme. It deals with the need of examiners to see cases through to the end. In doing so, they need to find a solution, which is not always possible, and have to account for all evidence, all of which may not be needed in an examination. Participants showed frustration at incomplete work because there is a human need to follow through to the end. Those who have a high need for closure have an increased need to find a conclusive answer. This does not always result in incorrect decisions, however. If their initial thoughts were correct then they may make correct judgements as well (Charlton, Fraser-Mackenzie, Dror, 2010). An example of motivational bias at work is Fred Zain, a forensic lab technician at the West Virginia state crime laboratory. The results he reported would regularly favor the prosecution. Even after he left to accept a position in San Antonio, Texas, the prosecution in West Virginia continued to send him evidence. When the West Virginia laboratory was unable to find biological samples on the evidence provided, it was shipped to Texas, where Zain found blood consistent with that of the victim. Motivational bias is present here because Zain had been known for being “pro-prosecution.” His work reflected his views as much of his results were in agreement with the prosecution’s statements (Giannelli, 2010a). Motivational bias can also have an effect on confirmation bias. It is natural for humans to formulate opinions and then unconsciously apply them to their work. Humans seek to form desired conclusions or make precise judgements without consciously intending to. We always want to be right as being wrong is usually disapproved of. It is hard for some examiners to admit that their fingerprinting work is subjective because theoretically the practice is supposed to be objective. This "illusion of objectivity" prevents us from seeing that our cognition is being influenced by motivating factors (Kassin, 2013).

Chapter 4.5: Biases in Fingerprint Analysis

Since bias cannot be completely eradicated, as Itiel Dror has stated, there needs to be an implementation of improvements that can lessen the effects of bias. Dror's own research has shown that there are no current guidelines that pertain to the issue of cognitive bias. Since bias is an ever-present part of our lives, we must account for its effects in forensic work. Any and all practices that fingerprint experts follow should be validated and approved by cognitive neuroscientists, according to Dror. By approving such procedures, we can eliminate the preventable effects of bias and control the inevitable effects (Russell, 2009). The ACE-V process has already begun to improve the status of fingerprints as evidence in the forensic world because it provides a common set of steps that all examiners follow and forces them to work in a linear fashion. Many of the advances stem from the idea that fingerprint examiners must be isolated from an investigation and perform a well-documented analysis before making any comparisons. The flow of information in crime laboratories needs to be controlled in order to decrease the irrelevant information that examiners are often exposed to (President's Council of Advisors, of Science and Technology, 2016).

During a fingerprint analysis, it is looked down upon for examiners to backtrack to find more evidence. The ACE-V process consists of phases that need to be followed in the same order beginning with the Analysis and ending with the Verification. An examiner needing to return to a previous stage means that either not enough information was collected, or the process is being performed incorrectly. Most often backtracking happens during the Comparison stage. By this time, the unknown print has been marked with as many clear minutiae points that can be found and the examiner must find a known print that matches. By backtracking to the analysis stage, this leaves room for confirmation bias because the examiner has now already seen the known print and might subconsciously search for markings on the unknown print that match the known. The known print would provide a starting point for comparison, rather than the unknown print (Dror, 2015). During the Analysis stage, the unknown print must be thoroughly documented before an examiner moves on to comparison. This circular movement is open to biasing effects. Working in a linear fashion will be able to lessen the effects of confirmation bias because it prevents any possible false additional evidence from being used. If an examiner does need to return to the Analysis stage for any reason, it should be thoroughly documented and justified (Kassin, 2013).

The final stage of the ACE-V process is the most important step because it acts as a form of peer review. Verification is essential to the examination of a fingerprint as it allows examiners to double check the work of others. By the verifier performing the same examination, the initial results can be either confirmed or denied, depending on the second conclusion. However, it is important that the verifier not know who the initial analyst was nor what their conclusion was. This is because bias can play a role in affecting the answer of the second examiner. By knowing the initial conclusion, the verifier might be more inclined to agree, even if their examination produced different results. Very rarely will verifiers achieve different results, but the outcome is possible, more so for high quality prints than prints of lower quality. Another suggestion to help prevent bias is to prevent the verifier from knowing who the initial examiner was, what their conclusion was, or be selected by the examiner. Any interpersonal issues or workplace conflicts could arise from the two examiners knowing each other. In addition, there is often pressure for the examiner and verifier to agree. Disagreements are viewed negatively and therefore procedures are set in place to discern who is correct (Dror, 2015). This type of verification where examiners are prevented from obtaining outside information is called blind-verification. To date, this is the most effective form of verification in preventing bias because it keeps examiners isolated (Kassin, 2013). The remaining steps of ACE-V, Analysis, Comparison, and Evaluation, should also be made into blinding steps so that examiners can only focus on the relevant case information (Dror, 2015).

The isolation of examiners from irrelevant casework has been a main focus of eliminating bias from fingerprinting. However, there is another take on the idea of isolation that advocates the removal of crime laboratories altogether from law enforcement. This idea stems from the fact that many of the influences that examiners face come from law enforcement personnel and prosecutors. The solution would be to create independent laboratories that are removed from the pressures of police. The police often want evidence to be examined as quickly as possible, which often puts pressure on the examiners involved. They may rush their analyses and in the end, present incorrect results. By removing the police factor, examiners can perform at a pace they are comfortable with. Independent laboratories can set their own goals and priorities rather than follow the ones set for them. They can also decide how to use their own budgets given to them. The prevention of bias is the most important advantage these independent crime laboratories would have since bias is a large part of why errors and incorrect conclusions are made. However, there are some disadvantages to having independent laboratories. There is a concern that the separation will limit the effectiveness of the laboratory in criminal investigations. By being separated, they may not be able to perform at the same level they once did. Due to some laboratories' small staff, becoming independent may not even be possible. Funding may also be hard to come by and independent laboratories might not be able to receive the amount that they need. Since these crime laboratories will be working with law enforcement regardless of separation, close working relationships between examiners and police may be inevitable due to how frequent the police use the laboratories, negating the main goal of laboratory isolation. Despite the disadvantages, there is still an advocation for the separation of crime laboratories and law enforcement due to how well bias would be prevented (Giannelli, 2010b).

Bias can also be prevented in many other ways that involve careful planning and meticulous review. For any part of the ACE-V process and for this very process to become the standard framework, an examiner must take detailed notes and document all of his or her findings (Stickel, 2016). This will not only be useful if the examiner needs to review part of the analysis, but also to prevent biasing information from being found. Biasing information would include anything that is found purposely to confirm or deny a hypothesis that the examiner might have developed. This detailed and extensive documentation should be comprehensive so that others may be able to read and understand the report. An explanation of significance can also be included to prove why certain evidence is needed and is being used (Giannelli, 2010b). One of the reasons fingerprinting has been questioned over the years is its lack of an error rate. The courts require the process of ACE-V to have its error rate declared, but due to the subjectivity of the process, it is very hard to calculate. The presence of an error rate would show that identification is not absolute and that "testing procedures do not allow for an absolute determination" (Stickel, 2016). In terms of IAFIS and other databases that contain millions of fingerprints, bias can be lessened through how possible candidates are presented. The list of candidates must be of a reasonable length so that the examiner may be able to get through all of the prints (Kassin, 2013). The candidates within the list should be randomized as well so that the most similar match is not at the top. Without randomization, an examiner might be more inclined to make an identification with the first candidate, simply because it was at the top of the list (Dror, 2015). Many of these methods are able to be applied during casework, but there is another way that bias can be lessened or prevented that can occur before an examiner receives their first case. During training, examiners are taught the skills they need in order to perform at their highest level. Since bias can affect nearly every aspect of fingerprinting, basic psychology training should be included. This psychology would need to be relevant to forensic work and be able to accurately prepare examiners for any and all biases they could come across (Kassin, 2013). This, in addition with the other methods mentioned earlier, will be able to effectively lessen the effects of bias during fingerprint examinations.

Chapter 5.1: The Cases of Shirley McKie and the Madrid Bombing

Bias in fingerprinting is a dangerous factor that can be detrimental to both low- and high-profile cases. In any situation, the examiner is responsible for an erroneous decision because of the human factor. The consequences of an erroneous decision can lead to the imprisonment of an innocent person, while the true suspect goes free. Since biases such as cognitive bias cannot be prevented, one must take caution in a fingerprint examination, by performing all ACE-V steps properly and ensuring that no external information is used. However, in other cases, the examiner may be well aware of the bias presented, but take no precautions to avoid it. Two cases will be used as examples to explain the real-life dangers of bias and the consequences it has already brought to the forensic science world.

Chapter 5.2: The Cases of Shirley McKie and the Madrid Bombing

On January 14th, 1997, Marion Ross was murdered in her home in Kilmarnock, Scotland. At the crime scene, nearly 400 fingerprints were found on Ross's possessions. One of the fingerprints, found on a doorframe to a bathroom, was claimed to be the left thumbprint of Constable Shirley McKie, one of the officers working the case. When confronted, McKie stated she had never been inside the house as she was conducting interviews in the area. The four Scottish fingerprint experts that identified the fingerprint to her were adamant about their conclusion, despite the fact that McKie had never stepped foot on the property. A year later, in 1998, McKie was arrested and charged with perjury. If found guilty, she would face several years in prison. In 1999, two United States experts, Pat Wertheim and David Grieve conducted their own examination and determined that the fingerprint did not belong to Shirley McKie (Russell, 2009). Due to this, the jury unanimously acquitted her of the charge. The question of how the Scottish examiners achieved a match remained a debate. After a thorough investigation, it was found that the main reasons for the misidentification was a disagreement over the number of corresponding minutiae points and a lack of blind verification (Stevenage, 2016). This changed Shirley McKie's view on fingerprinting forever, as she had originally thought of the practice as the gold-standard of forensic science. Many had believed that when someone was identified by a fingerprint, they were guilty. The misidentification of her fingerprint was enough to convince her otherwise (Russell, 2009).

The significance of this misidentification is that this error could have easily been prevented had the proper procedures been acted upon. A disagreement on the number of points can lead to an inconclusive decision if the examiners do not come to an agreement. In this case, the examiners went ahead and deemed the prints a match despite there being different numbers of points that corresponded. The lack of a blind verification also severely affected the outcome of the examination. Had there been a verifier that conducted his or her own examination, the mistake would have been caught early on. This might have also caused disagreement with the initial examiners, but would have prompted further action to be taken in order to come to an agreement.

Chapter 5.3: The Cases of Shirley McKie and the Madrid Bombing

While the case of Shirley McKie's misidentified fingerprint caught the attention of many in the forensics world, the biggest case to date where the most dangerous misidentification took place had yet to come. The infamous Madrid Bombing occurred on March 11, 2004 in Madrid, Spain. 191 people were killed and many more were injured. Within days, authorities had collected many pieces of evidence, including a fingerprint taken from a plastic bag of detonators that would become the reason for the future review of the fingerprint examination process. The print removed from the plastic bag, along with other evidence, was sent from Spain to the FBI for analysis (Stacey, 2011). Michael Weiners, a unit chief in the FBI, assigned Terry Green to perform the IAFIS search. The search resulted in 20 possible candidates that matched to the print taken from the plastic bag. The first three on the list were rejected, but the fourth print caught the eye of the FBI. The fingerprints of candidate #4 belonged to Brandon Mayfield, a lawyer from Portland, Oregon. A match was made between the unknown print and Mayfield's known prints. A verifier, John Massey, was assigned to review the analysis and concluded the prints to be a match as well, based on his own examination and a copy of the latent and known fingerprint cards. Neither examiner documented their findings. Mayfield was subsequently arrested as a material witness. In addition, when the case went to court, Kenneth Moses, a highly qualified examiner, was appointed by the court to review the identification. His own analysis confirmed the FBI's conclusion (Schmidt, 2008). However, at the same time the Spanish National Police conducted their own investigation and found that they disagreed with the FBI on their conclusion (Stacey, 2011). Despite the seven points of corresponding minutiae found, there were inconsistencies within the print that could not be ignored, such as the entire upper left portion of the print which did not match the equivalent area on Mayfield's print (Schmidt, 2008). The Spanish authorities' own examination resulted in an inconclusive decision, stating that they did not believe Mayfield's print matched the one taken from the plastic bag. Furthermore, they were able to identify another individual to the unknown print, one that was a more likely suspect as he was in Spain at the time of the bombing. This man was named Ouhnane Daoud, an Algerian, whose fingerprints were on record for an immigration violation (Schmidt, 2008). The FBI, despite their extensive and detailed explanations on the matching of the prints, apologized to Mayfield and his family when they realized their error (Stacey, 2011). Michael Weiners asked Stephen Meagher, another unit chief, to conduct an "objective examination" to determine what went wrong. Together, they concluded that the unknown print pulled from the plastic bag was of "no value" for identification purposes (Schmidt, 2008).

In a newspaper article written by the New York Times about the misidentification, the FBI stated that there had been multiple reasons for why the error occurred. They specified that the image quality of the print sent over from Spain was poor and therefore made making an identification more difficult. The FBI also mentioned that their experts were able to determine the print to be of value for a comparison, while the Spanish authorities determined that same match to be inconclusive. The FBI's results had been independently analyzed and confirmed by outside experts, which added to their confidence in their decision. Bias played an important role in why the FBI continued to suspect Brandon Mayfield while Spain suspected another individual. Mayfield believed that the FBI considered him to be the source of the fingerprint because of his Islamic faith. He had not been raised a Muslim, but converted in 1989. The FBI denied these accusations, but it is possible that this information was biasing to the FBI examiners (Kershaw & Lichtblau, 2004). Another New York Times article discussed the aftermath of the misidentification, which prompted the FBI into forming a review committee that would evaluate the process used in the identification and the error itself. This panel of forensic experts that was formed concluded that Brandon Mayfield was wrongfully convicted for a variety of reasons. The initial examination of the fingerprint had been incorrect and therefore tainted all subsequent examinations. While blind verification would have prevented this, "FBI culture discouraged fingerprint examiners from disagreeing with their superiors." This means that the error was due to the human factor and not the method or the technology used. All verifiers were expected to agree with the previous analysis, despite the first conclusion not being "sufficiently scrutinized."

The review following this case would examine the complete fingerprint process to expose any flaws that may have contributed or allowed this error to occur (Stout, 2004).

The review committee's findings determined that bias was a major part of why the misidentification occurred. The first examiner's decision was swayed by the IAFIS match, which caused the beginning of confirmation bias within the examination. Since Brandon Mayfield's prints were fourth on the list of candidates from the search, the examiners believed he was more likely to be the match rather than someone at the bottom of the list. This, along with possible factors like his faith, convinced the FBI that Mayfield was the match (Stacey, 2011). The initial exam found seven minutiae points that corresponded between the unknown and Mayfield's known prints, which influenced the mindset of the examiner to assume that other matching minutiae points must exist as well. In doing so, the examiners accepted features that did not exist and rejected many that did (Schmidt, 2008). The biggest factor to contribute to confirmation bias was the lack of a blind verification system. All subsequent fingerprint examiners knew the outcome of the previous examination, and due to the discouragement of disagreeing, came to the same conclusions. The review committee also found that similarities between the two prints were present and determined that it was understandable why the print was not immediately excluded (Stacey, 2011). Another bias that was present in this case was motivational bias, and partly contextual bias. The high-profile of this case created a pressure for the examiners that caused them to want to solve the case as quickly as they could. They were influenced by an "emotionally charged situation" due to the number of people that were killed and the act of terrorism in a post-9/11 world. There was an intense want and need to find the suspect who created the prints and the first individual to appear to be a match was blamed (Russell, 2009). The review committee concluded that more information should have been requested, such as images with better quality and for orientation purposes. The methodology of the ACE-V process was determined to have been appropriate, but there was a failure in the application of the process (Stacey, 2011).

Conclusion

Fingerprinting is a very important part of forensic science as it is one of the most well-known and useful tools for solving crime. The uniqueness of each print, characterized by various patterns and made individual by small ridge details are what allows examiners to make matches and help law enforcement in criminal investigations. The process by which examiners perform their analyses, ACE-V, has become the standard method by which all examiners follow. Unfortunately, fingerprinting is a subjective science, but the implementation of the ACE-V process has allowed examiners to follow a unified set of steps. In addition, as with any science, knowing the history behind how the practice developed is often beneficial, especially for fingerprinting. Use of fingerprints in court is paramount to criminal investigations. The cases of Daubert, Frye, Jennings, and Llera Plaza have all shaped forensic evidence into what it is today, establishing that all evidence must be based on accepted scientific knowledge and practices.

Any science has its disadvantages and the main drawback of fingerprinting is its susceptibility to bias. Cognitive bias and motivational bias are the main forces that affect the minds of examiners, whether it be the context of a case, emotional circumstances, pressures of law enforcement, or even their own ambitions. Bias is a threat to the admissibility of fingerprints in court and must be dealt with carefully. Dr. Itiel Dror states that there is no way to eradicate bias, as it is an unconscious part of being human. Procedures need to be put in place in order to mitigate the biasing effects. The most bias occurs during the verification stage of ACE-V, where a second examiner must make his or her own decision that will confirm or deny the initial examiner's conclusion. Blind verification is the only way to prevent any sort of bias from altering the analysis. Keeping the verifier from knowing the original decision or who the examiner was will allow them to make an accurate conclusion. The consequences of not employing this system can be seen in the cases of the Madrid Bombing and Shirley McKie, where innocent people were imprisoned due to a lack of proper procedures. This is why it is important that all shortcomings of fingerprints be acknowledged and thoroughly researched so to be prevented in the future. Although it is no longer considered the "gold-standard" of forensic science, fingerprinting still has its advantages, making it an essential aspect of criminal investigations.

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