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Escaping the Fingerprint Crisis: A Blueprint for Essential Research

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ESCAPING THE FINGERPRINT CRISIS: A BLUEPRINT FOR ESSENTIAL RESEARCH

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There is a fingerprint crisis in the courts. Judges and jurors regularly convict criminal defendants based on fingerprint evidence, but there are serious questions about the accuracy and reliability of this evidence. The few studies delving into the accuracy and reliability of fingerprint examiners' work suggest a high error rate and demonstrate that, when faced with the same prints under different conditions, fingerprint examiners frequently reach different results than they previously reached. Further, there is no scientific basis for fingerprint matching. It is unknown whether and to what extent fingerprints are unique; the degree to which fingerprints change under various forces relevant to the creation of latent fingerprints remains a mystery; and computerized fingerprint matching algorithms are even less successful than the questionable subjective matching methods of fingerprint examiners. This Article charts a scientific escape from the debacle, explaining that lawyers must work hand-in-hand with scientists to determine whether they can build a scientific foundation for fingerprint evidence. Detailed research on the uniqueness of fingerprints, the biomechanics of touch, and computerized matching algorithms is central to this endeavor, and more robust studies about fingerprint examiners' accuracy and reliability could also be useful. If researchers pursue these four tracks of essential research, courts can dig their way out of this existing fingerprint crisis.

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I. INTRODUCTION

Fingerprint evidence is not what it seems. Popular television shows like *CSI: Crime Scene Investigation* depict fingerprint evidence as infallible, and fingerprint examiners regularly testify that their fingerprint matches are 100% accurate.[1] Further, judges consistently admit fingerprint examiners' testimony in court, and juries regularly convict criminal defendants based on fingerprint evidence.[2] But beneath the surface lies an insidious truth: fingerprint evidence stands on a shaky foundation. Despite claims by fingerprint examiners to the contrary, the practice of matching latent fingerprints found at a crime scene to the exemplar prints that an individual has on file is not based on science.[3] First, there are real questions about the extent to which individuals' fingerprints are even unique such that they are useful for the purpose of identification.[4] Second, there is little scientific research establishing a methodology to accurately match fingerprints.[5] Further, the very limited research on fingerprint matching has not clearly established that the current practice of matching latent prints to exemplar prints is accurate or reliable.[6]

Perhaps even more shocking than the unscientific nature of fingerprint matching and the related concerns about accuracy and reliability is that this should not be news to key players in the criminal justice system; yet fingerprint

1. *See* NAT'L RESEARCH COUNCIL, STRENGTHENING FORENSIC SCIENCE IN THE UNITED STATES: A PATH FORWARD 48, 141–42 (2009) [hereinafter STRENGTHENING FORENSIC SCIENCE]; *cf. generally* Simon A. Cole, *Individualization Is Dead, Long Live Individualization! Reforms of Reporting Practices for Fingerprint Analysis in the United States*, 13 LAW, PROBABILITY & RISK 117 (2014) (providing an overview of how fingerprint testimony—by at least some examiners—has changed over the years but suggesting that it makes little difference). This Article refers to "fingerprint matching," but it focuses primarily on matching latent fingerprints rather than on tenprint matching. *See infra* text accompanying notes 47–49.
2. *See infra* Section III.B.
3. *See* STRENGTHENING FORENSIC SCIENCE, *supra* note 1, at 142–45; *infra* Part IV.
4. *See infra* Section IV.B.
5. *See infra* Sections IV.C–D.
6. *See infra* Section IV.A.

evidence continues to serve as a basis for criminal convictions. Prosecutors routinely present fingerprint examiners' testimony in court, the examiners often testify to the certainty of their match conclusions, judges continue to admit that testimony, and judges and jurors regularly convict criminal defendants based upon this unscientific, unproven evidence.[7] When defendants raise objections to fingerprint evidence in criminal cases, judges generally have one of two responses: They either apply a perfunctory *Daubert*- or *Frye*-type evaluation and conclude with little analysis that fingerprint evidence is indeed reliable evidence, or else they conclude that a reliability analysis under *Daubert* or *Frye* is not even applicable because fingerprint evidence has such a long historical pedigree of being used in the criminal justice system.[8] Concerningly, "scientific" evidence like this seems to regularly receive less scrutiny in the criminal context than in the civil one despite more being at stake—a defendant's life or liberty rather than just money.[9]

The questions surrounding fingerprint evidence, paired with its continued prominent use in criminal cases, has created a crisis in the courts. Are innocent defendants being falsely identified and even wrongfully convicted based on this questionable evidence? Perhaps the best-known story of an inaccurate identification by fingerprint evidence is the false identification of Brandon Mayfield as the Madrid train bomber in 2004.[10] Mayfield, an Oregon attorney and Muslim convert, was held for two weeks for the train-bombing terrorist attack that killed 191 people.[11] He was implicated based almost entirely on fingerprint evidence.[12] Authorities found a latent fingerprint on a bag containing bomb materials that was near the crime scene.[13] The FBI's Integrated Automated Fingerprint Identification System ("IAFIS")[14] identified Mayfield's print, which was in the FBI database, as a possible match to this latent print, and an FBI fingerprint examiner subsequently manually matched the latent print to Mayfield's exemplar print,

7. *See infra* Section III.B.

8. *See infra* Section III.B.

9. For further analysis of this issue, see Meghan J. Ryan, *The Misguided Case of Civil v. Criminal Scientific Evidence Standards*, manuscript (SMU Working Paper, 2019) (on file with author).

10. *See generally* OFFICE OF THE INSPECTOR GEN., A REVIEW OF THE FBI'S HANDLING OF THE BRANDON MAYFIELD CASE 1 (2016) [hereinafter MAYFIELD REV.] (describing the incident); Sarah Kershaw et al., *Spain and U.S. at Odds on Mistaken Terror Arrest*, N.Y. TIMES (June 5, 2004), https://www.nytimes.com/2004/06/05/us/spain-and-us-at-odds-on-mistaken-terror-arrest.html (same).

11. *See* MAYFIELD REV., *supra* note 10, at 1–2; Elaine Sciolino, *Bombings in Madrid: The Attack; 10 Bombs Shatter Trains in Madrid, Killing 192*, N.Y. TIMES (Mar. 12, 2004), https://www.nytimes.com/2004/03/12/world/bombings-in-madrid-the-attack-10-bombs-shatter-trains-in-madrid-killing-192.html.

12. *See* MAYFIELD REV., *supra* note 10, at 1–3.

13. *See id.* at 1; Kershaw, *supra* note 10.

14. The FBI has since decommissioned IAFIS and now uses "Advanced Fingerprint Identification Technology" ("AFIT") as part of its larger "Next Generation Identification System" ("NGI"). Alice Lipowicz, *FBI Deploys Faster Fingerprint ID System*, GCN (Mar. 9, 2011), https://gcn.com/articles/2011/03/09/fbi-deploys-faster-fingerprint-identification-system.aspx; Ellen Messmer, *FBI Turns Up Faster, More Accurate Fingerprint Identification System*, NETWORK WORLD (Mar. 8, 2011), https://www.networkworld.com/article/2201167/fbi-turns-up-faster--more-accurate-fingerprint-identification-system.html.

concluding that Mayfield's print was a 100% match to the latent print.[15] Two additional FBI fingerprint examiners, as well as a court-appointed independent examiner, verified this match conclusion.[16] The FBI opened an investigation into Mayfield, and, although it discovered he was Muslim, was married to an Egyptian immigrant, had contacts with suspected terrorists, and had represented a convicted terrorist in a child custody dispute, the FBI found nothing linking Mayfield to the bombing.[17] In fact, Mayfield did not have a valid passport, and he had apparently not left the United States since the 1990s.[18] Further, the Spanish National Police determined that Mayfield's print was *not* a match to the latent print found at the crime scene.[19] After discussing the matter with the FBI, the Spanish National Police vowed to reassess whether the prints were a match.[20] In the meantime, the FBI detained Mayfield and intensified its investigation into him.[21] Subsequently, the court appointed an independent fingerprint examiner—a renowned expert in the field—to compare the latent print to Mayfield's exemplar print, and the expert concurred with the FBI that the prints were a match.[22] That same day, though, the Spanish National Police alerted the FBI that it had matched the latent print to someone else—an Algerian national.[23] After Mayfield was released to home detention, the FBI once again reviewed its match determination and finally reversed its conclusion.[24]

Although Mayfield was not wrongfully convicted based on the erroneous fingerprint identification, others have not been so lucky. Since 1989, there have been 623 known wrongful convictions based on faulty forensic evidence,[25] and about 3% of these were convictions based on fingerprint evidence.[26] As commentators have explained, these figures likely drastically underestimate the number of people actually wrongfully convicted, and underestimates are likely exacerbated when a conviction is based on fingerprint evidence because courts are unlikely to look skeptically at fingerprint evidence even though it has a shaky

15. *See* Application for Material Witness Order and Warrant Regarding Witness: Brandon Bieri Mayfield, *In re* Federal Grand Jury Proceedings 03-01, 337 F. Supp. 2d 1218 (D. Or. 2004) (No. 04-MC-9071).

16. *See* Mayfield v. United States, 599 F.3d 964, 966–67 (9th Cir. 2010); MAYFIELD REV., *supra* note 10, at 2 ("This conclusion was verified by a second LPU examiner and reviewed by a Unit Chief in the LPU, who concurred with the identification.").

17. MAYFIELD REV., *supra* note 10, at 2.

18. *See* Mayfield v. United States, 504 F. Supp. 2d 1023, 1033 (D. Or. 2007), *vacated by Mayfield*, 599 F.3d 964; MAYFIELD REV., *supra* note 10, at 58.

19. *See* Kershaw et al., *supra* note 10.

20. *See* MAYFIELD REV., *supra* note 10, at 2.

21. The FBI held Mayfield as a material witness. *See id.* at 2–3.

22. *See id.* at 3.

23. *Id.*; Kershaw, *supra* note 10.

24. *See* MAYFIELD REV., *supra* note 10, at 3.

25. *See Browse Cases*, NAT'L REGISTRY OF EXONERATIONS, http://www.law.umich.edu/special/exoneration/Pages/detaillist.aspx (last visited Apr. 18, 2020) (listing exoneration cases in which the underlying conviction involved false or misleading forensic evidence). This accounts for approximately 24% of known wrongful convictions. *See id.*

26. *See id.*; *see also infra* text accompanying notes 88–95. Note that this percentage is variable. In March of 2019, a slightly greater percentage of known wrongful convictions based on faulty forensic evidence were convictions based on fingerprint evidence.

scientific foundation.[27] In recent years, courts have reversed or vacated convictions based on other questionable forensic evidence, though.[28] Bite mark evidence, for example, has come under considerable scrutiny, and several defendants who were convicted based on bite mark evidence have since been exonerated.[29] But judges do not seem as concerned about fingerprint evidence.

There are a few reasons why judges might admit fingerprint evidence at trial even though there are real questions about its accuracy and reliability as evidence. One possibility is that judges simply are unaware that serious questions exist about the accuracy and reliability of fingerprint match determinations—that fingerprint examiners regularly produce false positive and false negative match conclusions, that they are inconsistent in these determinations and have an inter-rater reliability problem, and that the discipline is not built upon a scientific foundation.[30] At this point, though, lack of knowledge seems unlikely. Questions about the accuracy and reliability of fingerprint evidence have become fairly widely known within the criminal justice community.[31] Another possibility is that judges simply do not believe that there could be real questions about the accuracy or reliability of fingerprint evidence and are unwilling to even entertain this possibility. Such a position may be based on the habit of admitting such evidence for well over a century,[32] but this position also likely is buttressed by a concern—whether conscious or unconscious—that if one gives in to the accuracy and reliability questions of fingerprint evidence, the system could very well collapse. First, there are an overwhelming number of individuals in prison whose convictions were based at least in part on fingerprint evidence.[33] Will courts have to review all of these cases if judges conclude that fingerprint evidence is actually inaccurate or unreliable? Second, considering fingerprint evidence is often the primary evidence upon which criminal defendants are convicted,[34] will the effectiveness of achieving important convictions in the criminal justice system

27. *See infra* Part III.

28. *See, e.g.*, *Ex parte* Chaney, 563 S.W.3d 239, 274–78 (Tex. Crim. App. 2018) (finding the petitioner "actually innocent" where his conviction was based on bite mark evidence).

29. *See All Cases*, INNOCENCE PROJECT, https://www.innocenceproject.org/all-cases/#bitemark-analysis (last visited Apr. 7, 2020) (displaying a set of cases that involved faulty bitemark analyses); NAT'L REGISTRY OF EXONERATIONS, *supra* note 25 (displaying cases filtered out by "bitemark"); *see, e.g.*, Ex parte *Chaney*, 563 S.W.3d at 274–78 (finding the petitioner "actually innocent" where his conviction was based on bite mark evidence); *In re* Richards, 371 P.3d 195, 207–08, 211 (Cal. 2016) (granting habeas relief for a conviction based on bite mark evidence). It is important to note that these exonerations have generally not been based solely on the unreliability of bite mark evidence, though. In In re *Richards*, for example, the bite mark expert from trial had repudiated his testimony and the petitioner was able to offer additional expert testimony suggesting that the bite mark evidence against him was unreliable. *See* In re *Richards*, 371 P.3d at 207–08. In Ex parte *Chaney*, the prosecution conceded that the bite mark evidence in the case was faulty and did not constitute proof of guilt in the case. *See* Ex parte *Chaney*, 563 S.W.3d at 258.

30. *See infra* Part IV.

31. *See infra* Part III.

32. *See* United States v. Baines, 573 F.3d 979, 990 (10th Cir. 2009); United States v. Mitchell, 365 F.3d 215, 238 (3d Cir. 2004); *see also* STRENGTHENING FORENSIC SCIENCE, *supra* note 1, at 136 ("Fingerprints, palm prints, and sole prints have been used to identify people for more than a century in the United States.").

33. *See generally* STRENGTHENING FORENSIC SCIENCE, *supra* note 1 (discussing the role of forensic science evidence, including fingerprint evidence, in criminal cases).

34. *See generally id.*

plummet? Avoiding wrongful convictions—based on fingerprint or even other questionable evidence—is critical, but one should not overlook the importance of punishing guilty offenders. The legitimacy of criminal law depends on it. These concerns are real. As at least one judge has privately asked, why should judges exclude fingerprint evidence when there is no clear-cut evidence that it is *not* accurate or reliable?[35] From the perspective of criminal defenders across the country, this position may be shocking because evidentiary rules ordinarily provide that only *reliable* scientific testimony and evidence is admissible.[36] But, if judges continue to think this way, it is important to address this concern as well.

This Article focuses on finding a scientific escape from many of these concerns by setting forth an agenda for research that scientists, hand-in-hand with lawyers, should conduct to finally determine whether there is a scientific basis for fingerprint examination that would make the practice useful for identifications. The science could completely disprove the utility of the practice, but, more likely, it will show how this discipline can be vastly improved to provide greater accuracy and reliability, as well as provide probabilities associated with determining how much weight decisionmakers should give fingerprint evidence. Despite the growing awareness within the criminal justice community about the questions swirling around fingerprint evidence, much of the general public remains unaware of the accuracy and reliability issues at stake with this type of evidence.[37] This includes scientists. Because the general public, and scientists too, often assume that there is satisfactory science shoring up the practice of fingerprint matching, there has been little movement within the scientific community to research questions related to the practice.[38] The criminal justice system's heavy reliance on this questionable practice, however, highlights the necessity of lawyers and scientists collaborating to push forward this agenda.

This Article outlines four main tracks of essential research. The first is studying how consistent fingerprint examiners are—and how accurate they are—in their conclusions.[39] The recent awareness of the problems with fingerprint evidence has spurred some small studies along this track[40] —with mixed results—but there is more work to do here. This Article suggests how to improve on the existing studies. The second track of essential research relates to individualization. There is surprisingly little research assessing whether each individual has a unique fingerprint.[41] Examining this question is in some ways more difficult than looking at individualization in the DNA context, but this Article proposes some useful avenues of inquiry here. The third track of necessary research is investigating the biomechanics of touch (and other related variables) as they relate to

35. Author conversation with anonymous judge.

36. *See, e.g.*, FED. R. EVID. 702 (providing that "[a] witness who is qualified as an expert by knowledge, skill, experience, training, or education may testify in the form of an opinion or otherwise if," among other things, "the testimony is based on sufficient facts or data," "the testimony is the product of reliable principles and methods," and "the expert has reliably applied the principles and methods to the facts of the case").

37. *See infra* Part III.

38. *See infra* Part IV.

39. *See infra* Section IV.A.

40. *See infra* text accompanying notes 184–214.

41. *See infra* Section IV.B.

fingerprints.[42] Fingers deform when they press against surfaces, and how they deform can relate to variables such as the shape of the surface on which they are pressed and the force with which they are pressed.[43] This Article proposes a handful of experiments to further explore how the biomechanics of touch affect fingerprints. Finally, the last essential research track is building effective computerized matching programs.[44] In other disciplines, there has been a fair amount of effort put into developing computer programs that can match one image to another.[45] This matching is complicated with respect to fingerprints, though, because there is need for a computer program that can accurately identify and quantify the degree of difference between two similar images. The difference between, for example, an exemplar print and a latent print found at a crime scene could result from the simple biomechanics of touch or from the fact that the prints were derived from different individuals.[46] It would be useful to measure this difference to help determine the probability that the prints originated with the same individual.

By setting forth this ambitious research agenda, I hope that this Article spurs collaboration between lawyers and the scientific community to conduct the necessary research so that we can finally find an escape from the current fingerprint crisis. This research should provide significant insight into whether fingerprint examination is a useful enterprise offering accurate and reliable information or whether it is pure junk science.

II. THE MECHANICS OF FINGERPRINT MATCHING

Modern fingerprint analysis is not as straightforward as is presented on television and in the movies. There are basically two types of fingerprint examination.[47] In "tenprint" examinations, authorities capture images of all ten of an individual's prints, which are then often compared to other prints on file.[48] In latent print examinations, the authorities find a latent print at a crime scene, capture the print, and compare the print to exemplar prints on file.[49] Tenprint examinations usually take place when an individual has been arrested and is being processed.[50] Latent print examinations are generally employed when attempting to uncover the identity of the perpetrator from evidence found at a crime scene.[51] This second type of fingerprint examination is often more difficult because of the

42. *See infra* Section IV.C.

43. *See* STRENGTHENING FORENSIC SCIENCE, *supra* note 1, at 137.

44. *See infra* Section IV.D.

45. *See infra* Section IV.D.

46. *See* STRENGTHENING FORENSIC SCIENCE, *supra* note 1, at 137–38.

47. *See* Anil K. Jain & Jianjiang Feng, *Latent Fingerprint Matching*, 33 IEEE TRANSACTIONS ON PATTERN ANALYSIS & MACHINE INTELLIGENCE 88, 88 (2011); Kristi Mayo, *AFIS Interoperability*, EVIDENCE TECH. MAG., Jan–Feb. 2008.

48. *See* Jain & Feng, *supra* note 47, at 88.

49. *See id.*

50. *See id.*; Kenneth R. Moses et al., *Automated Fingerprint Identification Systems (AFIS)*, NAT'L INST. JUST, THE FINGERPRINT SOURCEBOOK 6-9 to 6-10 (2011) (Alan McRoberts ed., 2011), https://www.ncjrs.gov/pdffiles1/nij/225320.pdf.

51. *See* Jain & Feng, *supra* note 47, at 88.

decreased quality and quantity of the latent prints available for comparison.[52] Moreover, while authorities acquire exemplar prints under at least somewhat controlled conditions, individuals create latent prints under generally unknown conditions.[53] This translates into latent prints that can significantly differ from the exemplar prints on file, making match determinations more difficult.[54]

Unlike what one might see on *CSI: Crime Scene Investigation*, attempting to match a latent print to an exemplar print on file is generally a two-part process. First, a latent print is compared to suspects' prints or electronically run against a database of known prints—prints associated with particular individuals—using an automated fingerprint identification system ("AFIS").[55] Employing a proprietary computerized algorithm, the AFIS generates the closest possible matches to the latent print.[56] Some jurisdictions have access to both their local database of known prints and also the more extensive federal database of known prints.[57] The FBI maintains a large database within its Next Generation Identification system, which includes fingerprints for more than 120 million people.[58] Not all police departments have the luxury of easily employing this database, though, as gaining access to the database can take time, and maintaining local terminals that can communicate with the FBI system can be expensive.[59]

After an AFIS arms examiners with one or more possible matches to the latent print, the fingerprint examiners engage in a manual study of the latent print and the relevant exemplar print(s),[60] analyzing the characteristics of the prints to determine whether they are similar enough to conclude that they are a match.[61] Today, fingerprint examiners in the United States typically analyze prints using

52. *See id.* at 88–90. Latent prints are usually of low quality, often lack significant overlapping area with the exemplar print on file, may appear on a complex background that makes it difficult for the system to pick up the print alone, and are affected by nonlinear distortion. *See id.*

53. *See* STRENGTHENING FORENSIC SCIENCE, *supra* note 1, at 137.

54. *See id.* at 137–40.

55. *See id.* at 139, 269; Moses et al., *supra* note 50, at 6-27.

56. *See* Interview with James Loudermilk, Senior Dir. for Innovation and Customer Solutions, IDEMIA Nat'l Sec. Solutions (July 15, 2019). Of course, it is the computerized algorithm that culls the "closest" prints from the database, so these prints are the closest according to the algorithm, *see* Moses et al., *supra* note 50, at 6-28, which does not necessarily mean that these prints are the closest according to all methods of comparison.

57. *See* STRENGTHENING FORENSIC SCIENCE, *supra* note 1, at 270–71.

58. *See* E-mail from James Loudermilk, Senior Dir. for Innovation and Customer Solutions, IDEMIA Nat'l Sec. Solutions, to Meghan J. Ryan, Professor of Law, Southern Methodist University Dedman School of Law (Apr. 29, 2020, 17:15 CDT) (on file with author). In recent years, NGI replaced IAFIS. *See Forensic Database Biometrics Table*, NAT'L INST. OF STANDARDS & TECH. (Jan. 9, 2017), https://www.nist.gov/oles/forensic-database-biometrics-table (last visited Apr. 7, 2020); *supra* note 14.

59. See STRENGTHENING FORENSIC SCIENCE, *supra* note 1, at 270–71; E-mail from James Loudermilk, *supra* note 58; Interview with James Loudermilk, *supra* note 56; *see also* William Jackson, *Law Enforcement, NIST Making Fingerprint Files Easier to Search*, GCN (Mar. 25, 2013), https://gcn.com/articles/2013/03/25/afis-fingerprint-matching-standards.aspx (describing the incompatibility between AFIS terminals and efforts to "enable interoperable searches between law enforcement agencies using AFIS solutions from different vendors").

60. *See* STRENGTHENING FORENSIC SCIENCE, *supra* note 1, at 139 ("Although some Automated Fingerprint Identification Systems (AFIS) permit fully automated identification of fingerprint records related to criminal history (e.g., for screening job applicants), the assessment of latent prints from crime scenes is based largely on human interpretation.").

61. *See id.*

an ACE-V—Analysis, Comparison, Evaluation, and Verification—approach.[62] This involves assessing the quality and quantity of detail in the latent print and considering the skin's condition, residue that may be present, mechanical deformation of the print, the type of surface touched, the method used to capture the print, and the percentage of the print captured.[63] Each of these factors can affect the details and shape of the print.[64] Examiners compare the latent print to an exemplar print, looking at details such as ridge flows, ridge counts, the shape of the print's core, delta locations, delta shape, scar shapes, and crease patterns.[65] They then evaluate whether there are enough similarities between the latent and exemplar print to declare a match.[66] There is not a standard number of similarities that examiners must find to declare a match; instead the examiner's own experience should inform his or her opinion about whether there is sufficient agreement between the prints to reach such a conclusion.[67] Moreover, fingerprint examiners often simply conclude whether their evaluations resulted in identification or exclusion, or whether they were inconclusive.[68] Standard analysis in this area does not include assessing error rates such as in DNA analysis.[69] Finally, there is a verification step—at least in some laboratories—by which another examiner determines whether he or she agrees with the original examiner's

62. *See id.* at 137.

63. *See id.* at 137–38; Lyn Haber & Ralph Norman Haber, *Scientific Validation of Fingerprint Evidence Under* Daubert, 7 LAW, PROBABILITY & RISK 87, 90 (2008).

64. *See* STRENGTHENING FORENSIC SCIENCE, *supra* note 1, at 137–38; Haber & Haber, *supra* note 63, at 90.

65. *See* STRENGTHENING FORENSIC SCIENCE, *supra* note 1, at 138; Haber & Haber, *supra* note 63, at 90.

66. *See* STRENGTHENING FORENSIC SCIENCE, *supra* note 1, at 138; Haber & Haber, *supra* note 63, at 91.

67. *See* STRENGTHENING FORENSIC SCIENCE, *supra* note 1, at 139. As NAS relates:

> [T]he ACE-V method does not specify particular measurements or a standard test protocol, and examiners must make subjective assessments throughout. In the United States, the threshold for making a source identification is deliberately kept subjective, so that the examiner can take into account both the quantity and quality of comparable details. As a result, the outcome of a friction ridge analysis is not necessarily repeatable from examiner to examiner.

Id.

68. *See id.* at 141 (noting that "[the Scientific Working Group on Friction Ridge Analysis, Study and Technology (SWGFAST)] has promulgated three acceptable conclusions resulting from latent print comparison: individualization (or identification), exclusion, or inconclusive").

69. *See, e.g.*, People v. Pettis, No. 4-18-0328, 2019 WL 441958, at *4 (Ill. App. Jan. 31, 2019) ("Moore testified her comparison of a fingerprint on exhibit T and the latent fingerprint resulted in a match, indicating the same person made both prints."); State v. Martinez, No. A-1-CA-35021, 2018 WL 3867856, at *2, 4–5 (N.M. Ct. App. July 31, 2018) (stating that the police officer "match[ed] four different latent prints to four fingers on [Martinez's] ten-print card . . . [and] testified that he was one hundred percent certain that it was a match, and that, if he felt that he was not certain, then he would not have called it an identification"); STRENGTHENING FORENSIC SCIENCE, *supra* note 1, at 141–42 (explaining that, because statistical models are insufficient, "the friction ridge community actively discourages its members from testifying in terms of the probability of a match"); *see also* STRENGTHENING FORENSIC SCIENCE, *supra* note 1, at 143 ("Some in the latent print community argue that the method itself, if followed correctly (i.e., by well-trained examiners properly using the method), has a zero error rate. Clearly, this assertion is unrealistic, and, moreover, it does not lead to a process of method improvement."); Brandon Garrett & Gregory Mitchell, *How Jurors Evaluate Fingerprint Evidence: The Relative Importance of Match Language, Method Information, and Error Acknowledgment*, 10 J. EMPIRICAL LEGAL STUD. 484, 485 (2013) ("At a criminal trial involving fingerprint evidence, a fingerprint examiner will typically testify that she followed a standard procedure for comparing prints recovered from the crime scene to reference sample prints and opine that this procedure resulted in a conclusion that the defendant was the source of the crime scene prints . . . .").

reasoning and conclusion.[70] Importantly, the second examiner is generally not blinded from the original examiner's conclusion in reaching his or her own results.[71] Further, the original examiner is generally not blinded from information the authorities have about the suspects at issue in the case and the sources of the exemplar prints.[72]

III. THE FINGERPRINT CRISIS

Fingerprint matching has come under heavy scrutiny in recent years. At the federal level, the National Academy of Sciences ("NAS"), as well as the President's Council of Advisors on Science and Technology ("PCAST"), have offered sharp criticism of the practice, emphasizing the lack of a scientific foundation for fingerprint matching.[73] Yet courts continue to admit testimony from fingerprint examiners, and courts and juries continue to convict criminal defendants based on this evidence. This creates a significant concern about wrongful identifications and convictions, but the practice persists.

A. *Questions About Accuracy and Reliability*

Unlike DNA analysis, which developed in the research laboratories of universities, fingerprint examination sprouted from the forensic needs of police departments and was cultivated in that environment alongside other forensic disciplines like ballistics and hair analysis.[74] And just like their distinct origins, DNA analysis and fingerprint matching have very different foundations. DNA analysis is based on years of rigorous scientific research.[75] Fingerprint matching lacks any indicia of a scientific foundation.

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70. *See* STRENGTHENING FORENSIC SCIENCE, *supra* note 1, at 138; Haber & Haber, *supra* note 63, at 91.

71. *See* Haber & Haber, *supra* note 63, at 97 ("[M]ost verification testing in crime laboratories is non-blind, which permits contamination and bias to reduce the chances of detecting errors . . . ."); *see also* STRENGTHENING FORENSIC SCIENCE, *supra* note 1, at 138 ("Verification occurs when another qualified examiner repeats the observations and comes to the same conclusion, although the second examiner may be aware of the conclusion of the first.").

72. *See* Itiel E. Dror, *Biases in Forensic Experts*, 360 SCI. 243, 243 (2018) ("Forensic experts are too often exposed to irrelevant contextual information, largely because they work with the police and prosecution. Extraneous information—from a suspect's ethnicity or criminal record to eyewitness identifications, confessions, and other lines of evidence—can potentially cause bias."); Itiel E. Dror et al., *Contextual Information Renders Experts Vulnerable to Making Erroneous Identifications*, 156 FORENSIC SCI. INT'L 74, 77 (2006) ("Our study shows that it is possible to alter identification decisions on the same fingerprint, solely by presenting it in a different context.").

73. *See* STRENGTHENING FORENSIC SCIENCE, *supra* note 1, at 142 (stating that fingerprint examiners' claims of infallibility are "not scientifically plausible"); PRESIDENT'S COUNCIL OF ADVISORS ON SCI. AND TECH., FORENSIC SCIENCE IN CRIMINAL COURTS: ENSURING SCIENTIFIC VALIDITY OF FEATURE-COMPARISON METHODS 95–96 (2016) [hereinafter PCAST REP.] (emphasizing the potentially high error rates of the subjective practice of fingerprint matching).

74. *Compare* Stephen Mayhew, *History of Biometrics*, BIOMETRIC UPDATE, https://www.biometricupdate.com/201802/history-of-biometrics-2 (last visited Apr. 7, 2020) (explaining that fingerprint identification practices grew out of police departments), *with* STRENGTHENING FORENSIC SCIENCE, *supra* note 1, at 41 (stating that "DNA analysis . . . originally developed in research laboratories in the context of life sciences research").

75. *See* STRENGTHENING FORENSIC SCIENCE, *supra* note 1, at 40–41.

In 2009, NAS issued a report—*Strengthening Forensic Science in the United States: A Path Forward*—heavily criticizing almost every forensic science discipline except for DNA analysis.[76] Fingerprint (and other friction ridge) analysis was no exception.[77] The report explains that there has been insufficient research to support the discipline of fingerprint analysis.[78] In particular, the authors were concerned about the subjectivity involved in fingerprint examinations,[79] the flexibility in methodology among examiners,[80] and the lack of scientific evidence supporting the ACE-V method.[81] After its analysis, the authors concluded:

> Historically, friction ridge analysis [including fingerprint examination] has served as a valuable tool, both to identify the guilty and to exclude the innocent. Because of the amount of detail available in friction ridges, it seems plausible that a careful comparison of two impressions can accurately discern whether or not they had a common source. Although there is limited information about the accuracy and reliability of friction ridge analyses, claims that these analyses have zero error rates are not scientifically plausible.[82]

This was a gracious conclusion considering the lack of sufficient research to shore up current practices of fingerprint analysis.

PCAST, while also criticizing fingerprint analysis, was similarly rather charitable:

> PCAST finds that latent fingerprint analysis is a foundationally valid subjective methodology—albeit with a false positive rate that is substantial and is likely to be higher than expected by many jurors based on longstanding claims about the infallibility of fingerprint analysis. The false-positive rate could be as high as 1 error in 306 cases based on the FBI study and 1 error in 18 cases based on a study by another crime laboratory. In reporting results of latent-fingerprint examination, it is important to state the false-positive rates based on properly designed validation studies.[83]

Aside from expressing concern about accuracy, PCAST noted that the practice of fingerprint examination faces some additional major challenges, including confirmation bias, contextual bias, and a lack of proficiency studies.[84] Validity of the practice, PCAST explained, depends upon addressing these important

76. *See generally id.* at 127–82 (criticizing various forensic science disciplines).

77. *See id.* at 136–45. The report classifies fingerprint analysis as a form of "friction ridge analysis." *Id.* at 136. Friction ridge analysis also includes the examination of palm and sole prints. *See id.*

78. *See id.* at 142–45.

79. *See id.* at 139.

80. *See id.* at 141.

81. *See* STRENGTHENING FORENSIC SCIENCE, *supra* note 1, at 143 (quoting Haber & Haber, who concluded that they had "reviewed available scientific evidence of the validity of the ACE-V method and found none").

82. *Id.* at 142.

83. PCAST REP., *supra* note 73, at 9–10.

84. *See id.* at 10.

issues.[85] In addition to these stated deficiencies, however, there is the looming concern of a lack of research validating the practice in general.[86]

As would be expected in a discipline not based on scientific research, there are several known cases of wrongful conviction and wrongful identification based on fingerprint evidence. Brandon Mayfield is not the only one who has suffered as a consequence of the broad use of fingerprint evidence in court.[87] Stephan Cowans served six and a half years of a thirty- to forty-five-year sentence for a murder conviction based largely on fingerprint evidence.[88] Multiple fingerprint examiners were involved in the case and concluded that Cowans's print was a match to a latent print found at the crime scene.[89] Post-conviction DNA evidence later exonerated Cowans, though, suggesting the conclusion that his fingerprint was a match to the latent print was erroneous.[90] In another case, an individual—Richard Jackson—was convicted of murdering his lover, Alvin Davis.[91] A supposedly matching fingerprint was the only evidence supporting the conviction, and Jackson was sentenced to life in prison.[92] Three fingerprint examiners had concluded that Jackson's fingerprint was a match to a print found at the scene of the crime.[93] At trial, Jackson's defense counsel put two of its own experts on the stand who testified that Jackson's fingerprint was not a match to the latent print, but this did not persuade the jury.[94] Jackson was later excluded as the source of the latent print, and Jackson was released from prison after serving two years.[95]

Despite these stories, it remains unclear exactly how many individuals have been wrongfully convicted based on faulty fingerprint evidence. There are only about two dozen generally known cases like this,[96] but, for a number of reasons,

85. *See id.*

86. *See id.* at 10–11.

87. *See supra* text accompanying notes 10–24.

88. *See* Simon A. Cole, *More Than Zero: Accounting for Error in Latent Fingerprint Identification*, 95 J. CRIM. L. & CRIMINOLOGY 985, 986–87 (2005) ("In January, Stephan Cowans was freed after serving six and a half years of a 30- to 45-year sentence for shooting and wounding a police officer. Cowans had been convicted solely on fingerprint and eyewitness evidence, but post-conviction DNA testing showed that Cowans was not the perpetrator."); *Stephan Cowans*, INNOCENCE PROJECT [hereinafter *Cowans*, INNOCENCE PROJECT], https://www.innocenceproject.org/cases/stephan-cowans/ (last visited Apr. 7, 2020); *Stephan Cowans*, UNIV. MICH.: NAT'L REGISTRY EXONERATIONS [hereinafter *Cowans*, NAT'L REGISTRY EXONERATIONS], https://www.law.umich.edu/special/exoneration/Pages/casedetail.aspx?caseid=3127 (last visited Apr. 7, 2020). Cowans's conviction was also based on erroneous eyewitness testimony. *See Id.*

89. *See* Cole, *supra* note 88, at 986–87; *Cowans*, INNOCENCE PROJECT, *supra* note 88; *Cowans*, NAT'L REGISTRY EXONERATIONS, *supra* note 88.

90. *See* Cole, *supra* note 88, at 986–87; *Cowans*, INNOCENCE PROJECT, *supra* note 88; *Cowans*, NAT'L REGISTRY EXONERATIONS, *supra* note 88.

91. *See* Cole, *supra* note 88, at 1011.

92. *See id.*; *Richard Jackson*, NAT'L REGISTRY EXONERATIONS, http://www.law.umich.edu/special/exoneration/Pages/casedetail.aspx?caseid=3318 (last visited Apr. 7, 2020).

93. *See* Cole, *supra* note 88, at 1011; *Richard Jackson*, *supra* note 92.

94. *See* Cole, *supra* note 88, at 1011; *Richard Jackson*, *supra* note 92.

95. *See* Cole, *supra* note 88, at 1011; *Richard Jackson*, *supra* note 92.

96. *See* Cole, *supra* note 88, at 997–1016, 1067–70 tbl. 1 (identifying twenty-two cases of wrongful conviction or identification based on fingerprint evidence). Authorities continue to uncover cases of erroneous fingerprint match determinations, however. For example, in 2012, a fingerprint examiner in Lana Canen's case changed his match opinion about the latent print at issue, which led to Canen's exoneration. *See Lana Canen*,

it is exceedingly difficult to identify such cases. Experts have explained that exoneration numbers overall almost certainly underestimate the true number of wrongful convictions.[97] Further, such underestimates are probably greater where fingerprint evidence is involved, because judges and juries generally consider fingerprint evidence very persuasive.[98] As Simon Cole has said, "No forensic expert witness can more convincingly place a suspect at the scene of crime than the latent fingerprint examiner . . . . Juries have consistently shown themselves willing to convict on fingerprint evidence alone, and such convictions have been upheld by the courts."[99] Indeed, prosecutors have been using fingerprint evidence to convict defendants for more than a century.[100] Moreover, this acute persuasiveness of fingerprint evidence certainly has an effect on plea-bargaining, as deals are struck in the shadow of what is possible at trial.[101] More than 90% of

UNIV. MICH.: NAT'L REGISTRY EXONERATIONS, http://www.law.umich.edu/special/exoneration/Pages/casedetail.aspx?caseid=4047 (last visited Apr. 7, 2020). Canen was released after serving seven years of a fifty-five-year sentence for murder. *See id.* In 2015, Beniah Alton Dandridge was released from prison after serving nineteen years of a life sentence when, due to witness recantations, the fingerprint evidence in the case was reviewed and the latent prints were determined to belong to someone other than Dandridge. *See Beniah Alton Dandridge*, UNIV. MICH.: NAT'L REGISTRY EXONERATIONS, http://www.law.umich.edu/special/exoneration/Pages/casedetail.aspx?caseid=4768 (last visited Apr. 7, 2020).

97. *See* JON B. GOULD, THE INNOCENCE COMMISSION: PREVENTING WRONGFUL CONVICTIONS AND RESTORING THE CRIMINAL JUSTICE SYSTEM 19 (2008); Jon B. Gould & Richard A. Leo, *One Hundred Years Later: Wrongful Convictions After a Century of Research*, 100 J. CRIM. L. & CRIMINOLOGY 825, 834–36 (2010).

98. *See* Simon A. Cole, *Witnessing Identification: Latent Fingerprinting Evidence and Expert Knowledge*, 28 SOC. STUD., SCI. 687, 688 (1998); Sarah Lucy Cooper, *Challenges to Fingerprint Identification Evidence: Why the Courts Need a New Approach to Finality*, 42 MITCHELL HAMLINE L. REV. 756, 757 (2016) ("[F]ingerprints are considered 'powerful' evidence against defendants."); James S. Liebman et al., *The Evidence of Things Not Seen: Non-Matches as Evidence of Innocence*, 98 IOWA L. REV. 577, 601 (2013) ("A fingerprint is powerful because the collection of many tiny lines and intersections found in a latent partial fingerprint at a crime scene match those taken from a suspect.").

99. *See* Cole, *supra* note 98, at 688.

100. *See* United States v. Baines, 573 F.3d 979, 990 (10th Cir. 2009) ("Fingerprint identification has been used extensively by law enforcement agencies all over the world for almost a century."); United States v. Calderon-Segura, 512 F.3d 1104, 1109 (9th Cir. 2008) ("As other courts have recognized, fingerprint identification methods have been tested in the adversarial system for roughly a hundred years."); United States v. Mitchell, 365 F.3d 215, 238 (3d Cir. 2004); Jeffery G. Barnes, *History*, *in* NAT'L INST. JUST., *supra* note 50, at 1-17 to 1-19 (stating that the *People v. Jennings* case in 1911 "was the first American appellate case regarding the admissibility of fingerprint expert testimony" and that the *People v. Crispi* case, which was decided that same year, "is considered to be the first conviction obtained with fingerprint evidence alone in the United States").

101. *See* William J. Stuntz, *Privacy's Problem and the Law of Criminal Procedure*, 93 MICH. L. REV. 1016, 1020 (1995) ("[A]ll procedural rules have substantive effects. But it is useful to see how criminal procedure casts its substantive shadow, and how the size and shape of that shadow depends on the interests the law chooses to protect."); *see also* Robert H. Mnookin & Lewis Kornhauser, *Bargaining in the Shadow of the Law: The Case of Divorce*, 88 YALE L.J. 950, 997 (1979) ("Individuals in a wide variety of contexts bargain in the shadow of the law."). *But cf.* Stephanos Bibas, *Plea Bargaining Outside the Shadow of Trial*, 117 HARV. L. REV. 2464, 2466–67 (2004) (explaining that this shadow-of-trial model is oversimplified); William J. Stuntz, *Plea Bargaining and Criminal Law's Disappearing Shadow*, 117 HARV. L. REV. 2548, 2549–50 (2004) (stating that "[t]he shadow the law casts on plea bargaining is different for different crimes and different at the federal and state levels" and explaining that, "[f]or many crimes, law's shadow may disappear altogether . . . [and] plea bargains take place in the shadow of prosecutors' preferences, voters' preferences, budget constraints, and other forces—but not in the shadow of the law").

cases end in guilty pleas rather than trial convictions,[102] and it is much more difficult to establish one's innocence after one has pled guilty.[103] Accordingly, the numbers of individuals wrongfully convicted—whether by trial or plea—based on fingerprint evidence could be staggering.

B. *Admissibility*

Despite the significant concerns about the accuracy and reliability of fingerprint analysis, courts continue to routinely admit expert testimony from fingerprint examiners, and juries continue to rely heavily on this testimony in convicting criminal defendants.[104] Over the course of the last couple of decades, there have been several challenges to such testimony. For example, in *United States v. Crisp*,[105] the defendant argued that a fingerprint expert's testimony that the defendant's palm had produced the print on an incriminating note should be excluded under the admissibility test for expert testimony set forth in *Daubert v. Merrell Dow Pharmaceuticals, Inc.*[106] In *United States v. John*,[107] the defendant argued that "the district court 'abdicated its gatekeeping function' by failing to [even] hold a *Daubert* hearing" before admitting fingerprint testimony into evidence.[108] And in *United States v. Baines*,[109] the defendant objected to the reliability of fingerprint testimony tying him to the illegal possession of a duffel bag full of guns and ammunition.[110] In each of these cases, the courts deftly rejected the defendants' challenges.

Courts have uniformly dismissed these and similar challenges. In *Crisp*, for example, the Fourth Circuit emphasized fingerprint evidence's long historical pedigree in the United States, stating that "[f]ingerprint . . . analysis ha[s] long been recognized by the courts as [a] sound method[] for making reliable identifications" and that "[f]ingerprint identification has been admissible as reliable evidence in criminal trials in this country since at least 1911."[111] Then, pursuant

102. *See* Lafler v. Cooper, 566 U.S. 156, 170 (2012) ("[C]riminal justice today is for the most part a system of pleas, not a system of trials. Ninety-seven percent of federal convictions and ninety-four percent of state convictions are the result of guilty pleas.").

103. *See Innocents Who Plead Guilty*, NAT'L REGISTRY OF EXONERATIONS 1 (2015), http://www.law.umich.edu/special/exoneration/Documents/NRE.Guilty.Plea.Article1.pdf. As the *National Registry of Exonerations* has explained:

> Innocent defendants who plead guilty have an exceptionally hard time convincing anybody of their innocence, or even getting a hearing. Judges, prosecutors, police officers, journalists, friends, lawyers, even innocence organizations are all less likely to believe in the innocence of a defendant who pleads guilty. Procedural obstacles prevent these defendants from filing appeals, petitioning for consideration of new evidence, obtaining DNA testing.

Id.

104. *See* United States v. Stone, 848 F. Supp. 2d 714, 718 (E.D. Mich. 2012) ("Wholesale objections to latent fingerprint identification evidence have been uniformly rejected by courts across the country.").

105. 324 F.3d 261 (4th Cir. 2003).

106. *See id.* at 265. Although not technically fingerprint evidence, palm print evidence is very similar and suffers from the same deficiencies.

107. 597 F.3d 263 (5th Cir. 2010).

108. *Id.* at 274.

109. 573 F.3d 979 (10th Cir. 2009).

110. *See id.* at 980–82.

111. *Crisp*, 324 F.3d at 265–66.

to its *Daubert* analysis, the court stated that "the principles underlying fingerprint identification . . . bear the imprimatur of a strong general acceptance, not only in the expert community, but in the courts as well."[112] Accordingly, the court concluded that "wholesale exclusion of [such] a long-accepted form of expert evidence" would be a "drastic step" and applauded the district court's ruling to admit it.[113] In *John*, the Fifth Circuit determined that the district court was correct in not even holding a *Daubert* hearing on the admissibility of the evidence because, again, "[f]ingerprint identification has been admissible as reliable evidence in criminal trials in this country since at least 1911."[114] Moreover, the court explained, "the reliability of the technique has been tested in the adversarial system for over a century," "has been routinely subject to peer review," and, "as a number of courts have noted, the error rate is low."[115] In *Baines*, the Tenth Circuit applied a more rigorous version of the *Daubert* test than did the Fourth Circuit in *Crisp*, but, taking into account the deferential abuse-of-discretion standard of review, concluded that the lower court had not erred in admitting fingerprint evidence.[116] Under *Daubert*, which the court emphasized is a flexible test,[117] the court found that: (1) fingerprint matching had not been subjected to rigorous scientific testing but that examiner certification and proficiency tests suggested that this testing factor "weigh[ed] somewhat in favor of admissibility, although not powerfully";[118] (2) the government failed to show that the peer review and publication factor favored admissibility;[119] (3) although "[t]here may . . . be[] erroneous identifications that [have] never [come] to light," and even though "the actual error rate for FBI examiners may be higher than" the "one per 11 million" figure to which the government's expert testified, "the *known* error rate remains impressively low" and favors admissibility;[120] (4) "[t]he ACE-V system is a procedural standard but not a substantive one," as "[c]ritical steps in the process depend on the subjective judgment of the analyst," but, ultimately, "determination of this factor is not critical to our decision";[121] and (5) "acceptance by a community of unbiased experts would carry greater weight, [but] . . . acceptance by other experts in the field," as is present here, is

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112. *Id.* at 268.

113. *Id.* Although the court emphasized the importance of the long general acceptance of fingerprint evidence, it did explain that *Daubert* applied and briefly explained that, beyond general acceptance, fingerprint analysis had "the requisite 'standards controlling the technique's operation'" and a "negligible error rate" that satisfied the *Daubert* factor. *Id.* at 269 (quoting Daubert v. Merrell Dow Pharms., Inc., 509 U.S. 579, 593 (1993)).

114. United States v. John, 597 F.3d 263, 274–75 (5th Cir. 2010) (quoting *Crisp*, 324 F.3d at 266).

115. *Id.* at 275.

116. *See* United States v. Baines, 573 F.3d 979, 992 (10th Cir. 2009) ("In reaching a conclusion after this process of focusing on each of the *Daubert* factors in turn, we must return to two overriding principles": a deferential standard of review and the flexibility of *Daubert* and *Kumho Tire*.).

117. *See id.* at 989 ("The inquiry is a 'flexible one,' as *Daubert* itself teaches.").

118. *Id.* at 990.

119. *Id.*

120. *Id.* at 990–91 (emphasis added).

121. *Id.* at 991. The court added: "We hasten to add that subjectivity does not, in itself, preclude a finding of reliability. But in searching this record for evidence of standards that guide and limit the analyst in exercise of these subjective judgments, we find very little." *Id.*

"overwhelming" and sufficient.[122] As *Baines* demonstrates, even when courts remain truer to *Daubert* and apply more than perfunctory analyses like the courts did in *Crisp* and *John*, they still end up admitting fingerprint evidence despite its lack of scientific foundation.

In only one reported case has a judge refused to admit this testimony. In the 2002 *United States v. Llera Plaza*[123] case, Judge Louis H. Pollak of the Eastern District of Pennsylvania carefully examined the information presented to him on fingerprinting techniques and analyzed the reliability of the practice under the admissibility factors set forth in *Daubert*.[124] He found that there was little scientific testing shoring up the practice,[125] it had not been sufficiently subjected to the peer review process,[126] and there was no known error rate—either at the methodological or practitioner level—or controlling standards governing the practice.[127] Ultimately, he concluded that "[t]he failure of fingerprint identifications fully to satisfy the[se] first three *Daubert* factors militates against heavy reliance on the general acceptance factor"[128] and that general acceptance cannot "by itself . . . sustain the government's burden in making the case for the admissibility of fingerprint testimony under Federal Rule of Evidence 702."[129] In making this determination, Judge Pollak ignored the long historical pedigree of fingerprinting on which so many judges before him had relied and found persuasive.[130] Based upon his examination, Judge Pollak concluded that the parties could present only limited expert fingerprint testimony.[131] Their experts could "describ[e] how any latent and rolled prints at issue in th[e] case were obtained"; "identify[], and plac[e] before the jury, such fingerprints and any necessary magnifications"; and "point[] out any observed similarities and differences between a particular latent print and a particular rolled print alleged by the government to be attributable to the same persons."[132] Judge Pollak did not, however, allow the parties "to present testimony expressing an opinion of an expert witness

122. *Baines*, 573 F.3d at 991.

123. United States v. Llera Plaza, 179 F. Supp. 2d 492 (E.D. Pa. 2002) (withdrawn from bound volume), *vacated and superseded* by United States v. Llera Plaza, 188 F. Supp. 2d 549 (E.D. Pa. 2002).

124. *See Llera Plaza*, 179 F. Supp. 2d at 504–16 (analyzing the practice of fingerprint matching under *Daubert*). Examining expert testimony and methods under *Daubert* for admissibility involves assessing whether the method can be or has been tested, whether it has been published and subjected to peer review, its rate of error and whether there are standards controlling its operation, and whether it enjoys general acceptance within the relevant scientific community. *See* Daubert v. Merrell Dow Pharms., Inc., 509 U.S. 579, 593–94 (1993).

125. *See Llera Plaza*, 179 F. Supp. 2d at 506–08.

126. *See id.* at 508–09 (asserting that, although there have been a number of publications discussing the techniques of fingerprint identification, "it is not apparent that the[se] publication[s] constitute[] 'submission to the scrutiny of the scientific community' in the *Daubert* sense" because "[e]ven those who stand at the top of the fingerprint identification field . . . tend to be skilled professionals who have learned their craft on the job and without any concomitant advanced academic training" so "[i]t would thus be a misnomer to call fingerprint examiners a 'scientific community' in the *Daubert* sense" (quoting *Daubert*, 509 U.S at 593)).

127. *Id.* at 509–14.

128. *Id.* at 515.

129. *Id.*

130. *See id.* at 494–517.

131. *See Llera Plaza*, 179 F. Supp. 2d at 517–18.

132. *Id.*

that a particular latent print matches, or does not match, the rolled print of a particular person and hence is, or is not, the fingerprint of that person."[133]

Judge Pollak's decision sent reverberations throughout the criminal justice community—but not for long. Just over two months later, Judge Pollak reversed himself.[134] In this later decision, Judge Pollak explained that, upon reconsideration, it seemed that, although fingerprint examination is not scientific, it is a technical discipline and, in that sense, there has been sufficient peer review and publication and sufficient knowledge of error rate and maintenance of standards under *Daubert*.[135] The "testing" factor of *Daubert* was still not met,[136] but this, he determined, would not prevent the admissibility of testimony on fingerprint identifications.[137] "[T]o postpone present in-court utilization of this 'bedrock forensic identifier' pending such [useful] research," Judge Pollak explained, "would be to make the best the enemy of the good."[138]

Thus was the end of the brief victory by criminal defendants over the questionable practice of admitting "expert" testimony on fingerprint identifications. Since Judge Pollak's brave analysis in his initial opinion carefully analyzing the forensic discipline under *Daubert*, there have been no other even slightly successful challenges to this evidence in court.[139] Judges seem to have taken a uniform stance in admitting this evidence despite questions about the accuracy and reliability of human fingerprint examiners and the AFISs on which they regularly rely.

133. *Id.* at 518.

134. *See* United States v. Llera Plaza, 188 F. Supp. 2d 549 (E.D. Pa. 2002), *vacating and superseding Llera Plaza*, 179 F. Supp. 2d 492. Judge Pollak's initial decision on this question of admissibility was issued on January 7, 2002. *See Llera Plaza*, 179 F. Supp. 2d at 492. His later decision reversing this was issued on March 13, 2002. *See Llera Plaza*, 188 F. Supp. 2d at 549.

135. *See Llera Plaza*, 188 F. Supp. 2d at 560–71.

136. *See id.* at 571 ("Having re-reviewed the applicability of the *Daubert* factors through the prism of *Kumho Tire*, I conclude that the one *Daubert* factor which is both pertinent and unsatisfied is the first factor—'testing.'").

137. *See id.* at 571–72.

138. *Id.* at 572.

139. *See, e.g.*, United States v. Baines, 573 F.3d 979, 992 (10th Cir. 2009) ("On the whole, it seems to us that the record supports the district judge's finding that fingerprint analysis is sufficiently reliable to be admissible. Thus, we find no abuse of discretion."); United States v. Calderon-Segura, 512 F.3d 1104, 1110 (9th Cir. 2008) ("The procedures adopted by the district court for determining evidentiary reliability, and for permitting the defense to inquire into the expert's qualifications and bases for his proffered opinions, were well within the court's discretion in fulfilling its gatekeeping function. Thus, the expert testimony was properly admitted."); United States v. Abreu, 406 F.3d 1304, 1307 (11th Cir. 2005) ("We agree with the decisions of our sister circuits and hold that the fingerprint evidence admitted in this case satisfied *Daubert*."); United States v. Mitchell, 365 F.3d 215, 246 (3d Cir. 2004) (finding that the lower court did not abuse its discretion in admitting fingerprint identification evidence); United States v. Collins, 340 F.3d 672, 682 (8th Cir. 2003) ("Fingerprint evidence and analysis is generally accepted."); United States v. Crisp, 324 F.3d 261, 269 (4th Cir. 2003) (finding that the lower court did not abuse its discretion in admitting fingerprint identification testimony). Although this Article focuses on federal cases, the same is true with respect to state cases.

Although judges routinely admit fingerprint evidence, courts generally allow defense counsel to cross-examine the expert to try to expose the shortcomings of fingerprint evidence.[140] By doing this, courts state that data about the inaccuracies and unreliability of fingerprint evidence goes to the weight of the evidence.[141] But there are limits to what courts will allow on cross-examination. In *Gee v. United States*,[142] for example, the district court refused to allow the defense to specifically rely on the NAS report in his cross-examination of the prosecution's fingerprint examiner.[143] Defense counsel attempted to have the report admitted as a learned treatise to be used for substantive and impeachment purposes, but the court denied this request, finding that it disagreed with parts of the report, as did the prosecution's fingerprint expert.[144] Even if courts do not limit cross-examination in this way, studies show that the cross-examination of expert witnesses often does little to change the minds of jurors, who are largely impressed by expert witnesses and their so-called scientific evidence.[145] As a result, relying on cross-examination to ameliorate the effects of fingerprint examiners' testimony seems to be ineffective.

Beyond cross-examination, the defense is often unable to present its own evidence about the inaccuracies and unreliability of fingerprint evidence. As Judge Michael explained in his dissent in *Crisp*:

> In most criminal cases, particularly those in which the defendant is indigent, the defendant does not have access to an independent expert who could review the analyses and conclusions of the prosecution's expert. Lack of money is only one problem. Lack of independent crime laboratories is another. The great majority of crime laboratories are operated by law enforcement agencies. More important, criminal defendants do not appear to have access to experts who could challenge the basic principles and methodology of fingerprint and handwriting analysis.[146]

140. *See, e.g.*, *Baines*, 573 F.3d at 983–85 (describing the defense's cross-examination regarding the errors associated with fingerprint identifications and noting the district court's determination that defense arguments about such errors go to the weight of the evidence, which can be addressed during cross-examination).

141. *See, e.g.*, United States v. John, 597 F.3d 263, 275–76 (5th Cir. 2010) ("Issues regarding the accuracy of fingerprint evidence in a particular case generally go 'to the weight and credibility of the evidence' and are 'best left to the finder of fact, not an appellate court.'").

142. 54 A.3d 1249 (D.C. 2012).

143. *See id.* at 1253–55. The court refused to take judicial notice of the NAS report as a learned treatise. *See id.* at 1268.

144. *See id.* at 1262–68.

145. *See* Erica Beecher-Monas, *Reality Bites: The Illusion of Science in Bite-Mark Evidence*, 30 CARDOZO L. REV. 1369, 1407 (2009) ("Although cross-examination and the presentation of contradictory expert testimony are the traditional cures for 'attacking shaky but admissible evidence,' expert testimony that lacks any empirical foundation is resistant to this kind of correction."); *see also* Sarah Lucy Cooper, *The Collision of Law and Science: American Court Responses to Developments in Forensic Science*, 33 PACE L. REV. 234, 262, 275 (2013) (stating that "studies have rejected the idea that cross-examination cures 'shaky' evidence" and that "studies have found that a vast majority of jurors agree that fingerprint identification is a 'science' and that fingerprints are the most reliable means of identification").

146. United States v. Crisp, 324 F.3d 261, 273 (4th Cir. 2003) (Michael, J., dissenting); *see also* SIMON A. COLE, SUSPECT IDENTITIES: A HISTORY OF FINGERPRINTING AND CRIMINAL IDENTIFICATION 280 (2001) (explaining that is rare for the defense to challenge fingerprint evidence because it lacks the funds to hire experts and reporting that police officers have been known to fabricate fingerprint evidence for this reason); Paul C. Giannelli,

Aside from fingerprint examiners, who have a vested interest in maintaining public perceptions of the usefulness of their profession, there are a very limited number of individuals who have the qualifications to testify as an expert in this area. Generally, scientists are not engaged in research related to the accuracy or reliability of fingerprint evidence,[147] and courts have raised concerns about academics who study the area but have not, themselves, tested fingerprint accuracy and reliability.[148] Overall, "[t]he maldistribution of forensic scientists"—and those allowed to testify about forensic science—"so favors the prosecution that the defense has little access to any [useful forensic science testimony], which prevents the adversary process from working, as intended, to expose error."[149]

Even when the defense does have access to an expert, courts often deny defense counsel's request to present this counterevidence. In *United States v. Pitts*,[150] for example, the court refused to allow the defense expert to testify, concluding that his testimony would not be helpful to the jury.[151] According to the court, "The only opinion Defendant seeks to introduce is that fingerprint examiners 'exaggerate' their results to the exclusion of others. However, the government has indicated that its experts will not testify to absolutely certain identification nor that the identification was to the exclusion of all others."[152] Court decisions like these are surprisingly common.[153] On occasion, however, courts emphasize the importance of allowing the defendant to present his own fingerprint expert. In *State v. Sheehan*, for example, the Utah Court of Appeals criticized the district court's exclusion of testimony by the defense's expert

The Abuse of Scientific Evidence in Criminal Cases: The Need for Independent Crime Laboratories, 4 VA. J. SOC. POL'Y & L. 439, 470 (1997) ("Considering the professional relationship between crime labs and police departments, pro-prosecution bias in forensic science is not surprising. In fact, seventy-nine percent of the labs are governed by the police, and most examine only evidence submitted by the prosecution team."); Paul C. Giannelli, *"Junk Science": The Criminal Cases*, 84 J. CRIM. L. & CRIMINOLOGY 105, 118 (1993) ("Forensic laboratory services . . . are not generally available to criminal defendants. A survey of approximately 300 crime laboratories revealed that 'fifty-seven percent . . . would only examine evidence submitted by law enforcement officials.'"); Jennifer L. Mnookin, *Fingerprint Evidence in an Age of DNA Profiling*, 67 BROOK. L. REV. 13, 38–39 (2001) (explaining that the rarity of challenges to fingerprint evidence has contributed to the persuasiveness and power of this evidence).

147. *See infra* Part IV.

148. *See, e.g.*, People v. Caradine, No. A121968, 2012 WL 599252, at *16 (Cal. Ct. App. Feb. 23, 2012) ("The court's conclusion that Cole, a historian and sociologist who had read and written on the subject of fingerprint analysis but had never himself studied fingerprints, did not qualify as an expert on the reliability of fingerprint analysis as it related to this case was not an abuse of discretion.").

149. Michael J. Saks, *Merlin and Solomon: Lessons from the Law's Formative Encounters with Forensic Identification Science*, 49 HASTINGS L.J. 1069, 1093 (1998).

150. No. 16-CR-550 (DLI), 2018 WL 1169139 (E.D.N.Y. Mar. 2, 2018) (summary order).

151. *See id.* at *3–4. The government argued that the expert—Dr. Simon Cole, who is a criminology professor at the University of California Irvine and who specializes in fingerprint evidence— was "not a trained fingerprint examiner," had "not published peer-reviewed scientific articles on the topic of latent fingerprint evidence," and had "not conducted any validation research in the field." *Id.* at *1 (quoting the government's brief in support of its motion to preclude the testimony).

152. *Id.* at *3 (citation omitted).

153. *See, e.g.*, *Caradine*, 2012 WL 599252, at *15–16 (affirming the district court's denial of the defendant's request to present the expert testimony of Dr. Simon Cole); State v. Armstrong, 920 So.2d 769, 770–71 (Fla. Dist. Ct. App. 2006) (quashing the district court's order allowing the defendant's expert to testify about the reliability of fingerprint identification).

witness.[154] The district court had refused to allow the expert to testify because his testimony would undercut the accuracy and reliability of fingerprint evidence, and the courts in the state had already determined that fingerprint evidence is accurate and reliable.[155] The district court had then concluded that cross-examination of the government's fingerprint examiner was a sufficient tool to make the defendant's argument against the accuracy and reliability of fingerprint evidence.[156] The Utah Court of Appeals reversed the district court's holding on this issue, however, clarifying that the courts' determination that fingerprint evidence is reliable "does not automatically exclude any contradictory expert testimony from trial, as long as the competing expert qualifies" under the evidentiary rules.[157] The appellate court thus remanded the case to the district court for a determination of whether the expert did indeed qualify.[158] In contrast to the Utah Court of Appeals' decision, though, "the vast majority of cases reject appeals of this nature and rely on [cross-examination] to protect defendants."[159]

IV. A BLUEPRINT FOR INVESTIGATION

As the NAS report explains, there is little scientific basis for the current practices of fingerprint matching.[160] That does not necessarily indicate that currently employed fingerprint methodologies are entirely inaccurate and unreliable, but only that more work must be done in this area. In the wake of the NAS report, though, some researchers have attempted to scientifically assess the accuracy and reliability of fingerprint matching and also improve upon its methods.[161] They primarily have conducted this research in terms of assessing examiners' error rates and consistency.[162] Researchers have generally not, however, ventured much into establishing a scientific basis for fingerprint matching.[163] Although they have conducted very limited studies in this area, it is not enough, and progress has generally stagnated.

There are a number of reasons that progress on investigating, or even improving, the accuracy and reliability of fingerprint evidence has stalled. First, there has been no clear blueprint on what research must be done to undergird the field of fingerprint matching. This Article lays out such a map of the essential research scientists must work on. Relatedly, there has been little communication between the legal community and scientists about the gaps in research that must

154. *See* State v. Sheehan, 273 P.3d 417, 425–28 (Utah Ct. App. 2012).

155. *See id.* at 425–26.

156. *See id.* at 420–21.

157. *Id.* at 425, 430.

158. *See id.* at 428. The defendant has since pleaded guilty. *See* State v. Sheehan, Case No. 061908535 (3d Dist. Ct., Salt Lake, Utah).

159. Cooper, *supra* note 98, at 759, 776.

160. *See* STRENGTHENING FORENSIC SCIENCE, *supra* note 1, at 144–45.

161. *See infra* Sections IV.A–D.

162. *See infra* Section IV.A.

163. Sharath Pankanti et al., *On the Individuality of Fingerprints*, 24 IEEE TRANSACTIONS ON PATTERN ANALYSIS & MACHINE INTELLIGENCE 1010, 1010–11 (2002).

be filled to flesh out the practice of fingerprint matching.[164] While an increasing number of lawyers are aware of the scientific insufficiency of fingerprint and other forensic science evidence, scientists are generally unaware of this gap in the scientific literature.[165] Like most members of the general public, many scientists assume that, if fingerprint evidence is routinely used in criminal cases and other important areas like national security, it must be accurate and reliable.[166] This belief is further bolstered by the high-tech depiction of fingerprint and other forensic science evidence in the media, such as on television shows like *CSI: Crime Scene Investigation*.[167] A handful of brief articles on the shortfalls of the forensic sciences have been published in prominent scientific journals like *Nature* and *Science*,[168] but apparently this has not captured the attention of scientists like it should. Perhaps because they are novices in the forensic science discipline and it thus may not seem obvious what research is necessary to shore up the practice, scientists who have the requisite expertise to fill this void generally seem unaware of it.[169] Biomedical engineers specializing in tissue, for example—while a small community themselves—for the most part have not put their expertise to use in this alternative arena.[170] Finally, the lack of scientific research in this area can at least partially be chalked up to a lack of resources. Financial resources—especially federal funds—often drive scientific research.[171]

164. *See* Interview with Tré Welch, Assistant Professor, Cardiovascular & Thoracic Surgery, UT Southwestern Medical Ctr., in Dallas, Tex. (Feb. 21, 2020) (on file with author).

165. *See* Brandon L. Garrett & Gregory Mitchell, *Forensics and Fallibility: Comparing the Views of Lawyers and Jurors*, 119 W. VA. L. REV. 621, 632–33 (2016) (finding that polled lay persons "placed considerable confidence in fingerprint evidence," whereas a considerable number of polled lawyers "characterized fingerprint evidence as somewhat to very unreliable"); Interview with Tré Welch, *supra* note 164.

166. *See* Tamara F. Lawson, *Can Fingerprints Lie?: Re-Weighing Fingerprint Evidence in Criminal Jury Trials*, 31 AM. J. CRIM. L. 1, 2 (2003) ("If truth be told, 'everyone' believes that fingerprint evidence is reliable, even infallible, evidence. In the average layman's understanding of criminal law, fingerprint identification evidence is equated with guilt, while the lack of fingerprint identification evidence infers a weakness in the prosecution's case."); Michael J. Saks & Jonathan J. Koehler, *The Individualization Fallacy in Forensic Science Evidence*, 61 VAND. L. REV. 199, 202 (2008) (suggesting that judges and juries generally assume that declared fingerprint matches and other forensic science individualization determinations have significant probative value); Interview with Tré Welch, *supra* note 164.

167. *See* Saks & Koehler, *supra* note 166, at 202 ("Popular television programs such as *CSI* and *Forensic Files* reinforce the notion of individualization in the collective public imagination by offering confident pronouncements from scientists about whose hair was recovered from the knife or which gun fired the murderous bullet.").

168. *See, e.g.*, Kelly Servick, *Reversing the Legacy of Junk Science in the Courtroom*, SCI. MAG. (Mar. 7, 2016, 4:30 PM), https://www.sciencemag.org/news/2016/03/reversing-legacy-junk-science-courtroom (describing some frailties of the forensic science disciplines, as well as new research efforts underway to hopefully improve them); Laura Spinney, *Science in Court: The Fine Print*, 464 NATURE 344, 344–46 (Mar. 17, 2010) (describing deficiencies in the practice of fingerprint matching).

169. *See* Interview with Tré Welch, *supra* note 164.

170. *See id.*

171. *See* Dr. Samuel L. Stanley, Jr., *Federal Funding Drives U.S. Innovation*, HUFFPOST (June 7, 2016), https://www.huffpost.com/entry/federal-funding-drives-us_b_10336004 (explaining that federal funding drives scientific innovation); W. Nicholson Price II, *Grants*, 34 BERKELEY TECH. L.J. 1, 4 (2019) ("Through their scale and ubiquity, grants significantly shape the progress of science and innovation. Grants help determine which areas of science are studied and how, make or break the careers of academic and non-academic scientists alike, and guide the creation of new institutes and discipline-spanning resources."). *But see* Jeffrey Mervis, *Data Check: U.S. Government Share of Basic Research Funding Falls Below 50%*, SCI. MAG. (Mar. 9, 2017,1:15 PM),

Scientists and universities ordinarily rely heavily on outside funding to support their work.[172] Relatively few resources have been devoted to research in the forensic sciences, however.[173] This explains why, aside from the disciplines that grew out of universities—such as DNA and controlled substance analyses—very little scientific research has been done in the forensic science disciplines.[174] Under the Obama Administration, some funding was earmarked for the forensic sciences, but former Attorney General Jeff Sessions of the Trump Administration pulled this funding in 2017.[175] Further, Sessions disbanded the National Commission on Forensic Science, which was formed under the Obama Administration and was charged with improving the accuracy and reliability of forensic science.[176] Indeed, the Trump Administration has seemingly put a stop to researching the accuracy and reliability of the forensic sciences, including the practice of fingerprint matching.[177]

There are several areas that should be thoroughly investigated for fingerprints to have solid support. First, building on social scientists' investigations into how accurate and reliable fingerprint examiners' determinations of matches actually are may be useful. More important, though, is conducting research necessary to establish a scientific foundation for fingerprint matching. Pursuant to this goal, it is essential to assess the extent to which individuals' fingerprints are actually unique. Further, there is a need to examine how fingerprints change based upon the conditions under which they are made. And finally, there must be a more concerted effort to improve computer-based fingerprint matching algorithms. Researchers must further investigate each of these areas before fingerprint examination could be said to have a sound scientific basis.

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https://www.sciencemag.org/news/2017/03/data-check-us-government-share-basic-research-funding-falls-below-50 ("For the first time in the post–World War II era, the federal government no longer funds a majority of the basic research carried out in the United States.").

172. *See* Art Jahnke, *Who Picks Up the Tab for Science?*, THE BRINK (Apr. 6, 2015), http://www.bu.edu/articles/2015/funding-for-scientific-research.

173. *See* STRENGTHENING FORENSIC SCIENCE, *supra* note 1, at 142–45.

174. *See id.* at 128, 133, 142–45.

175. *Fundamental Measurement, Quantum Science and Measurement Dissemination*, NAT'L INST. OF STANDARDS & TECH. (Dec. 1, 2018), https://www.nist.gov/director/congressional-and-legislative-affairs/fy-2019-presidential-budget-request-summary-0-4 (noting a $6.7 million reduction in forensic science investments in the FY 2019 budget request).

176. *See* Pema Levy, *Jeff Sessions Wants Courts to Rely Less on Science and More on "Science"*, MOTHER JONES (Apr. 24, 2017), https://www.motherjones.com/politics/2017/04/sessions-forensic-science/.

177. *See id.*; Liliana Segura & Jordan Smith, *Bad Evidence*, THE INTERCEPT (May 5, 2019, 7:00 AM), https://theintercept.com/2019/05/05/forensic-evidence-aafs-junk-science/.

A. *Fingerprint Examiner Accuracy and Reliability*

Although there has been very little research about the science behind fingerprint matching, a handful of social scientists have attempted to assess the accuracy and reliability of fingerprint examiners' match determinations under particular conditions.[178] Generally, these studies suggest that examiners' decisions are unreliable[179] and, moreover, they might reach erroneous identification conclusions at a concerning rate, ranging up to and perhaps even exceeding about 4.2% of the time.[180]

178. *See* Philip J. Kellman et al., *Forensic Comparison and Matching of Fingerprints: Using Quantitative Image Measures for Estimating Error Rates through Understanding and Predicting Difficulty*, PLOS ONE (2014), at 18 ("Relatively few studies have examined expert performance in fingerprint matching tasks . . . ."); *see also, e.g.*, *infra* text accompanying notes 184–207 (summarizing some of these studies). The PCAST report explains that many of these studies actually "were not intended as validation studies, although they provide some incidental information about performance." PCAST REP., *supra* note 73, at 91. It also notes that, "Remarkably, there have been only two black-box studies that were intentionally and appropriately designed to assess validity and reliability—the first published by the FBI Laboratory in 2011; the second completed in 2014 but not yet published. Conclusions about foundational validity thus must rest on these two recent studies." *Id.*

179. *See, e.g.*, Dror et al., *supra* note 72, at 76 (finding that, when presented with contextual information, 80% of examiners reached different match conclusions on the same prints that they had previous examined).

180. *See infra* text accompanying notes 184–208 (summarizing the error rates in these studies). The PCAST report, which examines a slightly different list of studies than those discussed in this Article, provides the following table of examiner false positive rates:

Study	**False Positives**			
	Raw Data	Freq. (Confidence bound)	Estimated Rate	Bound on Rate
Early studies				
Langenburg (2009a)	0/14	0% (19%)	1 in ∞	1 in 5
Langenburg (2009b)	1/43	2.3% (11%)	1 in 43	1 in 9
Langenburg et al. (2012)	17/711	2.4% (3.5%)	1 in 42	1 in 28
Tangen et al. (2011) ("similar pairs")	3/444	0.68% (1.7%)	1 in 148	1 in 58
Tangen et al. (2011) ("dissimilar pairs")	0/444	0% (0.67%)	1 in ∞	1 in 148
Black-box studies				
Ulery et al. 2011 (FBI)**	6/3628	0.17% (0.33%)	1 in 604	1 in 306
Pacheco et al. 2014 (Miami-Dade)	42/995	4.2% (5.4%)	1 in 24	1 in 18
Pacheco et al. 2014 (Miami-Dade) (excluding clerical errors)	7/960	0.7% (1.4%)	1 in 137	1 in 73

* "Raw Data": Number of false positives divided by number of conclusive examinations involving non-mated pairs. "Freq. (Confidence Bound)": Point estimate of false positive frequency, and upper 95 percent confidence bound. "Estimated Rate": The odds of a false positive occurring, based on the observed proportion of false positives. "Bound on Rate": The odds of a false positive occurring, based on the upper 95 percent confidence bound—that is, the rate could reasonably be as high as this value.

** If inconclusive examinations are included for the FBI study, the rates are 1 in 681 and 1 in 344, respectively.

PCAST REP., *supra* note 73, at 98.

As Dror et al. have stated, "Being a scientist or forensic expert is rooted in the ability to examine evidence reliably and objectively."[181] Today's approach to fingerprint matching is subjective, rather than objective, however.[182] NAS has explained:

> [T]he ACE-V method does not specify particular measurements or a standard test protocol, and examiners must make subjective assessments throughout. In the United States, the threshold for making a source identification is deliberately kept subjective, so that the examiner can take into account both the quantity and quality of comparable details. As a result, the outcome of a friction ridge analysis is not necessarily repeatable from examiner to examiner.[183]

Further, studies show that fingerprint examiners regularly reach different match determinations than they previously made when comparing the exact same prints.[184] For example, in a 2005 study, Dror et al. found that 80% of the examiners they tested reached different match conclusions when presented with biased contextual information.[185] In a subsequent study, Dror and Charlton found that examiners who were not even presented with contextual information—a condition less reflective of real practices—reached match determinations different from their previous ones approximately 8.3% of the time.[186] When presented with biased contextual information, the fingerprint examiners made inconsistent decisions 16.6% of the time.[187]

Not only are fingerprint examiners' match decisions unreliable, but their error rates, and in particular their false positive rates, are at concerning levels.[188] A false positive rate of 4.2% for examiners means that about four in one hundred individuals convicted primarily on fingerprint evidence could actually be innocent. That is a high risk of wrongful conviction. According to the studies, examiners' false negative error rate is even higher, ranging up to about 8.7%.[189] In the context of defendant rights in the criminal law, this higher error rate is less concerning, as it relates to failure to perceive an identification rather than a false identification that could lead to wrongful conviction.[190] But it also means that some perpetrators might be going free, which could affect overall crime rates. It is important to note that these false positive and negative rates probably

181. Dror et al., *supra* note 72, at 74.

182. *See* STRENGTHENING FORENSIC SCIENCE, *supra* note 1, at 139.

183. *Id.*

184. *See* Dror et al., *supra* note 72, at 76.

185. *Id.* It is worth noting that the study tested just five examiners. *See id.* at 72.

186. *See* Itiel E. Dror & David Charlton, *Why Experts Make Errors*, 56 FORENSIC IDENTIFICATION 600, 611 (2006). Note that the study tested just six examiners. *See id.* at 606.

187. *See id.* at 606, 610.

188. *See* PCAST REP., *supra* note 73, at 98.

189. *See infra* text accompanying notes 193–209 (summarizing the error rates in these studies).

190. This is consistent with the maxim that it is "better that ten guilty persons escape, than that one innocent suffer." 4 WILLIAM BLACKSTONE, COMMENTARIES *352.

overestimate the accuracy of fingerprint examiners, though, as there are significant limitations to the studies that likely underestimate the risk of errors.[191]

Understanding the significance of these error rates requires digging into the study designs.[192] For example, a 2006 study by Wertheim et al. asked ninety-two examiners with at least a year of experience to compare latent prints and exemplars of varying levels of difficulty using the ACE method.[193] Of the comparisons, the examiners found 6,441 positive identifications, and eighty-one of those were erroneous.[194] The researchers discarded sixty-six of those erroneous results as clerical errors, yielding a false positive rate of 0.23% and a clerical error rate of 1.02%.[195] The researchers also concluded that "the data of greatest interest are the [5,861] individualizations made at [the highest] confidence rating,"[196] leading them to calculate a more specific false positive rate of 0.034%. This new rate stemmed from categorizing two of the sixty-one erroneous individualizations in this highest confidence group as true errors and discarding the rest as clerical errors.[197] In a follow-up study, the researchers found that sixteen subject examiners attempting to verify the two false positives of the original study using the ACE-V method did not make the same erroneous conclusions, dropping the false positive rate to 0%.[198] A 2009 study by Langenburg et al. found a false positive rate of 2.3% and a false negative rate of 7.1% when fifteen subjects each made six comparisons.[199] In a different study in 2009, Langenburg relied on six fingerprint examiners each making sixty ACE comparisons and sixty ACE-V

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191. *See* Anil K. Jain et al., *Fingerprint Matching*, BIOMETRICS, Feb. 2010, at 42 ("Although many researchers have attempted to estimate the inherent individuality of fingerprints, the actual problem of estimating the error rate of latent fingerprint identification, which involves human factors in many stages—latent development, encoding, matching—is not yet solved."); *infra* text accompanying notes 215–45 (discussing the limitations of the studies).

192. Due to space limitations, the following examination of study designs is incredibly limited. If this topic interests you, I strongly urge you to read the papers reporting the researchers' results, which are cited within the following brief examination. Please do not be apprehensive just because they are, for the most part, social science papers.

193. *See* Kasey Wertheim et al., *A Report of Latent Print Examiner Accuracy During Comparison Training Exercises*, 56 J. FORENSIC IDENTIFICATION 55, 55–56, 61–62, 65 (2006). Each of the ninety-two examiners had at least a year of experience. *See id.* at 55, 65.

194. *See id.* at 65. It is worth noting that all of the source prints were included in the exemplars provided to the subjects in this study. *See id.* at 56–57.

195. *See id.* at 65.

196. The researchers defined this category as: "Highest level of confidence. The participant recorded this level of confidence if the participant would report this individualization in casework." *Id.* at 66.

197. *Id.* at 67.

198. *See id.* at 83–85.

199. *See* Glenn Langenburg et al., *Testing for Potential Contextual Bias Effects During the Verification Stage of the ACE-V Methodology When Conducting Fingerprint Comparisons*, 54 J. FORENSIC SCI. 571, 572–75 (2009). For the purpose of calculating error rates, I focused on only the control group. For the false positive rate, I assessed the number of incorrect individualization conclusions (1) out of the total number of conclusive match determinations where the ground truth was that the prints were derived from different sources (43). For the purpose of calculating the false negative rate, I assessed the number of incorrect exclusion conclusions (3) out of the total number of conclusive match determinations where the ground truth was that the prints were derived from the same source (42). The researchers in this study also tested the effects of biasing information on experts'—as well as novices'—match determinations. *See id.*

comparisons to assess the accuracy and reliability of these methods.[200] Under the ACE method, Langenburg found a 0% false positive rate (excluding one false positive attributed to transcription error) and a 25% false negative rate.[201] Under the ACE-V method, the false positive rate remained 0% and the false negative rate increased to 33.3%.[202] As Langenburg noted, "when the initial examiner was aware that someone was going to double-check his work during verification, the number of false negatives doubled."[203] In other words, examiners who knew they were being watched became more conservative in reaching conclusions of identification. In a relatively large 2011 study, Ulery et al. had 169 examiners each compare around 100 prints and found a 0.1% false positive error rate and a 7.5% false negative error rate.[204] Ulery et al. suggested that independent verification under the ACE-V method would further lower these error rates.[205] A 2014 study by Pacheco et al. had 109 examiners look at eighty latent prints and found a false positive rate of 4.2% and a false negative rate of 8.7% for ACE examinations.[206] When a verification step was added to the method (ACE-V), the false positive rate fell to 0% and the false negative rate fell to 3%.[207]

Overall, these studies demonstrate that examiners sometimes exhibit concerning false positive rates and even worse false negative rates in some studies. The PCAST report explains that the studies by Ulery et al. and Pacheco et al. are the most useful, as they are "black box" studies, meaning that "many examiners render decisions about many independent tests (typically involving 'questioned' samples and one or more 'known' samples) and the error rates are determined."[208] It is important to note that these two studies produced some of the

200. *See* Glenn Langenburg, *A Performance Study of the ACE-V Process: A Pilot Study to Measure the Accuracy, Precision, Reproducibility, Repeatability, and Biasability of Conclusions Resulting from the ACE-V Process*, 59 J. FORENSIC IDENTIFICATION 219, 224–25, 240 (2009).

201. *See id.* at 230–34. It is worth noting that the sample Langenburg used contained somewhere around just 4–20% of prints where the source was not present in the array of prints presented to the examiners, making the possibility of a false negative match determination less likely. *See id.* at 224–25, 230–34.

202. *See id.* at 240–41.

203. *Id.* at 242. Langenburg continued: "Yet, the verifiers caught every false positive, including close non-matches that were attempted to be passed off as accurate identifications. This may be a critical finding and could be quite revealing about the mental attitudes of examiners." *Id.* He further suggested, "When the initial analyst was aware that someone was going to check his work . . . he subconsciously did not look as hard [for a match] . . . [and] the verifier subconsciously did not search as thoroughly as he 'normally' would." *Id.* Langenburg described this as "a strong bias loop." *Id.* He also noted that "this bias was not present for the false positives," as "[t]he verifiers actually appeared to be more scrutinizing towards identifications as verifiers than they would have been as the initial analysts." *Id.*

204. *See* Bradford T. Ulery et al., *Accuracy and Reliability of Forensic Latent Fingerprint Decisions*, 108 PNAS 7733, 7735–36 (2011). The rate for false negatives was considerably higher—7.5%. *See id.* at 7736.

205. *See id.* at 7735 (stating that the data "suggests that [the] erroneous individualizations would have been detected if blind verification were routinely performed").

206. *See* Igor Pacheco et al., *Miami-Dade Research Study for the Reliability of the ACE-V Process: Accuracy & Precision in Latent Fingerprint Examinations* (Dec. 2014), at 2, 7, 53, https://www.ncjrs.gov/pdffiles1/nij/grants/248534.pdf. The study involved "using 80 latent prints with varying quantity and quality of information from ten known sources and were distributed to 109 latent print examiners across the United States. *Id.* at 2. The false positive and negative figures exclude inconclusive determinations (although the study authors also calculate error rates including inconclusives). *Id.* at 53–55.

207. *See id.* at 7, 55.

208. PCAST REP., *supra* note 73, at 5–6.

highest false positive rates—0.1% and 4.2%, respectively—and the actual false positive rates could be higher as a result of the biases present in real casework that were not mimicked in the studies.[209]

Aside from this research, proficiency tests from participating laboratories could perhaps shed some light on examiner error rates. Collaborative Testing Services ("CTS") regularly invites forensic laboratories to participate in such tests, providing a trove of relevant data.[210] In a test from 2007:

> [P]articipants received photographs of eleven latent prints from an alleged crime scene, four sets of known finger and palm imprints, and a short scenario that described a bank robbery. Nine of the eleven latents matched some of the known prints, two did not. Examiners were not told whether any of the knowns produced any of the latents.[211]

The 351 responses indicated a false positive rate of 2.3%.[212] The usefulness of such data is somewhat limited, however, because "[t]est participation is voluntary, examinees know that they are participating in a test, and it is not clear whether examinees work by themselves, in groups, or with assistance from supervisors."[213] As Koehler has explained, although the results "demonstrate[] that some examiners are likely to commit false positive errors on occasion," there are a number of reasons why these CTS tests cannot be relied on for false positive rates.[214] The same is true with respect to all of the studies.

An important limitation to these studies is that they generally do not sufficiently mirror real examiners doing real work.[215] As one expert has explained, "[t]hese studies took place in experimental conditions quite different from actual casework," and "[e]rror rates from these studies likely do not fully reflect real-world performance."[216] For example, the examiners in these studies were aware that their work was being tested.[217] Under these conditions, examiners likely

209. *See id.* at 97 ("We . . . note it is conceivable that the false-positive rate in real casework could be higher than that observed in the experimental studies, due to exposure to potentially biasing information in the course of casework.").

210. *See* Jonathan J. Koehler, *Fingerprint Error Rates and Proficiency Tests: What They are and Why They Matter*, 59 HASTINGS L.J. 1077, 1091 (2008).

211. *Id.*

212. *See id.* at 1091–92. Koehler explains that "four [of the 351] examiners (1.1%) incorrectly matched one of the latent prints to one of the knowns; three examiners matched a latent to an innocent suspect; a fourth examiner matched a latent to an innocent bank employee." *Id.* at 1092.

213. *Id.* at 1091.

214. *Id.* at 1092. Koehler explains:

> First, there is the baserate problem . . . . Second, the CTS tests tend to be conducted under unreasonable test conditions (*e.g.*, non-blind conditions that use relatively easy materials). This means that the error rates on existing proficiency tests are probably lower than those encountered in ordinary casework. One might think of these error rates as the lower boundary for actual casework error rates. *Id.* at 1092–93. He also explains, however, that one could design proficiency tests to be useful estimates of examiners' error rates.

See id. at 1093–98.

215. *See* PCAST REP., *supra* note 73, at 95 (noting that the studies vary in the "degree to which they represent the circumstances, procedures and pressures found in casework").

216. Kellman et al., *supra* note 178, at 2.

217. *See, e.g.*, Langenburg, *supra* note 200, at 251 (stating that participant knowledge of observation is a "common experimental design limitation" that "was present in th[e] study"); Ulery et al., *supra* note 204, at 7734

would be more hesitant to reach match conclusions that would correspond with possible wrongful convictions.[218] In other words, examiners would be more conservative in their conclusions, which would lower false positive rates. In fact, Langenburg discussed the possibility of examiners "sandbagging"—finding significantly fewer matches but having a much improved accuracy rate by avoiding difficult match determinations and declaring difficult-to-match print pairs inconclusive.[219] Despite this risk, Langenburg concluded that "it is difficult, if not impossible, in a case work environment to do [large] trials in a blind or double-blind fashion."[220] Similarly, Ulery et al. suggested that such an approach would be very difficult, approaching "infeasibility."[221]

Another representativeness problem with these studies and the error rates they have produced relates to print difficulty levels.[222] Examiners assess a wide array of prints in their casework, and these prints can vary substantially in their levels of difficulty for examination and potential matching.[223] Yet, the studies testing examiner error rates often neglect to assess print difficulty or to have a sufficiently robust measure of it.[224] But difficulty affects examiners' accuracy rates. Kellman et al. found a negative correlation "between average accuracy and difficulty ($r(198) = -0.050, p<0.001$)."[225] They identified several significant predictors of examiners' accuracy in making their conclusions, which, roughly, include the available information about ridges in the print, the proportion of the latent print area compared to the area of the known print, the visibility of deltas in the latent print, and the average and standard deviations of the contrast and

(suggesting that the examiners were aware they were being tested in the study and conceding that, "[i]deally, a study would be conducted in which participants were not aware that they were being tested").

218. *Cf.* Koehler, *supra* note 210, at 1092 (explaining that examiner proficiency tests administered by Collaborative Testing Services "tend to be conducted under unreasonable test conditions (e.g., non-blind conditions that use relatively easy materials)," meaning that the resulting "error rates . . . are probably lower than those encountered in ordinary casework"). *But see* Kellman et al., *supra* note 178, at 13 (explaining that, in their study, "the constraints [the researchers] imposed on examiners" may have led to observed error rates higher than "error rates in forensic laboratory settings").

219. *See* Langenburg, *supra* note 200, at 236.

220. *Id.* at 251.

221. Ulery et al., *supra* note 204, at 7734.

222. *Cf.* PCAST REP., *supra* note 73, at 95 (noting that the studies vary in their "selection and difficulty level of latent-known pairs").

223. *See Defining the Difficulty of Fingerprint Comparisons*, NAT'L INST. JUST. (Mar. 21, 2018), https://nij.ojp.gov/topics/articles/defining-difficulty-fingerprint-comparisons ("Fingerprint comparisons are often portrayed as straightforward in TV crime shows, but the forensic fingerprint community knows that latent print comparisons can be a complex process with significant variations in the degree of difficulty involved in specific comparisons.").

224. *See* Langenburg, *supra* note 200, at 251 (noting that "a more robust measurement of difficulty is desired").

225. Kellman et al., *supra* note 178, at 7, 13 (noting that this correlation was weaker than the correlation between difficulty and examiners' confidence ratings about their conclusions and that the "distribution of errors [in the study] strongly indicates that error rates do vary depending on the visual content of the specific comparisons"). Kellman et al. also found "a strong negative correlation between average difficulty and [examiners'] confidence ratings ($r(198) = -0.91, p<0.001$)" and "a strong positive correlation between [examiners'] response time . . . and difficulty ($r(198) = -0.71, p<0.001$)." *Id.*

intensity levels in the prints.[226] The difficulty of prints that researchers have had experts compare under study conditions may vary across studies. And perhaps even more importantly, it remains unknown whether the difficulty levels of prints that researchers have presented to examiners in these studies are at all representative of the prints that examiners are asked to assess in their daily work.[227] Accordingly, the error rates reached in these studies are of very limited value. Examiners are more likely to have higher accuracy rates and produce fewer false positives if the prints they are assessing are low on the difficulty level.[228]

Aside from the concern about print difficulty levels, a complicating factor in this research is that a variety of experience and skill levels were represented among the subject examiners in the various studies.[229] This is another reason that it is difficult to compare studies and also to see how the results of each study stack up against fingerprint examiners' work in general or against the work of a particular examiner used in any case. In addition to differences in experience and skill level, examiners may differ in how much caution they use in reaching match conclusions, their biases, and the contextual information to which they are exposed before making their match determinations.[230] All of these factors may affect examiners' error rates as well.[231] Overall, not enough information is known about the conditions under which examiners conduct their work, and accounting for all of these conditions would be challenging anyway, as examiners do their work under a wide variety of conditions and pursuant to a range of variations on the ACE-V methodology.[232] For all of these reasons, the usefulness of these studies' error rates remains quite limited.[233]

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226. *Id.* at 11 ("Six features in particular were found to be important predictors of accuracy: Ridge Sum, Area Ratio, visibility of Deltas in the latent print, Mean Block Contrast of the known print, interaction between SD Block Contrast for latents and known prints, and the interaction between DEAI (deviation from expected average intensity) for the latents and known prints.").

227. Kellman et al. have stated that "it is . . . very limited (and can even be misleading) to talk about an overall 'error rate' for the field as a whole." *Id.* at 13.

228. *See id.* at 7.

229. *See* Ulery et al., *supra* note 204, at 7737 ("Currently, there is no generally accepted objective measure to assess the skill of latent print examiners. Skill is multidimensional and is not limited to error rates"); Jain et al., *supra* note 191, at 42 ("Match/nonmatch decisions are made subjectively by human experts whose error rates are difficult to estimate and can vary significantly from person to person.").

230. *See* Gary Edmond & Itiel E. Dror, *Contextual Bias and Cross-Contamination in the Forensic Sciences: The Corrosive Implications for Investigations, Plea Bargains, Trials and Appeals*, 14 LAW, PROBABILITY & RISK 1, 2 (2014) ("[R]elatively few forensic scientists are actively shielded from information with the potential to mislead . . . . [E]ven though incriminating expert evidence is routinely developed in conditions that are known to produce errors, it is nevertheless portrayed as independent, objective and sometimes even 'error-free.'"); *cf.* Dror et al., *supra* note 72, at 76 ("This study shows that fingerprint identification decisions of experts are vulnerable to irrelevant and misleading contextual influences.").

231. *See* Edmond & Dror, *supra* note 230, at 2.

232. *See* Pacheco et al., *supra* note 206, at 13 (testing only a limited set of conditions).

233. Indeed, several studies reveal that examiners are often swayed by bias and certain contextual information revealed to them prior to their match decisions. *See* Itiel E. Dror & Simon A. Cole, *The Vision in "Blind" Justice: Expert Perception, Judgment, and Visual Cognition in Forensic Pattern Recognition*, 17 PSYCHONOMIC BULL. & REV. 161, 163–66 (2010); *see also, e.g.*, Itiel Dror & Robert Rosenthal, *Meta-Analytically Quantifying the Reliability and Biasability of Forensic Experts*, 53 J. FORENSIC SCI. 900, 903 (2008) (demonstrating "circumstances in which [fingerprint] experts were both relatively unreliable and biasable"). *But see* Lisa J. Hall & Emma Player, *Will the Introduction of an Emotional Context Affect Fingerprint Analysis and Decision-Making?*, 181

Another constraint is that studies of this kind differ in their designs, methods, and overall quality.[234] One inconsistency among the studies is sample size[235] and the composition of that sample. Sample size is important, because the reliability of the study ordinarily increases as the sample size increases.[236] Of the mentioned studies, sample size ranges from 258 to 16,900—a tremendous span for similar studies.[237] At the low end with a sample size of 258, the study by Langenburg et al. asked forty-three examiners to each make six print comparisons.[238] At the high end with a sample size of about 16,900, Ulery et al. asked 169 examiners to each make approximately one hundred print comparisons.[239] Other sample sizes from the aforementioned studies include the Langenburg study, which asked just six examiners to make sixty print comparisons, with a resulting sample size of 360,[240] and the CTS proficiency studies, which collected comparisons from 351 examiners, who each made just eleven print comparisons, resulting in a sample size of 3,861.[241] Digging into these studies shows that not only does the sample size differ among studies, but the way the sample was composed—by the number of examiners and the number of prints they compared—varies significantly. The Langenburg study looked at just six examiners' results, but those examiners looked at a relatively large number of prints (sixty).[242] In contrast, the CTS proficiency tests assessed the results of a large number of examiners—351 of them—but each examiner made only a small number of print comparisons (eleven).[243] Testing a limited number of examiners exacerbates the representativeness problem with that group, but asking examiners to compare a small number of prints exacerbates the print difficulty problem. Composing the sample in a lopsided way and not teasing apart these distinct variables may magnify these study difficulties.

Another variation among studies to consider is that some of the researchers employ the ACE methodology while others add a verification step, which tends to decrease the resulting number of false positives.[244] As we have seen, some studies show an increased false negative rate when researchers add the

FORENSIC SCI. INT'L 36, 37–38 (2008) (finding that changing the emotional context of the examination by varying the offense at issue did not affect fingerprint examiners' results, although the examiners' believed that the emotional context affected their analyses).

234. *See* PCAST REP., *supra* note 73, at 95 (explaining that the various "studies . . . cannot be directly compared for many reasons—including differences in experimental design, selection and difficulty level of latent-known pairs, and degree to which they represent the circumstances, procedures and pressures found in casework").

235. *See id.*

236. *See* ROBERT S. WITTE & JOHN S. WITTE, STATISTICS 211 (11th ed. 2017) ("Clearly, any increase in sample size causes a reduction in the standard error of the mean.").

237. *Compare* Langenburg et al., *supra* note 199, at 572–73 (asking forty-three examiners to each make 6 comparisons), *with* Ulery et al., *supra* note 204, at 7734 (asking 169 examiners to each make 100 comparisons).

238. *See* Langenburg et al., *supra* note 199, at 572–73.

239. *See* Ulery et al., *supra* note 204, at 7734.

240. *See* Langenburg, *supra* note 200, at 224–25.

241. *See* Koehler, *supra* note 210, at 1091.

242. *See* Langenburg, *supra* note 200, at 224–25.

243. *See* Koehler, *supra* note 210, at 1091.

244. *See* Langenburg, *supra* note 200, at 232.

verification step, however.[245] Although a high rate of false negatives is probably less concerning than a high rate of false positives, because only the latter directly relates to wrongful convictions, a high false negative rate means that the testing is less sensitive and could lead to perpetrators not being identified, apprehended, and convicted.

To some observers, the studies assessing fingerprint examiners' accuracy and reliability might initially suggest that fingerprint evidence is correct and its methodology reliable. Indeed, one might not be appalled by a 4.2% false positive rate and may not be convinced that the several limitations to the studies raise a concern that the rate is actually higher. But even if the false positive rates were within this range, there should still be cause for concern. A false identification rate of 4.2% is actually staggering. Compare this to the probabilities we see with DNA evidence, where about one in a billion persons is falsely identified according to the statistics.[246] Although a false positive rate of 4.2% may seem small, consider the figure in another context. If 4.2%—756—of the 18,000 flights that arrive and depart from the Atlanta-Hartsfield-Jackson airport every week crashed, panic would spread across the country.[247] This would certainly lead to an immediate cessation in airport operations.[248] In the same way, we should be concerned about wrongful identifications and possible wrongful convictions based on erroneous conclusions of fingerprint examiners, even if they reach false positives only 4.2% of the time.

Even a small rate of error among fingerprint examiners is concerning, and it would indeed be helpful to have a better sense of the magnitude of the error rate, and particularly the false positive rate. As NAS has explained, some error rate among examiners is unavoidable.[249] This is despite the fact that examiners often assert no chance of error during their trial testimony on fingerprint matches.[250]

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245. *See* Langenburg et. al., *supra* note 199, at 581.

246. *See* Koehler, *supra* note 210, at 1079 & n.13 (explaining that, "[o]n the diagnosticity side, the chance of a coincidental DNA match is often extremely small (e.g., one in many millions, billions, or trillions)," but noting that, "[o]n the reliability side, the chance of a false match that arises from, say, a sample handling mistake is much larger").

247. *See Operating Statistics*, DEPT. AVIATION HARTSFIELD-JACKSON ATLANTA INT'L AIRPORT (Nov. 2, 2018), https://www.atl.com/wp-content/uploads/2018/12/ATL-Traffic-Report-Nov-2018.pdf (indicating that 71,952 flights arrived or departed at the airport during November of 2018); *cf.* Robert J. Smith, *Recalibrating Constitutional Innocence Protection*, 87 WASH. L. REV. 139, 143–44 (2012) (stating that "[r]oughly 18,000 flights arrive or depart Atlanta's Hartsfield-Jackson Airport each week" and citing the airport's data from June 2011).

248. *Cf.* Smith, *supra* note 247, at 143–44. Smith makes a very similar analogy in the broad context of wrongful conviction:

> Roughly 18,000 flights arrive or depart Atlanta's Hartsfield-Jackson airport each week. If five of those planes crashed—roughly .027% of flights—operations at the airport would cease immediately. So, too, would 125 people wrongfully imprisoned annually (.027% of all state court felony convictions) represent a disturbing number of wrongful convictions.

Id.

249. STRENGTHENING FORENSIC SCIENCE, *supra* note 1, at 142.

250. *See* FORENSIC FINGERPRINTS xv (Max M. Houck ed., 2016) (explaining that, in response to evidence of fingerprint identification errors, the fingerprint community has generally not entirely conceded that the practice is not infallible); *cf.* STRENGTHENING FORENSIC SCIENCE, *supra* note 1, at 142 ("Although there is limited

Having a better sense of examiner error rates will require additional, more robust, studies. One key component of future studies would be to assess examiners' work without their knowledge. This would require the broad cooperation of police departments and forensic laboratories. But, as critics continue to attack the accuracy and reliability of forensic evidence more generally,[251] it is unclear how much cooperation might be forthcoming. It would also be useful for future studies to take better account of variations in print difficulty and examiners' skill and experience levels. Regularly assessing these variables and working to make these variables better match the true functioning of examiners' work would be a significant step in the direction of better understanding examiners' error rates. Further, striving to design studies that better reflect the working conditions of examiners should also involve asking study subjects to employ methodologies that examiners actually use in their work. And, finally, it is important for future studies to use large enough sample sizes that the work is representative and reliable.

In addition to helping us better understand how often examiners reach false positive and false negative conclusions, more thorough examinations of how accurate and reliable fingerprint examiners' match determinations are could also inject probability estimates into the analyses and examiners' testimony. In the DNA context, experts testify that, for example, there is only one chance in a billion that the blood found at the crime scene could have come from someone other than the defendant.[252] Because it is virtually impossible that a fingerprint examiner can know with 100% certainty that a latent print is a match to an exemplar print,[253] injecting probability determinations into these analyses makes more sense. Indeed, some scholars have suggested such an approach.[254] Despite creeping progress, the fingerprint community still generally remains opposed to including probabilities in their fingerprint matching conclusions.[255]

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information about the accuracy and reliability of friction ridge analyses, claims that these analyses have zero error rates are not scientifically plausible."). *But see* MAYFIELD REV., *supra* note 10, at 8 (asserting that FBI "examiners no longer testify that they are '100% certain,' and that they now "[i]nstead . . . testify that they are confident in the conclusion, would not expect to see the same amount of information repeated if the fingerprints originated from different people, and find no physical evidence causing them to doubt that the fingerprints are from the same source").

251. *See, e.g.*, STRENGTHENING FORENSIC SCIENCE, *supra* note 1, at 142 (stating that fingerprint examiners' assertions are implausible); PCAST REP., *supra* note 73, at 101 (concluding that fingerprint analysis generally has "a false positive rate that is substantial and is likely to be higher than expected by many jurors based on longstanding claims about the infallibility of fingerprint analysis").

252. PCAST REP., *supra* note 73, at 76.

253. *See* STRENGTHENING FORENSIC SCIENCE, *supra* note 1, at 142 ("Although there is limited information about the accuracy and reliability of friction ridge analyses, claims that these analyses have zero error rates are not scientifically plausible.").

254. *See, e.g.*, Jonathan J. Koehler & Michael J. Saks, *Individualization Claims in Forensic Science: Still Unwarranted*, 75 BROOK. L. REV. 1187, 1202 (2010) ("[F]orensic scientists should do what other scientists do: offer suitably cautious conclusions that make use of the tools of probability and statistics.").

255. *See* DEP'T OF JUSTICE, APPROVED UNIFORM LANGUAGE FOR TESTIMONY AND REPORTS FOR THE FORENSIC LATENT PRINT DISCIPLINE 1 (2018), https://www.justice.gov/file/1037171/download (stating that "[t]he examiner may offer any of the following conclusions: 1. Source identification (i.e., came from the same source)[;] 2. Inconclusive[;] 3. Source exclusion (i.e., came from different sources)"); STRENGTHENING FORENSIC SCIENCE, *supra* note 1, at 142 (referencing examiners' tendency to testify that their match decisions are 100%

Important to this effort for further research on the topic is funding. Finding the monetary resources to conduct this type of work is sometimes difficult,[256] and the work can be time-consuming and often requires a large number of participants. The funding environment today can be especially challenging, as the Trump Administration appears not to support this type of work.[257]

Although conducting more robust examiner studies is a step in the right direction in improving the fingerprint matching enterprise, this will not be as useful as establishing a scientific basis for fingerprint matching by pursuing studies examining fingerprint uniqueness, the biomechanics of touch, and computerized matching algorithms. Unlike these other areas of investigation, examiner accuracy and reliability studies do not get at the foundation of fingerprint matching. Examiners employing the ACE-V method are engaged in a subjective identification approach, which is not scientific in nature.[258] Various examiners apply the method differently, and there is no consistency on matters such as how many match points are necessary to declare an identification.[259] These differences, along with matters such as variances in print difficulty, examiner experience, and skill level, make it nearly impossible for examiner studies to provide a reliable sense of accuracy associated with the method.[260] Moreover, because examiners

accurate); *Guideline for the Articulation of the Decision-Making Process Leading to an Expert Opinion of Source Identification in Friction Ridge Examinations* (draft), ORG. OF SCI. AREA COMMS. FOR FORENSIC SCI., 9–10, https://www.nist.gov/system/files/documents/2017/10/17/guideline_for_the_articulation_of_the_decision-making_process_leading_to_an_expert_opinion_of_source_identification_in_friction_ridge_examinations.pdf (stating that the examiner's level of confidence in a fingerprint identification determination "shall not be reported in absolute terms and should not be reported numerically"). *But see* Forensic Tech. Ctr. for Excellence, *IPTES 2018 Workshop: Statistical Interpretation Software for Friction Ridge Skin Impressions (FRStat)*, NAT'L INST. OF JUSTICE 2 (2018), https://www.ncjrs.gov/App/Publications/abstract.aspx?ID=273812 ("The Defense Forensic Science Center (DFSC) developed FRStat in response to criticisms from legal and scientific commentators on the lack of an empirically demonstrable basis to substantiate conclusions in pattern evidence. This tool is intended to provide a statistical estimate of the strength of evidence to be used in conjunction with the examiner's own conclusion.").

256. *See, e.g.*, INTERNATIONAL ASSOCIATION FOR IDENTIFICATION, 180 DAY STUDY FINAL REPORT 5 n.2, https://www.ncjrs.gov/pdffiles1/nij/grants/213423.pdf.

257. There is some funding, however. In 2015, the National Institute of Standards and Technology ("NIST") established the Forensic Science Center of Excellence, based at Iowa State University, which is tasked with improving the statistical basis for certain forensic science disciplines, including fingerprint evidence. *See New NIST Center of Excellence to Improve Statistical Analysis of Forensic Evidence*, NAT'L INST. OF STANDARDS & TECH. (May 26, 2015), http://www.nist.gov/forensics/center-excellence-forensic052615.cfm; *Statisticians Take the Lead on Forensic Science Research*, ROYAL STATISTICAL SOC'Y, Aug. 2015, at 2, https://rss.onlinelibrary.wiley.com/doi/pdf/10.1111/j.1740-9713.2015.00837.x. Up to $20 million has been earmarked to support this investigative endeavor. *See Statisticians Take the Lead on Forensic Science Research*, *supra*. The parameters for the Center's work are not entirely clear, but further focus on the statistics related to fingerprint evidence will be useful.

258. *See* Jain et al., *supra* note 191, at 42 ("The only viable solution in the near term may be to keep improving automated fingerprint systems' performance and ultimately replace human experts with automated systems."). *But cf.* PCAST REP., *supra* note 73, at 9 (finding "latent fingerprint analysis [to be] a foundationally valid subjective methodology—albeit with a false positive rate that is substantial and is likely to be higher than expected by many jurors based on longstanding claims about the infallibility of fingerprint analysis").

259. *See* STRENGTHENING FORENSIC SCIENCE, *supra* note 1, at 139 ("In the United States, the threshold for making a source identification is deliberately kept subjective, so that the examiner can take into account both the quantity and quality of comparable details. As a result, the outcome of a friction ridge analysis is not necessarily repeatable from examiner to examiner.").

260. *See id.* at 142.

apply the method differently anyway, any true error rates say little about the accuracy of any particular examiner in a case. Only with the objectivity associated with a scientific foundation could examiners apply the method consistently across cases. Only with the objectivity associated with a scientific foundation for fingerprint matching would error rates be indicative of the likelihood of a false identification conclusion in any particular case.

B. Fingerprint Uniqueness

Central to the enterprise of fingerprint matching is the assumption that each individual possesses unique fingerprints that can be distinguished from other fingerprints such that a latent print can be matched to an exemplar print and thus lead to the positive identification of an individual.[261] If individuals shared fingerprint patterns, or at least if there were a significant enough probability that a particular fingerprint pattern matched others' fingerprint patterns, then a fingerprint match would lack meaning or at least would be tremendously less useful; a latent fingerprint found at a crime scene could potentially belong to several different individuals. As the number of individuals sharing a fingerprint pattern increases, the usefulness of the fingerprint match decreases correspondingly.

Simple observation reveals that individuals' fingerprints do indeed vary. Jain et al. have explained that this uniqueness stems from both genetic and embryotic environmental forces.[262] There are even studies establishing that identical twins have fingerprints that differ,[263] so this could suggest that completely unrelated individuals certainly have different prints. In fact, fingerprint identifications could even be an improvement over DNA identifications in this regard, as, in contrast to fingerprints, identical twins share DNA; one twin generally cannot easily be distinguished from the other based on DNA alone.[264]

261. *See id.* at 144 ("Uniqueness and persistence are necessary conditions for friction ridge identification to be feasible . . . .").

262. *See* Jain et al., *supra* note 191, at 37 ("It is generally understood that friction ridge patterns are influenced not just by genetic factors but also by random physical stresses and tensions during fetal development. These random effects in the formation of fingerprints provide their uniqueness.").

263. *See* Xungquiang Tao et al., *Fingerprint Recognition with Identical Twin Fingerprints*, 7 PLOS ONE 1, 6–7 (2012) ("In this paper, we have investigated the ability of the fingerprint verification matcher to discriminate between identical twins. The experimental results demonstrated that the identical twins can be distinguished by a state-of-the-art method . . . ."); *see also* Jonathan M. Raser & Erin K. O'Shea, *Noise in Gene Expression: Origins, Consequences, and Control*, 309 SCIENCE 2010, 2010 (2005) ("The fingerprints of identical twins are readily distinguished on close examination.").

264. Recent advances in science, however, have suggested that, while twins share DNA, they may have epigenetic differences—differences in gene expression affected by environmental factors. *See* Erika Hayasaki, *Identical Twins Hint at How Environments Change Gene Expression*, ATLANTIC (May 15, 2018), https://www.theatlantic.com/science/archive/2018/05/twin-epigenetics/560189/; Cathy Tran, *Identical Twins Not So Identical*, SCI. MAG. (July 5, 2005, 12:00 AM), https://www.sciencemag.org/news/2005/07/identical-twins-not-so-identical; *see also* Jessica Hamzelou, *Police Can Now Tell Identical Twins Apart—Just Melt Their DNA*, NEW SCIENTIST, (Apr. 24, 2015), https://www.newscientist.com/article/dn27411-police-can-now-tell-identical-twins-apart-just-melt-their-dna/ (explaining that Dr. Graham Williams found that identical twins' DNA have different melting points based on epigenetic differences—a finding that has laid the groundwork for "a quick 'n' easy" test police may use to distinguish identical twins' DNA).

Despite this common logic, no one has proved that each individual possesses unique fingerprints. The assumption that each person has unique prints is just that: an assumption.[265] There has been insufficient research done on this point,[266] and the Department of Justice has even conceded that there is no adequate scientific basis for the fingerprint uniqueness assumption.[267]

Several researchers have attempted to investigate the uniqueness of fingerprints,[268] but their efforts have some marked limitations. They generally have studied fingerprints by one of two approaches. First is the "empirical" approach, pursuant to which researchers gather known fingerprints into a database and assess whether any fingerprints from different subjects match.[269] The second approach is a "theoretical" one, pursuant to which researchers enter known (or "realistic") forces affecting fingerprints and use that data to model various print permutations and calculate the probabilities of different individuals having the same fingerprints.[270]

The empirical approach poses several difficulties, because it is dependent on a sufficiently large database of prints, the accuracy of the matcher, and the

265. *See* Soweon Yoon & Anil K. Jain, *Longitudinal Study of Fingerprint Recognition*, 112 PROC. NAT'L ACAD. SCI., 8555, 8555 (2015) ("Despite its successful deployment, the fundamental premise of fingerprint-based identification—persistence and uniqueness of fingerprints—has not yet been well studied . . . ."); *cf.* Pankanti et al., *supra* note 163 ("The notion of fingerprint individuality has been widely accepted based on a manual inspection (by experts) of millions of fingerprints. However, the underlying scientific basis of fingerprint individuality has not been rigorously studied or tested.").

266. As one researcher has put it, "the underlying scientific basis for fingerprint individuality has not been rigorously studied or tested." Pankanti et al, *supra* note 163, at 1011.

267. *See* NAT'L INST. JUST., FORENSIC FRICTION RIDGE (FINGERPRINT) EXAMINATION VALIDATION STUDIES 3–4 (2000), https://www.ncjrs.gov/pdffiles1/nij/sl000386.pdf (soliciting proposals for funding on fingerprint research and explaining: "Friction ridge print evidence has historically been 'understood' to hold individuality based on empirical studies of millions of prints. However, the theoretical basis for this individuality has had limited study and needs additional work to demonstrate the statistical basis for identifications."); NAT'L. INST. JUST., FORENSIC SCIENCES: REVIEW OF STATUS AND NEEDS 29 (1999), https://www.ncjrs.gov/pdffiles1/173412.pdf (stating that "[f]riction ridge print evidence has historically been 'understood' to hold individuality based on empirical studies of millions of prints"; "the theoretical basis for this individuality has had limited study and needs a great deal more work to demonstrate that physiological/developmental coding occurs for friction ridge detail, or that this detail is purely an accidental process of fetal development"; and "[s]tudies to date suggest more than an accidental basis for the development of print detail, but more work is needed"). The NAS report states that there is "[s]ome scientific evidence support[ing] the presumption that friction ridge patterns are unique to each person and persist unchanged throughout a lifetime," STRENGTHENING FORENSIC SCIENCE, *supra* note 1, at 143–44, but the sources it cites for this evidence are questionable. For example, one of the more current sources the NAS cites—a 2005 article in *Science*—mentions fingerprints only in passing, stating that the varying prints of identical twins is an "[e]xample[] of possible stochastic influences on phenotype." Raser & O'Shea, *supra* note 263, at 2010.

268. *See* Jain et al., *supra* note 191, at 42 ("[M]any researchers have attempted to estimate the inherent individuality of fingerprints . . . ."); *see also, e.g.*, Yi Chen & Anil K. Jain, *Beyond Minutiae: A Fingerprint Individuality Model with Pattern, Ridge and Pore Features*, 5558 ADVANCES IN BIOMETRICS 523, 524 (Massimo Tistarelli & Mark S. Nixon eds., 2009) ("evaluat[ing] fingerprint individuality by modeling the distribution of minutiae, ridge and pore features"); Cédric Neumann et al., *Computation of Likelihood Ratios in Fingerprint Identification for Configurations of Any Number of Minutiæ*, 52 J. FORENSIC SCI. 54, 54–64 (2006); Pankanti et al., *supra* note 163, at 1010–25; Yongfang Zhu et al., *Statistical Models for Assessing the Individuality of Fingerprints*, 2 IEEE TRANSACTIONS ON INFO. FORENSICS SECURITY. 391, 391–401 (2007) (developing statistical models for fingerprint individuality).

269. Pankanti et al., *supra* note 163, at 1012.

270. *Id.*

power of the matcher.[271] Many databases employed pursuant to the empirical approach are too small to provide an accurate estimation of the probability that a random fingerprint is actually unique.[272] Moreover, "even if a large database of fingerprints . . . is used for an empirical evaluation of . . . fingerprint individuality," it could be computationally demanding.[273] Perhaps even more troublesome, even if the size and variability of the database were sufficient and the processor power did not pose a challenge, the entire operation of assessing fingerprint uniqueness is dependent on the accuracy of the matcher.[274] Again, there are significant questions of accuracy where human and computerized matching systems are involved.[275]

The theoretical approach is also problematic. It requires inputting known forces on the fingerprint, but many of these forces remain unknown.[276] Researchers have spent some time studying the formation of fingerprints.[277] They have found that print patterns depend on the "shape, size, and placement of volar pads," and "[i]t is generally understood that friction ridge patterns are influenced by . . . genetic factors [and] . . . random physical stresses and tensions during fetal development."[278] But, despite this research, many aspects of fingerprint formation remain a mystery.[279] As a result, researchers make a number of assumptions. For example, they assume that fingerprint minutiae are the stock features to measure.[280] They often also assume that minutiae are independent, meaning that the appearance of one minutia is independent of the appearance of another

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271. *See id.*

272. *See id.*; *infra* text accompanying notes 361–68 (explaining that the databases against which computerized matching algorithm designers can test their new approaches are insufficient).

273. Pankanti et al., *supra* note 163, at 1012 (suggesting that using the FBI database for this could take 127 years). *But see* DAVIDE MALTONI ET AL., HANDBOOK OF FINGERPRINT RECOGNITION 259 (2003) (reiterating Pankanti et al.'s statement but calculating the number of required years for a match to be "(200 x 10^6 x 200 x 10^6 / (10^6 x 60 x 60 x 24 x 365) ≅ 1270)!"). The FBI has recently completed such a comparison and concluded that the database contains the prints "of more than 120 million persons with objectively determined distinct fingerprints." E-mail from James Loudermilk, *supra* note 58. The FBI database now contains more fingerprints to sort through for matches, increasing computing time. *See supra* Part II. Processor speed is undoubtedly faster now, however, perhaps counterweighting this increased computing time. According to Moore's Law, the number of transistors on a silicon chip should double about every two years, although the industry seems to be flagging in this regard in recent years. *See* Katherine Bourzac, *Intel: Chips Will Have to Sacrifice Speed Gains for Energy Savings: A Major Technological Shift is Needed in the Next Few Years If Computer Chips Are to Keep Improving*, MIT TECH. REV. (Feb. 5, 2016), https://www.technologyreview.com/s/600716/intel-chips-will-have-to-sacrifice-speed-gains-for-energy-savings/; Tom Simonite, *Moore's Law Is Dead. Now What?*, MIT TECH. REV. (May 13, 2016), https://www.technologyreview.com/s/601441/moores-law-is-dead-now-what/.

274. *See* Pankanti et al., *supra* note 163, at 1012; *see also infra* Section IV.D (discussing the shortcomings of automated fingerprint identification systems).

275. *See* Pankanti et al., *supra* note 163, at 1012. This is especially true when attempting to match latent to exemplar prints. *See id.*; *infra* Section IV.D.

276. *See* Pankanti et al., *supra* note 163, at 1012.

277. *See* Jain et al, *supra* note 191, at 37.

278. *Id.* "Volar skin" is a term "derived from *vola*, an ancient Roman term for the palm of the hand and the sole of the foot." *Id.*

279. *See* Pankanti et al., *supra* note 163, at 1012.

280. *See* QIJUN ZHAO ET AL., A GENERATIVE MODEL FOR FINGERPRINT MINUTIAE, INT'L CONF. ON BIOMETRICS 2 (2013); *see, e.g.*, Pankanti et al., *supra* note 163, at 1016–17 (explaining their focus on minutiae).

(or even the same) minutia in a fingerprint or some smaller region.[281] The many assumptions researchers must rely on in these assessments shed considerable doubt on the accuracy of their conclusions that fingerprints are certainly unique.

One difficulty with both the empirical and theoretical approaches—and a problem with using fingerprints for identification overall—is that there is some evidence that fingerprints change over time. Yoon and Jain found that, although prints are generally stable for at least twelve years, stability decreases after that point in time.[282] This means that, if an exemplar print predates the latent print by a significant period of time, a match—even if the print is from the same individual—is less likely, undermining the identification process.

It is understandable that the researchers working on this problem have failed to establish uniqueness, as uniqueness is exceptionally difficult to prove. In the context of DNA analysis, one can estimate uniqueness based on underlying information known about DNA.[283] For example, in a commonly used method of DNA analysis, examiners make use of each DNA strand's short tandem repeat ("STR") sequences and the limited number of variations these take on to estimate the likelihood of finding them all in any particular individual's DNA.[284] Because so little is known about the development of fingerprints, there is a dearth of information on which to base frequency analyses like those seen in the DNA context. This makes proving the uniqueness of fingerprints exceptionally difficult.

Despite the difficulty of establishing uniqueness, further research is necessary in this area because the uniqueness assumption is essential to the fingerprint matching enterprise. A couple of approaches to this problem come to mind.

First, one way to examine uniqueness is by building on the empirical approach by creating a large database of fingerprints and using advanced computerized algorithms to assess the variations among prints.[285] An extraordinarily large database would likely be necessary to make such a study meaningful. The FBI's Next Generation Identification system[286]—with the prints of more than 120 million individuals—is a useful starting point. A database consisting of

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281. *See, e.g.*, Pankanti et al., *supra* note 163, at 1016–17 (assuming that "[c]orrespondence of a minutiae pair is an independent event and each correspondence is equally important").

282. *See* Yoon & Jain, *supra* note 265, at 8555 (examining the fingerprints of 15,597 subjects for more than five years and concluding that fingerprints are generally stable for at least twelve years, at which point stability decreases). *But see* HAROLD CUMMINS & CHARLES MIDLO, FINGER PRINTS, PALMS AND SOLES: AN INTRODUCTION TO DERMATOGLYPHICS 147 (1961); FRANCIS GALTON, FINGER PRINTS (1892); WILLIAM HERSCHEL, THE ORIGIN OF FINGER-PRINTING 31 (1916) (suggesting that fingerprint patterns are persistent).

283. *See* JOHN M. BUTLER, FORENSIC DNA TYPING 2 (Mark Listewnik et al. eds., 2d ed. 2005).

284. *See id.*; *Short Tandem Repeats (STRs)*, DNA DIAGNOSTICS CENTER, http://www.forensicdnacenter.com/dna-str.html (last visited Apr. 7, 2020). It is worth noting, though, that the often-small random match probabilities presented in cases do not establish that each individual (other than identical twins) possesses unique DNA. As a 1992 National Research Council report states, "[r]egardless of the calculated frequency, an expert should—given . . . the relatively small number of loci used and the available population data—avoid assertions in court that a particular genotype is unique in the population." NAT'L RESEARCH COUNCIL, DNA TECHNOLOGY IN FORENSIC SCIENCE 92 (1992); *cf. id.* at 74–75 (noting that "substantial controversy has arisen concerning the methods for estimating the population frequencies of specific DNA typing patterns").

285. *See infra* Section IV.D (explaining the need to develop improved computerized matching algorithms).

286. *See supra* note 14 (noting that NGI's AFIT—Advanced Fingerprint Identification Technology—replaced IAFIS in 2011).

prints acquired under more controlled conditions—and with assurances that individuals are not entered multiple times in the database under different identities—would further enhance this approach. Once a large enough database is created, researchers could apply an advanced computerized algorithm capable of examining and measuring the differences among prints. The accuracy and reliability of this matching is essential to the empirical approach. As described in Section IV.D, though, researchers still need to make significant headway in developing computerized algorithms up to this task.[287] In this sense, establishing the uniqueness of fingerprints is likely largely dependent on furthering research in this other area. Not only would this require the investment of significant resources in computerized matching algorithms and in compiling a sufficient database, but, because processing speed remains an issue, significant resources might need to be invested in this regard as well to make the empirical approach a successful one.

The second approach to the uniqueness conundrum is to learn more about how fingerprints form and to thus build on the theoretical approach. This area of research would likely require years of focused study by geneticists or embryologists. As of now, it appears that there is insufficient research being conducted in this area, so it is wide open for new investigators. Someone could really make her name in this field, but it would be hard going because there is very little research upon which to build an expertise.

C. *The Biomechanics of Touch*

An important aspect of fingerprint matching that has proven challenging is the changeability of prints based on the conditions under which they are made.[288] Even if two fingerprints are from a single source—one individual's right index finger, for example—the fingerprints may look quite different.[289] Perhaps the first fingerprint was an exemplar print made at a police station. The officer rolling the print made sure that the entire print was transferred onto the flat fingerprint card or livescan machine, and it was rolled under thirteen Newtons (or about three pounds) of force. Under these somewhat controlled conditions, the fingerprint image is probably quite clear. Now, suppose that the second fingerprint is a latent print made at a crime scene. The individual made the print when he picked up a cylindrical glass, using nine Newtons (or about two pounds) of force. This second print may be smudged or only a partial print because it was not made under controlled conditions. Moreover, this second print, because it was made on a differently shaped object, on another type of material, and under a lesser force, will look different than the exemplar print.[290] These many varying

287. *See infra* Section IV.D.

288. *See* STRENGTHENING FORENSIC SCIENCE, *supra* note 1, at 137 (noting the importance of factors such as the "[c]ondition of the skin," "[t]ype of residue," "[m]echanics of touch," and "[n]ature of the surface touched" in creating fingerprints").

289. *See id.* (describing how many factors can "affect the quality and quantity of detail in the latent print and also introduce variability in the resulting impression").

290. *See id.*

conditions under which the print was made affect the fingerprint layout more generally, posing a challenge for fingerprint matching that is significantly less pronounced in other areas of pattern evidence, like with shoe or tire tread print matching.[291] These challenges are quite unique to the fingerprint matching arena.

Unlike with accuracy and reliability rates of fingerprint examiners,[292] or even the uniqueness question,[293] researchers have done very little investigation into how these various conditions affect fingerprints and how examiners can account for these conditions in their match determinations. These questions of biomechanics are perhaps the areas in which further investigational research is most needed, and it could be quite difficult to pursue. Scientists and fingerprint experts currently know very little about how fingerprints deform under various forces, how they change when touching differently shaped surfaces, and how they fluctuate based on the subject's varying characteristics like weight and age.[294] A whole host of studies ought to be pursued to further examine these related questions.

One relevant area in which there is some preliminary research is on the issue of how human tissue moves under varying conditions. Some existing fingerprint studies have premised their conclusions on the assumption that skin is elastic in nature—meaning that, when the skin is stretched, such as when a subject presses down on an object, the skin spreads out uniformly.[295] Research suggests, however, that skin is actually viscoelastic under these circumstances—it stretches nonuniformly—which undercuts older studies analyzing fingerprints.[296] This also makes examining fingerprints more difficult, as the traditional focus on prints' minutiae is complicated when skin does not stretch uniformly under pressure.[297] It further adds to the already existing matching hurdles related to the biomechanical properties that vary with sex, age, ultraviolet light exposure, and other characteristics.[298]

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291. *Compare id.* (identifying the importance of conditions under which fingerprints are made), *with id.* at 145–50 (failing to mention the relevance of these conditions).

292. *See supra* Section IV.A.

293. *See supra* Section IV.B.

294. *See* STRENGTHENING FORENSIC SCIENCE, *supra* note 1, at 145.

295. *See, e.g.*, Sunpreet S. Arora et al., *3D Targets for Evaluating Fingerprint Readers*, MICH. STATE UNIV. TECHNICAL REP. 2 (2015) ("We fabricate 3D targets with material similar in hardness and elasticity to the human finger skin specifically such that they can be worn on a finger and placed on the fingerprint reader platen in a natural manner . . . .").

296. *See* Meghan J. Ryan & Tré Welch, *Developing Simulated Fingerprint Deformation Through Force-Based and Non-Contact Fingerprint Technology* 3–4 (S. Methodist U. Dedman Sch. of Law, Working Paper, 2019) (on file with authors). Ryan and Welch suggest that the skin's viscoelastic quality exists because the skin is comprised of three layers—the epidermis, dermis, and hypodermis—having different biomechanical properties that act viscoelastically under loading, like rubber. *See id.*

297. *See id.* at 14.

298. *See* STRENGTHENING FORENSIC SCIENCE, *supra* note 1, at 137–38 (emphasizing the importance of the "mechanics of touch" in fingerprint creation); Ryan & Welch, *supra* note 296, at 14; *see also* Ajay Kumar & Cyril Kwong, *Towards Contactless, Low-Cost and Accurate 3D Fingerprint Identification*, 2013 IEEE CONF. ON COMPUTER VISION & PATTERN RECOGNITION 3438, 3438 (2013) ("Such frequent degradation in fingerprint image quality is often attributed to skin deformations, moisture, reside [sic] of finger dirt, finger sweat, finger slips, and smear or due to sensor noise.").

Some progress could be made in the field of fingerprint matching by investigating a three-dimensional approach to the subject rather than following the typical two-dimensional path. Or, as the National Institute of Standards and Technology ("NIST") has phrased it, by pursuing "contactless fingerprint" technology.[299] This three-dimensional, or "contactless," approach to fingerprint matching would use multiple cameras, or even LED illuminators, to capture a variety of images or views from varying perspectives.[300] These images or views would then often be "stacked" to create a three-dimensional representation of the print.[301] The goal would be to capture the print without the deformation resulting from outside forces, circumventing this major hurdle for fingerprint matching.[302] One research group has made some headway in this area by using five cameras to attempt to create such a three-dimensional image.[303] Perhaps the best way to pursue this research, however, is by employing metrology tools—such as optical profilometers—like those more frequently used in industry, often to reverse-engineer parts.[304] The profilometers used in industry generally also have more sensitive sensors than the sensors often used by law enforcement today.[305]

A contactless fingerprinting approach offers the advantage that law enforcement may take a subject's entire print without any deformation of the print by the finger being placed on glass or a fingerprint card.[306] This could certainly improve matching when the prints at issue are both captured using this contactless methodology.[307] Of course, latent prints, which are not created under controlled conditions, will still be deformed and not constitute exact matches of the exemplar prints, including the three-dimensional version of the print.[308] In this sense, even if this method were perfected, contactless fingerprint technology

299. *Contactless Fingerprint Capture*, NAT'L INST. OF STANDARDS & TECH., https://www.nist.gov/programs-projects/contactless-fingerprint-capture (last visited Apr. 7, 2020).

300. *See* Geppy Parziale et al., *The Surround Imager™: A Multi-Camera Touchless Device to Acquire 3D Rolled-Equivalent Fingerprints*, *in* ADVANCES IN BIOMETRICS 244, 244 (David Zhang & Anil K. Jain eds., 2006) (describing a "multi-camera system acquir[ing] different finger views that are combine[d] to generate a 3D representation of the fingerprint"); Giuseppe Parziale & Yi Chen, *Advanced Technologies for Touchless Fingerprint Recognition*, *in* HANDBOOK OF REMOTE BIOMETRICS FOR SURVEILLANCE & SECURITY 83, 83–85 (Massimo Tistarelli et al. eds., 2009); Yi Chen et al., *3D Touchless Fingerprints: Compatibility with Legacy Rolled Images*, BIOMETRICS SYMP. (2006); Kumar & Kwong, *supra* note 298, at 3438–39 (using a "*single* camera" and "7 symmetrically distributed LED illuminators" to create a three-dimensional image of a finger).

301. *See* Parziale et al., *supra* note 300, at 244; Parziale & Chen, *supra* note 300, at 83–85; Chen et al., *supra* note 300; Kumar & Kwong, *supra* note 298, at 3438–39.

302. *See* Parziale & Chen, *supra* note 300, at 83; Chen et al., *supra* note 300; Kumar & Kwong, *supra* note 298, at 3438; Ryan & Welch, *supra* note 296.

303. *See* Geppy Parziale et al., *supra* note 300, at 244–45; *see also* Kumar & Kwong, *supra* note 298, at 3438 (achieving contactless fingerprint technology through the use of one camera and Lambertian reflectance).

304. *See* Ryan & Welch, *supra* note 296, at 2.

305. *See id.*

306. *See* Chen et al., *supra* note 300, at 1; Kumar & Kwong, *supra* note 298, at 3438; Ryan & Welch, *supra* note 296, at 2–3.

307. Researchers have noted that contactless fingerprint technology can offer benefits in addition to improving accuracy to the extent it can do that when prints are made under controlled conditions. Although perhaps minor in comparison to accuracy, these additional benefits include convenience and hygiene. *See* Kumar & Kwong, *supra* note 298, at 3438 ("In order to avail the benefits of higher user convenience, hygiene, and improved accuracy, contactless 3D fingerprint recognition techniques have recently been introduced.").

308. *See* STRENGTHENING FORENSIC SCIENCE, *supra* note 1, at 137–38.

could not alone solve the matching problem that examiners face on a daily basis. Further accuracy and reliability could be achieved if contactless fingerprint research were to address the biomechanical properties of the finger, but thus far researchers have not sufficiently probed this intersection of disciplines. Additional limitations of contactless fingerprinting technology are its bulk and expense.[309]

A real possibility for advancing latent fingerprint matching is by examining how biomechanical properties affect depressed fingers under discrete condition sets and then applying finite element analysis—an "in silico" approach—to extrapolate and create a full set of possible permutations of any original fingerprint acquired.[310] This would allow a latent print to be matched against all possible states of exemplar fingerprints, minimizing—or perhaps even eliminating—the guesswork that results from fingerprint examiners trying to account for deformations in prints resulting from the various biomechanical conditions under which the print was made.[311] Using contactless fingerprint technology to capture the prints would be ideal under this approach to minimize unintended and unrecorded deformations in the prints.[312] Research in this area is still in its infancy, though, and related research would likely yield significant dividends.

Much of this research on the biomechanics of fingerprints may be expensive and could take years to adequately develop in ways that would allow law enforcement agencies to implement it.[313] Of course, tight budgets constrain the types of technology that may be used in police stations and in the field, but, provided initial funding, fingerprint research could make use of more thorough, precise, and expensive techniques, and the information gained by the research could then be applied in cost-effective ways to be used in the field. For example, the previously mentioned research relying on optical profilometry and finite element analysis could require extensive bulky laboratory equipment and numerous test subjects to complete,[314] but the ultimate information gained by pursuing this research could be reduced to software that police officers could use on local fingerprint scanners.[315] In this sense, the research could be miniaturized for effective use in the field.

D. *Computerized Matching Algorithms*

In addition to researchers' examination of the consistency, reliability, and accuracy of fingerprint examiners' match determinations—and researchers' limited forays into investigating fingerprint uniqueness and biomechanics—scholars

309. *See* Kumar & Kwong, *supra* note 298, at 3438 ("One of the main obstacles of emerging 3D fingerprint technologies to replace the conventional 2D fingerprint system is their *bulk* and *high cost*, which mainly results from the nature of imaging technologies employed for the 3D fingerprint reconstruction." (emphasis added)).

310. For further information on this approach, see Ryan & Welch, *supra* note 296, at 3.

311. *See id.* at 14.

312. *See id.* at 2–3.

313. *See* Kumar & Kwong, *supra* note 298, at 3438.

314. *See* Ryan & Welch, *supra* note 296, at 2. As Kumar and Kwong noted, "[T]here is no 3D fingerprint database available in the public domain." Kumar & Kwong, *supra* note 298, at 3442.

315. *See* Ryan & Welch, *supra* note 296, at 4–7.

in the biometrics and electrical engineering communities have worked on improving computerized algorithms involved in fingerprint identification.[316]

Developing an effective computerized algorithm for latent print identification has proven difficult. First, exemplar prints must be enrolled in the system, and then the algorithm must work toward identifying the latent print by matching it to the exemplar print.[317] This matching process involves the algorithm sensing the details of the prints, extracting the prints' features, and, finally, matching the latent to the exemplar print.[318]

Most computerized algorithms match prints through the use of the prints' minutiae[319]—an approach unique to the fingerprint context. Algorithm designers adopt this course for several reasons. First, relying on fingerprint minutiae is the approach that examiners have employed for more than a century, and they are generally thought to have done so successfully.[320] Second, reliance on minutiae is admissible in court.[321] Third, this minutiae-based approach is storage efficient.[322]

There are a number of unique challenges of algorithm-based matching in the latent print context. The performance of a computerized matching system depends on a number of factors. First, algorithms based on minutiae extraction depend significantly on the quality of the inputted image.[323] This print quality is

316. *See, e.g.*, Miguel Angel Medina-Pérez et al., *Latent Fingerprint Identification Using Deformable Minutiae Clustering*, 175 NEUROCOMPUTING 851, 852 (2016) ("In this paper, we propose a novel clustering algorithm to improve the performance of popular minutiae descriptor matching algorithms for latent fingerprint identification.").

317. *See* Jain et al., *supra* note 191, at 38–40.

318. *See generally* Ziad Abu-Faraj et al., *Fingerprint Identification Software for Forensic Applications*, 7 IEEE INTERNATIONAL CONFERENCE ON ELECTRONICS, CIRCUITS, & SYSTEMS 299, 299–302 (2000) (describing the use of algorithms in fingerprint identification); Jain et al., *supra* note 191, at 38–40.

319. *See* Abu-Faraj et al., *supra* note 318, at 299; Jain et al., *supra* note 191, at 39–40 ("Minutiae-based representation is commonly used [for fingerprint matching algorithms] . . . ."). Some algorithms instead adopt an image correlation, phase matching, or skeleton matching approach. *See* Jain et al., *supra* note 191, at 39 ("Most fingerprint-matching algorithms adopt one of four approaches: image correlation, phase matching, skeleton matching, and minutiae matching"). These approaches are much more commonly used outside the fingerprint matching context. "Today's state-of-the-art (SOTA) AFIS systems, like all automated SOTA pattern matching systems, employ computational neural networks of various types. Due to the cost of AFIS systems, [though,] the transition from the installed base to SOTA capabilities will be slow." E-mail from James Loudermilk, *supra* note 58.

320. *See* Jain et al., *supra* note 191, at 39 (stating that algorithm designers adopt the minutiae-based approach because "forensic examiners have successfully relied on minutiae to match fingerprints for more than a century"). *But see supra* Section IV.A (explaining that fingerprint examiners have potentially high error rates, suggesting that their examinations of minutiae in assessing whether fingerprints match may not be so successful after all).

321. *See* Jain et al., *supra* note 191, at 39–40 (stating that algorithm designers adopt the minutiae-based approach because "expert testimony about suspect identity based on mated minutiae is admissible in courts of law").

322. *See id.* at 39 (stating that algorithm designers adopt the minutiae-based approach because "minutiae-based representation is storage efficient").

323. *See* Abu-Faraj et al., *supra* note 318, at 299 ("The performance of a minutiae-extraction-algorithm relies heavily on the quality of the input fingerprint image."). Resolution of the fingerprint images is central to accuracy. Andrea R. Roddy & Jonathan D. Stosz, *Fingerprint Features—Statistical Analysis and System Performance Estimates*, 85 PROCEEDINGS OF THE IEEE 1390, 1416 (1997). As Jain et al. explain, "Latent fingerprints

sometimes compromised by the print being lifted off a moist or dirty surface, or an image recorded off of a complex background, where it is difficult to distinguish between the friction ridges and, for example, a design on the background.[324] More broadly, low quality may result from smudges, partial prints, or even low-resolution image capture techniques.[325] According to Jain et al., "A typical good-quality fingerprint image contains about 20–70 minutiae points; the actual number depends on the size of the sensor surface and how the user places his or her finger on the sensor."[326]

Performance also depends on the system's ability to find corresponding minutiae in different prints despite the print deformation that results from the plasticity of the finger and other factors.[327] The automated systems deal with this complication by building in an allowance for the particular feature's location and particulars.[328] Thus, performance of these matching programs is based on the selected tolerance for false positives and negatives.[329] The size of the area in which the program searches for a particular feature or minutia—known as Σ, or the "feature" or "search" area—affects the allowance for print deformation under various conditions.[330] A large Σ provides more room in which the program can find minutiae that were displaced as a result of movement like a rotation or nonlinear distortion resulting from finger plasticity.[331] The greater this allowance, meaning the greater the search area, translates into a greater likelihood of false positives and a smaller likelihood of false negatives.[332] Depending on the reason the program is being used, there might be a greater or lesser tolerance for false positives and negatives.[333] For example, one might accept more false positives for gaining access to an iPhone than for obtaining evidence on which to base a criminal conviction.[334] In the case of the iPhone, the risks stemming from false

generally suffer from low image quality, small overlapping area, and nonlinear distortion as well as the presence of a complex background." Jain et al., *supra* note 191, at 42.

324. *See* Jain et al., *supra* note 191, at 42. Indeed, performance depends on additional factors such as environmental conditions like temperature and humidity, the characteristics of the sensor recording the images, and the number and demographic distribution of the population whose prints are included as exemplars in the relevant database. *See id.* at 41.

325. *See id.* at 41–42.

326. *Id.* at 38.

327. *See* Roddy & Stosz, *supra* note 323, at 1395 ("The distance between two features can change significantly due to plasticity of the finger."); *supra* Section IV.C (discussing the biomechanics of touch involved in fingerprinting).

328. *See* Roddy & Stosz, *supra* note 323, at 1395 ("[A]utomated matching requires accommodation of phenomena such as plasticity and distortion; therefore, parameters such as search areas are built in to allow a degree of flexibility in feature detection.").

329. *See* Jain et al., *supra* note 191, at 40–41; Roddy & Stosz, *supra* note 323, at 1395.

330. *See* Roddy & Stosz, *supra* note 323, at 1395.

331. *See id.*

332. *See id.*

333. *See* Jain et al., *supra* note 191, at 41.

334. Jain et al. use the example of comparing the risks of false positives and negatives in the contexts of gaining access to an ATM and entrance to Disney World: "[T]he required [false match rate] and [false nonmatch rate] depend on the specific application—for example, Disney World's fingerprint-based entry system operates at a low [false nonmatch rate], so as not to upset paying customers, at the expense of a higher [false nonmatch rate]. On the other hand, an ATM fingerprint verification system may require low [false match rate] at the expense of higher [false nonmatch rate]." *Id.*

negatives are high because, if the correct user is routinely barred from gaining access to the device, that user will likely become frustrated and perhaps even discard the iPhone and purchase an Android device instead. The risks related to false positives are much lower, because very few people other than the correct user will likely try to access the device. In the case of using computerized algorithms to obtain evidence for conviction, the risks stemming from false positives are quite high, as a false positive could translate into depriving an innocent person of his life or liberty. The risks related to false negatives are lower, as this would likely translate into only losing evidence for conviction. This consequence is undesirable as well, but, consistent with the maxim that it is "better that ten guilty persons escape than that one innocent suffer,"[335] a false negative in this context is preferable to a false positive. "Practically, Σ should be large enough to account for effects such as plasticity of the finger and deviations in feature position due to variations in the data, as well as effects of the processing algorithms, but not large enough for areas associated with distinct features to overlap."[336] When working with latent prints, subjective human intervention is ultimately used as a stopgap to prevent undesirable false positives.[337] It is questionable whether human intervention is an effective prophylactic here, though, as examiners' false positive rates are potentially quite high.[338]

Some algorithm-based matching systems provide similarity scores, which depend on factors such as the number of matching minutiae, the percentage of matching minutiae, the consistency of ridge count, and the distances and angles between corresponding minutiae.[339] One such program, known as FRStat, has recently been deployed in the U.S. Army Criminal Investigation Laboratory at the Department of Defense, allowing fingerprint examiners to testify in military courts about the supposed probability that a latent print and exemplar print were from different sources.[340] FRStat's developer, who is the former chief of the Latent Print Branch at the Defense Forensic Science Center, claims that the program "strengthen[s] the foundations of [fingerprint] science."[341] But it remains unclear how the results produced by FRStat, which are based on measuring the distances

335. 4 WILLIAM BLACKSTONE, COMMENTARIES *352; *see also supra* note 190 and accompanying text.

336. Roddy & Stosz, *supra* note 323, at 1395.

337. *See id.* ("In a forensic comparison, plasticity and distortion of the finger are accounted for by human processing, but in an automated process, tolerances such as Σ must be incorporated to accommodate these inherent variations.").

338. *See supra* Section IV.A.

339. *See* Jain et al., *supra* note 191, at 40 ("[T]he algorithm computes a similarity score to reflect the degree of match between two fingerprints based on factors such as the number of matching minutiae, the percentage of matching minutiae in the overlapping area of two fingerprints, and the consistency of ridge count between matching minutiae."); H.J. Swofford et al., *A Method for the Statistical Interpretation of Friction Ridge Skin Impression Evidence: Method Development and Validation*, 287 FORENSIC SCI. INT'L 113, 114–15 (2018).

340. *See* Nicole Wetsman, *Fingerprint Analysis Could Finally Get Scientific, Thanks to a New Tool*, GIZMODO (May 15, 2018, 8:30 AM), https://gizmodo.com/fingerprint-analysis-could-finally-get-scientific-than-1825607912 (explaining how a fingerprint examiner from the Department of Defense testified about "the probability that the similarity between two fingerprints in question would be seen in two prints from the same person").

341. *Id.* According to LinkedIn, the developer, Henry Swofford, is now the Program Manager at In-Q-Tel instead. *See* Henry Swofford, LINKEDIN, https://www.linkedin.com/in/henry-swofford-4052b633/ (last visited Apr. 7, 2020).

and angles between minutiae in fingerprints, correspond to probabilities that two prints were derived from the same source.[342] Although the program measures the similarity in prints according to the underlying algorithm's understanding of similarity, this does not necessarily translate into an assessment of the likelihood that the prints share the same source. As one statistician has explained, "There are . . . multiple ways to establish probability scores for prints, and people may disagree on the best approach to take."[343] Probably more accurately, there are multiple ways to assess print *similarity*, depending on how that term is defined. The probability that prints share the same source, or even the probability that the prints are identical once deformation and other permutations are accounted for, is a more complicated question.

Algorithm performance also depends on the particular database used for the search.[344] As the number of exemplar prints in the database increases, there is an increased chance that the system will deliver false positives, thus negatively affecting performance.[345] Considering that there are more than 120 million individuals' prints in the federal government's database, for example, the effect on performance because of this factor could be significant.[346] Additionally, although there seems to be little to no research on the point, it is reasonable to believe that, if the database is narrow with respect to demographic distribution, there would be an increased chance that the prints would be more similar to each other, making the differentiation of prints more difficult. This would similarly negatively affect the system's performance.[347] Using large databases is also computationally demanding, posing another challenge to apply computerized matching algorithms in the fingerprint context.[348]

Considering all these factors, there is wide variability in the accuracy of computerized algorithms when used to match latent prints to exemplar ones. Some of the best programs in this regard are recorded as having an accuracy of about 54% (or 58% for VeriFinger).[349] This is in contrast to an accuracy score of about 99% when used for identification under more controlled

342. *Cf.* Wetsman, *supra* note 340 (reporting that FRStat "isn't a perfect solution to the issues with pattern evidence," because "[p]rograms like FRStat can't create empirical certainty around fingerprint analysis" and noting that "[t]here are . . . multiple ways to establish probability scores for prints, and people may disagree on the best approach to take").

343. *See id.*

344. *See* Jain et al., *supra* note 191, at 40–41.

345. *See id.* at 40; *see also* Medina-Pérez et al., *supra* note 316, at 856 ("Accuracy when very large background databases are employed is a further challenge in latent fingerprint identification. Typical latent searches for law enforcement agencies are made on background databases with millions of fingerprints.").

346. *See* E-mail from James Loudermilk, *supra* note 58; *cf.* Medina-Pérez et al., *supra* note 316, at 851 ("IAFIS . . . houses records of approximately 73 million known criminal subjects [and] receives an average of 700 latent search requests per day from authorized law enforcement agencies.").

347. *See* Jain et al., *supra* note 191, at 41 (suggesting that a computerized algorithm's performance depends in part on "the number and demographic distribution of the population enrolled in the system").

348. *See* Abu-Faraj et al., *supra* note 318, at 300 ("Automatic fingerprint identification is computationally demanding, especially when large databases are considered.").

349. *See* Medina-Pérez et al., *supra* note 316, at 851; *see also id.* ("The accuracy of algorithms used in latent fingerprint identification is moderate (54.0% rank-1 identification performance when tested on a large fingerprint database).").

circumstances—in situations not involving latent print matching.[350] Indeed, "a good verification algorithm is not necessarily good for identification";[351] instead, latent print matching requires greater acumen from the matching program, which is difficult to achieve.[352]

Ultimately, all these problems make a computerized approach to fingerprint matching so difficult that "current automated fingerprint identification systems require extensive manual intervention in latent encoding (feature extraction) and in verifying a candidate list returned by the system."[353] Moreover, many experts suggest that human matching is superior to these computerized matching programs where latent prints are involved.[354] Not coincidentally, for fingerprint matching conclusions to be entered into evidence in court, the rules generally require the expertise of a testifying fingerprint examiner.[355]

Great leaps forward in existing computerized matching programs will be necessary for accurate match determinations between latent and exemplar prints. Although researchers have been working on improving this technology,[356] there is still much to do.

A major obstacle for advancement in this area is the proprietary nature of much of the work. Companies researching and developing computerized algorithmic approaches to fingerprint matching understandably want to keep the details of their technology secret so that they can continue profiting off of their work. For example, the FBI makes use of technology from IDEMIA.[357] But even the FBI does not have access to the underlying algorithm and source code that produces the closest fingerprint matches on which FBI fingerprint examiners rely in beginning their match assessments.[358] This shroud of secrecy also prevents

350. *See id.* (comparing the moderate accuracy of computerized matching algorithms when applied to latent prints to "the high accuracy (99.0%) of algorithms used with rolled/plain impressions").

351. *Id.* at 852.

352. Medina-Pérez et al. explain that this "is why the current tendency is to create specific algorithms for latent fingerprint identification." *Id.*

353. Jain et al., *supra* note 191, at 42. One expert has suggested that "industry research reflects comparable performance between manual and auto-encoding" but that "the latent examiner community has been reluctant to embrace automated encoding." E-mail from James Loudermilk, *supra* note 58.

354. *See id.* at 44 ("Although fingerprint recognition is one of the earliest applications of pattern recognition, the accuracy of state-of-the-art fingerprint-matching systems is still not comparable to human fingerprint experts in many situations, particularly latent print matching."); *see also* Medina-Pérez et al., *supra* note 316, at 852 ("Some authors conclude, not surprisingly, that the accuracy of latent fingerprint identification is better when the features are extracted by human experts.").

355. *See* Jain et al., *supra* note 191, at 39–42; *cf.* STRENGTHENING FORENSIC SCIENCE, *supra* note 1, at 139 ("Although some . . . AFIS[s] . . . permit fully automated identification of fingerprint records related to criminal history (e.g., for screening job applicants), the assessment of latent prints from crime scenes is based largely on human interpretation.").

356. *See, e.g.*, Abu-Faraj et al., *supra* note 318, at 299 (developing an automatic fingerprint identification system that is more cost-effective and reliable than others); Medina-Pérez et al., *supra* note 316, at 852–53 (proposing a novel clustering algorithm to match latent prints).

357. *See MorphoTrak Chosen as Biometric Provider for FBI Next Generation Identification Program*, SAFRAN: MORPHO (Sept. 8, 2009), https://web.archive.org/web/20141119030554/http://www.morpho.com/actualites-et-evenements/presse/morphotrak-chosen-as-biometric-provider-for-fbi-next-generation-identification-program.

358. The secrecy about the program's details, and the questions about accuracy that secrecy raises, is troublesome. *See generally* Meghan J. Ryan, *Secret Conviction Programs*, 77 WASH. & LEE L. REV. 269 (2020)

outside researchers from examining—and criticizing—the computer algorithm and source code implementing it.[359] It is also often difficult for researchers to gain access to even just the results produced by these matching programs, as access to these programs can be expensive.[360] Without transparency, there are real questions about the extent to which fingerprint matching algorithms are actually useful.

Another significant hurdle slowing advances in the development of computerized matching algorithms is the dearth of adequate databases on which to test matching programs.[361] Access to large databases of latent and exemplar prints, where known matches and mismatches exist, is essential.[362] But most databases are insufficient in one way or another.[363] Some databases are too small, and others are based on prints that have been matched by examiners so the ground truth of whether prints actually match is unknown.[364] For example, one particular database that researchers have historically used for computerized algorithm evaluation and that has been described as a "popular public database employed in most of the published literature" is NIST SD27.[365] The database contains just 258 latent and exemplar print matches, and those matches are not actually known but are instead matches as determined by fingerprint examiners.[366] Further, this database was removed by NIST in January 2018, and is no longer publicly available.[367] Lack of availability is a broader problem, too. Some databases are proprietary, so researchers lack access to them, and others are too expensive to allow researchers ready access.[368] Researchers' lack of access to databases on which to test new computerized matching algorithms is slowing progress on improving fingerprint matching overall.

Finally, to further the fingerprint matching enterprise, researchers and funding sources need to focus on improving computerized algorithms so that they are up to the task of matching latent and exemplar prints and also quantifying differences between prints that translate into true probabilities that the latent and

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(laying out the difficulties that these secrecy and the concomitant accuracy concerns pose). The secrecy and accuracy issues may even rise to the level of constitutional concern. *See id.* at 329–41.

359. *See id.* at 330.

360. *See* Abu-Faraj et al., *supra* note 318, at 299.

361. *See id.*; Medina-Pérez et al., *supra* note 316, at 862 (noting that "public benchmarks for comparing the algorithms are scarce and small").

362. *See* Abu-Faraj et al., *supra* note 318, at 300.

363. *See* Medina-Pérez et al., *supra* note 316, at 862 ("[P]ublic benchmarks for comparing . . . algorithms are scarce and small . . . ."). For a taste of how algorithm developers employ various databases, see Swofford et al., *supra* note 339, at 118 (describing five different databases on which the authors tested FRStat).

364. *See* Medina-Pérez et al., *supra* note 316, at 862.

365. *Id.* at 856.

366. *See id.*

367. *See* NAT'L INST. OF STANDARDS & TECH., NIST SPECIAL DATABASE SD27/27A, https://www.nist.gov/itl/iad/image-group/nist-special-database-2727a (last visited Apr. 7, 2020). The NIST website provides:

> It has been determined that this dataset lacks the documentation required by NIST for distribution. This dataset has been withdrawn and is no longer available for purchase or download from NIST. NIST regrets any inconvenience from the withdrawal of this dataset. NIST researchers are working to replace the withdrawn data as quickly as possible.

Id. The message was posted on January 30, 2018. *Id.*

368. *See* Abu-Faraj et al., *supra* note 318, at 299; Medina-Pérez et al., *supra* note 316, at 862.

exemplar prints are, accounting for permutations due to deformation and other characteristics, identical. This figure, paired with research on the uniqueness of prints, could then be translated into probability assessments that the latent and exemplar print were derived from the same source. Concentrating on developing large, publicly available databases that contain known latent and exemplar matching prints is also key to advancing computerized matching algorithms that can provide a more objective and scientific approach to fingerprint matching in the future.

V. CONCLUSION

Researching the uniqueness of fingerprints, the biomechanics of touch, and computerized matching algorithms is essential to building a scientific foundation for fingerprint evidence. And further investigating the accuracy and reliability of fingerprint examiners' current methods could also be helpful. This research is key in providing courts with an avenue by which they can dig themselves out of the existing fingerprint crisis. Countless men and women across the nation have been convicted based on fingerprint evidence,[369] and judges and jurors continue to reach guilty verdicts every day based on this evidence. Yet it remains unclear whether and to what extent this evidence is accurate and reliable, or whether fingerprint evidence is entirely useless.[370] Still, prosecutors continue to base their cases on this shaky evidence, and judges continue to admit it.[371] Courts' hesitancy to exclude fingerprint evidence at trial is based on the evidence's long historical pedigree and perhaps the notion that the whole justice system could collapse if it were determined that fingerprint evidence is inaccurate or unreliable. But we certainly cannot continue convicting individuals based on questionable evidence. For these reasons, it is crucial to determine whether the practice of fingerprint matching can actually produce accurate and reliable evidence or, rather, whether the practice is pure junk science. Research by scientists working with lawyers is the key to discovering the answer and leading the way out of this crisis.

369. *See supra* Section III.A.
370. *See* STRENGTHENING FORENSIC SCIENCE, *supra* note 1, at 142–45.
371. *See supra* Section III.B.