A CRITICAL REVIEW OF APPROACHES TO MITIGATING BIAS IN FINGERPRINT IDENTIFICATION

By

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Declaration

I declare that this thesis does not contain any material submitted previously for the award of any other degree or diploma at any university or other tertiary institution. Furthermore, to the best of my knowledge, it does not contain any material previously published or written by another individual, except where due reference has been made in the text. Finally, I declare that all reported experimentations performed in this research were carried out by myself, except that any contribution by others, with whom I have worked is explicitly acknowledged.

Signed: Christie Ashton

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Literature Review

A CRITICAL REVIEW OF APPROACHES TO MITIGATING BIAS IN FINGERPRINT IDENTIFICATION

Abstract

Fingerprint identification is a discipline used within forensic science which assists in criminal investigations[1, 2]. The process of fingerprint identification involves the comparison of crime scene evidence with known exemplars. This form of examination is heavily reliant on human examiners and their conclusions as to whether there is an identification, exclusion or insufficient information to identify[3]. This form of forensic identification has become a focus due to concern of the effects of cognitive bias on examiners conclusions. Concerns have prompted research into the area of approaches to mitigate bias throughout forensic fingerprint protocols. Research into the common sources of bias during a fingerprint examination was conducted to gain an understanding of how bias may potentially be reduced. Throughout this dissertation the psychological and forensic approaches to bias were reviewed and the international and Australian approaches to bias mitigation were discussed. This found that there was evidence of a widespread issue regarding human cognitive bias in fingerprint examiners, however, there were no uniform mitigation strategies in place. Limitations to recommended approaches and currently implemented strategies have been reviewed, identifying that there is still a need for further research into the theoretical approaches to overcome bias. Therefore, leading to the formation of a study that aims to identify the theoretical approaches as suggested by literature, and critically review the effectiveness of these methods in controlling and reducing bias. The potential outcome from the suggested study may result in a useful document that will provide the practical field of forensic science with a comprehensive and critical review of approaches to assist in the development of standardised protocols.

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List of Abbreviations

AFIS	Automated Fingerprint Identification System
ACE-V	Analysis, Comparison, Evaluation, Verification
ANZPAA NIFS	Australia New Zealand Policing Advisory Agency National Institute of Forensic Science
CIM	Context Information management
DNA	Deoxyribonucleic Acid
ISO	International Organisation of Standardisation
LSU	Linear Sequential Unmasking
NAS	National Academy of Science
NATA	National Association of Testing Authorities
NFI	Netherlands Forensic Institute
NIST	National Institute of Standards and Technology
OIG	Office of the Inspector General
PCAST	President's Council of Advisors on Science and Technology
SWGFAST	Scientific Working Group on Friction Ridge Analysis Study and Technology
SOP	Standard Operating Procedure
VPFSD	Victoria Police Forensic Services Department

1. Introduction

Forensic science depends on various disciplines within the field to assist in linking individuals to a scene[1]. Forensic fingerprinting is a heavily relied upon form of evidence in processing criminal investigations[2]. Fingerprint examinations are based on the recognition and identification of ridge patterns within a fingerprint[4, 5]. The analysis is performed by a human fingerprint expert who would be required to visually examine fingerprints to identify minutiae and points of similarity. The common classes for identification of fingerprints are known as loops, whorls and arches, these are also divided up into subclasses which is how an expert would identify various aspects of a questioned fingerprint and compare to that of a known print[3]. Much like other pattern matching and mixture interpretation disciplines the human examiner plays a major role in a fingerprint examination[6]. The process of fingerprint analysis can involve the use of an Automated Fingerprint Identification System (AFIS), however, this system will only provide limited information[7]. Hence, the examination heavily relies upon human input, it is this process involving human examiners where cognitive bias can influence the analysis and conclusions reached[8].

Cognitive bias exists in humans and has become of interest in certain settings as it can impact the way something is interpreted. Cognitive bias as defined by the Scientific Working Group on Friction Ridge Analysis, Study and Technology (SWGFAST) is "the effect of perceptual or mental processes on the reliability and validity of ones observations and conclusions"[9]. There are various types of cognitive bias that can potentially affect forensic science such as; expectation bias, confirmation bias, anchoring effects or focalism, contextual bias, role effects, motivational bias and reconstructive effects[10]. The main biases

that affect forensic fingerprinting analyses are contextual, confirmation, motivational and cultural bias. Contextual bias occurs when peripheral information and stimuli may be offered to an examiner during an examination, such as unnecessary information pertaining to the case which ultimately effects the conclusions made by the examiner[9, 11]. Confirmation bias results from unconsciously interpreting information to support a certain viewpoint[9, 12]. Motivational, cultural and confirmation bias are closely related as the elements causing these biases generally result in an individual working to achieve a certain outcome. As a result of bias during an investigation the decisions reached by experts may be altered when provided with unnecessary information[13].

The purpose of this paper is to critically review approaches to overcoming biases that impact on forensic fingerprint examiners. This has become necessary as a result of growing concern from disciplines related to forensic science surrounding bias, the review will aim to:

- Address research on human bias in relation to forensic fingerprint identifications.
- Identify practical and theoretical approaches to mitigating bias in forensic fingerprint examinations.
- Consider the effects of bias and critically analyse identified approaches to overcoming bias in forensic fingerprinting.

This review will address international and national approaches to overcoming bias in a forensic setting. Various studies, national and international reports were investigated to gain knowledge in order to achieve the objectives of the review. The following paper will discuss a basic background of the fingerprint examination process to gain some

understanding of the procedure. A psychological and forensic approach to bias will then be discussed to provide a foundation for the evaluation of approaches employed by various national and international forensic agencies. The information gathered throughout may assist in future developments of protocols and methods of overcoming cognitive bias, allowing forensic fingerprint evidence to have the best possible chance at being a reliable and trusted source of information.

2. Forensic Fingerprinting

Fingerprints are commonly used as evidence in crime scenes as it is believed that the possibility of two identical fingerprint patterns is very small, therefore they have been deemed a reliable source of identification[4]. The arrangement of ridges and grooves known as friction ridges, are generally unchanging throughout a person's life[4, 10]. Prior to the examination of a fingerprint, there is important information to be considered surrounding the circumstances of the fingerprint, described below (*2.1 Analysis*)[10].

Forensic fingerprinting is a heavily relied upon aspect of forensic science, therefore, Standard Operating Procedures (SOP) have been employed to ensure uniformity between examiners. Organisations such as the Scientific Working Group on Friction Ridge Analysis, Study and Technology (SWGFAST)[9] provide the recommended terminology and standard guidelines for the analysis of fingerprints. The standard procedure used by forensic examiners during a fingerprint analysis is the ACE-V methodology; this involves Analysis, Comparison, Evaluation and Verification[3]. The ACE-V method is not a strictly linear or one-way procedure (more of a guideline) and can allow an examiner to go back over the previous steps in the method at any stage for review. The lack of rigidity in the protocol has

sparked discussions due to examiners becoming prone to circular reasoning which will be described further throughout the review.

2.1 Analysis

The analysis is essentially the assessment of the fingerprint and whether it is suitable for further examination[3, 7, 10]. In this analysis three main factors are considered[10]:

- Deposition Surface
- Distortion
- Clarity, quality and quantity of detail

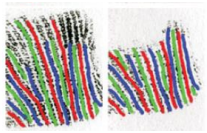
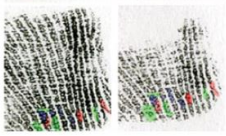
These variables require careful consideration as they impact the decisions made by the examiner. The deposition surface and pressure can impact on the quality of the print and amount of detail present for examination[3]. The level of detail available from a print determines the clarity and potential for comparison with a reference print[3, 7]. The decision of whether a fingerprint passes this criteria is made by an expert based on their training and prior experience[3]. This first stage of examination is quite critical as it can determine whether the fingerprint is worth pursuing. If contextual bias were to be introduced at this stage it may sway an examiner to, for example, further pursue an examination on a false positive print.

2.2 Comparison

The comparison stage of examination refers to the side by side comparison of the questioned fingerprint with a reference print by an examiner[3, 7]. During this process the examiner would be required to compare the ridge characteristics and perform measurements to determine a level of similarity between the prints[3]. As previously

determined in the analysis stage, the examiner would have to consider variations due to deposition surface for the questioned print and reference print[10]. The comparison stage requires an examiner to make determinations based on first, second and third levels of detail[3]. The three levels of detail are a system for describing the information gathered from a fingerprint[3] and are described below in *Table 2.1*. During the comparison stage contextual and confirmation biases may be unknowingly introduced. The information provided with a comparison fingerprint could potentially bias an examiner to achieve a certain outcome.

Table 2.1 Three levels of detail for fingerprint identification. Descriptions and images have been summarised from The Fingerprint Source Book[3]

Level of Detail	Description	Example
Level 1	General friction ridge flow direction.	
Level 2	Specific path of individual ridges – ridge path refers to: starting point, path of ridge, length of ridge path, where the ridge path ends and minutiae.	
Level 3	Specific shapes and morphology of structures within fingerprint – including: edges, textures, pore placement/ structure.	

2.3 Evaluation

The evaluation stage of the examination refers to the overall classification of the fingerprints (questioned and reference) and whether there is an individualisation[14] (or agreement) or exclusion[14] (or disagreement) of the questioned print. The evaluation of the prints will require the examiner to consider all information gathered at the analysis and comparison phases, unless at least the first and second levels of detail are satisfied an

individualisation cannot be determined[3]. Some instances may result in an inconclusive result where there may not be enough agreement or disagreement of details in the analysis and comparison stages of examination[3, 14]. If any bias were to be introduced at the preceding stages of examination the extent of that bias would be exemplified in the evaluation, especially if an erroneous identification or exclusion resulted.

2.4 Verification

The verification stage refers to the independent examination of the same prints performed by another examiner to verify the conclusions reached by the original examiner[7]. The verification process can sometimes be followed by a review process depending on agency policies[9]. This stage of the process is vital as it reviews the original examiners work and determines whether each examiner reaches the same conclusion. Bias effects would potentially increase if both examiners happen to be biased in their decisions, however, this stage could also assist in prevention of bias by determining if the prior examiner was influenced in their conclusion.

2.5 Summary

A basic understanding of the fingerprint examination process is important when considering the effects of cognitive bias. Although on the surface it would seem there is a sufficient procedure for conducting fingerprint examinations the information discussed throughout this paper may demonstrate otherwise. The ACE-V protocol may not be as robust as expected. Despite the guidelines provided by SWGFAST[9] surrounding fingerprint protocols it is still possible that there are areas where bias may become an issue. To

understand how bias can affect fingerprint examinations and the ACE-V protocols a psychological explanation of human bias and tendencies will be explained.

3. What is Bias: Psychological Approach

There are various studies and ideas concerning human cognitive bias and how it impacts decision making. In general, when discussed in relation to forensic science cognitive bias can be explained as "a tendency to make a systematic error in thinking or reasoning"[15]. Although one of many interpretations of the definition of cognitive bias, this one by Leighton[15] sums it up quite succinctly. The many definitions of cognitive bias all seem to be based around the same idea, which is that it results in inaccuracy or an altered perception of reality[16]. It is thought that bias is more prevalent when making a quick decision or using prior knowledge to take shortcuts in thinking[15]. On the other hand, heuristics and bias can be seen as adaptations[17]. This in itself does not necessarily mean it is a negative thing but perhaps a defence mechanism that has been developed over time shaped by experiences. Understanding where bias stems from and how it occurs will assist in overcoming its effects. Some reasons that bias may occur can be explained by; developing shortcuts that may tend to work in most situations, creating biased solutions to reduce negative effects, and performing tasks that the mind is not designed to comprehend[17].

Research conducted by Haselton[17] breaks cognitive bias into three types: Heuristic, Error Management Bias and Artefact. Haselton[17] supposed that these three categories of bias assisted in gaining an understanding of why bias occurs. Heuristic bias was described by Haselton[17] as a result of information processing constraints due to factors such as time and motivation. It has been seen in various studies that when a person is making decisions under pressure, with time constraints their decisions are made differently to that of when

they have ample time to work through a situation[17]. Another factor involved in heuristic bias is when someone's motivation for accuracy is reduced[17]. There is almost a trade-off situation where the decision can either be made quickly or accurately. Error management bias works on the principle of working towards the least costly error[17]. The main factors at play in error management are the tasks of judgement, probability and uncertainty[17]. In some situations, it may mean that the error rates are high, however, cost is reduced. Artefact bias occurs when the bias and errors result in artefacts from research strategies[17]. This means for example, placing humans in uncommon situations or settings; or applying inappropriate normative standards that can result in artefacts[17].

The table below outlines some different types of bias commonly referred to throughout literature on forensic science examinations. There are varying definitions of each type of bias, however, they have been summarised in general below. The types described in the table are not exclusively evident in forensic science and nor are they the only ones. These particular types of bias have been included in the table as some of them are similar in meaning and will be referred to throughout this review.

Table 3.1 Definitions of common types of bias referred to in relation to forensic science.

Type of Bias	*Meaning*
Confirmation	Testing a theory by looking for something specific and discounting contrary findings.[10]
Contextual (Information)	Having additional information which is not considered essential to the task.[10]
Anchoring or Focalism	Relying heavily on primary information or evidence and making judgements based mainly on that.[10]
Motivational	Working to reach a more favoured outcome.[10]
Cultural	When perceptions of information are influenced by the environment where an individual is involved.[10]
Role Effects	When an examiner places themselves as working for either the prosecution or defence.[10]
Reconstructive Effects	Arises when a person relies on memory rather than documentation on what occurred. Memories may be influenced by knowledge of protocols, hence, filling in gaps with what should have occurred.[10]

3.1 Summary

As detailed above there are many contributing factors to the way human decisions are made. As a result, it has been discovered that there are a number of biases that can be attributed to causing potential errors. The need to make difficult decisions quickly and under pressure is commonly held responsible for promoting bias to take place. This information provides the underlying knowledge for being able to identify areas in forensic science that need to be addressed to reduce such biases having a detrimental effect on fingerprint examinations. This does not mean that all human biases are the results of bad

decisions or sinister purpose, however, depending on the domain it can become an important factor to consider and reduce as much as possible. Now that the psychological basis of bias and human decision making has been discussed, a forensic understanding of the sources of bias will be introduced.

4. What is Bias: Forensic Approach

Bias is of interest in forensic fingerprinting as it can unconsciously affect the decision-making process of an examiner. SWGFAST[9] defines cognitive bias as "the effect of perceptual or mental processes on the reliability and validity of one's observations and conclusions". Cognitive bias occurs when individuals see what they expect to see, this generally stems from previous experiences that have shaped how information is filtered into the brain based on its importance[11, 18]. This filtering of information could potentially lead to information being left out which becomes crucial in forensic science. On the contrary, this cognitive process may introduce inaccuracies and peripheral information resulting from assumptions.

There have been several instances that have prompted the field of forensic science to become concerned about bias. Some specific cases where forensic fingerprinting has suffered the effects of cognitive bias are the Brandon Mayfield Case (2006)[10, 19] and the Shirley McKie Case (1999)[10, 20]. In both cases it was found that circular reasoning where working backwards from the known print became an issue, also the process in which fingerprint analyses were performed and verified was noted as inconsistent[10]. Circular reasoning falls into the category of confirmation bias, this is where the knowledge of the known print causes an examiner to revisit their prior analyses and make amendments[21]. The inconsistencies mentioned in the above cases will be explained throughout this review.

To understand bias and how to reduce its effects on experts in an examination it is important to identify specifically where bias is introduced throughout the process.

4.1 Sources of Bias

Dror[22] identifies seven main sources of bias (Figure 2.1) that may influence forensic science, ranging from human nature and cognitive based sources, environmental (work culture) and experience to case specific factors. Each of the elements in the taxonomy shown in *Figure 2.1* will be explained below. The pyramid structure displays towards the bottom the inherent human based factors, moving up the pyramid through the more environmental and evidence-based factors. This would suggest that the larger factors at the base of the pyramid are perhaps, more difficult to address considering they are deeply engrained in the human cognitive architecture. Factors toward the top of the pyramid may be easier to address and potentially reduce as a biasing factor due to the ability to somewhat control them.

Figure 4.4.1 Seven sources of bias taxonomy. Source: Dror 2017

4.1.1 Case Evidence

The case evidence refers to the information gathered from the specific evidence collected at a crime scene such as DNA, fingerprints and shoe impressions[22]. Certain evidence would be deemed necessary to the examination, however, should be carefully considered[22]. For a fingerprint examiner it may not be necessary to know information regarding other evidence collected at the scene.

4.1.2 Reference Materials

During the examination of fingerprints and evidence from a scene it is common to have reference materials to compare the collected evidence to. Knowing further information such as that pertaining to a person of interest would not be necessary for the purpose of fingerprint examination, this would be biased in the fact that the examiner would be working to find the suspect in the evidence rather than the examiner making observations and evaluations independently on the evidence[22]. This relates to the next level in the taxonomy; irrelevant case information.

4.1.3 Irrelevant Case Information

Irrelevant case information is likely to bias an examiner and could include information from police and their opinions on a suspect or on other leads of the investigation[22]. During a forensic fingerprint examination, it is important that the examiner focuses only on the information pertaining to the specific evidence (fingerprint) provided to them[23]. As suggested by various research the information fed to an examiner should be limited so that contextual information does not mislead them in their analysis[11, 23].

4.1.4 Base Rate Expectations

Base rate expectations can stem partially from an examiners experience of certain outcomes. For example, the use of AFIS in fingerprint examinations gives results of possible matches for an examiner to analyse against a reference, and has been known to give more likely matches at the top of the list[22, 24]. Therefore, examiners become used to that occurrence and are more likely to conclude a positive match with a print that was higher on the list[22, 24]. The resulting expectations formed by examiners can cause various cognitive affects and have an impact on resulting evaluations[24]. For instance, an examiner may be biased to spend less time examining matches lower on the list and focussing their attention to those toward the top of the list. This thought process could potentially lead to examinations being centralised around an incorrect print.

4.1.5 Organisational Factors

Organisational factors refer to the environment and culture that the examiner is exposed to when performing their work. This can even lead to adversarial allegiance which means an examiner may be biased to a certain side (defence or prosecution) depending on who may have called them as a witness[22]. Many forensic laboratories have a very close relationship with law enforcement agencies which could have a subconscious impact on the forensic examiners and the results of their examinations[12].

4.1.6 Training and Motivation

The next stage of the taxonomy refers to training and motivation of the examiner, biases can be introduced during training and their personal motivations can influence the way they work[22]. Training can have an effect on an examiner as it can serve to reduce bias

and produce uniformity and objectivity in procedure such as scientific methods[25]. Training is an essential contributor to quality assurance measures within an organisation[26].

4.1.7 Cognitive Architecture and the Brain

The final level of the taxonomy identifies cognitive architecture and the brain as acrucial element in biasing an examiner. There are many different biases present in the human brain and the way it works is very much a contributing factor to bias in the forensic field[22]. Cognitive bias occurs in all areas of thinking one of which is decision making; a very crucial aspect of forensic examinations[27].

4.2 Bias in ACE-V Protocol

It is argued that the ACE-V protocol does not rule out bias and as far as scientific method goes it does not meet the standard[28]. A ruling was previously made as a result of the Daubert v Merrell Dow Pharmaceuticals[29] case in 1993 where the admissibility of scientific expert evidence came into question[2]. Criteria was set for the validity of scientific method which must be based on[2, 30]:

- Testability and falsifiability
- Peer-review and publication
- Error rates
- Standards and controls
- Acceptance by scientific community

Some of the concerns for bias within the ACE-V protocol overlap with the areas identified in Dror's[22] seven sources of bias. Several studies have mentioned that the process of ACE-V is not strict enough, the different steps are merely seen as a guide,

hence, gaps have occurred where bias can seep in[28]. This was exemplified in the study by Ulery[31] where it was found that during comparison, examiners may review initial assessments made in the analysis stage and will often change opinions on minutiae that may or may not have been present. It was also suggested by Ulery[31], that there is insufficient documentation and guidelines set for the procedures of ACE-V protocols, despite SWGFAST guidelines it is generally individual agencies that determine their own standard operating procedure.

4.3 Summary

When considering approaches to overcome bias in a forensic setting it is important to understand the areas in which bias can become an issue. The common trend throughout the literature on sources of bias in forensic fingerprint examinations is largely contributed to the interaction of examiners with information or other investigators that is closely linked to the crime scene, but not essential for the task at hand. Although human cognition and the way the brain works plays a part in bias these effects seem to be more prevalent when unnecessary information or interactions are introduced. Now that the main types and sources of bias have been identified it is possible to consider potential strategies to reduce it.

5. International Approaches to Mitigating Bias

There have been various reports formulated addressing issues within forensic science. These reports have been in response to growing concerns by forensic and law enforcement agencies around the world following some significant cases that highlighted such gaps and errors made in the field of forensic science. Reports such as those from the President's

Council of Advisors on Science and Technology (PCAST), National Academy of Science (NAS), National Institute of Standards and Technology (NIST), Forensic Science Regulator and the McKie Inquiry Scotland address bias in forensic fingerprint examinations and include recommendations on overcoming these biases.

5.1 United States - Federal Bureau of Investigation (Latent Print Unit)

The Federal Bureau of Investigation (FBI) in America underwent a review following the Brandon Mayfield case which resulted in a process of blind verifications being introduced[10]. During the Mayfield case it was not only one examiner that made the erroneous identification of the fingerprint but the verification by multiple examiners of that primary identification[32]. In the case of Brandon Mayfield it is suspected that prior to examination the examiners already believed him to be the source of the fingerprint which ultimately biased their judgement of the necessary information presented to them[32]. The FBI standard for blind verification outlines that the verifying examiner and primary examiner must not have been in previous consultation; the conclusions of the primary examiner should be unknown; and any case specific information should not be known[10].

It is understood by the FBI that in some areas it is necessary for experts to consult one another and share expertise. However, they state when situations arise where any factors interfere with the interpretation of fingerprints that explicit documentation and supporting data must be presented[10]. Similarly it was also suggested in recommendation 3.2 by the 2012 NIST[33] report on improving latent print examinations, that any modifications made to an assessment after viewing a comparison print must be documented as such and approached with caution. This recommendation essentially falls in line with the linear approach to examinations. The 2009 NAS[19] report includes specific recommendations for

approaching bias, in particular, recommendation 4 and 5. Recommendation 4 outlines the need for separation of forensic laboratories from law enforcement which would assist in the reduction of contextual influences on examinations[19]. Recommendation 5 discusses the necessity of further research into human observer bias and error in order to develop standard operating procedures to minimise potential bias effects[19].

5.2 Scotland - Scottish Police Authority Forensic Services (Fingerprint Unit)

The Scottish Police Authority (SPA) Forensic Services implemented work streams to address good practice regarding cognitive influences as a result of the McKie case[10]. The McKie case resulted in an erroneous identification and was determined a result of cognitive bias and psychological factors. The SPA accepted that although some case context is necessary for examiners to make an initial assessment it is not necessary for secondary examiners to be aware of this information in all cases[10]. A number of mitigation approaches to cognitive bias were employed by the SPA as outlined in the Forensic Science regulator Report[10] which included:

- Improvements to note taking.
- Blind technical review process which requires examiners to provide technical reports (and visuals) of impressions following an independent review. This process ensures that examiners involved in the technical review have no access or knowledge of case information or previous examiners findings.
- Blind verifications which ensure verifying examiners are unaware of any previous technical findings or contextual information and communication documents for that fingerprint.

- Regular sampling of all completed casework.
- Training programmes to address cognitive bias and the influence it has on human decision making.

5.3 England - Surrey and Sussex Forensic Identification Services Unit

The surrey and Sussex Forensic Identification Services Unit (FISU) shadowed the SPA and employed similar techniques to address cognitive bias in fingerprint examinations[10]. However, in addition implemented cognitive profiling recruitment testing, which assists in predicting cognitive skills of new staff and hence allows effective management of cognitive influences[10]. Another consideration by the FISU is to conduct studies on accuracy, performance and cognitive processes to implement technologies that will assist in mitigating bias[10].

5.4 Minimum Points of Identification Standard

The minimum point standard is a somewhat controversial topic when it comes to fingerprint examinations. This method requires that there is a minimum number of points of similarity between two prints in order to be deemed admissible as evidence[34]. There are varying ideas as to how many points of similarity should be a minimum and whether it is necessary at all. Although the method is employed in some countries, others have chosen to discontinue using this process. Agencies throughout England and Wales employ a 16-point standard, in a study by Evett and Williams[34] they discuss that the opinions of some British fingerprint experts was that they have a higher quality of examinations due to the 16-point standard. On the other hand, agencies throughout the US once employed a 12-point standard which under recommendation from the Office of the Inspector General

(OIG) was discontinued[21]. The reasons for discontinuation as outlined by the OIG[21] report were that the point standard did not fall in line with the aim of developing a more quantitative approach. At the time of the OIG[21] report the process of investigating a minimum quantitative approach had not begun. Throughout the Evett *et al*[34] study it was also found that Holland, Germany and France employed a 12-point standard in fingerprint examinations and the US and Canada did not.

Although the British experts argued that they had a more superior method of fingerprint examinations over those who did not employ the minimum point standard, it has been said that this process can introduce bias itself[34]. This may occur if an examiner were to specifically search for points of similarity to satisfy the minimum, thus, identifying similarities that are potentially incorrect. It was also found in the Evett *et al*[34] study that various international forensic agencies had found fingerprint pairs that consisted of more than 8 points of similarity even though they were from different sources. These pairs did not necessarily cause trouble for the experts as they were able to identify that they were similar but from differing sources[34].

5.5 Netherlands

The Netherlands Forensic Institute (NFI) has made steps towards addressing contextual bias in forensic examinations[8]. Sequential unmasking and Context Information Management (CIM) procedures have already been employed by the NFI for DNA, firearms and document analysis[8, 35]. Their aim is to introduce context management procedures throughout as many areas of forensic examinations as possible[8]. Context management implemented by the NFI would involve[8]:

- Initial perusal of case files for relevant information by first examiner.

- Case and only relevant information then given to secondary examiner.
- Secondary examiner remains blind to extraneous case information.
- Secondary examiner conducts comparisons and forms conclusions.
- Prior to conclusions being finalised, all case information is revealed to ensure no relevant information was disregarded.
- If any alterations were to be made after viewing all case information this would be recorded.

This process of sequential unmasking and blind examinations in the NFI have been combined with the use of blind verification processes[36]. The NFI have tailored the blind verification process depending on the quality of evidence being examined, where fingerprints of a lower quality would receive additional verification steps[36]. The verification would involve an initial analysis of quality determining which process will be needed for that print. This approach would work to maximise the use of resources. This verification process has been implemented in the NFI complex fingerprint examinations, meaning prints of less complexity (higher quality) only require verification by one examiner and more complex (lower quality) prints require independent verification by three examiners[36].

The topic of blind verifications is a commonly debated issue within forensic fingerprinting as many hold the opinion that it weakens the process due to the verifier being unaware of how the examiner has reached their conclusions[36]. It is argued that this process only tests the consistency of a conclusion and not validity, hence, circumventing the scientific method[36]. On the other hand, it is said that verifications can ensure accuracy and validity, much like examinations the verifications should be performed without influence from potentially biasing information[36].

5.6 Summary

The current approaches and recommendations for forensic agencies to mitigate bias are of great similarity between the United States (US) and United Kingdom (UK). The future recommendations put forward by the reports are also very similar, this could be due to the US report being somewhat of an exemplar that has prompted, and guided inquiries carried out by other countries. The US reports, specifically the 2009 NAS report[19] is frequently referred to in other documents and research on issues of bias in forensic science. Unlike the US and UK where a large portion of recommendations at this stage are not in practice or widespread throughout jurisdictions, the Netherlands have taken active steps in the process of mitigating bias. The common theme throughout the practical approaches employed to mitigate bias in forensic fingerprinting are: the use of LSU, blind testing and verification; reducing contextual information available to examiners; training and recruitment processes; and reviews of SOP for documentation of examinations[10, 19, 37, 38]. In addition, the separation of forensic laboratories from law enforcement agencies is another common suggestion, however, this can pose difficulties due to forensic divisions generally relying heavily on law enforcement for funding[10]. The concerns of bias throughout international forensic agencies have assisted in prompting queries within Australian law enforcement and forensic laboratories.

6. Australian Approaches to Mitigating Bias

In addition to the concerns of cognitive bias from international agencies, Australian agencies also hold concerns of bias in fingerprint examinations and experts[38, 39]. There have been reports formulated to address cognitive bias in the Australian forensic field, however, information is limited. It is difficult to locate specific information regarding the techniques

employed currently by Australian law enforcement and forensic agencies, therefore, suggestions that have been made by various reports are still somewhat of a theoretical or experimental recommendation. The methods of research involved searching law enforcement and forensic agency websites and research databases for information. The key reports that have been formulated for reviews on forensic science in Australia have been from the Australia New Zealand Policing Advisory Agency National Institute of Forensic Science (ANZPAA NIFS).

The main concern addressed in the report from Venville[38] was contextual bias and its potential for legal implications. Venville[38] suggests that contextual and confirmation bias are of more concern in pattern analysis fields due to the evaluation (inclusion or exclusion) of a print ultimately being a matter of subjective assessment from the examiner. In addition the lack of a rigid process for examination allows the examiner to reassess the evidence after receiving information throughout the examination[38]. This is where vulnerabilities to bias occur and consequentially influence examiners in their decisions. The principal concerns surrounding bias outlined in the Venville[38] report was the issue of objectivity and ultimately leading examiners to an erroneous decision. It is also of concern that the current debate surrounding bias casts doubt on the overall reliability of forensic science[38]. Through exemplifying the international cases of Brandon Mayfield, Shirley McKie and Stephen Cowans, some options of mitigation were suggested[38]:

- Blind verifications
- Blind testing
- Independence of forensic laboratories
- Double blind proficiency testing

- Competitive self-regulation

However, the suggestions made in the report by Venville[38] are still at this stage theoretical approaches as suggested by literature, and does not confirm that these approaches are in place throughout Australian forensic agencies.

An additional report formulated by Brown[40] for ANZPAA NIFS involved contributions from eight police agencies throughout Australia in an effort to review the performance of these agencies in relation to volume crime. This report worked on identifying performance strategies that could be implemented as a national standard for forensic identification. Although this report did not specifically investigate human bias factors, the suggestions of a "quality-assured" fingerprint identification process to improve efficiency could in turn improve areas surrounding bias[40]. One example was from Queensland Police Service (Forensic Services Branch) where an increased reliance on technology was involved, including on-screen examinations[40]. As suggested in some of the international reports a more technological approach would reduce bias by minimising human interaction with the examination process. As a result of a case study from the Australian Federal Police (AFP) on forensic intelligence, it was noted that more focus on improving the AFIS databases by populating them with more information could assist in turning this technology into a powerful tool for fingerprint examinations[40]. One suggestion on how to achieve this was the education and training of frontline law enforcement officers[40].

ANZPAA NIFS released a "Current Status Report"[41] in 2017, outlined are various areas of forensic science and updates of priorities for the Research and Innovation Strategy over the next 5 years in Australia and New Zealand. One of the main focuses for development in the fingerprint field is to utilise a fully automated system where human input will not be

required for the purpose of reporting potential matches[41]. This area of development will work alongside efforts to verify skills and processes used by examiners[41]. It is also mentioned in the report that much of the work is directed at identifying and reducing the effects of human bias, this includes the investigation and development of a reliable peer review process[41].

A study by Found and Ganas[42] explains approaches utilised by the Victoria Police Forensic Services Department (VPFSD) in the control of contextual bias in handwriting and document examinations. In this approach the evidence submitted for examination had unnecessary information removed by the use of a case submission form that has been altered to only require relevant detail for examination[42]. The flowchart in *Figure 6.1* sets out the process for context management employed by VPFSD for document examination employed since 2009[42].

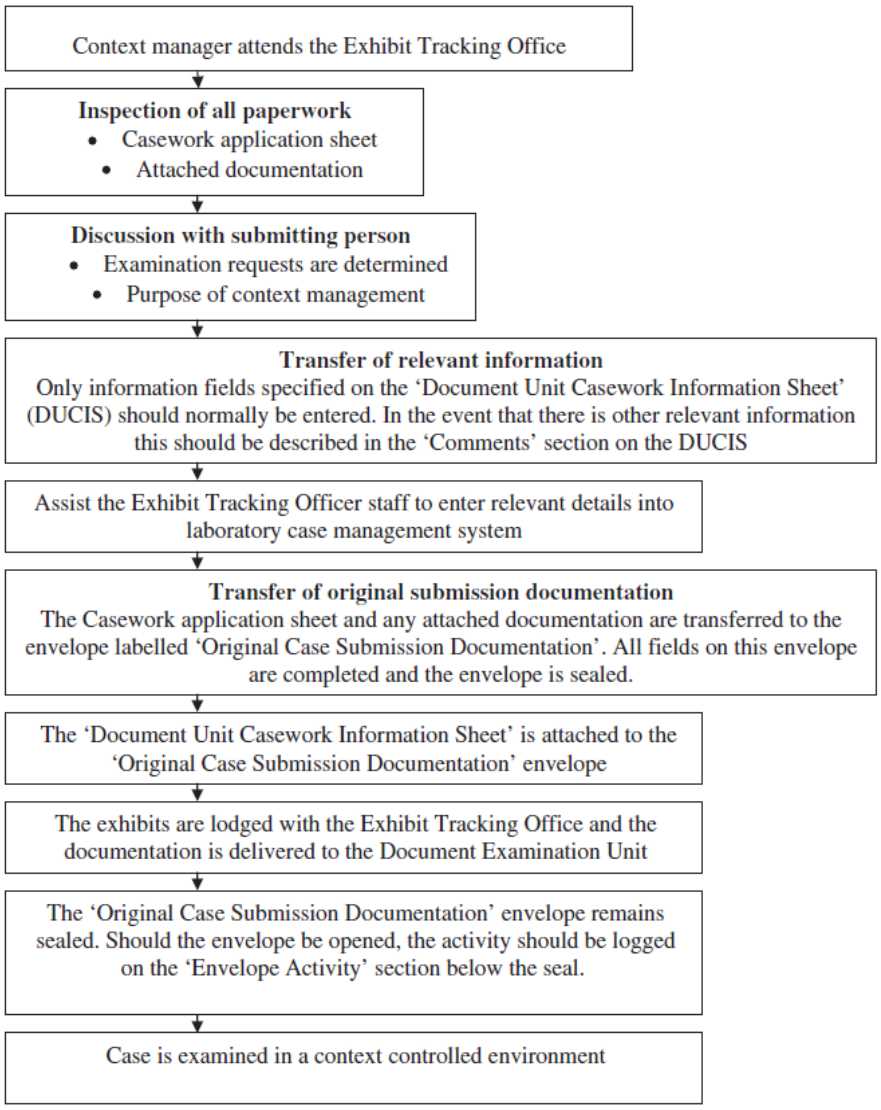


Figure 6.1Process of context management for document examinations in Victoria Police Forensic Services Department. Source: Found et al 2013

This process employed by VPFSD for document analysis may be adaptable to various areas of forensic science such as fingerprinting. The use of documentation to assist the sanitisation of information for examiners would require original case submissions to be sealed after filling in the adjusted case submission form[42]. This is necessary to monitor any context management that occurs. This method may prove beneficial as it could potentially address the issue of generally requiring more personnel to achieve the information filtering process. this method may still require additional examiners to be involved in the process,

however, may be minimal compared to other approaches. Some limitations were outlined by the author which were that due to the inability to fully sanitise document casework there may still be some contextual influences[42]. It was also noted that peer review does not occur independently of initial examinations in these cases and hence, confirmation bias can still be a contributor[42]. Overall it was reported that this method had been successful and negative outcomes had not occurred.

In addition to the recommendations and approaches put forward by reports, it is noted that Australia has possessed an accreditation program for national forensic science laboratories since early 1990's[39]. The National Association of Testing Authorities (NATA) is the governing body for accreditation of forensic laboratories in Australia under the International Organisation of Standardisation ISO/IEC 17025[39, 43]. The general belief is that this system serves as a method of risk minimisation and provides some consistency of procedures[39, 44]. Although, this belief may be correct in some ways there are many criticisms of the system and conflicting suggestions that the accreditation does not necessarily live up to this belief. In support of this notion, the standards do not specifically serve to standardise procedures as they do not explicitly address the various areas of forensic science[45]. Evidence collection, packaging, labelling, transport, continuity, examination, reporting and interpretation are some of the areas that are governed by this generalised standard[45]. It could be argued that a non-specific standard would not be sufficient in minimising error as the diverse nature of forensic evidence is highly varied and should have more specific standards for each area to achieve true consistency.

6.1 Summary

There is a lack of information available on current techniques used by forensic agencies in Australia, however, this may be an indicator that further research needs to be conducted. Although difficult to access information on current methods employed by Australian agencies to mitigate bias in forensic fingerprint identifications it was still possible to gain some insight as to future directions. The common themes expressed throughout the reports on forensic science in Australia were: managing contextual information; a focus on education and training in cognitive bias; and working towards automated systems. It is obvious that the issues present within the international forensic communities and concerns for cognitive bias in relation to fingerprint examinations is not specific to those countries and is a widespread issue throughout the world of forensic science[39]. This overlap between countries means that it is possible to work together and seek advice from international agencies on approaching the issues of bias in forensic fingerprinting[39, 46]. The practical approaches and recommendations can be built upon by theories and suggestions from the research world. In order to develop effective approaches to mitigation of bias it is necessary that a close relationship between practicality and sufficient research has been done to ensure the best outcome. In addition to building on approaches suggested by international reports the approaches employed by other forensic disciplines may provide vital information that will assist the studies on bias.

7. Approaches to Bias in Other Forensic Disciplines

Various disciplines make up forensic science, some of these include; document and handwriting analysis, DNA, odontology, hair analysis, and entomology. It has been acknowledged that bias is not exclusive to fingerprints and is becoming a widespread

concern. Other disciplines of forensic science have also proposed bias mitigation strategies, however, may not be in practice yet. It is important to include these studies in research on fingerprint bias as the approaches may be adaptable and assist in research for other fields.

Studies on forensic entomology have discussed concerns for contextual bias effects throughout examinations. As discussed by Archer and Wallman[47] information pertaining to when the deceased person was last known to be alive carries most concern. This information is case based contextual information, however, may not be necessary for the examiner to know straight away. Therefore, it has been suggested that a method of filtering contextual information and sequential unmasking may be a possible solution for entomologists[47]. Trials of sequential unmasking in casework led to the implementation of context reducing methods within Victorian forensic entomology casework[47]. The flowchart in *Figure 7.1* was developed to show the potential order in which stages of entomological analysis would be performed utilising sequential unmasking. This schematic also indicates the problem areas where bias is most likely to become an impacting factor. Suggested forms of documentation were also demonstrated throughout the Archer *et al*[47] study. The examples of documentation and procedures may be helpful in assisting fingerprint examinations as recommendations of sequential unmasking have been made to the fingerprint community. Limitations to this approach such as lack of staffing are also a common consideration as these processes require more personnel per case in order to successfully filter information.

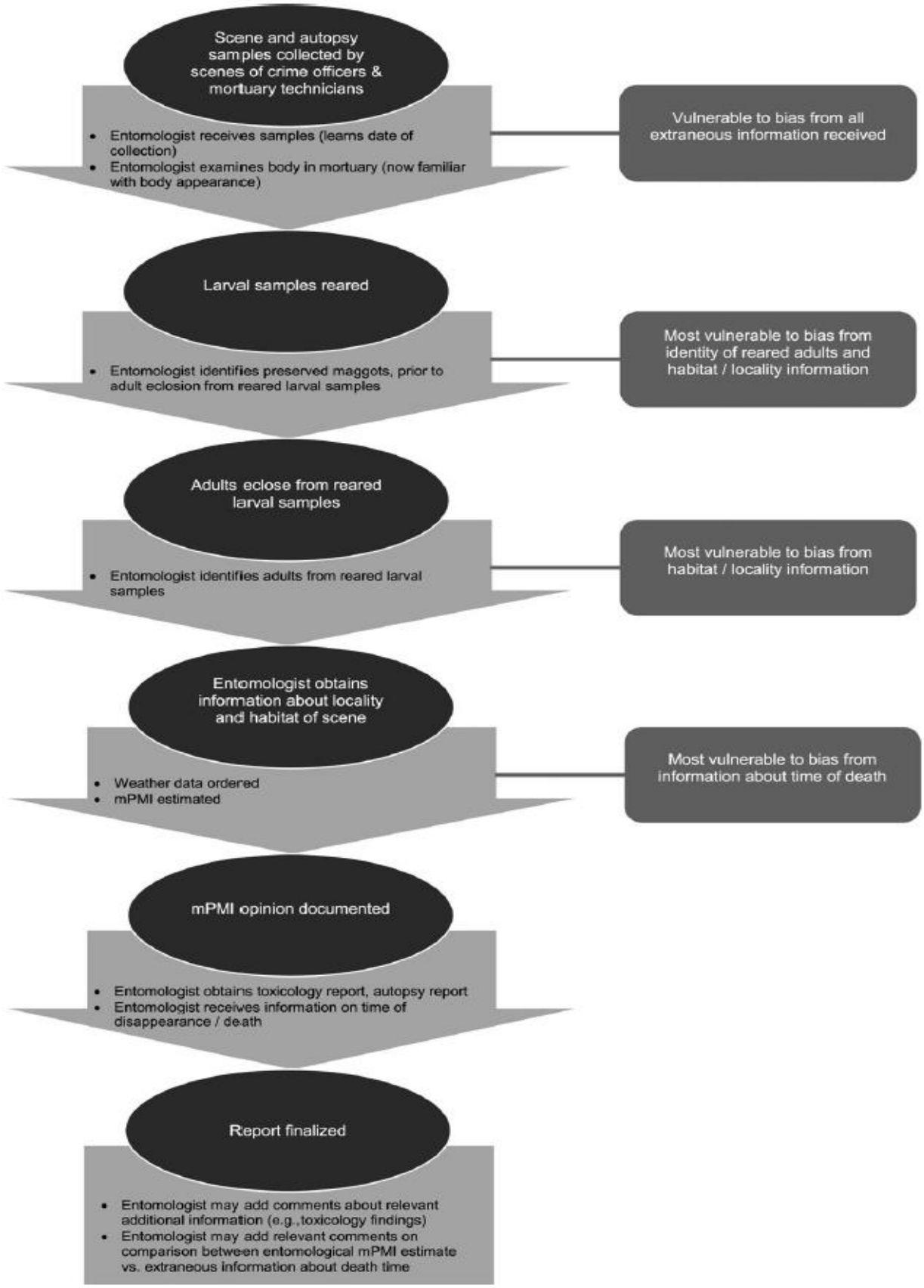


Figure 7.1 Proposed workflow of entomology examinations using sequential unmasking. Source: Archer et al (2017)

Forensic odontology is another field where investigations into bias have begun. Similarly to entomology, context control and sequential analyses have been suggested[48]. Page, Taylor and Blenkin[48] discuss that role, conformity and emotional effects can be reduced by examiners having minimal involvement with law enforcement, victims or lawyers. Similarly to approaches mentioned in fingerprint studies they suggest that the analysis and comparison stages of examination should be separated[48]. This suggestion would depict that of a sequential unmasking approach. In addition, it is mentioned that the analysis of poor quality bitemark evidence should be avoided as the ambiguity has been seen to lead to greater disagreements in conclusions[48]. These methods are not currently in practice, however, the ideas put forward support some aspects of the recommendations made to the fingerprint domain and may assist in the development of approaches.

An early study by Miller[49] on human hair identification described that procedures of examination involved the known and questioned samples to be sent together with a synopsis of case information to the laboratory. This study suggested that in some cases the main objective for obtaining evidence was to build enough proof for a conviction[49]. This mentality may then be passed on to the forensic examiner where they believe that the suspect is guilty[49]. It is suggested that these interactions with law enforcement may influence the forensic examiner and hence, alter their interpretation of evidence. Miller[49] hypothesised that the use of a line-up procedure would be beneficial in overcoming biases present in hair examinations. Testing of this method revealed that there was an increase in accuracy of examinations when a sample was submitted along with similar known but non-matching samples. Studies regarding pattern matching examinations such as hair analysis

can be of great benefit when considering techniques to assist mitigation of bias in fingerprinting as they both rely heavily on human examiners.

Further support of the sequential unmasking strategy is displayed by DNA interpretations[50]. It is discussed that sequential unmasking may be the most effective way of reducing bias in DNA evidence[50]. The prevention of examiners knowing details surrounding submitted reference samples is expected to reduce effects on interpretations. The filtration of information to the examiner is commonly suggested through the use of a sequential unmasking process. A suggested protocol was outlined in a letter by eleven experts which detailed the following steps[50]:

1. Examiner interprets evidentiary evidence.
2. Documentation would be made regarding initial examination.
3. Sequential unmasking of information regarding reference samples would be revealed.
4. Reference sample and evidence would be compared prior to evaluating foreign donor.
5. Findings documented.
6. Frequencies would be determined.
7. Results documented.
8. Other submitted reference samples would be considered.

This process does not require examinations to be performed completely blind, however, information would be revealed throughout the process at the necessary stages. This letter suggested that performing examinations completely blind may not give the examiner the best chance of producing reliable conclusions[50].

7.1 Summary

It can be seen that through comparing the techniques employed and considered by the various disciplines in forensic science there is a common theme. The common theme all relates back to limiting irrelevant information and interactions that may increase the possibilities of bias occurring. These disciplines all share commonalities with fingerprinting in regard to the concerns for sources of bias and the suggestions for mitigation. The above suggestions of case managers and sequential unmasking of information possess great relevance to fingerprinting and methods that have been tested in regard to fingerprint analysis. As some of the areas of forensic science such as entomology, DNA and document analysis have performed practical testing and some implementation in case work there are protocols in place that may be adaptable to fingerprint examinations.

8. Study Objectives and Design

This dissertation discusses the various types of bias that commonly impact on forensic fingerprint examinations and identifies some of the mitigation strategies agencies have employed. However, there is a need to identify and critically review the theoretical approaches to mitigating bias. The current mitigation approaches discussed throughout the literature review give an indication of what can be done, although, there is no widespread uniformity as to which methods should be employed in forensic fingerprinting procedures. It is necessary to survey the proposed theoretical approaches as suggested by literature and determine limitations and experimental research that has been performed prior to implementation. Some of the practical approaches employed currently have been proven to assist in reducing bias throughout examinations, however, some are not specific to fingerprinting but may potentially be adapted in order to address these issues. The study

aims to critically review the theoretical approaches and combine them into one study, providing possible steps towards reducing bias in the practical world of fingerprint examinations.

The critical analysis of theoretical approaches will assist the field of forensics by providing possible outcomes and limitations of certain methods. By combining the theoretical approaches into one study it may become a useful tool in producing practical methods to address bias. The potential outcome from the suggested study may result in a useful document that will provide the practical field of forensic science with a comprehensive and critical review of approaches to assist in the development of standardised protocols.

9. Discussion and Conclusion

Forensic fingerprinting provides important information in the process of a criminal investigation[1]. Therefore, it is important that it is done in the most reliable and unbiased process possible. The human element involved in forensic fingerprint examinations introduces areas where human decisions and thought processes can affect conclusions reached. In order to ensure that the conclusions reached by fingerprint examiners is accurate and can be trusted by law enforcement, judicial systems and the public certain approaches to reduce bias need to be considered.

Despite the numerous reports and studies formulated on the issues regarding bias in forensic science and particularly fingerprint evidence, there is no unified approach to address the issue of human cognitive bias effects. The national and international reports released from NAS[19], PCAST[37], Forensic Science Regulator[10], ANZFSS[38, 41], Fingerprint Inquiry[20] and various others identified the main problem areas of forensic fingerprint

protocols and areas of concern for cognitive bias. Although these reports have been released in various countries the areas of concern for bias appear to be a common and widespread issue. This is useful as it promotes an environment where information and research on approaches to bias may be shared and duplicatable across jurisdictions and even worldwide. Aside from the cognitive architecture of the human brain and the way it works the main areas identified for promoting bias to occur were identified as being; training, organisation and cultural factors, base rate expectations, case information (evidence and reference materials)[18, 22, 24]. By understanding where bias is more likely to occur it is possible to seek solutions to overcome its effects.

The recommendations put forward by the above-mentioned reports, again shared many similarities. Consensus throughout the reports generally eluded to suggestions of:

- Blind testing, verifications and reviews
- Sequential unmasking techniques
- Separation of laboratories from law enforcement
- Standardised documentation and procedures
- Increased training to address cognitive bias
- Improved technology to assist examinations

Despite recommendations of these techniques being made there is still a lack of evidence to show the use of these approaches in a practical setting. There are also various other approaches that may be possible, however, have been suggested in theoretical settings which may give further avenues for research to determine their practicability.

It is necessary to the evidential value of forensic fingerprint identifications that approaches to mitigating bias effects be researched. It may not be possible to combat the issues with one individual approach, although, it may be an opportunity to utilise a combination of strategies to form a successful preventative strategy to cognitive bias. As suggested by research it is not always necessary to blind examiners completely to all information pertaining to a case[6]. However, the control of this information and determination of relativity to the task at hand is important. The development of a standardised protocol for fingerprint identifications with considerations of reducing biasing factors would greatly benefit the world of forensic science.

10.Future Research Directions

Future studies may be useful to build on this work, potential methods for testing the theoretical approaches in practical settings may be investigated. This could aim to address the limitations of prior studies on theoretical approaches and transform them into a useful technique for bias mitigation in fingerprint examinations. This may also include testing approaches used in other areas of forensic science such as; DNA, document examinations, and other pattern matching disciplines.

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- Part Two -

Manuscript

A CRITICAL REVIEW OF APPROACHES TO MITIGATING BIAS IN FINGERPRINT IDENTIFICATION

A CRITICAL REVIEW OF APPROACHES TO MITIGATING BIAS IN FINGERPRINT IDENTIFICATION

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Abstract

Fingerprints are commonly used to identify individuals in criminal investigations. Fingerprint examinations rely on human examiners; however, this can potentially introduce cognitive bias to the identifications process. Although there are standard operating procedures and guidelines such as the ACE-V protocol, there is evidence that cognitive bias influences the outcome of fingerprint examinations. Growing concerns of bias in examinations have become evident within forensic science and law enforcement. Cognitive bias generally results from adaptations to thinking based on prior experiences and knowledge of a situation. Therefore, it is important to identify the areas where bias may be introduced throughout the fingerprinting examination process and review approaches to bias mitigation. Currently, there is no uniform approach to overcome bias in the practical field of forensic fingerprint examinations, hence, a critical review of the recommended approaches is necessary. This review aims to cover the theoretical and practical approaches to mitigating bias in fingerprint examinations.

Key Words: Forensic Science, Fingerprints, Bias Mitigation, Human Decision Making, Theoretical Approaches, Cognitive Bias.

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List of Abbreviations

AFIS	Automated Fingerprint Identification System
ACE-V	Analysis, Comparison, Evaluation, Verification
CIM	Context Information management
DNA	Deoxyribonucleic Acid
FBI	Federal Bureau of Investigation
LIMS	Laboratory Information Management System
LR	Likelihood Ratio
LSU	Linear Sequential Unmasking
NAS	National Academy of Science
NFI	Netherlands Forensic Institute
OIG	Office of the Inspector General
PCAST	President's Council of Advisors on Science and Technology
PRC	Probability of Random Correspondence
SWGFAST	Scientific Working Group on Friction Ridge Analysis Study and Technology
SOP	Standard Operating Procedure
VPFSD	Victoria Police Forensic Services Department

Introduction

Fingerprint identification is used frequently in criminal investigations[1]. The friction ridge patterns that make up a fingerprint can provide a great deal of information in the process of identifying individuals[2]. Despite advances in technology, the task of fingerprint identification is highly dependent on human examiners[3]. Fingerprints examined in criminal investigations are generally of poor quality and commonly incomplete due to the varying substrates and circumstances surrounding their deposition[3]. These circumstances result in challenging conditions for the human examiner entrusted with the process of identifying such prints. While there are procedures in place to assist the process of examinations such as ACE-V[4, 5], due to the heavy reliance on human examiners and their judgement, the risk of human cognitive bias becomes a factor that requires consideration.

Cognitive bias can have an impact on the way information is interpreted. Bias results from adaptations to thinking, which stems from experiences shaping the way future decisions are made by an individual[6, 7]. Cognitive bias has gained attention in the forensic science field because of the growing concerns that it may affect objectivity during examinations[8-10]. The Scientific Working Group on Friction Ridge Analysis, Study and Technology (SWGFAST) defines cognitive bias as "the effect of perceptual or mental processes on the reliability and validity of ones observations and conclusions"[5]. Although there are many types of bias impacting on human decisions, there are certain key types related to forensic fingerprint examinations. These are; contextual, confirmation, motivational, and cultural biases. Contextual bias becomes evident when peripheral information such as that pertaining to case specifics effects the outcome of an examination[11]. Confirmation, motivational and cultural biases tend to have similar cause

and effect as they result in an examiner working to achieve a certain result due to the exposure of information unnecessary to the examination[11, 12]. Therefore, it is necessary to understand where these biases can become introduced throughout an examination to prevent biased results occurring.

It has been found that there are three dominant categories for identifying sources of bias which are closely related to the resulting key types of bias discussed earlier. Human nature; environment, cultural and experience; and case specific factors, which encompass the common sources of bias that should be considered during fingerprint examinations[13]. It can be said that the factors surrounding human nature will be more difficult to overcome as the possibility of altering the human cognitive architecture may not be achievable[13]. However, the potential for addressing environmental situations and case related evidence or information will be more easily controlled to reduce their biasability[13]. Through a review of the literature there have been many suggestions that bias mitigation should be considered in forensic fingerprint examinations. Discussions of approaches to reducing bias from international and Australian agencies indicate the desire to enact improvements across the field, however, there is little evidence of change since the recommendations were made[10]. This may be due to a lack of knowledge of the theoretical approaches and possibly a lack of practical analysis of those approaches. Hence this paper aims to identify theoretical approaches to mitigating bias and assist the conversion of theoretical strategies to practical uses for their implementation within the field.

Approaches to Mitigating Bias

Throughout the studies on cognitive bias in forensic science there have been recommendations on theoretical and practical approaches to mitigating bias:

- Blind testing, verification and proficiency testing
- Linear testing procedures
- Competitive self-regulation
- Technological advancements
- Laboratory independence
- Statistical modelling
- Training, education and recruitment

These approaches will be discussed below, including: a background of the approach; an insight to prior studies and experimental data that has been performed to test the theories; whether it is currently employed by any agencies, and a critical analysis of the approach. Throughout the studies that have been performed to test cognitive bias in forensic science and specifically fingerprint identification, the participants and conditions have varied greatly. Some experiments have utilised student groups, while others tested or compared trained forensic experts versus forensic novices. The experiments discussed include known and blind trials. These variations in participants and environmental conditions throughout experiments become important when considering practicality and adaptability to actual forensic settings.

Blind Testing

Forensic examiners are frequently exposed to case information that can affect their analyses. Hence, the separation of the fingerprint examiners from case information may assist in reducing bias effects[14-16]. If an examiner is depending only on the examination with no knowledge of the case it has been demonstrated that this will reduce cognitive bias[8, 17]. This process would involve using a case manager or "middle man", who would receive information regarding the case and pass on the necessary evidence for examination to the

independent examiner[14, 17, 18]. Prior to the forensic examiner receiving the evidence the case manager would remove any case specific (suspect/victim) identifiers leaving the examiner with completely objective information who would then perform the requested testing and comparisons on exhibits[17]. Various experiments have been conducted to test context effects on the analysis, comparison and evaluation of fingerprint identifications of which some will be explained below.

Various studies have been conducted to test the effects of contextual and observational information on examiners performing fingerprint identifications. These types of bias (contextual and observational) stem from knowing additional information which is not essential to the task[19]. In these studies, the participants were divided into various groups (control, low-emotional or high-emotional) and briefed on case specific information. Participants in the low-emotional context group were given information that was not emotional in nature. The high-emotional context groups received highly emotional case material including graphic images of a scene. This was done to determine the effects of varying contextual information on the examination[20, 21]. The studies by Dror *et al*[20] and Schiffer *et al*[21] included the use of student participants. In the study conducted by Dror *et al*[20]*,* the high emotional context had a greater effect on the conclusions reached than low or no context. It was noted that in cases where fingerprints were ambiguous, the context had a greater effect on the results. Unlike other studies, the experiments conducted by Schiffer *et al*[21] found that the analysis stage of examination was quite resistant to observational bias, knowledge of a known print and contextual information as they did not affect the examinations[21]. These results were obtained by observing the total number of

minutiae marked, type of minutiae and the classification of the fingerprint (exploitable or identifiable)[21].

A study into decisions made by fingerprint experts was conducted by Hall and Player[22], which aimed to determine whether written crime reports provided with the fingerprint evidence would affect the experts examination of a low quality print and if the expert was affected by emotional circumstances surrounding the case[22]. The experiment consisted of fingerprint experts divided into two groups, high-context (murder case) and low-context (forgery case)[22]. The experts were instructed to classify the fingerprint as either; identification, non-identification, insufficient or insufficient detail to establish identity[22]. Following the conclusions reached each participant was required to provide feedback as to whether they had viewed the crime scene information prior to analysis and if so, did they feel that information had influenced their judgement[22]. Ultimately, it was found that the context type and personal feedback of effect on the expert had a relationship. This was shown by 52% of the 30 experts who indicated they felt they were affected by the high-context information provided, and only 6% of the low-context group who responded that they had been affected[22]. In comparing the overall conclusions made by each group, the only significant differences were noted between decisions of insufficient for comparison and insufficient to establish identity. Unlike other research, this study showed that although the emotional nature of the crimes may have influenced the examiners, it did not ultimately affect their final conclusions[22]. This disparity was displayed through the variation in feedback from experts and the actual results from examinations.

A common factor with these studies is that in each of the situations, the participants were aware they were being tested. Therefore, covert studies have been conducted by

Dror, Charlton and Peron[23] and Dror and Charlton[24] which combined a mixture of the experts own previously completed casework and unknown prints throughout the experiments. Information was given to the experts prior to examination which consisted of either trivial case information or that there was an erroneous match made previously, misleading examiners to think that the prints were not a match[23, 24]. As a result of the experiment by Dror *et al*[23] it was found that in four out of five cases the participants had changed their conclusion from the result they had reached in previous years[23]. This study found that the extraneous information surrounding the fingerprints affected the outcome of the expert's decisions. The subsequent study by Dror *et al*[24] resulted in findings that supported the vulnerability of experts to extraneous information as it was found that two thirds of the examiners had unknowingly changed their opinions on fingerprints they had previously analysed[24].

In support of the blind testing approach detailed above a practical implementation in the form of blind testing has been carried out in the Victoria Police Forensic Services Department (VPFSD)[25]. This blind testing was in relation to document examinations; however, this is very relevant for fingerprint and other pattern matching disciplines. This method utilised context sanitisation through removing contextual information present within the evidence, this was achieved using a secondary examiner as a context manager to filter the relevant information through to examination[25].

Critical Analysis of Blind Testing

Blind testing is essentially aimed at addressing contextual bias, achieved through ensuring that the examiner only has access to critical information required for their examination[8, 17]. Through utilising a case manager, it may be possible to sanitise the

information filtered down from the crime scene investigators[17, 18]. It may not be viable to completely remove all biasing case information; however, it can certainly assist in reducing bias effects. It was seen in the studies discussed that a reduction in contextual information resulted in a reduction of bias in the conclusions reached by examiners and test subjects[18, 20-23]. The practicality of this approach may be questioned because of additional time required for examinations and the need for more personnel to achieve a method of contextual sanitisation. Some modification of the methods suggested throughout literature may be necessary prior to implementation. A study by Found and Ganas[25] discussed the processes implemented for context sanitisation during document analysis. The system outlined by Found *et al*[25] utilised existing examiners as case managers requiring no additional personnel to be recruited and a process of information filtering and evidence sanitisation. It was also noted that this system had been employed in the document analysis unit of VPFSD since 2009 and at the time the study was completed in 2013 no negative outcomes had resulted from the scheme[25]. This system could be adapted for fingerprint analysis and assist in the reduction of contextual bias. Blinding may potentially be included throughout the ACE-V methodology.

Blind Verification

Blind verification requires the verifying examiner to have no knowledge of the prior decisions made during the original examination and any contextual case information that may have been introduced throughout the prior examination[15]. This is unlike the existing verification stage in the ACE-V protocol where a verifier may have knowledge of the prior conclusions by the original examiner. This step aims to confirm if the original examiner has made an identification or exclusion by the verifier completing their own independent ACE

processing of the same fingerprint[26, 27]. If a discrepancy between examiners occurs then further investigation as to the determinations made must be carried out[28]. It has been seen in the Mayfield case where the knowledge of a previous examiners conclusions impacted on the decisions made by verifying examiners, which is a prime example of confirmation bias resulting from a non-blinded verification process[20]. It is therefore preferable that the verifier have no knowledge of the original examination, and that the original examiner does not select who verifies their own work[15]. It would also be preferred that the verifications were performed by other laboratories which similarly falls in line with suggestions of competitive self-regulation[29] which is elaborated later in this review.

In a study by Langenburg, Champod and Wertheim[30] bias effects were tested during the verification stage of fingerprint examinations. The study aimed to identify potential effects of knowing prior conclusions from an examiner, their identity or experience on the decisions made by a verifier[30]. The study included expert and novice participants who were randomly divided into three groups (A-Control, B-Low Bias and C-High Bias) [30]. The low bias group received information on the prior conclusions of a previous competent fingerprint examiner and asked whether they were in agreeance with those conclusions[30]. The high bias group received information that the prior conclusions had been made by a very highly recognised fingerprint expert and that the conclusions and commentary were from a real case[30]. Each group were provided pairs of fingerprints which included an exemplar (crime scene print) and comparison print for each pair[30]. The participants were required to provide an evaluation (identification, exclusion or inconclusive) for each pair and if inconclusive was the result an explanation was required[30]. In addition, the number of minutiae (agreement and disagreement) were to be counted and the quality of the fingerprint was to be rated[30].

The results found that although contextual information had an increased impact upon novice participants, the expert participants were also affected[30]. Unlike the novice group where the highly recognised expert had a greater effect on conclusions it is important to note that in the case of low and high bias, neither type biased the experts any more than the other[30]. As a result, the expert groups were biased towards forming an inconclusive result rather than an individualisation or exclusion[30]. The results clearly displayed that the control group of experts had a higher accuracy of determining individualisations or exclusions consistent with ground truth due to the absence of biasing information.

A blind verification scheme was implemented in what was called the Scottish experiment. The scheme worked to separate the identification and verification stages of examination and ultimately anonymise verifications[31]. Although separations were made ensuring that verification examiners were not involved in any comparison work the system was not completely anonymous[31]. Concerns of handwriting recognition from the reports may have led to verifiers knowing who had been involved in the stages preceding them[31]. This system was reviewed and discontinued in practice, focus was then placed on approaching these issues in other avenues[31]. Regardless of this the Fingerprint Inquiry Report[31] made recommendations in line with theoretical suggestions on verification procedures which were:

- Independent verifications
- Verifying examiners should not have knowledge of the prior ACE examination.
- Verifying examiners should not consult with original examiners until post verification.

In support of blind verifications, the Federal Bureau of Investigation (FBI) employed such protocols following a review that took place due to the Brandon Mayfield case[32]. The FBI procedure for blind verification outlines that the verifying and primary examiners must not consult the conclusions of the primary examiner or any case specific information should not be known to the verifier[32].

Critical Analysis of Blind Verification

Throughout the studies[30] discussed a common theme amongst experts was that false negatives outweighed the false positives. Meaning that the experts appeared to be more cautious in their decisions due to the fact they knew they had been exposed to potentially misleading evidence. Considering all results obtained throughout the study it can be concluded that similarly to the studies conducted by Dror[20, 23, 24], cognitive bias does impact decisions made by fingerprint experts and blind verifications could assist in reducing such bias. The comparison of the theoretical studies and practical trials (Scottish experiment[31]) it can be deduced that in order to build a successful process of blind verifications, knowledge needs to be taken from both the theoretical and practical worlds of forensic science. Verification of work is already a large aspect of the ACE-V protocol for fingerprinting[27], however, the addition of a blind process will further assist in reducing bias effects. Regarding practicality this approach would seem somewhat easily implemented. Although, it may take extra time requiring an independent examination of the same prints the requirement that the verifier have no prior knowledge of the examiners conclusions should not present too much difficulty for implementation[15]. Considering that there have been attempts to implement this approach in a practical sense (Scottish experiment[31]) which was later discontinued it may be useful for future research to identify exactly the

issues raised with the method implemented at that time. This information may assist in developing a better-rounded approach that may be successful in the future. It was ultimately found through the theoretical research that there was a reduction in bias effects using blind verifications[20, 23, 24]. Another possible approach to reduce bias may be in blind proficiency testing which will now be discussed.

Blind Proficiency Testing

Proficiency testing is a method of measuring the quality of an examiners work[33]. SWGFAST has developed a standard for the Friction Ridge Proficiency Testing Program which aims to "evaluate an examiners application of a methodology and the agency's procedures"[33]. As suggested in a report by the President's Council of Advisors on Science and Technology (PCAST)[34], proficiency testing should mimic circumstances of real casework and on samples where the true answer is known. This statement would suggest that blind proficiency testing should be the norm, where the examiner is unaware of being tested and thus operates as they would in real casework[35]. A blind proficiency test in forensic science would possibly involve using a "placebo" sample, meaning that it was a test sample which would appear to be a real crime sample[35]. However, this would be unknown to the examiner and would hence assist in testing the performance of the examiner and laboratory[35]. The placebo sample would have a known result in order to determine if the examiner being tested has achieved an accurate result[35]. In contrast, Thompson, Tangen and McCarthy[36] suggest that proficiency testing should not necessarily resemble real life. This is explained by alternatively finding balance between three factors when forming studies on human performance; fidelity, generalizability and control[36]. The term fidelity refers to similarity of the simulated task to fingerprint examinations[36]. Generalizability

describes the scope of the experiments results and how these can be applied to various situations[36]. The control aspect represents the freedom over variables by experimenters[36]. These factors will be further understood through discussing the experiment conducted.

An experiment conducted by Cowan and Koppl[35] did not specifically test for effects of contextual and confirmation bias but rather studied approaches to assist reducing such effects. These experiments were based on the "science game" which involves senders and receivers[35]. In this instance the sender symbolises crime laboratories and receivers symbolise judge and jury, therefore, there are multiple senders and one receiver[35]. In the treatments presented by Cowan *et al*[35], a sender will present information to a randomly selected receiver. Bias is introduced into the experiment by offering incentives for the sender to send a particular message[35]. There were three experimental treatments applied in the study to demonstrate blind proficiency testing. Blind proficiency testing in this scenario was demonstrated by auditing 10% of sender reports with a penalty for inaccurate reports[35]. The first treatment contained no audits of sender reports, however, still had bias treatments applied[35]. The second treatment involved audits with all other conditions mirroring the first treatment[35]. Finally, the third treatment was run identically to the second, however, the penalty for inaccurate reports was greater[35]. The results displayed that blind proficiency testing may potentially improve performance of forensic science. The resulting trends were somewhat expected, the non-audit group produced more inaccurate reports whereas the audited groups with a higher penalty presented lower inaccuracy. It was seen that the levels (high and low) of bias applied had a low impact, especially in the audited treatments.

The experiments conducted by Thompson *et al*[36] aimed to compare competency of experts as oppose to novices, and the frequency in which errors were made in failure to identify matches and inaccurate information being reported. This experiment was more representative of a real-life environment compared to Cowan *et al*[35]. The experiment involved fingerprint experts and university undergraduates being presented with pairs of fingerprints and a simulated crime scene, while some of the fingerprints matched, others were similar but not from the same source[36]. It was found that the experts resulted in a very high accuracy and novices considerably lower. The study was successful in determining standards of competency for expert examiners and could potentially be built upon to create a form of proficiency testing that further addresses the balance of fidelity, generalizability and control.

Cowan *et al*[35] suggests blind proficiency testing in forensics is possible although their main focus was on whether it would be beneficial rather than feasible. The experimental design in this study did not seem entirely blind in the sense that the participants knew there were certain penalties for incorrect reports. The approach utilised resembled a more monitored environment than blind testing. This would suggest that an approach of monitoring forensic laboratories with penalties for poor performance may prove successful. Contrary to common belief that proficiency testing should be performed blind, where participants have no knowledge of being tested, it is argued that this approach is somewhat flawed. Thompson *et al*[36] explains that in order to achieve an experiment that is as similar as possible to real life (high fidelity), it consequentially results in reduced generalisability and control. This can be seen in contrasting the two experimental designs where Thompson *et al*[36] consisted of a higher fidelity than Cowan *et al*[35].

Critical Analysis of Blind Proficiency Testing

Blind proficiency testing would aim to ensure the quality of work that is produced by examiners[33]. This form of testing does not specifically aim to address bias; however, it could assist in reducing its effects. This in turn would ensure that the examinations were being carried out in the correct manner and procedure and assist in identifying areas where bias has affected an examination. Whether the process of proficiency testing should be blinded or not is a matter of contention as it is argued that by making it a blinded process other important aspects of proficiency testing would be compromised[36]. If it were to be a blind process, this could be achieved by inserting placebo evidence into regular casework, hence, the examiner being unaware that they are being tested[35]. Some form of spot testing cases may also serve as proficiency testing and this monitoring of performance may provide an environment where examiners are more inclined to perform well[29, 35]. The process of randomly testing completed case work would act as a spot test for proficiency. Increased performance would potentially result in an overall reduction in error rates, encompassing bias as a contributing factor in error rates. The following section expands on linear sequential unmasking which may be seen as a further extension of certain blinding techniques.

Linear ACE or Linear Sequential Unmasking

The process of linear ACE or linear sequential unmasking (LSU) works somewhat similarly to the idea of blind testing, however, the difference being that certain information may be presented to the examiner throughout the process[14]. Although some information will be passed on to the examiner the main idea is to reduce the flow of information as much as possible. LSU refers to the analysis, comparison and evaluation stages of ACE-V

being performed in a way that prevents circular reasoning (a form of confirmation bias) from occurring[37]. It is argued that circular reasoning occurs due to the lack of rigidity in the guidelines for documentation of the fingerprint examination process[15, 37, 38]. Although SWGFAST sets the standard for documentation and procedures of performing ACE-V, there is no uniformity as to how this should be done[37]. The guidelines merely outline that documentation of the analysis and any subsequent re-examinations is necessary.

The linear method would require initial analysis to be examined independently without access to a comparison print[15, 38]. Following the independent analysis, the comparison print would be introduced to ensure any mark ups made on the originally provided print were not influenced by the comparison[38]. This approach to overcoming bias prevents the examiner re-assessing the original print once viewing the comparison print, this is a common practice in most fingerprint examinations[15]. The linear method has been recommended by various reports (National Academy of Science (NAS)[39], Venville[10], PCAST[34], Forensic Science Regulator[32]) and has been incorporated into various agencies (such as the FBI), Standard Operating Procedures (SOP) in an effort to improve the reliability of their procedures. The report from the Office of the Inspector General (OIG) in 2011[19] reviewed the progress of the FBI with reference to recommendations resulting from the Mayfield Case and discusses linear ACE-V. The OIG[19] report outlined that the revised SOPs do avoid bias by: examiners completing a fully documented analysis of a fingerprint prior to viewing a comparison print; explicit documentation of any data relied upon throughout comparison and evaluation; and blind verification is to be separately completed and ACE examination documented.

It is not always possible to completely remove all contextual information from an examination, as explained by Dror, Thompson, Meissner, Kornfield, Krane and Saks *et al*[40] some information although potentially biasing is relevant to the task at hand. It is however, necessary to control the release of this information providing it only if necessary and as late as possible[40]. It is also suggested that rather than performing the process in a way that prevents the examiner from changing their opinion or revisiting their work, but perhaps making the process more transparent[40]. The proposal was made for an LSU model that required the examiner to perform analysis stage in isolation and in conjunction allow well documented changes within certain guidelines[40].

A study presented by Ulery, Hicklin, Roberts and Buscaglia[37] analysed data from the "White Box" study which aimed to test the sufficiency for individualisation of fingerprints. The White Box approach looks at how much information is required to reach a conclusion[41]. The study centred around the comparison stage of examination when a fingerprint is compared to an exemplar and aimed to evaluate how an examiners opinions may change when presented with such information[37, 41]. Throughout the comparison and evaluation stage participants were required to annotate the exemplar and decide its value[37]. It was optional to review prior annotations and value determinations, however, any alterations after viewing the exemplar were recorded[37]. The results demonstarted that all examiners made some modifications throughout the comparison stage, ultimately resulting in an average increase of minutiae marked[37]. It was noted that the changes between analysis and comparison stages potentially indicated the analysis was not satisfactory or became influenced by viewing an exemplar[37]. This data raises concern surrounding the reliability of comparisons.

Langenburg[42] conducted a study to address potential observer effects by using LSU. The study was presented as four case studies in which two examiners were to review the same evidence[42]. This resulted in the examiners coming to varying conclusions depending on how LSU was utilised and how the information for each examiner differed. Langenburg[42] also included information on his personal experiences with utilising LSU in private consultation casework. Langenburg[42] explains that as a result of utilising the LSU method in his own casework, it has proven successful in the sense that defence attorneys with great scepticism toward forensic evidence seem to be accepting of the use of LSU in their cases.

Critical Analysis of LSU

LSU mainly focusses on addressing confirmation bias (circular reasoning). This approach would work similarly to that of blind testing, in addition, it would add some rigidity to the already existing ACE-V protocol[37]. The prior studies show evidence that it would serve to reduce bias and other factors that can influence an examiner during comparisons. The current state of the ACE-V procedure allows examiners to "repeat back" over their work whereas a linear approach would prevent the possibility of confirmation bias by encouraging a one-way process[37]. If the review of prior stages of examination were to occur it would be heavily documented and justified to ensure bias was not impacting on the final conclusions[19]. This approach would also benefit from better guidelines and uniformity of documentation across the discipline of fingerprint examinations, which would assist the success of LSU to bias mitigation. Similarly to the blind testing process, LSU may require more time for examinations as extra steps may need to be taken during the analysis stage, such as: removing all identifiers of the case from fingerprint cards and photographs; repetition of the whole process by verifiers; and autonomous documentation of the

subsequent examinations[42]. However, the method would result in further trust being built in fingerprint identifications for the public and law systems as prior explained by Langenburg[42]. Despite requiring more time for examinations, the implementation of such measures may not entail major changes to the current system and would assist in bias reduction. This leads to the discussion of competitive self-regulation which has a focus on creating accountability of examiners.

Competitive Self-Regulation

Competitive self-regulation refers to putting forensic laboratories into reviewing each other's work in order to create an environment of accountability[29]. Koppl[29] proposed that this approach would reduce errors encountered in forensic science and in turn, reduce conscious and unconscious effects. It is explained that unlike the society of general science where information is public and open to scrutiny, forensic science differs greatly[29]. Forensic science relies heavily on individual examiners and their personal expertise or qualities[29]. This also means that in some cases final conclusions come down to an individual's decision with limited input from other examiners[29]. Koppl[29] suggests that the environment of forensic science itself is somewhat embedded with opportunities for unconscious bias to creep in. Therefore, it is proposed that if forensic laboratories were responsible for checking each other's work then the likelihood of error would reduce due to an increased motivation to perform well. In order to achieve competitive self-regulation, the process can be broken into five main factors[29]:

I. Rivalrous redundancy
II. Evidence control officer
III. Statistical review

IV. Division of labour with vouchers

V. Privatisation

Rivalrous redundancy refers to introducing incentives for producing scientifically sound and accurate work[29]. If there are multiple laboratories in each jurisdiction competing with one another then samples may be chosen at random and tested at another laboratory to clarify results achieved. The incentive system would be introduced to encourage the discovery of errors, hence rivalrous redundancy[29]. If the incentives were not present, then the approach would in turn become sheer redundancy[29]. An example put forward by Koppl[29] explains that if two competing laboratories examine the same evidence given by police return differing results, a process to determine who is correct would take place. For the laboratory who was not correct they would not receive payment for their work, on the other hand, the laboratory that gave the accurate response would receive their own payment in addition to that of the failed laboratory's payment[29]. This factor, however, would be unsuccessful if both laboratories were biased toward the same decision[29]. If the situation were to arise that both competing laboratories were biased this method would have a converse affect and give validity to an incorrect result[29]. Therefore, incentives to encourage error detection would be necessary to successfully mitigate bias[29].

An independent evidence control officer would be necessary if competitive self-regulation were to be considered as an approach to mitigating bias. Although positions similarly named "evidence control officer" may already exist in forensic agencies, this position would differ slightly[29]. The purpose of evidence control officer in this scenario would be to break the flow of information between investigation officers and forensic examiners[29, 43]. This in turn means that any information surrounding the case would be

filtered down to the examiner to ensure extraneous information does not bias the examination. Additionally, this position could potentially use a numbering system for laboratories and testing facilities to randomise who examines evidence[29]. Independence of the evidence control officer from any forensic laboratories would be preferred, however, would not always be possible in areas with only one laboratory[29]. With that in mind there would be strict guidelines for the conduct of an evidence control officer and severe consequences for any misconduct[29].

Periodic statistical review would be utilised to monitor the performance of forensic laboratories involved. This process would require the cases examined by each laboratory to be broken into various categories and evaluated, if there are any unusual results (high or low number of cases in a specific category) then an investigation will need to be carried out[29]. This information could assist in ensuring that there has not been a breach in the filtration of information into the laboratory[29].

The division of labour with vouchers aims to address the current issue exemplified in the US where generally forensic examiners will consider themselves to be working for either the police or prosecution. This mentality has been proven to introduce confirmation or motivational biases[29, 43]. The division of labour refers to the separation of the performance of forensic tests from the interpretation of those tests. In conjunction with the separation of labour a recommendation for a standardised report to promote reproducibility and repeatability by secondary examiners[29]. The voucher system is based on the example that public defenders were given incentives to act in the interests of their clients rather than complying with the incentives of giving in to police or prosecutors[29].

The final factor in the process of competitive self-regulation would involve the privatisation of forensic laboratories from government (law enforcement) agencies. Three factors that would contribute to better quality outcomes in privatised laboratories are:

- Effective monitoring of employees and development of new technology[29].
- Upholding a reputation will be of high importance to ensure the success of a laboratory, hence, increasing accountability[29].
- A demand for high quality work will produce better quality results[29].

As suggested by Koppl[29] if all of the above five factors are combined the potential for increased standards is highly possible.

Critical Analysis of Competitive Self-Regulation

Competitive self-regulation would be aimed towards; the filtration of unnecessary case information, creating accountability and a system of inter laboratory verification, and statistical monitoring of performance to identify areas of potential biasability[29]. This approach would address various biasing elements (contextual, confirmation and motivational) and attempt to increase performance[29]. The approach of competitive self-regulation would rely on the co-operation of multiple forensic laboratories. This leads to questions of practicality due to the factors that would be required to ensure the success of this method. Competitive self-regulation shares aspects of other approaches combined into one methodology, however, implementing the five main factors to commence at the same time may prove difficult. This approach would require implementation of various stages prior to becoming fully operational. Overall, competitive self-regulation would form

a methodology to encourage unbiased work using a case manager, any remaining bias effects would be scrutinised and identified through rivalrous redundancy, and a system of checks or verifications would assist in stopping further bias effects[29]. In addition to the use of statistics for monitoring performance, statistical models can be used throughout the process of fingerprinting to add weight to evidence.

Statistical Modelling

Statistical modelling is a process which aims improve the scientific basis and transparency of the fingerprint comparison process[2]. Statistical models would be able to work alongside the ACE-V protocol, providing quantitative insights into fingerprint configurations and error rates[1]. Methods for quantitative assessments of fingerprint evidence is expected to provide support in the process of fingerprint selection, documentation and evaluation[2]. Ultimately, working towards a common standard between organisations.

An extensive critical review paper was conducted by Abraham, Champod, Lennard and Roux[1] on the theoretical and practical perspectives of recent statistical models and their use in support of fingerprint examinations. It was identified that two key methodologies exist; Probability of Random Correspondence (PRC), and Likelihood Ratio (LR)[1]. The PRC models work to calculate probabilities of feature occurrences within impressions from differing sources[1]. The LR statistic is common throughout the field of forensic science, namely DNA, and is comprised of a ratio of two likelihoods of instances occurring with different hypotheses resulting in empirical distribution[1]. A relationship between the PRC and LR models exist, however, the PRC model lacks the evidential ability to consider the variability within a finger mark[1]. The paper concluded that the most practical application

would be the use of LR models. Abraham *et al*[1] concluded some main points of assistance from the implementation of an LR model which would be:

I. Act as a support mechanism of opinions formed by examiners and provide accountability to claims and processes throughout the application of ACE-V, more specifically evaluation and verification.

II. The use of LR can also assist in the analysis stage of examinations by assigning value to the weight of information gathered from a fingerprint prior to comparisons.

III. LR models would also assist in the cases where a fingerprint is declared inconclusive. Guidance would be given from the LR model on the strength of features in agreement or disagreement.

In agreeance with the provision of a quantitative method for assessment of fingerprint evidence Neumann, Evett and Skerrett[2] discuss that it will provide greater transparency in the field of forensic fingerprinting. Neumann *et al*[2] outline a method for acquiring and organising information quantitatively from fingerprint minutiae. The method is summarised below:

I. Acquisition of minutiae features: This utilises triangles to form a polygon providing a unique structure defined by the position of minutiae[2].

II. Organisation of minutiae features: This requires identifying the distance, length, angles and types of minutiae[2].

III. Comparison of configurations: This involves the comparison of the quantitative information acquired from a control print and a crime scene

print. This consists of overlaying the two configurations and rotating until the distance between the configurations is reduced[2].

Critical Analysis of Statistical Modelling

It can be seen that through comparing the studies on statistical models for forensic fingerprint examinations there is a common goal to improve transparency, accuracy and consistency of the process[1-3]. Statistical modelling would mainly aim to address contextual bias involved in the ACE-V protocol. The statistical models would add scientific validity to the process and evaluations made by examiners[1]. Through reviewing the literature, the implementation of an LR model would be preferred over other statistical models as it would be the most practical for the purpose. LR models use information from within a fingerprint and between other fingerprints to create a similarity score, making this the preferred model[1]. This similarity calculation would assist in reduction of contextual bias as it is based on a statistical calculation rather than human based decisions. It is expected that the implementation of such a model would be relatively simple using the already existing AFIS databases and ability to use them as a platform to apply this information[1]. This type of validation to fingerprint examinations would bring the discipline in line with other forensic sciences where this type of procedure is already in place. The addition of this quantitative method would assist in the transparency of fingerprint examinations and offer uniformity to the individuals and organisations involved in the examinations[1, 2]. The implementation of statistical models would also be greatly supported by improvements to technology which will now be discussed.

Technological Improvements

In many aspects of forensic science there are opportunities to utilise technology, namely in forensic fingerprinting the use of AFIS plays a role in examinations[15, 38]. Although technology assists in fingerprint identifications it can also contribute to biasing an examiner. An AFIS searches fingerprints on a database and produces a selection of ranked fingerprints similar to the questioned print thereby influencing an examiner with base rate expectations[15, 38]. These biasing factors can lead to mis-identifications and false negatives[38]. A suggestion by Kassin, Dror and Kukucka[15] would be to ensure the results produced by the database would need to be considerable in length and randomised prior to viewing. This would allow the examiner to then fairly analyse each result[15]. In addition to the aims of reducing base rate assumptions, the use of technology may potentially assist in the documentation of examinations creating better quality information management[44].

A research study conducted by Dror, Wertheim, Fraser-Mackenzie and Walajtys[45] worked to determine how the ranking system of AFIS affects an examiners decisions. The experiment consisted participants who were all current practitioners in latent fingerprint comparison[45]. Latent prints of medium to low quality were used as it has been discussed that contextual information has a higher impact on degraded prints[20, 45]. Latent fingerprints pairs used for the experiment for which half a list of 10 possible matches was produced and for the other half a list of 20[45]. The corresponding prints were loaded into AFIS and the matching print was included into the list of potential matches. In some lists the match was located high on the list and in others it was located further towards the bottom. The results obtained displayed that overall the positioning of prints within the simulated list returned by AFIS influenced the fingerprint examiners. It was found that the examiners would spend

less time examining a print that occurred lower on the list[45]. Results showed that when less time was spent on comparison the higher the impact of print position on the list[45]. Another factor to consider was that the false positives generally occurred on prints placed higher on the list[45].

Research surrounding the Forensic Laboratory of the National Bureau of Investigation (NBI) of Finland outlined a methodology employed for fingerprint examinations which relied on a documentation platform working in conjunction with the ACE-V protocol[44]. The system utilised has moved away from the common practices of an individualistic fingerprint examination and introduced a system where at least four examiners will be involved in the process. As shown in *Figure 1.1* there are four distinct stages; registration, screening, identification, and statement production[44].

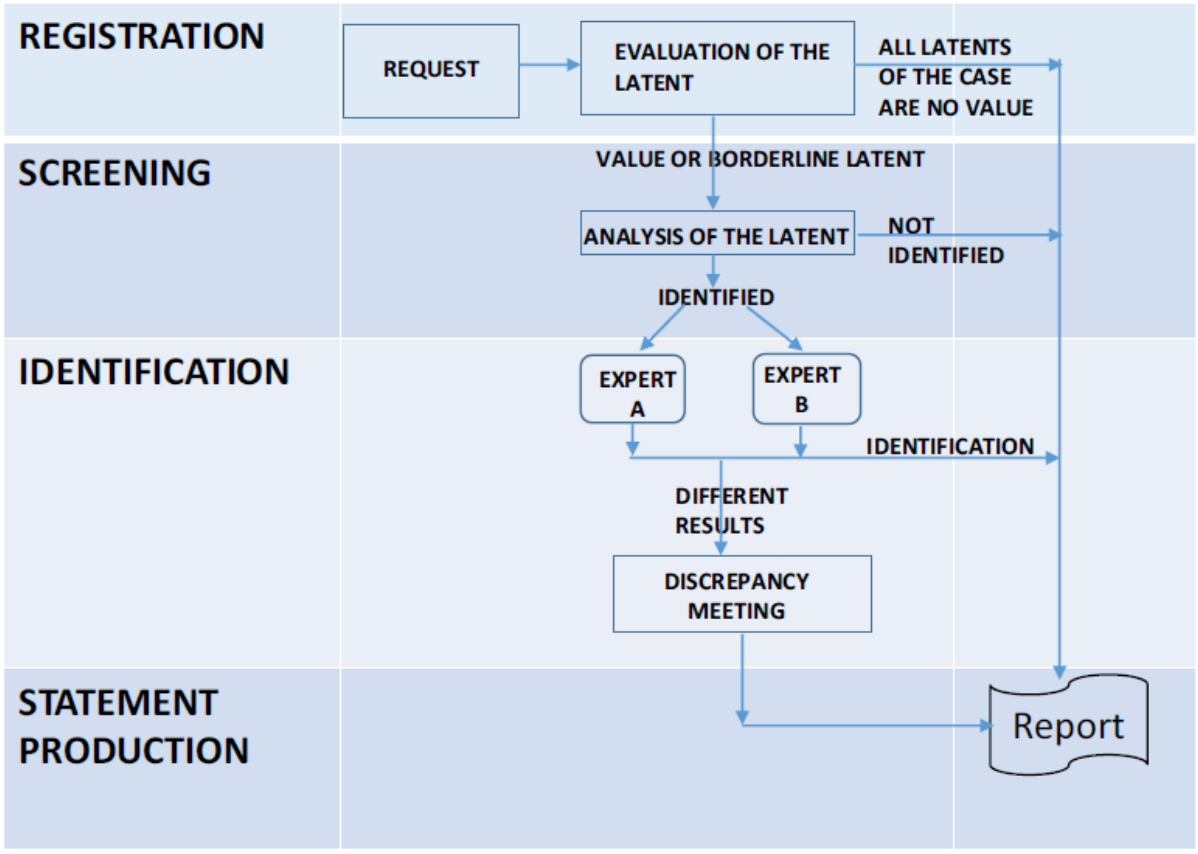

Figure 1.1 Model for fingerprint examinations using multiple examiners. Source Mustonen et al 2015.

The registration phase is carried out by a fingerprint examiner who analyses all information regarding a case and records it on a Laboratory Information Management System (LIMS)[44]. This stage of the methodology is not unlike the suggestions of a case manager approach. If the examiner determines no value to the fingerprints then the case is sent straight to statement production through LIMS, however, if there is value present for comparison the next step is the screening phase[44]. During screening, another examiner will conduct ACE on the digital fingerprint using AFIS and once assessed for possible value sufficient to examine then a comparison is carried out. If there was a match, the next stage is identification, however, if there are no matches then further comparisons using AFIS were conducted. The comparison using AFIS involves using photoshop for annotations with GYRO colours (Green, Yellow, Red, Orange), these colours are indicators used for coding the fingerprint throughout comparison[44]. Following the evaluations made during the screening stage the identification stage consists of two independent examiners who perform their own analyses and evaluations of whether there is an identification[44]. The final stage is the statement production phase which is then produced and sent electronically to the necessary investigator[44].

Critical Analysis of Technological Improvements

The way in which technology such as AFIS produces information has a biasing effect on fingerprint examiners[45]. Improvements would primarily assist with overcoming base rate expectations[15, 45]; however, it would also assist in areas such as providing a platform to conduct linear examinations and thus reducing confirmation and contextual biases. A practical example of how systems such as LIMS, can play a major role in assisting bias

mitigation for fingerprint examinations was demonstrated by the methodology implemented by the Finnish NBI[44].

Making improvements to the way that an AFIS database presents information during an examination can reduce the biasing tendencies of using such technology[45]. Technological advancements may also assist in the continuity of information and documentation throughout an examination. Technology will potentially aid when implementing other approaches regarding the sanitisation of contextual information which may be easier using technology.

Independence of Forensic Disciplines from Law Enforcement

Suggestions of the separation of forensic laboratories from law enforcement have been made in various reports and studies. Gianelli[46] mentioned that there is an "inbred bias of crime laboratories affiliated with law enforcement". Similarly with the United States, the United Kingdom hold their own concerns that relationships can subconsciously form between police and forensic agencies[46]. The NAS[39] report made the recommendation that:

> Recommendation 4:
>
> "To improve the scientific bases of forensic science examinations and to maximize independence from or autonomy within the law enforcement community, Congress should authorize and appropriate incentive funds to the National Institute of Forensic Science (NIFS) for allocation to state and local jurisdictions for the purpose of removing all public forensic laboratories and facilities from the administrative control of law enforcement agencies or prosecutors' offices."[39]

It is believed that the separation of forensic science from law enforcement would improve the functionality of forensic examinations[39]. In turn, this would reduce the effects of forensic scientists being driven to reach particular conclusions due to pressure imposed by law enforcement[39]. This approach is believed to increase fairness[10] and address motivational or confirmation biases in forensic examinations. Although this approach would seem to be an appropriate action for mitigating bias in forensic fingerprint examinations, there are concerns for its practicability.

The main conflicting factors for the privatisation of forensic laboratories rests with financial and time constraints to achieve this outcome[10, 46]. A general theme throughout most literature on this topic is the reliance of public laboratories on law enforcement for funding. It is expected by some studies that the separation of forensic science would cause the private agencies to compete for resources, hence, reducing their availability of funding[46]. In contrast to this standpoint, the NAS[39] report put forward that the separation would allow laboratories to be in control of their own budget henceforth, reducing their competition with governing law enforcement agencies. Gianelli[46] discusses that the effectiveness of criminal investigations will potentially be impacted negatively by the separation of forensic laboratories. Due to the importance of scientific input from forensic examiners in the early stages of investigations, the geographic separation of laboratories may reduce workflow[46]. In addition, an evaluation of US forensic laboratories was conducted in 2005 which revealed that a number of laboratories would not survive as a private organisation due to the minimal numbers of staff present[46]. This notion supports the issue of time constraints, whereas, the duration of examination would increase due to geographical separation, decreased staff and increased measures to mitigate bias.

Critical Analysis of Independence of Forensic Disciplines

Independence of forensic disciplines from law enforcement is a common suggestion when discussing the protection of forensic examiners from biasing information and effects. The current organisation of law enforcement and forensic examinations creates an environment where contextual information is easily shared between the two domains[39, 46]. The separation of forensic laboratories would aim to address various biases such as motivational, contextual, confirmation and other influences from field operations[46]. Although a common suggestion not necessarily one that is easy to implement. Due to the heavy reliance of forensic laboratories on law enforcement agencies for funding a large shift in the organisational structure that currently exists would be necessary[46]. This process would still require a relationship to be retained between forensic science and law enforcement as the forensic aspect of investigations would then have to be outsourced to the private laboratories. This change may cause an increase in the time taken to carry out investigations overall, however, benefiting in the reduction of external influences to fingerprint examinations.

Evidence Line-up

Evidence line-ups have been suggested as a method of reducing bias in forensic fingerprint examinations. An evidence line-up would work similarly to that of an eyewitness identification line-up[10]. An examiner would be given the questioned fingerprint along with other similar but non-matching prints and no additional information regarding the fingerprint[10]. The examiner would then be essentially working blind as to which print is the actual evidence. Venville[10] suggests, it is generally expected that forensic evidence will result in incrimination as it is collected on the basis of a crime. However, using an evidence

line-up where the examiner is aware some of the evidence is not connected to a particular crime it may result in expertise and reliability[10].

Langenburg[42] describes the process in which he undertakes an evidence line up in his own practical work which involves performing LSU prior to presenting an evidence line-up to the verifying examiner. Generally, the process would involve presenting a verifier with a group of prints including the reference prints to be examined and other unrelated reference prints[42]. In more complex incidents there may be unrelated latent prints introduced for further anonymity of latent prints[42]. This process is shown in *Figure 1.2* where the unrelated prints are labelled as "foils".

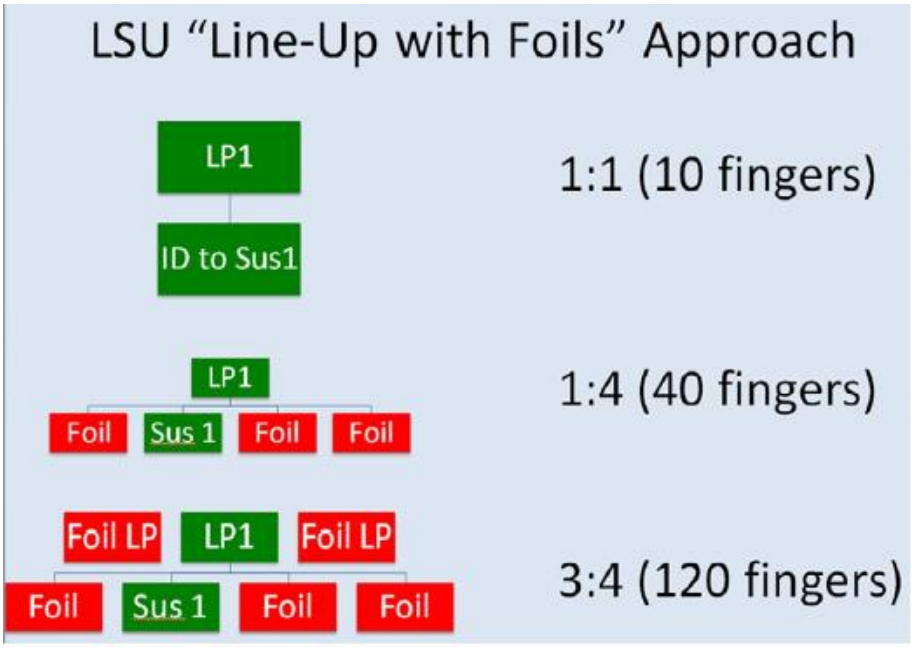

Figure 1.2 Schematic of evidence line-up the 1:1 indicates the examination by original examiner and 1:4/3:4 shows verifiers possible line-ups. Source: Langenburg 2017

This line-up approach would be significantly assisted by the use of an AFIS as it would be able to provide a quick easy way of obtaining various unrelated prints[42]. However, this would take much longer than regular ACE-V protocols as the verifying examiner would

essentially be repeating the whole LSU process rather than just viewing the potentially matching pair as determined by the original examiner.

An early study was conducted by Miller[47] to assess the potential use of a line-up procedure in forensic hair analysis. This study occurred due to concerns of the subjective nature of hair analysis and the resulting conclusions formed by examiners based largely on their expert opinion[47]. Miller[47] explained that presenting examiners with multiple known samples may increase the accuracy and reduce bias. Throughout this study, experiments were performed using 14 students trained in hair examination. Each student was presented with four cases, of which: two contained evidence that would generally be presented for examination (known exemplar and questioned sample); and the other two containing questioned sample along with five known unrelated samples[47]. The results found that the traditional method of examination led to a higher rate of incorrect conclusions, whereas, the line-up method drastically decreased the incorrect conclusions. Although, the incorrect conclusions decreased there was a higher rate of inconclusive results with the line-up. This does not indicate that the line-up method is a definite solution to mitigating bias, even though false positive conclusions decreased the inconclusive results suggests the examiners were more reserved in their opinions. The process does ultimately show a reduction in bias and may in some ways be adapted to assist in mitigation strategies for fingerprint and other forensic evidence.

Critical Analysis of Evidence Line-Ups

The use of evidence line-ups has moved from a purely theoretical approach towards a practical approach, through the examples given there are results presented from both practical work and theoretical testing. Both examples demonstrated a reduction in

contextual and confirmation bias[42, 47]. This approach would potentially take additional time to complete examinations, although, it is stated that the method was more accepted by the law sector than the current methods[42]. Evidence line-ups would be an approach aimed at reducing confirmation bias and essentially work into the verification stage of an examination[42]. This process of bias mitigation would be easily implemented with an approach like LSU. The main limitations to this method would be additional time taken to complete an examination due to the extension of the verification process, and the availability of "foil" prints[42]. However, availability of foil prints would not be an issue in law enforcement crime laboratories as the access to AFIS would overcome this[42]. There have been practical examples given where this approach has been implemented and proven successful[42, 47]. Studies on the use of line-ups in human hair examinations may assist in providing the building blocks to produce a method applicable to fingerprint examinations. Likewise, the approach explained by Langenburg[42] gives a practical example of how the method is employed through fingerprinting case work. The success of the Langenburg[42] methods can be seen through the increased acceptance by the law community and court system.

Training, Recruitment and Education

Understanding human cognitive bias is an important step in developing mitigation strategies. Suggestions of ways to assist in reducing bias within forensic science and fingerprint identifications is to provide training and education to examiners on the issue. It may be useful for forensic science disciplines to integrate training on human decision making[15]. Various studies mentioned regarding contextual bias have displayed that as expertise and experience increased, the impact of extraneous information decreased[30, 31] .

Although, the impacts were not completely eradicated by experience it was significantly lower. It is also proposed that the greatest way to regulate bias is through an individual's own integrity and objectivity[8]. This suggests that rather than ignoring bias it must be accepted that it exists and attempts to overcome it must be made.

Some studies suggest a process for recruitment where testing is performed to determine whether an individual fits the specific needs for a role[32, 38]. The development of cognitive profiles for recruitment in forensic fields would assist in providing a criteria for selection processes[38, 48]. Dror[38] outlines three specific guidelines for such tests which are:

I. Developed scientifically and validated
II. Relevant to abilities required for the position
III. Examination of fundamental abilities (not pertaining specifically to forensic evidence)

This selection process could potentially support the mitigation of bias by ensuring that competent individuals are selected. In addition, being aware that human cognition is a factor to be considered may assist in the reduction of bias[38].

Training is essential in forensic science and is commonly debated regarding standardisation of methods. However, when discussing training in the forensic field it may be effective if a few main points were implemented across the field. Dror[48] suggests three main aspects of human cognition that should be a focus when designing training techniques which are:

I. Individuals ability to acquire information.
II. Individuals ability to remember learned information.
III. Individuals ability to apply the learned information and skill.

These points may not completely make up the training regime, however, would have a positive effect on the standard of examiners that result due to the training being thorough and ensuring it is properly learned. Throughout the process of providing training to examiners on cognitive factors involved in forensic decision making it will assist in the examiners independence of mind[38]. It is suggested by Kassin[15] that this could be achieved by introducing basic psychology training on human decision making and perception through the use of forensic case materials.

Critical Analysis of Training, Recruitment and Education

It can be said that training and education are essential for forensic fingerprint examiners. The addition of providing awareness to the susceptibility of cognitive bias and psychological factors involved with human decision making could assist in the reduction of bias effects. Although it is not necessarily possible to knowingly disregard biasing information, the mere knowledge of the sources and effects of bias can allow an individual to avoid situations that may cause a biased outcome. This approach to bias mitigation would not be time costly like some other approaches, as it could be integrated into the already existing training regimes. The addition of selection criteria in the recruitment process would also assist in reducing bias as it would ensure the awareness and suitability of an examiner prior to induction for fingerprint examinations. This aspect of mitigation would not only address bias but additionally assist in an understanding of how humans make decisions and ultimately improve the quality of examiners[15]. The question of practicality does not become an issue when considering this topic as it can merely mean adding or altering content to the already existing frameworks. The addition of a basic understanding of psychology and human biases would not require a whole new training

regime but rather enhancing what already exists. The same idea extends to that of a recruitment process where a new method may not be required just the understanding of new information and adapted techniques.

Conclusions

It is evident that a relationship exists between the psychology of how humans make decisions and the ways in which this can impact on processes involved in forensic science. Forensic fingerprint examinations rely heavily on human examiners where cognitive bias has become a factor to consider. It may not be feasible to completely rule out bias although it can be reduced by employing some of the approaches discussed. It could be suggested that combining multiple approaches may be necessary to reduce bias in forensic fingerprint identifications. The use of a model that works on controlling contextual information from the crime scene and related evidence would potentially be most successful and practical. Limiting the flow of information has been proven through studies to reduce biasing effects on examiners[20-22, 42]. Using a technique such as LSU with improved documentation guidelines would assist the already existing ACE-V procedure to become more transparent. In addition to the use of LSU a blind verification process using an evidence line-up would add further validity to the conclusions. To achieve such a method the use of a case manager as previously suggested throughout literature would be necessary[15, 49]. To build a robust procedure, guidance can be taken from the models used in various other forensic domains with existing LSU models (DNA, entomology, document analysis). The LSU model would not require complete blinding but allow certain information to be revealed at various stages throughout examination. A potential framework detailed below has been adapted from various sequential unmasking protocols suggested by literature[25, 50].

1. Context manager or case manager receives evidence and case information.
2. Documentation of information received.
3. Necessary evidence and information given to fingerprint examiner.
4. Initial examination (analysis stage) of evidence documented by examiner.
5. Sequential unmasking of information and reference samples (comparison stage).
6. Comparison of reference and scene samples documented.
7. Matching and non-matching elements of fingerprint determined.
8. Evaluation and conclusions documented.
9. Blind verification with evidence line-up conducted.

The blind verification process that would follow the primary examination should not have any of the primary conclusions known to the verifier and would require the verifier to conduct their own ACE processing of the evidence[29, 30]. This verification process would be further improved by using a line-up approach when presenting the evidence for verification. The line-up approach would require a sufficient number of similar foil prints to the questioned print so that conclusions made by the primary examiner would not be obvious[42]. The suggestions made would not impose large changes to the already existing frameworks, however, may increase the time taken to complete an examination in full. The benefits that would result from the above suggested context management (LSU, blind verification, line-ups) and increased documentation guidelines would be a reduction in effects from extraneous information and greater transparency of methods employed by fingerprint examiners.

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