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Research Paper

Collaborative practise in forensic science and academia: The development of a documentation strategy for fingerprint examinations in an English fingerprint bureau in the ISO 17025 era

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ABSTRACT

The mandatory introduction of ISO 17,025 accreditation to fingerprint comparisons forced changes to the documentation procedures. Academic and grey literature consistently suggest that the documentation should provide a sufficient auditable trail, yet there is some dissimilarity in the guidance relating to documentation content, and subjectivity with its interpretation. The accreditation body, UK Accreditation Service (UKAS), was not prescriptive in the methods required to produce working notes and were open to different practises, which has provided a useful opportunity to compare approaches to casework and to work with practitioners to inform effective practise.

The research team carried out a gap analysis between pre-accreditation operational documentation practise and an ACE-V checklist, which was a summary of best practise guidance on documentation content. A white box study included thirty-one fingerprint examiners from six institutions, who were asked to undertake an 'Analysis' of eight friction ridge impressions. Participants were asked to produce working notes using their pre-accreditation documentation approach and a piece of software called 'PiAnoS', which prompted mark annotation and an assessment of mark quality. The notes were compared to the ACE-V checklist to determine which of the documentary suggestions were considered to obtain an understanding of experts' decision making. The results were used to develop a documentation strategy for an operational English fingerprint bureau, referred to as a "Mark Analysis Form". It consisted of content from the ACE-V checklist, supported by literature, and which received high response rates from experts alongside discussions by the research team to determine its relevance in the documentation strategy. The strategy met with the ISO 17,025 standard, evidenced by UKAS approval, and is currently used for casework.

1. Introduction

Documenting the examination of forensic evidence should be a routine task for forensic scientists across forensic disciplines [1,2]. When practicable, working notes should be produced contemporaneously [1,3]. The working notes, in whatever form, should be clear and comprehensive to allow another expert to follow the work undertaken [1,3]. Also, the original expert may have to revisit work or if the case goes to court, potentially several months or years later, the contemporaneous notes can be a reliable source of the thought processes during the original examination, as opposed to trying to recall the examination via memory alone [3]. The production of contemporaneous notes will not only support the experts' thought process through the examination, but also aid with the court report afterwards [4].

Section 19.3(3) of The Criminal Procedure Rules requires experts to disclose working notes created as part of an examination [5]. This is particularly useful in instances where 'differences of opinion' between experts arise, as the use of contemporaneous notes can help to explain differences and avoid instances such as those encountered within infamous cases, as detailed in the following text [6,7].

The England and Wales Court of Appeal (EWCA) in R-v-Smith (2011) [6] quashed a homicide conviction due to issues with the fingerprint

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examination process. An absence of working notes within the original and twice verified examinations contributed to the Court of Appeal judgement, which stated that, "no competent forensic scientist in other areas of forensic science these days would conduct a forensic examination without keeping detailed notes of his examination and the reasons for his conclusions" and suggested that quality standards should be enforced through a "robust and accountable system" [6].

The Fingerprint Inquiry [7] was the result of Her Majesty's Advocate (HMA)-v-McKie which included several misidentifications of fingermark evidence 86 recommendations were made, some of which related to the documentation of fingerprint evidence. In 2016, Bunter suggested that there had been little change to fingerprint examination documentation strategies since its publication [8], although the mandatory introduction of the ISO 17,025 standard in England and Wales by the Forensic Science Regulator, and its implementation to the Scottish Police Services Authority is a likely driver for change, which has happened since Bunter's publication [8]. The standard aims to ensure that laboratories are technically competent and includes references to the documentation of examinations. In this paper, the term 'documentation' is used to include contemporaneous notes, examination sheets and the findings from the examinations.

1.1. Documenting fingerprint examinations using the ACE-V process

ACE-V is a widely recognised cognitive process of the 'Analysis', 'Comparison', 'Evaluation' and 'Verification' of unknown fingermarks [1,3,9]. Research has examined the consistency of the approach's application in casework [10,11], although relatively less research has examined the production of effective contemporaneous note taking in fingermark examinations.

The reported content of the **Analysis** stage varies according to different sources of literature [1,3,8,12,13]. To summarise, examiners are assessing the value of the mark for comparison through the analysis of friction ridge detail[1] contained within it. In Bunter's account of examination practise in the UK, if the quality of the mark was deemed suitable, little notes, if any, were made [8]. If accurate, a publication date of 2016 would suggest that the recommendations of the Fingerprint Inquiry and R-v-Smith had not been implemented at the time of Bunter's publication [8].

During the **Comparison** stage, experts may compare features[2] of the unknown mark to a known mark or fingerprint [1,3,8,12]. Examiners may annotate similarly corresponding features, such as ridge characteristics[3], which may contribute to the documentation of the evidence. They may also annotate differences. This annotation can be completed electronically on an Automated Fingerprint Identification System (AFIS), which are databases of known and unknown friction ridge skin impressions that examiners use to find suitable comparison prints for unknown marks. Marking friction ridge detail using a pin on a physical photograph of the mark may also be used for annotation, or optical comparators may facilitate a magnified annotation using ink on a clear and wipeable screen. These approaches have been witnessed by the authors in UK fingerprint bureaux.

The Criminal Procedure and Investigations Act's (CPIA) general disclosure rules of 'Record, Retain, Reveal,' describe three key obligations that expert witnesses must abide by during an investigation [4], which is relevant to the documentation of evidence. The retainment obligation is an important consideration for any comparison which may be deemed as temporary, such as the use of comparator screens, as erasure of the 'mark-up' would not comply with the retention rules of the CPIA, unless a photograph of the screen using a camera or screen shot was taken prior to the deletion of the annotations. Erasure of a temporary comparison would also have implications for disclosure, since it is also difficult to establish exactly what has and has not been reported. These issues could be alleviated with the 'pricking out' approach, as observed by the authors in some fingerprint bureaux. According to Bunter [8], the annotation described in this section essentially completed the documentation created during the comparison phase [8] although, as with the analysis phase, this is likely to have been affected by the ISO 17,025 standard because of the requirement of technical records. The Forensic Science Regulator's Codes of Practice and Conduct states the minimum requirements for technical records to demonstrate the examination sequence contemporaneously [1,12].

According to some scholars, the application order of analysis and comparison should be strictly linear [14]. Alternatively, the examiner may use features that are selected in the known fingerprint prior to analysis of the unknown mark. This could lead to the analysis of the print suggesting features present in the mark, whereas an independent analysis of the mark may not have delivered the same assessment outcome. The effects of reverse order analysis have been explored in the literature and casework [15,16]. A suggestion for the documentation of fingermark examinations using a colour coded approach, which signifies the order of annotation of ridge characteristics (i.e., during analysis or comparison) has been suggested by Langenburg and Champod [17], referred to as the GYRO (green-yellow–red-orange) system.

As part of the **Evaluation** phase, experts provide a conclusion for their analysis and comparison [1].

The **Verification** phase refers to a peer review of the fingermark. This practise may be 'blind' or 'open' and is likely to vary in practise [1,12]. An absence of effective contemporaneous notes in an open verification at this stage would make it difficult for a subsequent examiner to follow the nature of the examinations undertaken and the basis for the conclusions.

1.2. Documenting fingerprint examinations in England and Wales: Streamlined Forensic reporting

Streamlined Forensic Reporting (SFR) was a process that was introduced to England and Wales in 2013 (after The Fingerprint Inquiry) and was designed to enable investigators, scientists, and prosecutors to comply with the Criminal Procedure Rules [18]. It reportedly reduced 'unnecessary cost' and 'delays' in the Criminal Justice System [19]. The SFR procedure was piloted for one year and reported an increase in guilty pleas and fewer discontinued cases following its use [19].

There are two types of reports that may be created: SFR1 and SFR2. The SFR1 report consists of a summary of the forensic evidence and is neither a witness statement nor an expert's report. Section 8.1 of the National Streamlined Forensic Reporting guidance states that the content of the SFR1 varies between circumstances, but it may contain the results that were obtained; a comparison of those results; and/or the result of the comparison or analysis [18]. In terms of fingerprint examination, if an expert had made an identification, contemporaneous notes were to include the name of the expert, the date of the examination, the name of the identified person and the digit or palm used in the identification. This knowledge was acquired through the authors observation of bureaux practise. If the reporting outcome did not report an identification, the outcome would simply be recorded on the case management system. There was an absence of reference to the analysis or comparison stages in the SFR1. This could make any subsequent audit of the work difficult to assess and reproduce, which could have significant implications for any instances where a 'difference of opinion' exists, such as that witnessed in the cases of HMA-v-McKie [7] or R-v-Smith [6].

[1] An area comprised of the combination of friction ridge flow, friction ridge characteristics, and friction ridge structure to include creases[31].

[2] These are any notable part of the friction ridge detail. All information assisting with establishing the identification of an area of friction ridge detail can be termed as 'features'[31].

[3] During the formation of friction ridge detail, the ridges may develop breaks or deviations which practitioners refer to as characteristics. The sequencing and position of the characteristics allow the friction ridge detail to be used as a means of human identification[31].

Furthermore, with R-v-Smith, fingermarks taken from the crime scene were re-examined. An absence of working notes failed to provide transparency to the examinations that were undertaken. Since the adoption of ISO 17,025 accreditation, where a difference of opinion has occurred and there is still disagreement between the experts involved then there is a requirement to communicate this in the SFR1.

If the case is disputed by the defence expert, an SFR2 report is produced which answers any questions and/or disagreements that the defence expert has [8]. It is presented as a witness statement, with an expert's declaration under Criminal Procedure Rules 19.4(j) [18] and the 2015 Criminal Practice Directions 19B, if required [20].

According to Bunter when a full evidential statement is made for court the notes maybe retrospectively recorded and not contemporaneous [8]. It is reasonable to accept that in some instances working notes are made at the point at which is practicably possible, such as following a DNA clean environment or filtered light analysis, where the working environment may prevent notes from being recorded. A significant issue and risk with the retrospective process is the opportunity for bias, since the scientist is writing notes to support a known conclusion. Without making notes at the time of the examination there is no evidence to support the opinion of the scientist that the notes concur with the thoughts and opinions that the person held at the time of the original examination. Also, the SFR1 and SFR2 reports are not necessarily completed by the same person, since the SFR1 may not be a statement produced by a person qualified to give evidence or who has undertaken the forensic analysis [19]. If the person writing the report is not the person that carried out the initial examination, then the difficulties associated with the production of retrospective note taking are likely to be magnified, as the reporting examiner must assume the opinion of the former examiner. However, in fingerprint examinations it would be unusual for a different expert to complete the SFR2. This is because the SFR2 is produced in response to the defence challenge to the original identification report (SFR1), and it may be best practice to have the original expert to address that challenge via the SFR2.

It is possible that evidence used for preparing a statement for court may include materials which were not used or available at the stage of the initial identification being made. For example, if the arrest set of fingerprints disclosed different areas of friction ridge skin to those originally used to identify the mark. This would understandably create differences between the content of the initial examination and any subsequent examination.

This research team have been investigating changes to documentation strategies in the wake of ISO 17,025 and working with fingerprint bureaux to identify effective strategies for documentation. The purpose of this paper was to establish a benchmark for documentation strategies relative to ISO 17,025 accreditation based on the examination of scientific and grey literature. This was followed by a white box study to gain an understanding of examiner thought processes during examinations, which have highlighted and supported a strategy for documentation that is now used in casework.

2. Methodology

Academic research publications and policies (grey literature) which contained suggested content for fingerprint examination documentation were used to create a checklist, referred to as the 'ACE-V checklist' throughout this paper and which can be seen in Fig. 1.

A gap analysis between the existing operational documentation practise (prior to IS0 17,025 accreditation) and the ACE-V checklist was conducted, to establish how the existing strategy aligned with best practise guidance and to create a template for participants to use during the white box study, as described below.

As part of this research, a white box study was conducted to understand experts' decision making during the 'Analysis' of eight friction ridge skin marks. The marks were carefully selected by the researcher and non-participating fingerprint experts from an existing ground truth database Some of the marks were affected to varying degrees by substrate interference, pressure distortion, deposition pressure and the visualisation process, to provide marks that were representative of those encountered in casework.

In operational UK Fingerprint Bureaux, fingermarks may be assessed according to the marks' 'sufficiency for identification'. The team used the following grading system to assess all marks' 'sufficiency for identification'. This system is currently used by the collaborating bureau for validation purposes. The research team are aware that there are alternative systems used to assess fingermarks but chose to work with the following system given that it was used by the collaborating institution and reassured the collaborating experts and therefore the research team that the marks were fit for purpose. For each grade, an associated description is provided.

Assessment of mark 'sufficiency for identification'

- Grade 1 – Clear 1st and 2nd level detail sufficient to see pattern or area of palm, clearly identifiable.
- Grade 2 – Clear 1st and 2nd level detail visible sufficient to identify, may not be able to establish pattern or area of palm, some areas not clear or distorted.
- Grade 3 – 1st and 2nd unclear, limited quantity, distortion, but sufficient for identification purposes.
- Grade 4 – poor quality 1st and 2nd level detail, quantity insufficient for identification purposes.

Images of the friction ridge skin impressions used in the white-box study are provided in Fig. 2 with information relating to factors that were introduced to purposely affect the marks. The definition of each grade is provided in this figure, which also shows which grade was assigned to each mark.

Thirty-one fingerprint experts from six UK fingerprint bureaux and two independent companies participated in the study. This study replicated the collaborating fingerprint bureau's existing documentation strategy (prior to ISO 17,025 accreditation), which concurred with other collaborating bureaux, where examiners were required to record the reporting outcome on their case management system. These outcomes were 'sufficient', 'insufficient' or 'suitable for suspect comparison only'.

- Sufficient - any mark that the examiner deemed had enough detail present to compare to another mark and which could be searched on the AFIS database, Ident 1.
- Suspect comparison only – any marks which were slightly distorted or had little friction ridge detail present but enough detail to identify the pattern[4] type for elimination purposes.
- Insufficient - any mark that lacked all levels of detail[5] and prevented a comparison.

If the mark was deemed 'sufficient' then the following information was entered. Experts' input which finger or area of palm they believed was present, the pattern type (if known) and which geographical database was to be searched for potential comparators (e.g., local, regional or national). When available, case information was provided to examiners in their routine casework and therefore a summary of a fictitious case was provided for the project. It contained the offence, location of the mark, development technique and how the mark was recovered. As the results were the product of research and not casework, a case management system was not used. Consequently, the process was

[4] The arrangement of friction ridges formed during foetal growth. The pattern is classified into one of a number of types of pattern[31].

[5] Three levels of detail are recognised. First level detail refers to the friction ridge flow and / or pattern type. Second level detail refers to ridge characteristics. such as ridge endings and bifurcations. Third level detail refers to friction ridge shape, relative pore location, edge details and ridge width[31].

ACE-V checklist	Present (✓) or Not present (X)
Unique reference number	
Date of examination	
Start time of examination	
End time of examination	
Materials used in examination	
If the friction ridge skin is consistent with finger or palm mark	
Which finger or area of the palm likely produced the mark	
If the friction ridge skin is part of a sequence, individual or multiple marks	
If there is a relationship to other marks which can aid with their decision	
Location of the mark on the surface	
Orientation of the mark	
Quality of the mark	
Quantity of the mark	
What the matrix is	
Volume of matrix	
Presence of contaminants	
Signs of movement	
Amount of pressure	
Substrate interference	
Any overlapping	
Any development technique effects	
What level 1 features are present?	
What level 2 features are present?	
What other features are present?	
Number of the level 2 features present	
Confidence level assigned to features observed	
What feature rich area is selected for comparison	
Level 1 features annotated	
Level 2 features annotated	
Any other features annotated	
Result of examination at Analysis stage	
Features in agreement	
Explanations	
Additional features recorded	
Reporting outcome at Evaluation stage	
Identifier	
Anatomical source	
Copy of reference prints	

Fig. 1. The ACE-V checklist.

replicated in paper hard copy. A free text box was added to allow experts to explain the reasons behind their conclusion and to meet with the needs of the white-box study (this was not a routine task prior to ISO 17,025 accreditation). In this paper, this method is referred to as the 'unprompted' method.

Two months later, the same examiners were asked to complete an analysis of the same eight friction ridge impressions using the online software 'PiAnoS'. A useful description of PiAnoS is captured in [17,21]. During the analysis, participants were prompted to annotate the impressions, assigning confidence levels relating to the quality of the mark and identify ridge characteristics using the GYRO system [17]. Following the annotations, participants were asked to explain the quality of the mark in a series of multiple-choice questions, including, general distortion factors; palm and finger segment positions; the general pattern; the quality of level one, two and three detail; and the suitability of the mark for comparison. Progression onto the next stage was dependent upon completion of each 'prompt'. In this paper, this method is referred to as the 'prompted' method.

The ACE-V checklist was divided into the following subcategories: generic information; factors affecting the mark; level one/two detail and annotations; and reporting outcome. A gap analysis was performed between the ACE-V checklist categories compared to each of the participant responses for the unprompted and prompted method. The results were compared to determine the consistency between examiners when using both methods. The frequency of themes entered as free text in the unprompted method was also recorded.

Chi-square tests were conducted to determine any association between the checklist subcategories and the grade of the mark for both methods. To investigate the impact of the significant associations effect size was calculated. For Chi-square this was reported as w. To calculate w, the square root of Chi ($\chi 2$) was divided by the number of responses and interpreted according to Cohen (1988), where a small effect size = 0.1, a medium effect size = 0.3, and a large effect size = 0.5 [22]. The required sample size was calculated using power analysis where initial results were non-significant. 0.8 was used to find the optimal sample size based on the effect size achieved [23].

The results of these studies were used to devise a documentation strategy for an operational English fingerprint bureau that contained a 'Mark Analysis Form' to record the working notes of the examiner.

3. Results and discussion

The content of the ACE-V checklist, which formed the basis of the gap analysis, was based on published guidance summarised in section 3.1.

The gap analysis between the pre- ISO 17,025 accreditation documentation approach and the ACE-V checklist is summarised in section 3.2.

Section 3.3 presents the results and discussion of the white-box study

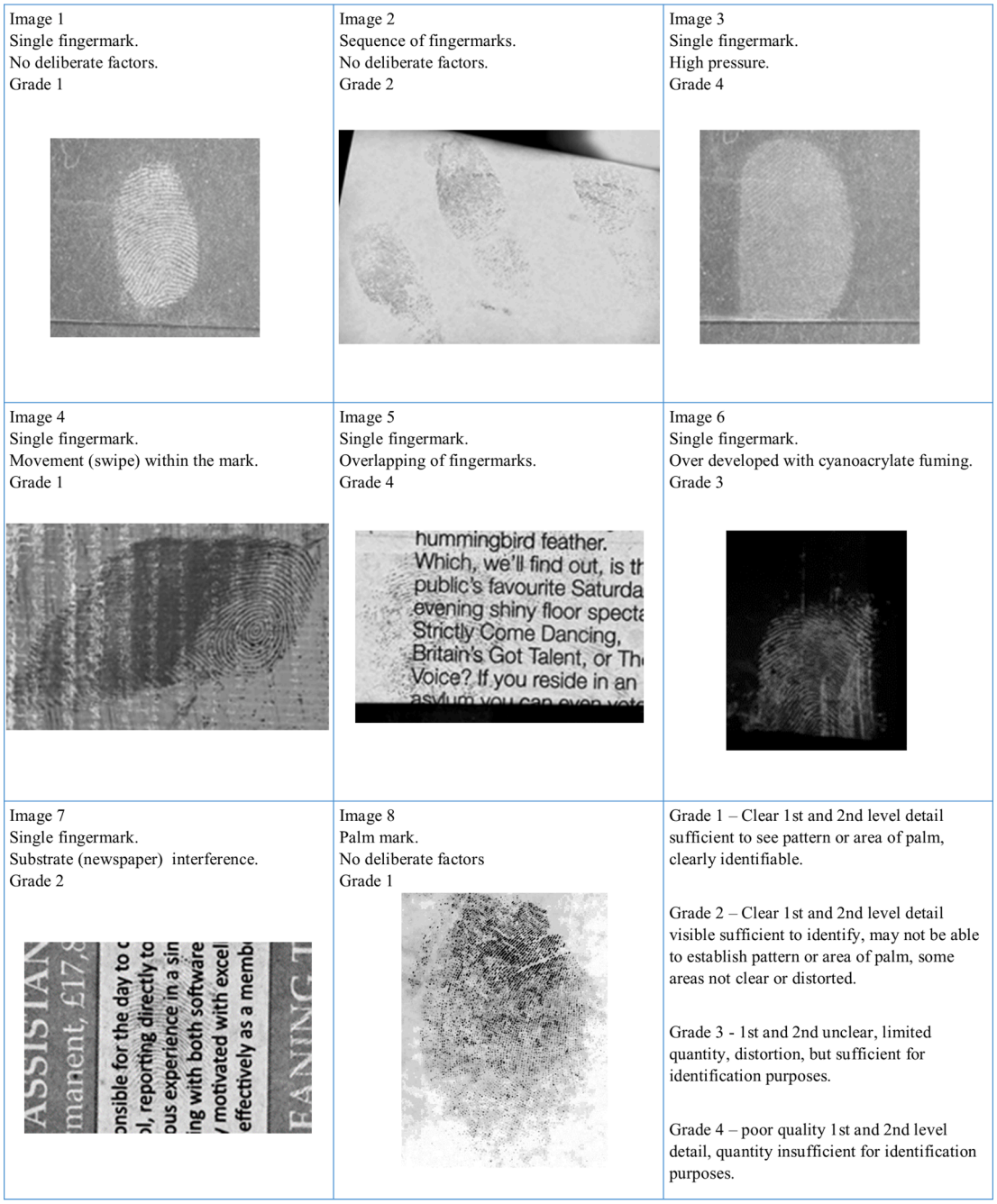

Fig. 2. The friction ridge skin impressions used in the white-box study with associated grades.

that was used to obtain the participating examiners' thought processes, and which contributed to the formation of the Mark Analysis Form, currently used in an English fingerprint bureau for casework.

3.1. Creating the ACE-V checklist

The information to be documented during fingerprint examinations that was suggested within published academic and grey literature is summarised in Table 1. The authors were surprised at the relative dissimilarity in the guidance, which was attributed to differences between those publications resulting from academic research and those aligned with the development of regulations for working practise, some of which existed prior to or without the need to refer to ISO 17025 accreditation. Only those which existed prior to accreditation have been used as part of the research, but for comprehension of literature in the paper, updates have been included.

According to The Crown Prosecution Service: Guidance for Experts, documentation should be produced contemporaneously, whenever practicable. Generic information such as the date, names of experts involved in the examinations, the materials used in the examination and all communications should be recorded, which concurs with the guidance provided by the Forensic Science Regulator [1,12].

It mentions the requirement for experts to produce 'sufficient detailed notes', which can be interpreted by another examiner with similar expertise to follow the nature of the work undertaken and understand the conclusions drawn [4]. This statement has also been seen in

Table 1
A summary of guidance relating to information to be recorded during fingerprint examinations according to published sources of literature.

	Sources of literature						
Information to be recorded	**CPS**	**Champod and Langenburg**	**The Fingerprint Inquiry**	**SWGFAST**	**ENFSI**	**Bunter**	**Forensic Science Regulator**
Year of Publication	**2010**	**2011**	**2011**	**2013**	**2015**	**2016**	**2020**
Name of the experts	X						X
Date/URN	X						X
Materials used	X						X
Any communications	X		X				X
Assigning confidence levels		X				X	
Assessment of mark quality			X		X		
Deltas and cores present					X		
Orientation of the mark				X			
What the matrix is				X			
Mark origin				X	X		
Presence of level 1				X	X		
Any signs of distortion			X	X	X		
Factors affecting the mark; e.g., superimposition, substrate				X	X		
Annotate the images		X				X	
Minutiae at analysis			X	X	X		
Minutiae at comparison			X	X	X		
Revisions at comparison			X				
Third level detail			X	X	X		
Explanation of mark differences			X				
Reasons for conclusions	X		X	X			X
Sufficient detailed notes	X						X
Records of examination							X
Sequence of recording contemporaneous notes							X
Reporting outcomes							X

the Forensic Science Regulator's Codes of Practice and Conduct [1,12], which provided guidance that is specific to fingermark examinations. A perceived issue with the term 'sufficient' was that it is subjective in nature, meaning that there are likely to be differences in the quantity and content of the notes that are produced, which may or may not meet with another examiner's opinion of 'sufficiency'.

Recommendations 50 to 53 (of 86) of the Fingerprint Inquiry [7] provided guidance on what, when and by whom notes should be taken. For example, recommendation 50 stated that "examiners should always take notes when they are examining marks that they consider to be complex", which is another subjective term without a universally accepted definition, although the term is recognised by the Forensic Science Regulator [12].

Recommendation 51 of the Fingerprint Inquiry [7] stated that "notes should be taken in any case in which a fresh comparison is made in response to a request from the Crown for a report". Although not necessarily linked, this recommendation is satisfied by the Streamlined Forensic Reporting process. There is evidence that additional examinations may lead to inter or intra examiner variability, as highlighted in the work of Ulery *et al* [24], where decisions were changed to or from 'inconclusive' or 'value for exclusion' by examiners repeating an analysis of 25 image pairs of fingermarks. Given that differences of opinion can exist with repeat comparisons (within and between examiners), effective note taking practise could and should establish the basis for any differences in the conclusions drawn. In addition, notes made at a later stage may be written with the knowledge of other forensic evidence, providing further opportunity for bias. A retrospective process poses difficulties for any expert who changes their mind, which can happen given that the process is cognitive.

Recommendation 52 of the Fingerprint Inquiry [7] stated that notes should be taken at each stage of the ACE-V process and individual notes by each expert involved in the examination. Whereas recommendations 50 and 51 related to note-taking for complex marks or additional examinations, recommendation 53 suggested that note-taking should become general practise for all fingerprint comparison work and that by recording this information, an expert would be explaining how they reached their conclusion for the fingermark. Although guidance for the content of contemporaneous notes is provided in recommendation 52, there are areas highlighted in alternative literature that are not considered here, as demonstrated in Table 1.

A significant problem raised by expert witness' in The Fingerprint Inquiry [7] was the length of time in which it could take to produce contemporaneous notes for each case. One expert stated that "it would not be practical to take notes for each case". According to expert witness' involved in the Inquiry, note-taking would have a major impact on productivity and efficiency. However, it was agreed that the quantity of the contemporaneous notes made would be influenced by the perceived quality of the fingermark under examination; the poorer the quality of the mark, the more detailed notes should be provided. According to the minutes of the Fingerprint Quality Standards Specialist Group published in 2018, the UK Accreditation Service was not prescriptive in the methods required to produce contemporaneous notes and were open to different practises to achieve the same goal [25]. This was perhaps useful given variations that exist in practise and the availability and usage of technology for examination. The authors have witnessed variations in working practise with the creation of working notes for fingerprint examinations following ISO 17025, although variations in documentation practise, including the contents of documentation are also yet to be independently compared and evaluated in this field.

In 2012, the Scientific Working Group on Friction Ridge Analysis, Study and Technology (SWGFAST) [26] published guidelines recommending the linear analysis of unknown marks. In agreement with the European Network of Forensic Science Institute (ENFSI) [27], the group suggested that the level of detail recorded should depend on the quality and quantity of friction ridge detail. Also, if known to the expert, the substrate, development technique and preservation method should be recorded and additional factors such as matrix, deposition pressure, movement, and level 3 detail, could be recorded if known [26]. In these guidelines, the features identified during the analysis would be relied upon during the comparison. The name and date of birth of the

individual identified and a reference number for the case was to be recorded during the comparison phase when an identification was made, only. However, if the known mark was deemed as 'insufficient for comparison', then they recommended that this was explained in the notes. According to SWGFAST [26], within the Evaluation phase, the expert should record the friction ridge impression examined, known prints used to reach the conclusion, the specific anatomical source and initials and signature of the expert. It must be noted that SWG (Scientific Working Groups) ended in 2014, and all their documents were transferred to OSAC (Organisation of Scientific Area Committees). These documents are still in use until new documents produced by OSAC are available.

There are some similarities between the Best Practice Manual for Fingerprint Examinations, published by the European Network of Forensic Science Institutes [27] and the Fingerprint Inquiry recommendation 52 [7]. The manual encouraged reference to any distortion or superimposition present, any effects due to development technique and whether friction ridge flow[6] or individual characteristics could be identified, which could be recorded during the analysis of a mark and used towards the comparison, dependent on the case. The manual requested explanations on experts' thoughts during the original examination. However, it also suggested providing more information regarding the number and type of ridge characteristics present, which is supported by SWGFAST [26] and understandable due to the contribution that ridge characteristics make to fingermark identification. The authors have witnessed differences in the choice to and approach to the recording of ridge characteristics, which supports the findings of the Fingerprint Quality Standards Specialist Group in terms of the openness of UKAS to different approaches to note taking [25].

In 2011 and previously referred to in this paper, a reportedly transparent approach to ridge characteristics annotation was proposed by Langenburg and Champod, referred to as the 'GYRO' system. This system was also recommended by Bunter [8], whereby the expert assigns a confidence level to each characteristic observed.

3.2. Gap analysis of pre-ISO 17-25 documentation approach and ACE-V checklis

Once the ACE-V checklist was completed, professional discussions commenced between the research team and a senior fingerprint expert in the collaborating bureau (who adopted the documentation approach) to establish existing working practise and to facilitate the gap analysis. Each section of the checklist was discussed in relation to the possibility that a fingerprint expert may observe it in an examination and subsequently record it for future reference.

It became apparent that most of the ACE-V checklist was not recorded in routine working notes prior to ISO 17,025 accreditation and although the content of the ACE-V checklist was supported by the senior expert, it was suggested that fingerprint experts would have cases where they would think about the documentary suggestions seen in the checklist, but there was no requirement to write this down. As discussed, this lack of contemporaneous notes was highlighted within R-v-Smith [6] whereby an expert did not provide a detailed account of the examination or reasons for the conclusion which ultimately led to the case being quashed and contributed to the requirement of ISO 17,025 accreditation, which in part refers to the production of contemporaneous notes.

The only information recorded was on a case management system called Socrates. This information included the reporting outcome at analysis stage, such as 'sufficient for comparison on Ident1′, 'sufficient for manual comparison' (against a suspect/victim's ten print card) or 'insufficient detail for comparison'.

If the mark was 'sufficient for comparison on Ident1′ the expert would input details to narrow the search for a comparison friction ridge skin impression from the national database. This information included which digit or area of palm it was likely to have originated from, the pattern type visible, and the geographical search location. There were four separate databases: police elimination database; local; regional; and national, and the expert would decide how wide the search would be dependent on the crime.

Using the information derived from the discussion, the form used for the white box study replicated documentary procedures prior to accreditation. This included the start date and end date of the examination, fictional mark information to aid with the examination (as this would be provided in casework), the reporting outcome at analysis (like the case management system) and Ident1 search information. To gain an understanding of the thought processes and to establish key points to record in future documentation procedures, a free text box was included. No guidance on what should or could be recorded was provided as it was of interest to the research team to see what they thought was important to record and if there was any consistency between experts.

3.3. White box study

A white-box study is an investigation of the internal logic and structure of a process. For example, understanding the decision making of an outcome by a fingerprint expert. A black box study only tests the fundamental aspects of that process and has no or little relevance with the internal logic and structure. For example, the variance within experts' reporting outcomes [28].

3.3.1. Generic information

The generic information category comprised key information to allow a traceable search of the case and a record of the procedures carried out by the original examiner, including the materials used and information about the area of friction ridge skin under examination. A summary of the results is available in Figs. 3a and 3b.

Over the eight images, each documentary suggestion within the generic information category was recorded at least once, which implied that the suggestions were relevant and recorded. There was clear evidence of increased consistency with responses using PiAnoS, which was not surprising because participants were prompted to answer questions about the marks.

According to the results of routine practise (unprompted), there was high consistency in participant responses for the Unique Reference Number, date, time, digit or palm selection, which is understandable given the role of this data in casework. The PiAnoS software was not used for casework by any of the participants, which explains why this information was not recorded.

There was a low response rate for the materials used, despite its inclusion in The Codes of Practice and Conduct for Fingerprint Comparisons [1,12]. This is likely to be because the codes would not have existed when the case management systems were created.

Participants recorded if the impression was a finger or palm for marks graded 1 to 3 and there was a consensus with the reporting outcomes. In operational work, when a mark is deemed 'sufficient' for an Ident1 search, an examiner may input the finger they believe the mark to have originated from, which explained the consistency of responses. Despite this consistency, not all participants agreed which finger or palm they believed the mark to have originated from. This type of human error may contribute to misidentifications, although recording this feature in working notes allows the error to be identified. Further prompts could establish the basis for this decision, based on shape, size and contours, significant ridge flows, the presence of a classifiable pattern or the presence of flexion creases. This could be an effective training tool to identify existing or ongoing training issues.

A relationship between the marks was only recorded in the free text

[6] The path and arrangement of the friction ridges across the surface of the hands and feet. The friction ridge flow on the top section of the fingers flows into patterns[31].

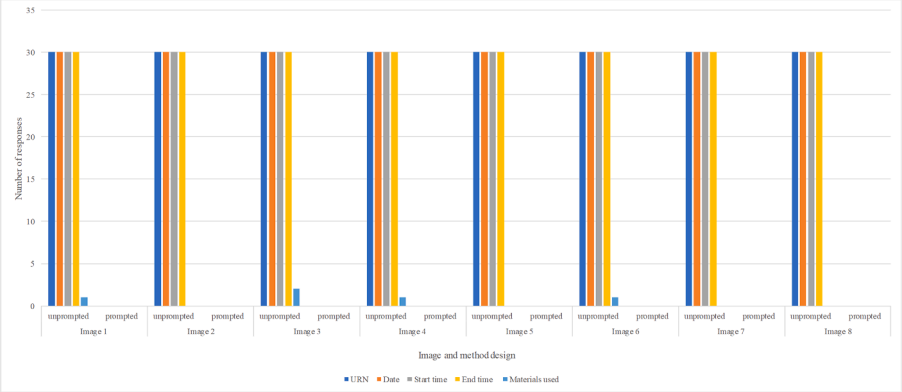

Fig. 3a. Generic information responses using unprompted and prompted methods part 1.

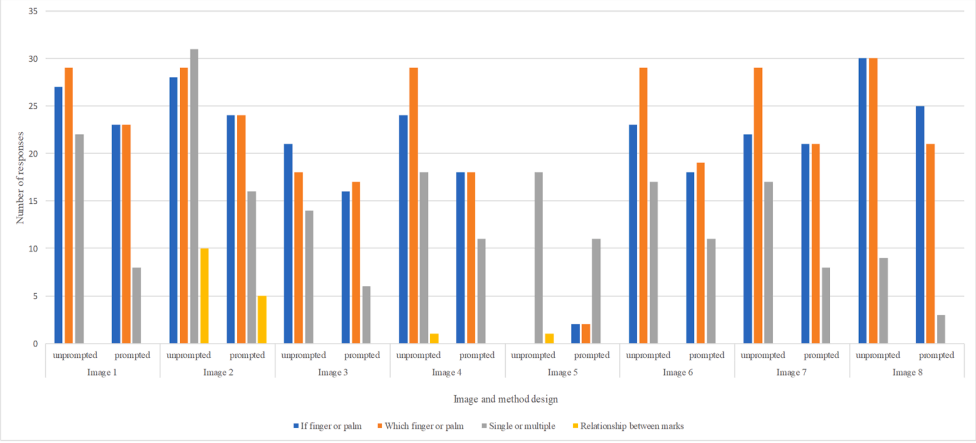

Fig. 3b. Generic information responses using unprompted and prompted methods part 2.

box when a sequence of marks or multiple marks were present, but the response rate was low, suggesting that this was not routinely recorded.

Chi square was used to identify any significant associations between the ACE-V checklist and the grade of the mark. Most tests found no significant association between the documentary suggestions and the grade of the mark, which implied there was more consistency between experts' response for a particular category, despite the grade of the mark.

A significant association between the ACE-V checklist and the grade of the mark was found when documenting generic information during the analysis using the unprompted approach ($\chi 2\ (9) = 17.97$, $p = 0.036$, two-tailed test). This implied a lack of consistency between experts', which was attributed to the observations already discussed in the 'relationship to the marks' category. This meant experts had recorded the fact the mark was part of a sequence. In comparison to the other marks reviewed through the other checklist categories, the participants were significantly higher than expected. The total count for a good mark (grade 2) was 10, whereas its expected value was 4. This difference was explainable because a count of 10 was an average taken from two grade 2 marks within the test, one of which was a sequence of marks as opposed to a single mark.

If the sequence marks were omitted, this would probably have resulted in no significant associations between the level of documentation recorded by experts despite the grade of the mark. This was supported by the initial observations, where higher consistency between examiners when prompted to record finger or palm and which finger or palm was requested.

3.3.2. Factors affecting the mark

The second category of the ACE-V checklist was 'factors affecting the mark', which related to the recording of information about the position of the mark, its quality and quantity, and factors affecting the visual quality of the mark (if any), such as substrate interference, development technique, pressure applied during deposition, movement, and overlapping of marks. These factors may explain why a mark is deemed 'insufficient for comparison' or 'inconclusive' and the results are

summarised in Figs. 4a and 4b.

Overall, there was less consistency between experts in this category compared to the 'generic information' category. This was expected due to the subjective and often difficult nature of the interpretation and the information recorded in this category was heavily dependent on the grade of the mark.

The location of the mark was not recorded on either documentation approach. This may be because it is recorded elsewhere in the case information. The matrix was also not recorded, although all marks were latent and therefore this would be difficult to define as such. Marks in alternative matrices, such as blood, may be defined as 'complex' and subsequently receive a different course of documentary action, consistent with the guidance of the Forensic Science Regulator [1]. This study did not include any marks deposited in blood therefore all impressions were documented in the same procedure, relevant to the bureaux guidelines.

The 'quality of the mark' was most frequently recorded, although not all participants recorded this using the unprompted approach whereas participants were asked about it directly using PiAnoS. Quality may be defined differently by examiners. For instance, Hinklin defines quality against two axes: clarity; and how useful the features in the mark may be during the examination of a mark [29]. A mark displaying low clarity, for example, may still retain a significant number of features that could be used for an examination. In this project, it is difficult to ascertain the participant's definition, and can only rely on the notes that were made. The quality of the mark was recorded more frequently for grade 1 and 2 marks compared to grades 3 and 4. For example, participants would state that the mark was of good quality (grade 1 and 2) or the mark was affected by a factor, rather than stating it was a poor-quality mark (grades 3 and 4). That said, the quantity of information was expected to be higher in poorer quality marks.

Image one was a grade one mark from the ground truth database, with deliberate, little interference to the mark from factors such as movement, pressure, substrate, overlapping and development technique. Images four and eight were also grade one marks, deliberately impacted with movement (left swipe) or the development technique. When the documentation was compared for these marks, there was more variety in response in the unprompted approach in comparison to the prompted approach. When participants are asked direct questions, there was more consistency. For example, of the 27 participants, when prompted, 17 recorded the presence of movement in image four, which was a higher response than the unprompted approach.

Images two and seven were graded two. Image two was a sequence of marks developed using ninhydrin, which caused a 'dotty' appearance to the ridges. The impact of the development technique on friction ridge detail was recorded by 13 participants (of 27) when prompted, which again, was a higher rate than the unprompted approach. It is possible that some experts were not confident in attributing the "dotty" appearance of the ridges directly to the use of Ninhydrin. Image seven was deliberately affected by background, where the newspaper prints ran through the friction ridge detail. All participants recorded this factor using the prompted approach, with the increase attributed to the patency of the situation.

Image six was the only grade three test mark image. It was over-developed with cyanoacrylate fuming, which reduced the clarity of the mark. This was only discussed by one participant over both approaches. Instead, participants focused on movement and pressure, which was their interpretation of the mark.

Images three and five were graded four. These are the two marks which had a difference of opinion in the reporting outcome. Despite having the same grade, the marks were affected by different factors, which may have explained the difference of opinion in the reporting outcome. Image three received a majority outcome of 'suspect comparison only'. This meant that participants believed they could see the pattern and some friction ridge detail, which may help with an exclusion, but the friction ridge detail could not be entered into Ident1. Nineteen participants discussed substrate distortion (the mark was intentionally impacted by heavy pressure). Only five participants recorded this as a factor using both approaches. Again, there was more consistency using the prompted approach compared to the unprompted approach although it is possible that examiners didn't produce any working notes relating to distortion because it didn't affect their examination.

Thirty participants stated image five was 'insufficient for comparison', with one exception of 'suspect comparison only'. The most recorded factor in the unprompted approach was overlapping (n = 16) (which was the deliberate factor affecting the mark). However, other factors contributed to the quality of the mark, such as substrate interference (the mark was deposited on newspaper) and visualisation effects from ninhydrin. These factors were recorded as well as pressure and movement. The results from the prompted approach showed the highest response was substrate (n = 25). This was closely followed by

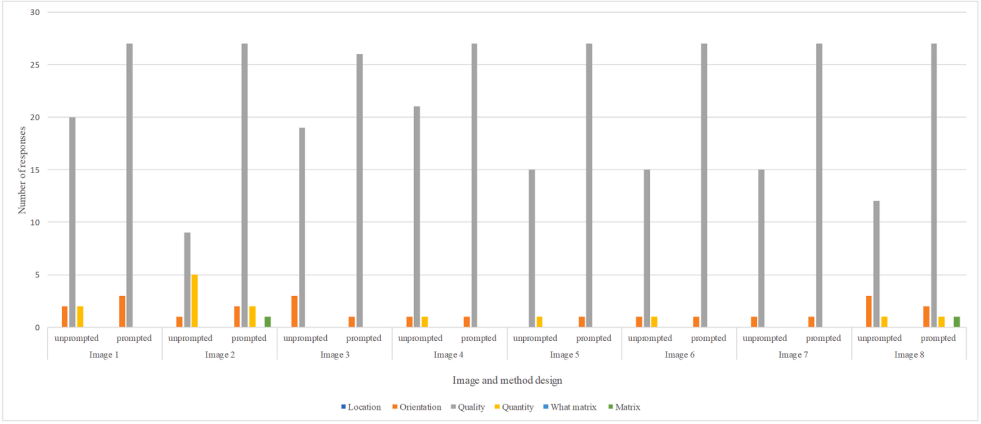

Fig. 4a. Factors affecting the mark responses using unprompted and prompted methods part 1.

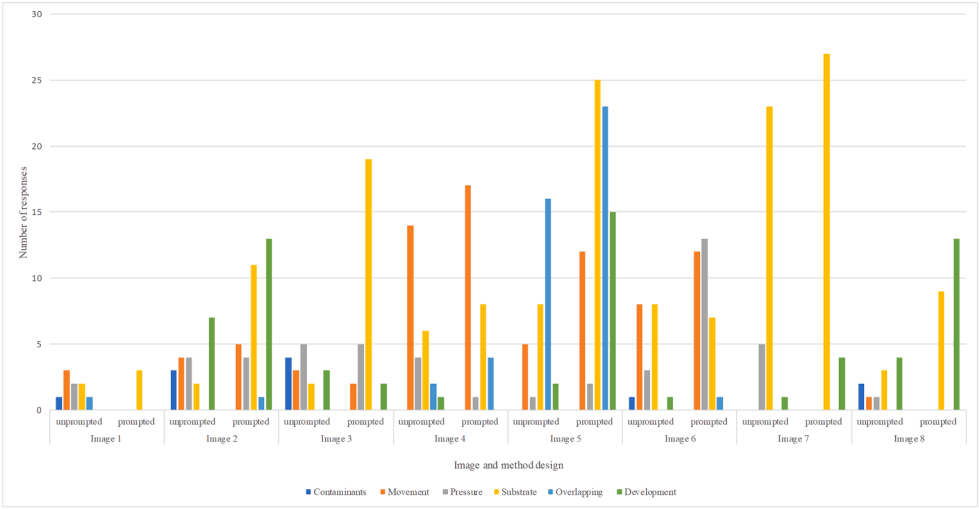

Fig. 4b. Factors affecting the mark responses using unprompted and prompted methods part 2.

overlapping (n = 23). Other factors were also recorded, as shown in Fig. 4b.

Orientation was not frequently recorded using either approach.

Due to the number of factors in this category, for the Chi square tests the category was split into two tests. The first test 'factors affecting the mark and the grade of the mark' involved orientation, quality, quantity, and the presence of contaminants in the mark. The second test 'more factors and the grade of the mark' involved presence of movement, substrate interference, pressure distortion, overlapping marks and development technique effects.

The significant associations lay between the documentary suggestions and the grade of the mark when documenting the second test factors during the analysis using the unprompted approach ($\chi 2$ (12) = 29.167, p = 0.004, two-tailed test). This implied there were inconsistencies between the experts' response, which is likely to be due to the use of a free text box. The biggest residuals appeared in the overlapping category between good and poor (-1.6 and −1.5). For both, there were significantly fewer people recording these factors than would be expected. Again, this was seen in the first test category in the good grade (-1.6), where there was also significantly less than expected.

A greater than large effect size of 0.97 was found according to the right level of power (it should be 0.8). This was a robust finding, supporting the fact that factors affecting the mark (first test) impacted the quality of the mark and may provide support that these factors should be recorded in working notes.

The second significant association lay between the documentary suggestions (ACE-V checklist) and the grade of the mark, when documenting the second test factors using the prompted approach ($\chi 2$ (12) = 52.023, p < 0.001, two-tailed test). This implied there was less consistency between the experts' response for that category across all grades of the marks. Even though the prompted approach encouraged experts to record different factors affecting a mark, there appeared to be inconsistencies between what experts identified as affecting the mark. In a cognitive process, this is to be expected as examiners can only give their opinion in the absence of ground truth. The highest residual was in the category 'pressure' for a poor grade mark, which was 3.9, meaning that more people recorded it than expected. When observing the expected counts, there was a clear increase, suggesting that experts were more likely to record factors affecting the mark (movement, pressure, substrate interference, overlapping and development technique) for poor and unusable marks, supporting the initial observations.

From the results, participants were most likely to record substrate interference over the other factors, potentially due to the ease of identifying this as a factor compared to less obvious factors, such as pressure applied during deposition.

A greater than large effect size of 1.39 was found according to the right level of power (0.8). Again, it was a robust finding, suggesting that factors affecting the mark impact on its quality and should be recorded in working notes.

3.3.3. *Level of detail and annotations*

The final category related to identifying fingerprint patterns and ridge characteristics. In routine casework, level one information was input to Ident1 when searching the database, which explained the high consistency between responses during the unprompted approach.

As shown in Figs. 5a and 5b, all participants recorded level one detail for marks graded 1 to 3 for both approaches. The results from the grade three mark coincided with this definition of '1st and 2nd unclear, limited quantity, distortion, but sufficient for identification purposes' because the reporting outcome was majority 'suspect comparison only' (n = 20), followed by 'sufficient for comparison' (n = 9), with both outcomes implying the pattern was present. The prompted approach included a question relating to the pattern type present within the mark, which explains the high response rate.

The remaining documentary suggestions within this category were less likely to be recorded within the unprompted approach (as they were requested in PiAnoS). This included the presence of level two detail (ridge characteristics) and other features (scars, pores), as well as annotating the mark to show these features.

As well as the presence of level two detail and the mark up of these characteristics, it was suggested to record the number of ridge characteristics present [7,26,27]. It was not common practise for this to be recorded prior to accreditation, which explained the low numbers (unprompted approach). It was a requirement of PiAnoS, hence the conformity. According to Ulery *et al* [24], since the numeric standard was abolished, fingerprint experts have not used an official threshold, more so a personal threshold.

In this study, using the prompted method, the position of the ridge characteristics, the characteristics identified, and the total number of ridge characteristics differed between participants and between marks.

There is evidence from the work of Ulery *et al* [24] to suggest that the number of ridge characteristics recorded may affect an examiners

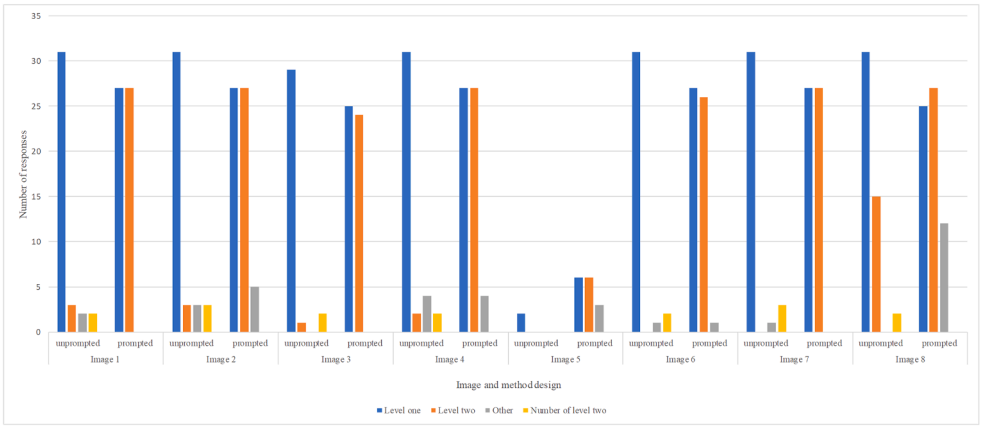

Fig. 5a. Level of detail and annotations responses using unprompted and prompted methods part 1.

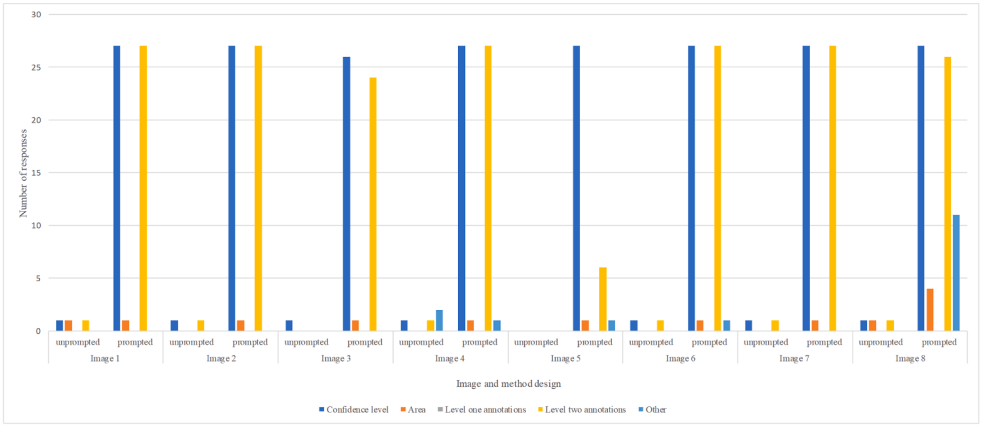

Fig. 5b. Level of detail and annotations responses using unprompted and prompted methods part 2.

decision of sufficiency. In this study, for an identification, one third of the participant group (n = 170) recorded eight or fewer ridge characteristics, whereas others had a minimum count of 14. When outliers were removed, the results showed identifications were made with as few as six corresponding ridge characteristics. In the authors' experience of reviewing annotations of friction ridge detail, it is not possible to ascertain whether ridge characteristic annotations are exhaustive of all ridge characteristics available (in the opinion of the examiner). If the number of ridge characteristics affects decisions made by examiners, it could be logical to assume that the decision to record ridge characteristics (or not) could equally contribute to differences in reporting outcomes, consistent with the work of Dror, where the written report itself is believed to influence the work that is produced [30]. The research team are interested in the impact of annotating ridge characteristics on the identification process, such as the effects of intra and inter examiner variations on an AFIS comparator list and, how annotations contribute to a 'sufficient auditable trail'.

Compared to the other categories, fewer notes were taken for the grade 4 mark, as expected due to its quality. There were no annotations for level one detail using the prompted approach, (this was not requested by the software). Future developments could include tools to indicate where deltas are within the mark.

No significant associations between the documentary suggestions for 'level of detail and annotations' and the 'grade of the mark' were found. Participants were more consistent when using the prompted approach because of the prompts compared to the unprompted approach, which supports the initial observations already reported.

3.3.4. *Production of the documentation strategy: The mark analysis Form*

The most frequently suggested documentary content from the ACE-V checklist and the results from the white box study were used to create a form that is used in operational practise to record the 'Analysis' phase of the ACE-V process, subsequently known as the 'Mark Analysis Form' (MAF), as shown in Fig. 6. The Mark Analysis Form adhered to ISO

URN:	Expert:	Date:

Exhibit	Area	Finger (F) Palm (P) Phalange (PH) Unknown (U)	Pattern /\ A W U N/A	Core (C)	DELTA (D) Left (L) Right (R)	SEQUENCE	CHARACTERISTICS	DISTORTION/MOVEMENT	BACKGROUND INTERFERENCE	OVERLAID	BLURRED/SMUDGED	GRANULATED (Dotty)	CREASES	SCARS	FAINT (F) DARK (D)	NOT SEARCHABLE (NS) SEARCHABLE (S) 1st LEVEL, EXCLUSION ONLY (1ST) INSUFFICIENT DETAIL (ID)	Second ✓ ✗	Checker Sign and date
						✗ ↘		✗ ↘	✗ ↘	✗ ↘	✗ ↘	✗ ↘	✗ ↘	✗ ↘				

Notes.

Fig. 6. Mark Analysis Form (MAF).

17,025 requirements and UKAS awarded accreditation to include this documentation process, which is currently used for casework at the collaborating bureau. The form included tick boxes, which accounted for the fact that participants generally recorded more information when they were prompted. A free text box was also included, for additional information.

Regulatory guidance and operational support for the inclusion of generic information, such as unique reference number, name and date justifies its inclusion in the MAF.

Digit or palm determination was frequently recorded in the white box study, as fingerprint experts were expected to record this on Ident1 to narrow the search of a suspect. This was also included in the online software, hence the high consistency between experts. Pattern type was also frequently recorded and requested on Ident1. Conversations with the senior fingerprint expert led to extending this to include the presence of cores and deltas to support the pattern type observed. For example, if an expert can see a distinctive pattern because there are two deltas, but only two clear ridge characteristics within the impression, then the impression may be deemed as 'suspect comparison only' but not entered to Ident1. The presence of cores and deltas were therefore included in the MAF.

The test images were predominantly single marks. However, there was a sequence of marks included to investigate how this impression would be documented. As expected, this criterion was not recorded regularly unless a sequence was present, and consequently, its inclusion was agreed.

Despite the numeric standard being abolished in the UK, in 2001, literature sources supported the annotation of impressions and/or highlighting ridge characteristics observed during the analysis and comparison phases. The number of ridge characteristics recorded within this study varied between individuals and impressions, and there were no significant Chi Square associations with this factor. The number of ridge characteristics observed can contribute to the reporting outcome at analysis. The collaborating bureau decided that the number of ridge characteristics recorded would be capped at 10. Any more than 10 would be recorded as 10 +. The bureau also requested inclusion of scars and creases, based on their use in operational work.

As seen in the ACE-V checklist, many sources of literature referred to factors known to impact on the quality of the mark and signs of distortion or factors affecting the mark, such as substrate interference, pressure, and development technique. The results of the white box study highlighted that poorer quality marks had more discussion points and as discussed, experts were more consistent with each other when prompted. The terminology that was included in the MAF was aligned to operational practise in the collaborating bureau. For example, development technique is referred to as 'granulated (dotty)', to highlight chemical treatment effects where the friction ridges may appear to be broken up, causing a dotty/granulated appearance. Due to the lack of ridge continuity, the friction ridge detail can be difficult to interpret and may have a direct impact on the reporting outcome [31].

The terms applied to describe the outcomes of the analyses were aligned to the collaborating bureau. Differing terminology was observed between bureaux but following conversations indicated that all have a term for marks that are 'insufficient for comparison', marks with only the pattern visible and used to exclude, or sufficient detail to compare manually or on Ident1.

If the analysis of an examiner was being reviewed or subjected to verification by a second examiner, there was a requirement to record this. In the MAF there is a box for the second examiner to sign and date (and tick if in agreement). If there is a disagreement, the examiner will put a cross in the box. A new mark analysis form is completed by the second and subsequent examiners. The second 'checker' will only sign the contemporaneous notes when an open verification has been completed and therefore the conclusions of the initial expert are made available for the second checker to review.

For a blind verification, the second 'checker' will not see the initial examiner notes as the initial conclusions from the process are not made available. They complete a separate mark analysis form. Blind verifications are conducted for the "lead" mark of each suspect identified. The lead mark is the first mark identified to one individual within the case. The other marks identified to the same suspect are checked via 'open' verification.

Other instances whereby blind verification is used is when a single mark has been excluded. This includes any cases which have multiple marks with only one mark that is 'suitable for comparison'. For example, if there were three marks in a case with a suspect and one of the marks had 'insufficient detail for comparison' (excluded), another with '1st level detail' (suitable to check against a suspect) and the third was a mark 'suitable for comparison' (using an AFIS), the mark 'suitable for comparison' would be submitted with the suspect prints for blind verification. When this has been completed and returned to the initial expert, the other marks within the case (excluded and 1st level detail) are handed to the 2nd checking expert for open verification.

For all other occasions all checks are carried out as 'open' verifications.

4. Conclusion

The results of this study have found that experts are more consistent in elements of their documentation when a prompted approach is used. Within the documentary suggestions that were identified from literature and which contributed to an 'ACE-V checklist', almost all of these were recorded by at least one expert, within one test mark. The location of the mark, what the matrix is, and level one annotations were the documentary suggestions that were not recorded.

The extent of the documentation produced was dependent on the

quality of the mark or case. In this study, more information about the mark was recorded for the grade 3 and 4 marks which represented the marks of least 'quality'.

The results of the study contributed to the formation of a 'Mark Analysis Form', which has been accepted by UKAS, evidencing that it is fit for the purposes of ISO 17,025 accreditation. Future work is examining the effectiveness of alternative strategies for documentation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

[1] The Forensic Science Regulator, Codes of Practice and Conduct: Fingerprint Comparison. Crown Copyright. Friction Ridge Detail (Fingerprint) Comparison (publishing.service.gov.uk) 2020, [Accessed: 24/09/2021].
[2] Crown Prosecution Service. Criminal Procedure and Investigations Act. Ministry of Justice, section 1996, 23(1).
[3] D. Ashbaugh, Quantitative-Qualitative Friction Ridge Analysis, CRC Press, 1999.
[4] Crown Prosecution Service. Disclosure: Experts' Evidence, Case Management and Unused Material, May 2010: Guidance Booklet for Experts. Crown Copyright. 2010, https://www.cps.gov.uk/legal-guidance/cps-guidance-experts-disclosure-unused-material-and-case-management [Accessed: 24/09/2021].
[5] Lord Chief Justice. Criminal Procedure rules and Practice Directions 2020. Crown Copyright. https://www.gov.uk/guidance/rules-and-practise-directions-2020, 2020, [Accessed 25/1/22].
[6] Regina v Smith. (2011) EWCA Crim 1296.
[7] Campbell, A. (2011) The Fingerprint Inquiry. Crown copyright. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.361.380&rep=rep1&type=pdf [Accessed: 24/09/2021].
[8] S. Bunter, ACE-V: Meaningful note-taking during its linear application, Fingerprint Whorld. 161 (2016) 10–28.
[9] GOV. Standard for fingerprint examinations. Available from Developing a quality standard for fingerprint examination (publishing.service.gov.uk) 2012, [Accessed: 24/09/2021].
[10] S.V. Stevenage, C. Pitfield, Fact or friction: Examination of the transparency, reliability and sufficiency of the ACE-V method of fingerprint analysis, Sci. Just. 267 (2016) 145–156.
[11] M. Triplett, L. Cooney, "The Etiology of ACE-V and its Proper Use: An Exploration of the Relationship Between ACE-V and the Scientific Method of Hypothesis Testing, J. Foren. Identific. 56 (2006) 345–355.
[12] The Forensic Science Regulator. Codes of Practice and Conduct: Fingerprint Comparison. Crown Copyright. 2017, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/638254/128_FSR_fingerprint_appendix_Issue2.pdf Accessed: 24/09/2021].
[13] G. Langenburg, Pilot study: a statistical analysis of the ACE-V methodology-analysis stage, J. Foren. Identificat. 54 (2004) 64–79.
[14] C. Champod, C. Lennard, P. Margot, M. Stoilovic, Fingerprints and other Ridge Skin Impressions, CRC Press, 2004.
[15] B. Schieffer, C. Champod, The potential (negative) influence of observational biases at the analysis stage of fingermark individualization, Foren. Sci. Int. 167 (2007) 116–120.
[16] R. Stacey, Report on the erroneous fingerprint individualization in the Madrid train bombing case, J. Foren. Identif. 54 (2004) 706–718.
[17] G. Langenburg, C. Champod, The GYRO System – A Recommended Approach to More Transparent Documentation, J. Foren. Identif. (2011).
[18] Crown Prosecution Service. (2015) Streamlined Forensic Reporting Guidance and Toolkit. Crown Copyright. https://www.cps.gov.uk/legal-guidance/streamlined-forensic-reporting-guidance-and-toolkit [Accessed: 21st July 2021].
[19] K. Richmond, Streamlined Forensic Reporting "Swift and sure justice?" The Journal of Criminal Law. Available from Doi: 10.1177/0022018318772701 2018, [Accessed: 24/09/2021].
[20] Courts and Tribunals Judiciary, Criminal Practice Directions: Amendment No. 8 effective from 1st April 2019. https://www.judiciary.uk/publications/criminal-practice-directions-amendment-no-8-effective-from-1st-april-2019/ (2019) [Accessed: 24/09/2021].
[21] PiAnoS Documentation. (2011-21) PiAnoS – Picture Annotation System dev documentation. Crown copyright. PiAnoS documentation — PiAnoS - Picture Annotation System dev documentation (unil.ch) [Accessed: 24/09/2021].
[22] J. Cohen, Statistical power analysis for the behavioural sciences, 2nd ed., Erlbaum, Hillsdale, NJ, 1988.
[23] D. Clark-Carter, Quantitative Psychological Research: A Student's Handbook, 3rd Ed., Psychology Press, Hove, 2010.
[24] B.T. Ulery, R.A. Hicklin, JoAnn Buscaglia, M.A. Roberts, C.K. Hsiao, Repeatability and Reproducibility of Decisions by Latent Fingerprint Examiners, PLOS one 7 (3) (2012) e32800.
[25] The Forensic Science Regulator. Fingerprint Quality Standards Specialist Group meeting minutes. Crown Copyright. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/760147/20180918_-_FQSSG_Minutes_September_18.pdf (2018) [Accessed: 24/09/2021].
[26] Scientific Working Group on Friction Ridge Analysis, Study and Technology (SWGFAST), Standard for Reporting Friction Ridge Examinations (Latent/Tenprint), Accessed: 24/09/2021, https://www.nist.gov/system/files/documents/2016/10/26/swgfast_examinations-conclusions_2.0_130427.pdf, 2012.
[27] European Network of Forensic Science Institutes, Best Practice Manual for Fingerprint Examination, Accessed: 24/09/2021, http://enfsi.eu/wp-content/uploads/2016/09/6._fingerprint_examination_0.pdf, 2015.
[28] M. Khan, A comparative study of White Box, Black Box, Grey Box testing techniques. International Journal of Advanced Computer Science and Applications. Vol 3. No 6. Available at - A Comparative Study of White Box, Black Box (thesai.org) 2012, [Accessed: 24/9/2021].
[29] R.A. Hinklin, J. Buscaglia, M.A. Roberts, S.B. Meagher, W. Fellner, M.J. Burge, M. Manaco, D. Vera, L.R. Pantzer, C.C. Yeung, T.N. Unnikumaran, Latent Fingerprint Quality: A Survey of Examiners, J. Foren. Identificat. 61 (4) (2011) p385–419.
[30] I. Dror, Cognitive Neuroscience in Forensic Science: Understanding and Utilising the Human Element 2012 Philosophical Transitions of the Royal Society B Biological Sciences, 370.
[31] The Forensic Science Regulator. Codes of Practice and Conduct Friction Ridge Detail (Fingerprint) Examination – Terminology, Definitions and Acronyms. Issue 2. Crown Copyright. Available from Friction Ridge Detail (Fingerprint) Examination – Terminology, Definitions and Acronyms (publishing.service.gov.uk) 2020, [Accessed: 24/09/2021].