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Research Paper

An evaluation of the ACE-V latent fingerprint examination process in the Indonesian National Police

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ABSTRACT

This study investigated the implementation of ACE-V (Analysis, Comparison, Evaluation, and Verification) as the standard protocol for fingerprint examination in the Identification Centre of the Indonesian National Police. An online questionnaire-based survey was developed, and 71 Indonesian fingerprint examiners participated. The results showed significant variation in the sequential steps used during the examination process, suggesting the value of exploring more standardized procedures and improving transparency. The findings revealed considerable disparities in compliance with the ACE-V, with each participant adhering to a different sequence of processes during the examination. Several significant deviations from the ACE-V standard protocol were also identified. These included apparent oversights in the examination of discrepancies between the fingermark and reference print, the failure to assess the adequacy of the reference print, and the omission of analysis of distortion in the fingermark.

An absence of consensus was noted among examiners in this study when assessing suitability of fingermarks of moderate quality, which is consistent with the findings of other published studies. The data also indicate that the fingerprint examiner participants adjusted their confidence levels regarding the presence of minutiae in a fingermark after scrutinizing the reference print. These findings indicate the importance of improving detailed documentation of minutiae annotation during the analysis and comparison phase. It is suggested that to ensure that examiners are equipped with a comprehensive understanding of friction ridge skin characteristics and incorporating approaches to ensure the transparency and consistency of the examination process, current training and agency certification processes should be considered.

1. Introduction

One of the most common protocols used in fingerprint examination is ACE-V, an acronym that describes four stages of examination: Analysis, Comparison, Evaluation, and Verification. Although the general concept of ACE-V has been mentioned in published studies conducted in the early 20th century [1,2], the Royal Canadian Mounted Police is often regarded as the first organization that developed and implemented the ACE-V process for forensic comparisons [3]. The premise of ACE-V hinges on the discovery of relevant information and involves the successive aggregation and correlation of information that accords with a hypothesis of individualization, exclusion, or inconclusive results. Even though ACE-V is considered the standard for friction ridge examination [4,5], the National Research Council (NRC) report [6] suggested that due to the lack of specificity and transparency of ACE-V, it can only be regarded as a general guideline for fingerprint examination practices.

While some organizations, such as SWGFAST, have made significant strides in developing guidelines for ACE-V in the global context, it can be argued that there is still a lack of transparency, standardization, and quantifiability in practice in local jurisdictions. The study conducted by Mattei et al [7], which involved 480 forensic science examiners across 19 different countries as participants, confirmed that ACE-V is widely implemented as a means of conducting examinations across several different pattern evidence disciplines, including fingerprint analysis. However, the results also demonstrated that the basis for written policies and procedures regarding the application of ACE-V varies significantly,

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which could result in variability of the examination outcomes. For instance, due to the absence of an established standard for assessing the quality of fingermarks examiners are compelled to exercise subjective judgment [8]. This subjectivity is often influenced by human factors as well as the individual training and experience of examiners, which can vary significantly across different jurisdictions and countries. [9]. Consequently, it is unsurprising that multiple studies have illustrated considerable variability in suitability determinations when different examiners evaluate the same fingermark [10–15].

Another demonstration of the variability in the application of the ACE-V can be observed in the process of establishing the sufficiency threshold for source attribution decisions, where two fundamental approaches exist: the holistic and the empirical standard (or numeric) approach. In the UK The Home Office and the Association of Chief Police Officers (ACPO) contended that a numerical standard was unwarranted and advocated for a holistic standard for fingerprint examination, which is presently employed in the UK, Israel, and the United States, among other countries [16]. However, several European countries still adhere to the 12-point standard, whereas Italy and South Africa respectively utilize the 16-point and 7-point standards [17–19]. There has been growing focus on exploring statistical models for quantifying the strength of fingerprint evidence [20], including the Likelihood Ratio (LR) and the Probability of Random Correspondence (PRC) models [21–24]. The adoption of statistical models has garnered support from forensic science organizations, notably the International Association for Identification (IAI) [25] and the European Network of Forensic Science Institutes (ENFSI) [26]. The integration of statistical models has the potential to enhance the transparency and objectivity of the fingerprint examination process. However, it may also result in increased variability in the implementation of the ACE-V methodology across different fingerprint jurisdictions globally, owing to differences in operational procedures and examiner expertise in statistical analysis.

Furthermore, some fingerprint jurisdictions have adopted blind and double-blind verification procedures, whereas others are unable to implement them due to cost and staffing limitations [19]. The absence of standardization in fingerprint analysis introduces a significant degree of subjectivity and vulnerability to the proper application of methods, potentially resulting in erroneous identifications [27,28]. The probability of misidentification tends to increase in complex cases, particularly when the quality of fingermarks is particularly challenging or when examiners are subjected to significant pressure. For instance, an examination of the FBI's handling of the Brandon Mayfield case [29] revealed that inadequate explanations of differences in appearance between the fingermark LP17 and Mayfield's fingerprints significantly contributed to misidentification. These misidentifications could be mitigated through meticulous documentation of detailed annotations by examiners during both the analysis and comparison phases, as recommended by SWGFAST [30] and ENFSI [5]. The GYRO documentation system has been proposed as a viable solution for enhancing the rigor of forensic documentation. This approach presents a straightforward and effective methodology for documenting the analysis and comparison phases of ACE-V, where a color-coding mechanism is utilized to indicate the examiner's level of confidence regarding the existence of specific features and the variations that these features may exhibit in corresponding reference prints [31].

The responsibility of fingerprint identification in Indonesia is exclusively entrusted to the Identification Centre, formerly known as the Indonesian Automated Fingerprint Identification System (INAFIS) department of the Indonesian National Police (INP). The country accommodates a total of 525 Identification departments distributed across 490 sub-regional police, 34 regional police, and a central headquarters [32]. However, the ACE-V framework was only integrated into Identification Centre in 2022, when the general concept of ACE-V was assimilated into the existing standard operating procedure of fingerprint examination [33]. The revised guideline, while less comprehensive than ACE-V protocols developed by the SWGFAST and ENFSI, incorporates certain enhancements. Notably, examiners can now render examinations as inconclusive when unable to determine an extremely high or extremely low probability that the donor of the fingermark was the donor of the print. The revised guideline also underscores the importance of analysing the fingermark before embarking on any further steps, such as conducting an AFIS search. However, certain aspects, such as the definition of varying levels of fingerprint characteristics and the terminology of different types of minutiae, are absent from the national guidelines. Furthermore, these changes have not been integrated into the national training program curriculum. Evaluation research is therefore needed to evaluate the implementation of ACE-V at the Identification Centre.

1.1. Objectives of this study

It is theorized that the lack of precise procedures within the ACE-V protocols may lead to discrepancies in the practices adopted by examiners. As a result, this study seeks to investigate the extent to which the implementation of ACE-V at the Identification Centre contributes to standardizing and enhancing the transparency of the fingerprint examination process. In so doing this study aims to address the whole process of the evaluation and assessment of fingermarks. The following questions were addressed:

1. What are the sequential steps followed by Indonesian fingerprint examiners in the process of fingerprint examination?
2. What criteria are utilized by Indonesian fingerprint examiners to ascertain the suitability of a fingermark?
3. How does the observation of the reference print impact examiners' confidence in the existence of minutiae in the fingermark?
4. What terminology do examiners use when reporting individualization?

Furthermore, this study sought to provide supplementary insights into the efficacy of training, agency certification, and experiential knowledge and expertise in augmenting the proficiency of fingerprint examiners. Therefore, the following question was also addressed:

5. How do experience, training, workload, and agency certification affect examiners' ability to recognize fingerprint characteristics?

2. Materials and methods

To address the aim of this study of determining potential variations in the implementation of ACE-V among Indonesian fingerprint examiners, an online survey was developed.

2.1. The questionnaire design

A questionnaire-based online survey was developed and subsequently published on Qualtrics (https://www.qualtrics.com). The survey comprised 12 questions, all presented in Indonesian. The survey was translated into an English version and the questions are provided as supplementary material for this paper. A variety of question types were employed in the survey, encompassing rank order, Likert scale, and free-text responses, with some of the questions including images of fingermark(s). The questionnaire was designed to ensure that participants could comfortably complete it within a time frame of 20 to 30 min. Table 1 shows the information gathered from the 12 questions included in the questionnaire. Experience-related questions were purposely placed at the end to minimize the effect of increased self-monitoring by the respondents.

2.2. Participants and procedure

The study design and method were considered by the relevant

Table 1
The conceptual framework of the questionnaire.

Aspect	Information gathered	Corresponding survey question (For full details, please refer to the supplementary information)
Adherence to ACE-V	The steps taken by examiners in fingerprint identification process	1, 4, 5
Analysis	The examiners' ability in recognizing the fingerprint characteristics	2
	The examiners understanding regarding the nature of the fingerprint characteristics	2
	The criteria in determining the suitability of a fingermark	3
Comparison	The impacts of observing the reference print on the examiners' confidence in the presence of minutiae in the fingermark	6, 7
Evaluation	Terminology used by the examiners in reporting individualization	8
Verification	The general perspective of the verification process	9, 10
Background Information	The work experience, level of training, annual workload, and agency certification status of the participants	11, 12

university ethics committee and given approval. Participation in this survey was entirely voluntary, and participants retained the freedom to retract their responses during the data collection period. All information obtained through this survey was securely and anonymously stored. The survey was distributed using a Qualtrics anonymous link, which does not collect identifying information such as name or mail address. Furthermore, anonymous responses were enabled to ensure that respondents' IP addresses and location data were removed from the results.

Invitations containing a brief introduction to the survey's purpose, the survey link, and an explanation of the incentives for participants were sent to potential participants via the "Identification Indonesia" WhatsApp™ group chat, which has 308 members. All participants are employed as fingerprint examiners at Identification Centre, each possessing diverse levels of professional experience and expertise. Table 2 shows the data related to participants' backgrounds, encompassing their work experience, yearly caseload, agency certification status, and level of training. In this study, the term "yearly caseload" is defined as the approximate number of cases per year in which the examiners participated. It is assumed that each case involved at least one comparison of fingermarks. Prior to commencing the survey, participants were provided with a 'Participant Information Sheet' that outlined the background, purpose, and data protection policy of the survey. Subsequently, they were required to provide informed consent by ticking a box on an online survey. The data collection period lasted for only two days in May 2024, when the target of 70 participants was reached.

2.3. Statistical analysis

In this study, 71 responses were collected. However, only 57 responses were received for question 1 in the questionnaire. This discrepancy can be attributed to the deliberate deactivation of the survey's back button, which consequently hindered participants from revisiting the initial question after bypassing it. Data were tabulated into spreadsheets and then analysed using STATA® software (version 18.5). The analysis conducted for research questions one to four involved descriptive statistical methods. In addition, several measures of association tests were conducted to evaluate the correlation between the participants' demographic backgrounds and the focus areas related to the second and fifth research questions. Given the considered small sample size [34] and the presence of several expected minimum cell counts below 5, Fisher's exact test was the most suitable option [35]. The assumptions of random sampling, mutually independent observations, binary data, and the mutual exclusivity of each observation were satisfied.

Table 2
Distribution of participant demographics pertaining to work experience, yearly workload, certification status, and training level.

Work experience	Frequency	Percentage
Less than a year	12	16.9
1 – 5 years	18	25.4
5 – 10 years	9	12.7
10 – 15 years	7	9.8
More than 15 years	15	21.1
Yearly caseload		
0 – 10 comparisons	31	43.7
11 – 20 comparisons	19	26.8
21 – 30 comparisons	12	16.9
31 – 40 comparisons	7	9.8
More than 40 comparisons	2	2.8
Agency certification		
Certified examiner	43	60.6
Uncertified examiner	28	39.4
Training level		
None	17	23.9
Basic	9	12.7
Advanced	15	21.1
Basic and advanced	30	42.3

3. Results and discussion

3.1. What are the sequential steps followed by Indonesian fingerprint examiners in the process of fingerprint examination?

Prior to discussing the findings, it is important to acknowledge the limitations inherent in this study. Table 2 indicates that 70.5 % of participants performed fewer than 20 fingerprint identifications annually, which diverges from the typical workload expected of Indonesian fingerprint examiners, although this observation lacks official supporting data. Moreover, nearly 25 % of participants have either not completed the basic or advanced training programs. While this may raise concerns regarding participant competency, the data also reveals that over 50 % have obtained agency certification. Additionally, the distribution of experience levels among participants is sufficiently balanced across categories. Therefore, the findings can still be regarded as representative of the current landscape.

In the first question of the questionnaire, participants were asked to describe the specific steps and the sequence they followed during their examinations in the past year. Table 3 presents the options delineated in question 1. Upon reviewing the responses, substantial variations in adherence to the ACE-V process are evident, with each respondent following a different sequence during the examination, although some employed a similar sequence of steps (Table 4). On average, the participants utilized 11 procedural steps during the examination process ($M = 11.9$, $SD = 3.14$). Some participants (n = 16) used 15-steps, and others (n = 12) used a 10-step process. Additionally, question 1 afforded respondents the opportunity to elucidate supplementary steps not outlined in the provided options; however, none availed themselves of this option.

The initial stages of the fingerprint examination process, as outlined in both the general ACE-V protocols [5,30,36] and the guidelines for

Table 3
The options presented to participants in question 1.

Step	Examination process
1	Analyse discrepancies between fingermark and reference print
2	Searching for a target group or focal point in the fingermark (core/delta/ flexion crease)
3	Determine the value/suitability of the fingermark
4	Searching for the possible candidate(s) in the AFIS
5	Annotate and counting the minutiae in the fingermark
6	Analyse the quality and clarity of the level 1 and 2 characteristics of the fingermark
7	Analyse the quality and clarity of the level 1 and 2 characteristics of the reference print
8	Verifying examiner reviewing the whole examination process
9	Formulate the conclusion of the examination
10	Determine the value/suitability of the reference print
11	Analyse correspondences between fingermark and reference print
12	Determine the pattern of the fingermark
13	Analyse relevant distortion in fingermark
14	Enhance fingermark images
15	Determine appropriate orientation and location (area of the skin) of the fingermark
16	Others (please specify) …..

fingerprint examination utilized by the INP [33], necessitates that examiners commence with a meticulous evaluation of the quality of the ridge detail and quantity within a fingermark before proceeding further. However, the analysis of survey responses shows that 20 out of 57 participants did not examine the quality and clarity of the fingermarks level 1 and 2 characteristics. The discovery is confounding as it presents a challenge in envisaging how examiners could appraise the adequacy of the fingermark without scrutinizing level 1 and level 2 characteristics. The terminology associated with Level 1 characteristics pertains to the general directional configurations of ridges, which can be classified into three primary types: loops, whorls, and arches. In contrast, Level 2 pertains to the specific trajectories of the friction ridges, commonly termed as minutiae. The concise definitions of these terms were included as a side note in Question 1. However, these terms are neither referenced in the fingerprint examination guidelines issued by the INP [33] nor utilized in the training program materials. As a result, this finding may be attributed to the examiners' lack of familiarity with the terminology "Level 1″ and "Level 2″ characteristics rather than an actual failure to conduct the analysis.

The responses to question 1 also indicate the procedures that the examiners frequently omit. Over half of the examiners (29 out of 57) neglected to scrutinize discrepancies between the fingermark and the reference print. The cause of this issue may be attributed to the numerical approach utilized by the INP, which may lead examiners to overly focus on identifying corresponding minutiae. Once they reach the required minimum number of correspondences, they might unintentionally overlook or not pay enough attention to analysing the discrepancy between the fingermark and the reference print. Moreover, it is important to note that the fingerprint reports generated by the INP do not mandate examiners to account for discrepancy between impressions; rather, they only request explanations for correspondences. Failure to address discrepancies between impressions, irrespective of their cause, significantly heightens the probability of erroneous identification. The case of Brandon Mayfield's misidentification [29] serves as a prominent example of the oversight of significant discrepancies between the fingermark and the Mayfield prints by FBI examiners. In addition, the data show that nearly half of the initial examiners (49.1 %) carried out the verification before reaching their conclusions, while 10.5 % omitted the verification process entirely (Table 4). In the INP, the second examiner is not mandated to duplicate the ACE process. Instead, their role is to verify the comparison between the fingermark and the reference print, as well as to assess the conclusion drawn by the first examiner regarding the comparison. Although the first examiner conducts the comparison independently, they typically do not formally document their results in the report. Instead, they await the second examiner's verification. Upon the second examiner reaching a conclusion, both examiners collaborate to document the findings as a unified result in the report. Consequently, if any discrepancies exist between their conclusions, these are not reflected in the final report.

In addition, the data also suggest that the verification process, which

Table 4
Participants' responses to question 1.

Participant	The sequence of the examination process
1	14 - 4 - 5 - 12 - 11 - 9 - 8
2	6 - 3 - 15 - 13 - 12 - 10 - 14 - 2 - 4 - 5 - 7 - 1 - 11 - 8 - 9
3	14 - 3 - 10 - 2 - 1 - 11 - 15 - 6 - 7 - 5 - 12 - 13 - 8 - 4 - 9
4	3 - 12 - 15 - 6 - 2 - 13 - 5 - 14 - 4 - 11 - 1 - 7 - 10 - 8 - 9
5	15 - 12 - 6 - 14 - 3 - 4 - 7 - 10 - 2 - 1 - 11 - 5 - 8 - 9
6	14 - 5 - 3 - 12 - 4 - 7 - 10 - 11 - 9 - 8
7	3 - 15 - 6 - 14 - 11 - 13 - 10 - 7 - 1 - 12 - 5 - 2 - 9 - 8 - 4
8	3 - 10 - 14 - 12 - 2 - 15 - 1 - 6 - 7 - 13 - 5 - 11 - 4 - 8 - 9
9	3 - 12 - 6 - 13 - 15 - 14 - 4 - 10 - 7 - 5 - 2 - 11 - 1 - 9 - 8
10	12 - 3 - 2 - 15 - 5 - 14 - 4 - 10 - 6 - 7 - 11 - 1 - 9 - 8
11	6 - 14 - 13 - 3 - 15 - 1 - 7 - 5 - 11 - 9 - 12 - 4 - 7 - 10 - 8
12	3 - 15 - 12 - 14 - 2 - 4 - 11 - 1 - 9 - 8
13	3 - 12 - 14 - 15 - 6 - 13 - 2 - 10 - 5 - 7 - 4 - 11 - 1 - 8 - 9
14	13 - 14 - 15 - 12 - 4 - 7 - 11 - 9 - 8
15	3 - 10 - 6 - 15 - 11 - 1 - 13 - 12 - 2 - 14 - 9
16	3 - 10 - 4 - 14 - 1 - 11 - 15 - 12 - 2 - 7 - 6 - 13 - 5 - 8 - 9
17	14 - 15 - 4 - 5 - 11 - 9
18	5 - 4 - 7 - 11 - 9 - 8
19	4 - 12 - 11 - 9 - 8
20	12 - 2 - 3 - 15 - 5 - 14 - 4 - 6 - 10 - 7 - 11 - 1 - 9 - 8
21	3 - 12 - 6 - 14 - 4 - 2 - 11 - 8 - 9
22	2 - 12 - 13 - 5 - 14 - 4 - 7 - 11 - 8 - 9
23	15 - 13 - 12 - 6 - 3 - 14 - 4 - 7 - 10 - 1 - 2 - 5 - 11 - 8 - 9
24	2 - 3 - 5 - 14 - 4 - 7 - 11 - 8 - 9
25	6 - 15 - 3 - 14 - 4 - 2 - 11 - 5 - 9
26	14 - 15 - 12 - 3 - 13 - 2 - 6 - 4 - 7 - 9
27	3 - 12 - 6 - 1 - 11 - 5 - 9
28	3 - 6 - 12 - 13 - 14 - 4 - 5 - 11 - 9 - 8
29	15 - 2 - 12 - 13 - 5 - 3 - 4 - 9 - 8
30	12 - 5 - 2 - 4 - 7 - 11 - 8 - 9
31	3 - 6 - 15 - 14 - 4 - 12 - 2 - 5 - 13 - 9
32	6 - 3 - 15 - 14 - 2 - 10 - 4 - 11 - 1 - 5 - 13 - 8 - 9
33	4 - 14 - 3 - 15 - 12 - 5 - 2 - 11 - 13 - 6 - 9 - 8
34	3 - 15 - 5 - 13 - 14 - 4 - 10 - 6 - 7 - 1 - 11 - 2 - 9 - 12 - 8
35	6 - 3 - 7 - 10 - 13 - 14 - 4 - 11 - 8 - 9
36	3 - 15 - 13 - 12 - 14 - 4 - 5 - 6 - 10 - 7 - 2 - 11 - 8 - 9
37	6 - 3 - 15 - 14 - 2 - 10 - 7 - 12 - 1 - 11 - 5 - 4 - 13 - 8 - 9
38	13 - 12 - 5 - 3 - 4 - 7 - 10 - 11 - 8 - 9
39	13 - 2 - 5 - 12 - 11 - 8 - 9
40	6 - 3 - 13 - 15 - 12 - 5 - 14 - 4 - 7 - 10 - 2 - 11 - 8 - 9
41	14 - 5 - 12 - 15 - 4 - 11 - 1 - 8 - 9
42	15 - 13 - 12 - 5 - 3 - 4 - 10 - 11 - 8 - 9
43	5 - 12 - 14 - 4 - 11 - 9 - 8
44	6 - 12 - 15 - 5 - 3 - 4 - 11 - 1 - 9 - 8
45	6 - 12 - 5 - 3 - 4 - 7 - 10 - 11 - 9 - 8
46	12 - 5 - 14 - 13 - 4 - 11 - 9 - 8
47	3 - 13 - 15 - 14 - 2 - 4 - 11 - 5 - 8 - 9
48	10 - 3 - 6 - 7 - 13 - 11 - 1 - 2 - 12 - 5 - 14 - 15 - 8 - 4 - 9
49	3 - 13 - 6 - 14 - 4 - 10 - 9 - 8
50	10 - 3 - 12 - 13 - 15 - 2 - 14 - 4 - 11 - 5 - 6 - 7 - 1 - 9 - 8
51	10 - 3 - 14 - 15 - 12 - 2 - 11 - 7 - 6 - 1 - 13 - 5 - 8 - 9 - 4
52	14 - 2 - 6 - 13 - 12 - 3 - 4 - 7 - 11 - 1 - 9 - 8
53	3 - 10 - 15 - 12 - 14 - 6 - 7 - 4 - 2 - 11 - 8 - 9
54	15 - 3 - 14 - 13 - 4 - 10 - 6 - 7 - 12 - 1 - 11 - 2 - 5 - 8 - 9
55	14 - 5 - 3 - 4 - 10 - 11 - 2 - 8 - 9
56	5 - 4 - 12 - 2 - 11 - 1 - 8 - 9
57	6 - 12 - 13 - 5 - 14 - 4 - 11 - 2 - 1 - 9 - 8

Table 5
Summary of responses to question 10 (b).

Question	1 (%)	2–3 (%)	More than 3 (%)
How many fingerprint examiners involved in the verification phase?	19.7	53.5	26.8

typically involves two to three verifying examiners (Table 5), predominantly adheres to an open model, indicating that verifiers are already aware of the initial examiner's conclusion (Table 6). There appears to be value in considering the practice manual developed by ENFSI [5], which recommends the implementation of blind verification to mitigate the risk of errors stemming from unconscious bias influenced by contextual information. This recommendation holds significant relevance within the working environment of the INP, wherein fingerprint examiners are intricately involved in crime scene investigations and maintain direct lines of communication with investigators. Consequently, examiners are consistently exposed to contextual information pertinent to the cases under investigation.

3.2. What criteria are utilized by Indonesian fingerprint examiners to ascertain the suitability of a fingermark?

An inquiry was conducted to ascertain whether specific criteria for determining the adequacy of a fingermark exist. The compiled participant responses detailed in Table 7 demonstrated divergent outcomes. Examiners tended to concur on the suitability of fingermarks of excellent quality (fingermark 1) and fingermarks of exceedingly poor quality (fingermark 6). However, an absence of consensus was noted among examiners when assessing fingermarks of moderate quality, in line with the findings of other published studies [10–12,15].

A comparative analysis was conducted on the decisions made by examiners, focusing on two demographic factors: experience level and agency certification status. These criteria are commonly employed to evaluate the level of expertise within the Indonesian criminal justice system. In general, Fig. 1 illustrates that examiners with over five years of experience tend to assess fingermarks as suitable compared to those with fewer than five years of experience. A similar trend is evident in Fig. 2, where certified examiners are more likely to classify fingermarks as suitable than uncertified examiners. However, the measures of association test (Table 8) indicated that a significant association was found exclusively in fingermark 3 when comparing certified and non-certified examiners ($p = 0.007$).

The guidelines established by SWGFAST [4] delineate two prevalent approaches to assessing suitability. The initial approach, commonly denoted as "of value of identification," entails the comparison of only those impressions that possess the potential for individualization. This approach is predominantly employed by fingerprint examiners in Indonesia, although it is not explicitly codified within the regulatory guidelines. Upon examination of the responses pertaining to fingermarks 2, 4, and 7, it became apparent that while the majority of INP examiners align with this approach, some opt for the second approach termed "of value for comparison," involving a comparison of impressions suitable for both individualization and exclusion. Examiners who adhere to the first approach employ a simple criterion for adequate fingermarks, mandating a minimum of 12 minutiae, as the INP still utilizes the 12-minutiae threshold to declare individualization. Conversely, those who subscribe to the second approach encounter a more intricate threshold, requiring a comprehensive analysis of friction ridge details and necessitating an in-depth comprehension of the various fingerprint features.

Moreover, the participants' decision about the suitability of fingermarks 4 and 7 suggests that the examiner's evaluation might have been influenced by the inclination to attribute the fingermark to a source, even in cases where it may have lacked enough features to do so. It is crucial to acknowledge that the INP fingerprint examiners are consistently exposed to contextual information which raises challenges for mitigating cognitive bias. For example, when conducting searches in the database for fingermarks, the system not only provides the candidates' fingerprints but also their demographic information and facial images. Furthermore, the examiners typically possess knowledge relevant to the cases as they are also tasked with conducting crime scene investigations even though it is now widely recognized that domain irrelevant information may affect the examiners' judgment [37]. The guidelines for fingerprint examination employed by the INP underscore the necessity for examiners to perform analysis prior to candidate search and specify that candidate searches are not permissible for fingermarks deemed unsuitable for comparison. However, participant responses in Table 9 reveal that many examiners did not adhere to these guidelines. Additionally, no systems are currently in place to minimize the examiners' exposure to case-related information. Consequently, the examiners are consistently exposed to arguably irrelevant details about the case, potentially influencing their judgment in determining the suitability of the fingermarks. Additional research is required to provide a comprehensive understanding of how Indonesian fingerprint examiners assess the suitability of fingermarks. This will allow for a thorough exploration of the methods and criteria used in their determination process.

In light of the complex nature of determining the value of fingermarks and the demonstrated variability of its outcomes, the utilization of automated fingermark quality metrics such as LQMetric [38–40] and Defense Fingerprint Image Quality Index (DFIQI) [41,42], has the potential to assist in standardizing the process and increasing the transparency when subjectivity is necessarily employed. While these tools may not supplant manual assessment by examiners, their combined utilization can potentially bolster the dependability of fingermark suitability determinations. Furthermore, the utilization of commercially available ACE-V software may serve to offer the potential to further standardize the ACE-V sequential process followed by Indonesian fingerprint examiners spread across more than 450 police precincts. However, it would be valuable to conduct further testing to evaluate whether the streamlined processes facilitated by these software solutions align with the requisites of fingerprint examination within the INP.

Table 6
Summary of responses to question 10 (a).

Question	Always (%)	Sometimes (%)	Never (%)
Is the verification process conducted in a blind manner?	71.8	8.5	19.7

Table 7
Fingermark properties in question 3 and a summary of participants' decisions regarding the value of the fingermarks.

Fingermark	Pattern	More than 12 minutiae	Possible candidates	Decision (%)
1	Can be determined	Yes	None	Suitable (95.8 %)
2	Can be determined	No	None	Suitable (59.2 %)
3	Can be determined	Yes	None	Suitable (53.5 %)
4	Cannot be determined	No	Yes (AFIS)	Suitable (67.6 %)
5	Can be determined	No	None	Suitable (59.2 %)
6	Cannot be determined	No	Yes (AFIS)	Unsuitable (85.9 %)
7	Cannot be determined	No	Yes (Suspect)	Suitable (53.5 %)

3.3. How does the observation of the reference print impact examiners' confidence in the existence of minutiae in the fingermark?

Question 6 of the survey required participants to express their confidence in the minutiae within the fingermark (Fig. 3). The minutiae were pre-marked; thus participants were only required to indicate their confidence regarding the existence of these minutiae. There were 10 minutiae in total, with minutiae 4 and 8 being false. The fingermark image referenced was obtained from a study [11], in which some

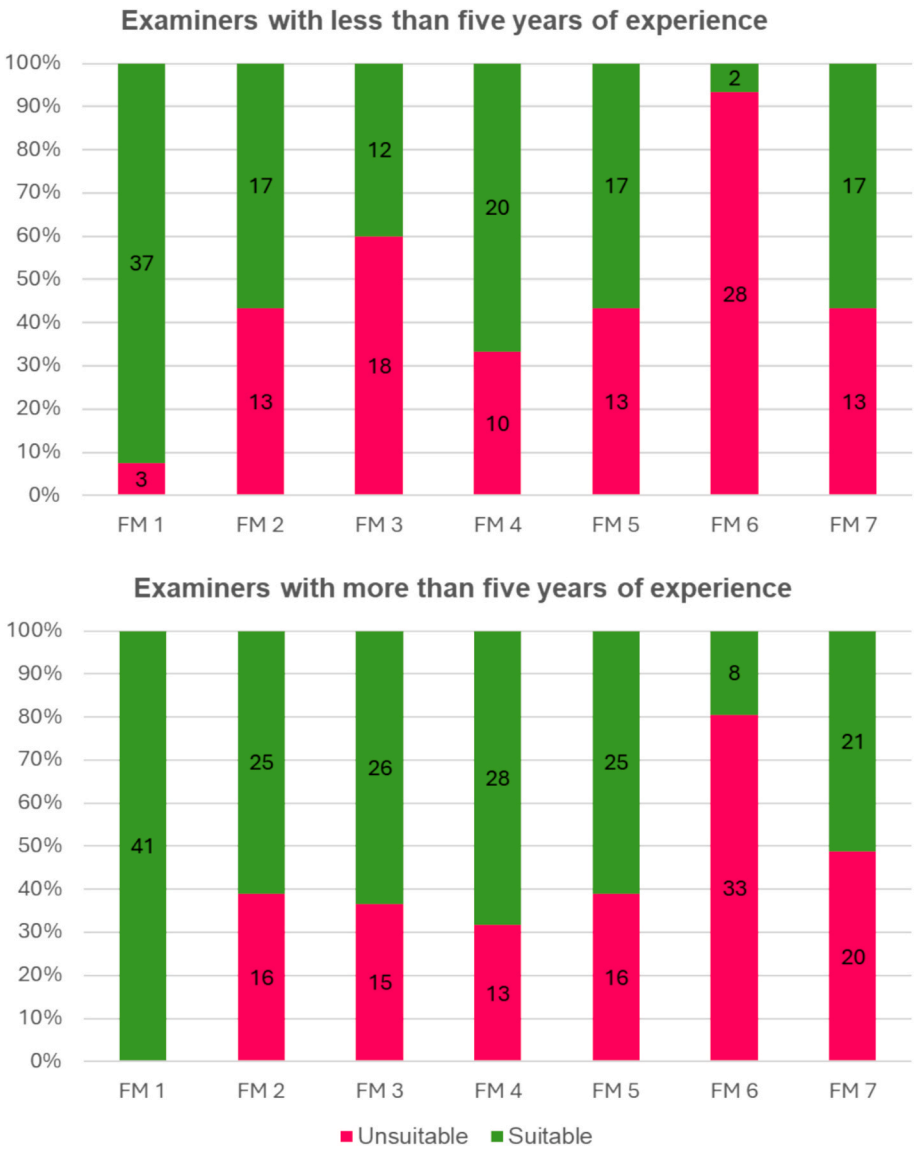

Fig. 1. Assessment of the suitability of seven fingermarks categorized based on the participants' levels of experience.

examiners erroneously marked false minutiae 4 and 8 as true minutiae. Participants in question 7 were instructed to replicate the task using the same fingerprint image. However, this time, they were provided with the opportunity to observe the potential source of the fingermark. Upon scrutiny of the data presented in Table 10, a discernible trend emerges, indicating that Indonesian fingerprint examiners adjust their confidence levels regarding the presence of minutiae in a fingermark after scrutinizing the reference print. In general, observing the reference print helps examiners disregard any false minutiae that were previously identified as true minutiae during the analysis phase. Conversely, the examiners' confidence in the presence of true minutiae increases when they observe the reference print. While the examination of a reference print may aid examiners in discerning true minutiae and disregarding false ones, substantial modifications during the comparison phase may denote deficiencies in the initial analysis or potential bias in the reanalysis attributable to the exemplar. Substantial additions or deletions of minutiae may also be ascribed to erroneous identification, as evidenced in a study by Ulery et al. [43]. In contrast, this study noted that examiners who exhibited high confidence in minutiae within fingermarks seldom altered their confidence levels (Table 11). While this study did not assess the impact of changes in confidence levels on examination accuracy, the tendency of many examiners to maintain their highest confidence levels regarding the presence of false minutiae 4 and 8 after reviewing the reference print suggests that excessive confidence also heightens the likelihood of erroneous identification. Given the potential impact of alterations in feature marking on the accuracy of the examination process, it is important going forward for fingerprint jurisdictions to closely monitor examiners' minutiae markup changes during the analysis and comparison phases. This proactive approach may mitigate the potential for misidentification.

Beyond ensuring the precision of the examination, shifts in confidence levels regarding the presence of minutiae are also intertwined with the examination's transparency. The guidelines published by SWGFAST [30] instruct examiners to thoroughly document both the analysis of a fingermark and any subsequent re-evaluations performed during the comparison phase, including any alterations in minutiae selection. The primary objective of this protocol is to help verifying examiners understand the actions and decisions made by the initial examiner during the examination. Furthermore, comprehensive documentation is likely to aid the initial examiners in recollecting their actions and decisions during the examination, particularly if the case is brought to court long after the examination has taken place. In certain jurisdictions, examiners are mandated to meticulously document the minutiae annotation of fingermarks during both the analysis and

Fig. 2. Assessment of the suitability of seven fingermarks categorized based on the participants' agency certification status.

Table 8
The correlation between participants' demographic backgrounds and their decisions regarding the suitability of fingermarks.

Fingermark	Certification	Experience (less than 5 years against more than 5 years)
1	$p = 0.558$	$p = 0.071$
2	$p = 0.809$	$p = 0.808$
3	$p = 0.007$*	$p = 0.059$
4	$p = 0.796$	$p = 1.000$
5	$p = 0.809$	$p = 0.808$
6	$p = 0.296$	$p = 0.174$
7	$p = 0.466$	$p = 0.810$

*. Correlation is significant at the 0.05 level.

Table 9
Participants' responses to questions 4 and 5.

Question	Always (%)	Sometimes (%)	Never (%)
Have you run automated searches for unsuitable fingermarks in the database over the past year?	39.4	38	22.6
Have you compared the unsuitable fingermarks against the suspect's reference print over the past year?	32.4	40.8	26.8

comparison phases. In contrast, INP fingerprint examiners are solely tasked with documenting minutiae annotations during the comparison phase. It is important to note that fingerprint jurisdictions also have varying approaches to annotating minutiae during the analysis phase. For example, fingerprint experts in the Netherlands, as outlined by

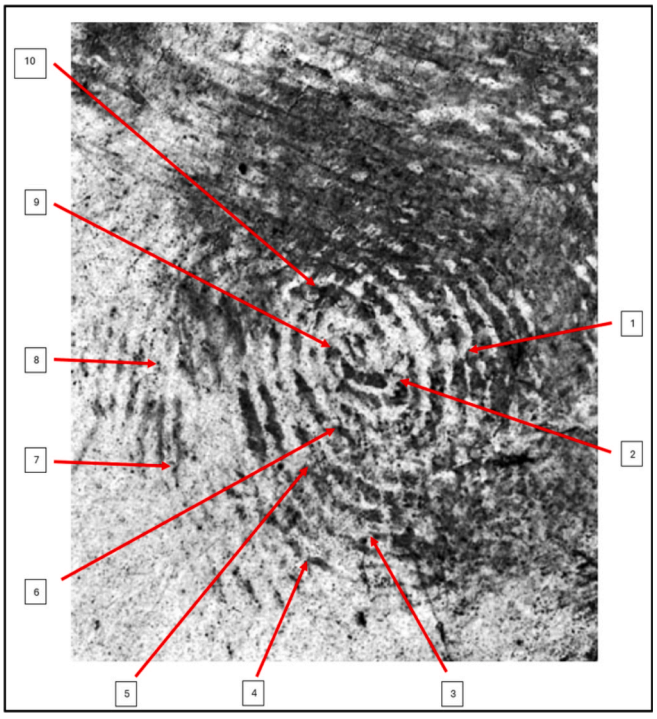

Fig. 3. The fingermark referenced in question 6 (reproduced from [11] with the permission of the author).

Table 10
Participants' overall confidence in the existence of minutiae within the fingermark before and after examining the reference print.

Condition	Minutiae Number	Not a Minutiae (%)	Unsure (%)	Fairly Confident (%)	Fully Confident (%)
Prior to observing the potential source of the fingermark	1	2.8	8.5	21.1	67.6
	2	5.6	7.0	26.8	60.6
	3	2.8	12.7	31	53.5
	(4)	5.6	15.5	24	54.9
	5	4.2	12.7	25.4	57.7
	6	1.4	14.1	32.4	52.1
	7	5.6	23.9	33.8	36.6
	(8)	5.6	26.8	24	43.7
	9	5.6	5.6	33.8	54.9
	10	5.6	19.7	29.6	45.1
Following the observation of the potential source of the fingermark	1	2.8	8.5	21.1	67.6
	2	5.6	7.0	26.8	60.6
	3	2.8	12.7	31	53.5
	(4)	5.6	15.5	24	54.9
	5	4.2	12.7	25.4	57.7
	6	1.4	14.1	32.4	52.1
	7	5.6	23.9	33.8	36.6
	(8)	5.6	26.8	24	43.7
	9	5.6	5.6	33.8	54.9
	10	5.6	19.7	29.6	45.1

Note: The false minutiae are enclosed in parentheses.

Bergman [44], only annotate clear and unambiguous minutiae during the analysis phase, and these marked minutiae must be used during the comparison. Conversely, Indonesian fingerprint examiners incorporate low-quality and questionable minutiae in the analysis phase, with no requirement to document this process in the fingerprint reports. As a result, the comprehensive insights into the examiners' perceptions of fingermark minutiae during the analysis phase are absent from the documentation. As indicated in a broad range of reports [6,29] and studies [11,12,45], it is clear that there is a need for examiners to meticulously document the specific features of fingerprints when rendering their assessments. This requirement holds particular significance in cases involving fingermarks of marginal quality, characterized by a restricted number of fingerprint traits.

The GYRO system, proposed by Langenburg and Champod [31], can be employed to convey the weight attributed to the minutiae in the fingermark during the analysis and comparison, as well as the confidence vested in the minutiae by the examiners. The GYRO system uses a colour tagging method to show examiners' confidence levels regarding the presence of minutiae on fingermarks and their corresponding tolerance levels. Green signifies a high level of confidence in the presence of minutiae. Yellow denotes minutiae with a moderate level of certainty, while red designates doubtful minutiae. Furthermore, orange is utilized to indicate minutiae that were not initially observed during the analysis phase but emerged during the comparison phase of the identification process. During the marking of the reference print, the colours used for the corresponding mated minutiae reflect the colours of

Table 11
A comprehensive summary of changes in examiners' confidence levels regarding the existence of minutiae before and after examining the reference print.

Minutiae	Confidence level before observing reference print	Number of participants	Percentage of participants who changed their confidence level after observing reference print (%) *
1	Not a minutia	2	100
	Unsure	6	83.3
	Fairly confident	15	26.7
	Fully confident	48	4.2
2	Not a minutia	4	75
	Unsure	5	80
	Fairly confident	19	36.8
	Fully confident	43	7
3	Not a minutia	2	100
	Unsure	9	66.7
	Fairly confident	22	45.4
	Fully confident	38	15.8
4	Not a minutia	4	100
	Unsure	11	45.4
	Fairly confident	17	29.4
	Fully confident	39	25.6
5	Not a minutia	3	66.7
	Unsure	9	77.8
	Fairly confident	18	38.9
	Fully confident	41	14.6
6	Not a minutia	1	0
	Unsure	10	70
	Fairly confident	23	34.8
	Fully confident	37	10.8
7	Not a minutia	4	75
	Unsure	17	52.9
	Fairly confident	24	45.8
	Fully confident	26	19.2
8	Not a minutia	4	50
	Unsure	19	47.4
	Fairly confident	17	47
	Fully confident	31	25.8
9	Not a minutia	4	75
	Unsure	4	100
	Fairly confident	24	45.8
	Fully confident	39	7.7
10	Not a minutia	4	50
	Unsure	14	35.7
	Fairly confident	21	38.1
	Fully confident	32	9.4

*. The changes in confidence level are not unidirectional.

the minutiae in the fingermark. This practice ensures that uncertainty is maintained when examining a reference print, maintaining it throughout the entire inductive process. The integration of the GYRO system into Identification Centre offers the potential to significantly improve the transparency of the examination process within the organization. The implementation of the GYRO system also facilitates comprehension of the examination process by verifying examiners, investigators, and court members.

3.4. What terminology do examiners use when reporting individualization?

Participants were presented with the comparison results between a fingermark and a reference print, revealing a correlation involving 12 minutiae and no significant discrepancies. Question 8 of the questionnaire was designed as an open-ended text query, providing participants with the opportunity to elucidate their specific terminology when reporting an individualization or identification. The analysis of responses to question 8 indicates that 70 % of examiners consistently employ absolute positive terms such as "identical," "same," and "perfectly match" (Table 12). This finding is in line with the guidelines set by the INP for fingerprint examination, which stipulate the use of "identical" or "same" to communicate individualization [33]. In the Indonesian language, the term "identical" denotes a state of perfect correspondence without any discernible variance [46]. Therefore, this term should not be used to describe the correlation level between a fingermark and a reference print, since achieving a perfect match between a fingermark and a reference print is unattainable due to variances in surface characteristics, deposition conditions, enhancement methods, and contact pressure.

Despite the lack of an evidence base for the approach, fingerprint experts have been presenting identification by using certainty terms [6,47,48]. These assertions are usually justified by reference to the extensive training and experiences that the fingerprint examiners have [49]. Others have supported such claims by pointing out the accuracy of the ACE-V examination procedure [50]. This way of presenting fingerprint individualization is in contrast to the recommendation from the Experts Working Group on Human Factors in Latent Print Analysis (EWGHF), which suggested fingerprint examiners should not testify to a source attribution to the exclusion of all other individuals in the world [51]. Recommendations have been made to discontinue the use of terms such as "100 percent certain" or "0 percent risk of error." However, the specific terminology to supplant such assertions commonly articulated by expert witnesses, including fingerprint examiners in the courtroom remains indistinct [52]. Concerns were expressed that alternative terms, such as "consistent with," may diminish the weight of fingerprint evidence in court. Published studies [52,53], within the context of brief written cases involving fingerprint evidence, have revealed that enhancing a match conclusion with additional claims about its certainty and disregarding the possibility of an alternative source for the prints failed to augment the significance attributed to the match. Nevertheless, the issue of the unscientific and unproven nature of absolute conclusion terms has not been raised by court officials, defence attorneys, or academics in Indonesia. Additional research is required to assess the potential impact of varying fingerprint individualization terminologies on the perceived credibility by Indonesian court judges.

Table 12
Terminologies employed by participants when reporting individualization.

Terminology	Percentage (%)
The fingermark is identical to the reference print	64.8
The fingermark is the same as the reference print	2.8
The comparison is perfect/highly accurate	2.8
There are similarities between the fingermark and the reference print	4.2
Suggesting similarities between the pattern/minutiae/ridge count of the fingermark and the reference print, but did not give a comment regarding source attribution	9.9
Unsure of the conclusion/suggesting changes in minutiae selection	8.5
Invalid response	7.0

3.5. How do experience, training, workload, and certification affect examiners' ability to recognize fingerprint characteristics?

The descriptive statistics presented in Table 13, show that the average percentage of participants able to correctly identify the type and persistence of eight fingerprint characteristics was 32 %. Among these characteristics, bifurcation, island, and short ridge were the only ones correctly identified by over half of the participants. Notably, none of the participants accurately identified the type and persistence of incipient ridge. It is of interest to note that in the context of Indonesian fingerprint analysis, the characteristic known as "enclosure" or "lake" in the published literature [54–56], is denoted as an "island" by Indonesian fingerprint examiners. Out of the participants, 45 identified it as an island, while only 1 recognized it as an enclosure. Conversely, characteristic 6, commonly known as an "island" in many references, is termed a "short ridge" by Indonesian fingerprint examiners. Among the participants, 34 identified it as a short ridge, while only 2 recognized it as an island. While the specific nomenclature for attributes may not bear significant weight, it is imperative that the examiners adhere to consistent terminology usage. Presently, the guidelines from the INP regarding fingerprint identification do not encompass a list of terminologies for different minutia types.

Furthermore, a test for association was conducted to ascertain the presence of a correlation between examiners' experience, training, workload, agency certification, and their capacity to discern fingerprint characteristics. Measures of association could not be computed for characteristic seven (incipient ridge) as none of the participants were able to correctly identify both the type and persistence of the characteristic. Overall, there was a lack of correlation between participants' demographic backgrounds and their capacity to precisely discern fingerprint characteristics 1, 2, and 5, denoting scar, flexion crease, and pores, respectively (Table 14). In relation to certification, significant associations were identified in only four out of eight characteristics, namely bifurcation ($p = 0.000$), enclosure ($p = 0.006$), short ridge ($p = 0.016$), and bridge ($p = 0.030$). However, no correlation was identified between the certification status and the ability to discern fingerprint characteristics in relation to the other four features. Upon analysis of the odds ratio (Table 15), it was evident that certified examiners exhibited a higher likelihood of accurately identifying four specific characteristics: bifurcation, enclosure, short ridge, and bridge. One possible explanation for this may be associated with the knowledge assessed during the fingerprint examiner certification process in Indonesia. While the certification evaluates expertise in fingerprint identification, it encompasses other areas, including fingerprint enhancement methods,

Table 13
Summary of responses to question 2.

Feature	Participants who correctly identified feature (%)	Participants who correctly identified persistency (%)	Participants who correctly identified feature and persistency (%)
Scar	29.6	38	14
Flexion crease	14	21.1	4.2
Bifurcation	76	91.2	70.4
Enclosure	64.8	91.5	64.8
Pores	16.9	63.4	11.3
Short ridge	50.7	87.3	50.7
Incipient ridge	0	67.8	0
Bridge	45.1	85.9	45.1

Table 14
The correlation between participants' demographic backgrounds and their proficiency in discerning fingerprint characteristics.

Feature	Certification	Experience	Yearly Caseload	Training
Scar	$p = 1.000$	$p = 0.805$	$p = 1.000$	$p = 0.329$
Flexion crease	$p = 1.000$	$p = 1.000$	$p = 1.000$	$p = 0.737$
Bifurcation	$p = 0.000$*	$p = 0.000$*	$p = 0.138$	$p = 0.002$*
Enclosure	$p = 0.006$*	$p = 0.000$*	$p = 0.009$*	$p = 0.095$
Pores	$p = 0.135$	$p = 0.456$	$p = 1.000$	$p = 0.904$
Short ridge	$p = 0.016$*	$p = 0.108$	$p = 0.733$	$p = 0.018$*
Bridge	$p = 0.030$*	$p = 0.526$	$p = 0.446$	$p = 0.306$

*. Correlation is significant at the 0.05 level.

Table 15
Odds ratio of examiners' agency certification status and their ability to discern the type and persistency of fingerprint characteristics 3, 4, 6, and 8.

Feature	Certification	Correct	Incorrect
Bifurcation	Certified	1.26	0.33
	Non-Certified	0.60	2.03
Enclosure	Certified	1.21	0.64
	Non-Certified	0.68	1.55
Short ridge	Certified	1.24	0.75
	Non-Certified	0.63	1.38
Bridge	Certified	1.24	0.80
	Non-Certified	0.63	1.30

collection of rolled fingerprints, and performing candidate searches in the AFIS. Consequently, the depth of examiners' understanding of fingerprint identification may not be comprehensively examined in the certification process, as the examination allocates time and scope across multiple subject areas.

Similarly, the data illustrate a compelling association between work experience and the proficiency of examiners in discerning fingerprint characteristics, namely bifurcation ($p = 0.000$) and enclosure ($p = 0.000$). On the other hand, the relationship between workload and examiners' ability to recognize fingerprint characteristics was found to be significant only for enclosure ($p = 0.009$). Likewise, a correlation between training and examiners' ability was only observed in bifurcation ($p = 0.002$) and short ridge ($p = 0.018$). The odds ratio demonstrated that examiners who received both basic and advanced training were more likely to correctly identify these characteristics, whereas those without any training or those who have only completed basic training were more prone to misidentifying them (Table 16). Intriguingly, while participants who completed the advanced training have a higher chance of identifying bifurcation correctly, the opposite applies for identifying short ridge minutiae. Similar to the certification process, the basic training program for fingerprint examiners within the INP encompasses an extensive array of subjects, encompassing crime scene investigation methodologies and forensic photography. Consequently, it is not expected that examiners will achieve mastery in this area upon the conclusion of their training.

The apparent lack of comprehension among the participants regarding the characteristics of fingerprint features and the prevalent use of absolute positive terminology in reporting individualization suggest a need for enhancements in the training and certification program. For example, as specified in the Standard for Friction Ridge Examination Training Program by the Friction Ridge Subcommittee of the Organization of Scientific Area Committees [57], trainees are required to comprehend the embryology of friction ridge skin and the underlying principles of the discriminability of friction ridge impressions. This encompasses a specific emphasis on embryological development, volar pad, and friction ridge formation, as well as the morphogenesis of primary and secondary ridges. These facets are absent from the present training program curriculum, which it is possible to argue is contributing to a lack of comprehensive understanding of the persistence of friction ridge skin features.

Table 16
Odds ratio of examiners' years of experience and their ability to discern the type and persistency of fingerprint characteristics 3 and 4.

Feature	Training level	Correct	Incorrect
Bifurcation	None	0.57	2.08
	Basic	0.77	1.60
	Advanced	1.30	0.24
	Both	1.16	0.58
Short ridge	None	0.46	1.55
	Basic	0.87	1.14
	Advanced	0.92	1.08
	Both	1.38	0.61

4. Conclusions

In this research an online survey was designed to assess the methodologies employed by Indonesian fingerprint examiners in conducting fingerprint examinations over the preceding 12 months and to appraise the utilization of the ACE-V method. The study also scrutinized the examiners' fundamental understanding of the nature of fingerprint minutiae characteristics, with a specific emphasis on their capacity to accurately discern such minutiae during the analysis phase.

Analysis of participant survey responses reveals significant variance in the sequential steps utilized during the examination process. One noteworthy finding is the apparent oversight in analysing discrepancies between the fingermark and reference print, as well as the tendency not to assess the adequacy of the reference print before comparison. Furthermore, the incorrect application of the verification procedure emerges as a recurring issue among examiners in this study, raising concerns regarding potential errors in identifications. It is important to acknowledge that although participants exhibit diverse levels of experience, 70.5 % of them conducted fewer than 20 fingerprint identifications in the last 12 months, a figure that significantly diverges from the average workload commonly expected of Indonesian fingerprint examiners.

There is a lack of consensus among Indonesian fingerprint examiners concerning the determination of the suitability of fingermarks. Most Indonesian fingerprint examiners use absolute positive terminology when reporting individualization, despite the absence of empirical validation for this practice. Although this study is based on a limited sample size, these insights indicate a need to consider strategies to ensure that there is a more consistent application of the ACE-V process (whether that is enhancing existing documentation, training etc.). This necessity is underscored by the lack of documentation concerning the annotation of minutiae in fingermarks throughout the Analysis and Comparison phases of ACE-V. Finally, these data suggest that considering the current training and agency certification process may be valuable, as the examiners in this study appeared to lack comprehensive knowledge of friction ridge skin characteristics. The reliance on examiners' experience must also be considered carefully, given the insight that experience is not a significant determinant of examiners' expertise.

Ethics statement

Upon review of the materials that the corresponding author provided, the Department of Security and Crime Science Ethics Committee has decided that the proposed research (Project ID 783) is exempt from requiring approval by the UCL Research Ethics Committee. This is because the proposed research either:

- Does not involve human participants and/or does not involve the collection and/or use of data derived from human individuals, or
- Corresponds to one or more of the following UCL exemption criteria (https://ethics.grad.ucl.ac.uk/exemptions.php).

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CRediT authorship contribution statement

Saesario Putra: Conceptualization, Data curation, Formal analysis, Funding acquisition, Methodology, Visualization, Writing – original draft. **Ruth M. Morgan:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Sherry Nakhaeizadeh:** Writing – review & editing, Supervision, Methodology, Conceptualization.

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.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scijus.2025.101316.

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