ESTIMATING A FACE: WHAT PREDICTING APPEARANCE FROM DNA REVEALS ABOUT THE NEED TO REGULATE GENETIC INVESTIGATIONS

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ABSTRACT

Reliance on flawed forensic disciplines has placed innocent people in prison with alarming frequency. In the past thirty years, forensic science has contributed to half of all the wrongful convictions that the Innocence Project has exposed, and one-quarter of all known wrongful convictions in the United States. One of the few forensic disciplines not developed for courtrooms but for life sciences research, DNA identity testing has helped to expose the inaccuracies of other, flawed forensic disciplines.

After the introduction of DNA identity testing into the legal system, national and state legislation established guardrails for its use. But legislation has not kept pace with the application of new genetic tools in the criminal legal system. This Article advocates for deliberative bodies to regulate investigative genetic techniques and examines forensic DNA phenotyping—a controversial investigative method to estimate the appearance of a suspect from his DNA—as an illustrative example.

This Article shines light on the use of forensic DNA phenotyping and similar genetic appearance estimation tools in the U.S. criminal legal system by drawing upon legal, medical, and forensic literatures; conversations with stakeholders; and original freedom of information requests. In so doing, this Article considers what is at stake when a genetic

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technology proliferates within the criminal legal system without independent oversight. It discusses whether the nature of the genetic analysis—the fact that forensic DNA phenotyping reveals far more than its legislatively authorized counterpart—matters for the Fourth Amendment after the Supreme Court's 2018 decision in United States v. Carpenter. *Finally, the Article draws upon international regulation of forensic DNA phenotyping to offer lessons for how legislators can, and why they should, regulate forensic DNA phenotyping and other genetic investigative techniques.*

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INTRODUCTION

In October 2022, the Edmonton Police Service of Canada (the "Service") published a computer-generated portrait of an alleged suspect in an assault case to its social media.[1] Unable to identify leads in the case, the Service had hired a private company to analyze DNA from the crime scene in order to estimate the physical characteristics of the person of interest, a practice known as "forensic DNA phenotyping." The image the Service published portrayed a Black man; statistics accompanying the portrait described the person of interest as being of East African ancestry, having dark brown or brown skin, and having either brown or black eye color.

Soon after publication, public outcry at the Service's distribution of and reliance upon this computer-generated "generic image" led the Service to remove the image from social media and apologize.[2] A spokesperson for the Service wrote, "The potential that a visual profile can provide far too broad a characterization from within a racialized community and in this case, Edmonton's Black community, was not something I adequately considered."[3] The Service's statement underscores a simple but perhaps stunning fact: in the purchase and application of a controversial technology to analyze a person's most intimate information, the Edmonton Police Service had been the sole decisionmaker.

This result is not an anomaly. Five years earlier, the New York City Police Department (NYPD) had hired the same company to use forensic DNA phenotyping to estimate the appearance of a person of interest in a murder case. This company represented to the NYPD that the person of interest was of African ancestry,[4] which led the NYPD to collect, compare,

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1. *See Advocates Urge Edmonton Police to Stop Using DNA Phenotyping Technology*, CBC (Oct. 20, 2022, 9:43 PM), https://www.cbc.ca/news/canada/edmonton/racial-profiling-dna-phenotyping-edmonton-police-1.6624397 [https://perma.cc/YL9Z-MG4P].

2. A coalition of eight Black-led organizations wrote to the Service: "It is troubling to issue a generic image that renders large numbers of Black males suspect. . . . Our community feels traumatized, scapegoated and humiliated. . . . The practice deepens historical mistrust and lowers confidence in our policing." *Id.*; *see also* Taylor Lambert, *DNA-Assisted Mug Shots in Law Enforcement Are Based on Dubious Science. So Why Would Edmonton Police Use Them?*, CBC (Oct. 7, 2022, 6:00 AM), https://www.cbc.ca/news/canada/edmonton/edmonton-police-phenotype-science-1.6609320 [https://perma.cc/7WJE-63CK].

3. *Edmonton Police Issue Apology for Controversial Use of DNA Phenotyping*, CBC (Oct. 6, 2022, 1:45 PM), https://www.cbc.ca/news/canada/edmonton/edmonton-police-issue-apology-for-controversial-use-of-dna-phenotyping-1.6608457 [https://perma.cc/ADG3-A6WK].

4. Amos Barshad, *When the NYPD Gets Desperate*, NATION (Nov. 28, 2022), https://www.thenation.com/article/society/chanel-lewis-karina-vetrano-nypd [https://perma.cc/7QPM-EE4U].

and store DNA from over 360 Black and Latinx community members.[5] This practice, in which law enforcement request a large number of people to share their genetic samples in order to identify a person of interest, has been described as a DNA dragnet.[6] The New York State Department of Health, which oversees private DNA laboratories operating in the State, had not approved the operation of the forensic DNA phenotyping company in New York State at the time.[7] Like the Service, the NYPD lacked legislative guidance, so they relied upon their own judgment about whether and how to apply this tool.[8]

Appearance estimation tools are one category among a panoply of genetic techniques and DNA collection practices that have transformed criminal investigations.[9] After investigators collect DNA from a crime

5. Some community members reported feeling embarrassed, intimidated, and stigmatized by the experience of officers appearing at their homes to request their DNA. *See* Max Rivlin-Nadler, *Bombshell Letter: NYPD Conducted a Bogus, 'Racialized' Investigation in Chanel Lewis Case*, GOTHAMIST (Apr. 1, 2019), https://gothamist.com/news/bombshell-letter-nypd-conducted-a-bogus-racialized-investigation-in-chanel-lewis-case [https://perma.cc/AT2P-UBTR]; Graham Rayman, *NYPD Detectives Demanded DNA Swabs from Hundreds of Black and Latino Men While Hunting Killer of Howard Beach Jogger*, DAILY NEWS (May 10, 2019, 3:46 PM), https://www.nydailynews.com/new-york/nyc-crime/ny-men-caught-up-in-nypd-jogger-dna-dragnet-object-to-the-tactic-20190510-h4i4q7p4wzhtbpmjmdilvxsc5u-story.html [https://perma.cc/EKU5-L4DE].

6. *See, e.g.*, Troy Duster, *DNA Dragnets and Race: Larger Social Context, History and Future*, GENEWATCH, Nov.–Dec. 2008, at 3, https://thetarrytownmeetings.org/sites/default/files/discussion/GeneWatch%20Issue-DNA%20Databanks%20and%20Race.pdf [https://perma.cc/F8JJ-68RJ]; Elizabeth E. Joh, Maryland v. King*: Policing and Genetic Privacy*, 11 OHIO ST. J. CRIM. L. 281, 284 (2013) (discussing DNA dragnets); Stephen Mercer & Jessica Gabel, *Shadow Dwellers: The Underregulated World of State and Local DNA Databases*, 69 N.Y.U. ANN. SURV. AM. L. 639, 667, 671–73 (2014) (same); Jan Ransom & Ashley Southall, *'Race-Biased Dragnet': DNA from 360 Black Men Was Collected to Solve Vetrano Murder, Defense Lawyers Say*, N.Y. TIMES (Mar. 31, 2019), https://www.nytimes.com/2019/03/31/nyregion/karina-vetrano-trial.html [https://perma.cc/LQ9P-LBBL].

7. The NYPD argued publicly that no state approval was necessary—the Department of Health disagreed. Laboratories that the NYPD utilizes for DNA analysis typically require approval from either the Department of Health or the New York State Commission on Forensic Science. The former has oversight of private laboratories, like the private laboratory that conducted forensic DNA phenotyping in this case. The latter has authority over public laboratories, which the Commission has interpreted to mean government laboratories. Ashley Southall, *Using DNA to Sketch What Victims Looks Like; Some Call It Science Fiction*, N.Y. TIMES (Oct. 19, 2017), https://www.nytimes.com/2017/10/19/nyregion/dna-phenotyping-new-york-police.html [https://perma.cc/A5Y3-A9N6] (noting that Parabon received a warning letter for operating without approval in New York State); *see also* Letter from Stephanie H. Shulman, Dir., Clinical Lab'y Evaluation Program, N.Y. Dep't of Health, to Dr. Steven Armentrout, CEO, Parabon Nanolabs (Sept. 15, 2017), [https://perma.cc/XTG9-28FM].

8. When evidence of the NYPD's use of forensic DNA phenotyping in the case came to light in 2019, the prosecution had not disclosed information about the ancestry estimation and resulting DNA dragnet to the defense. *See* Ransom & Southall, *supra* note 6. Mr. Chanel Lewis still maintains his innocence and seeks to have his conviction overturned. *See* Rocco Vertuccio, *Community Leaders Add More Pressure on Queens District Attorney to Reopen Murder Case Against Chanel Lewis*, SPECTRUM NEWS NY1 (July 13, 2021, 2:30 PM), https://www.ny1.com/nyc/queens/news/2021/07/13/pressure-grows-on-queens-da-to-reopen-chanel-lewis-case [https://perma.cc/LQH7-BN29].

9. These genetic investigatory techniques include investigative genetic genealogy, familial searching, rapid DNA testing, and probabilistic genotyping. *See generally, e.g.*, Erin Murphy, *Forensic DNA Typing*, 1 ANN. REV. CRIMINOLOGY 497 (2018) [hereinafter Murphy, *Forensic DNA Typing*].

scene, they typically compare the DNA to a database that contains the DNA profiles of, in part, previously convicted individuals. When there is no match between the crime scene DNA and the database, investigators may turn to other genetic techniques to try to solve the crime. Like forensic DNA phenotyping, these methods sometimes lack legislative authorization and may not require judicial approval to employ.[10]

To investigate persons of interest whose DNA profiles are not contained in an existing government database, law enforcement have collected DNA from a multitude of unusual sources[11]: a nine-year-old child's genetic screening data from when he was a newborn, to investigate the child's father;[12] a victim's DNA from a rape kit, to identify and arrest the victim in an unrelated burglary;[13] tissue from a daughter's Pap smear (a procedure to collect and test cells for cervical cancer), to investigate the child's father;[14]

10. Even when a regulatory scheme exists—as the New York example surfaced—the use of certain genetic tools may escape state oversight. Although the New York State Department of Health had not yet approved application of biogeographic ancestry estimation at the time NYPD used the tool, there were no public sanctions or repercussions, and the private company continues to contract with the NYPD. *See* CHECKBOOK NYC, https://www.checkbooknyc.com/smart_search/citywide?search_term=parabon [https://perma.cc/2CYD-8AWB] (noting purchase orders to Parabon from 2017 through 2023). This outcome is not unique to New York. In the case of the so-called Phantom of Heilbronn, in which law enforcement chased an unknown female serial killer, German police went to Austria to obtain biogeographic ancestry analysis that was at the time and remains today illegal in Germany. Ultimately, law enforcement discovered that a woman in a manufacturing plant for laboratory materials had simply contaminated the testing materials. *See* Turna Ray, *Push for Forensic DNA Phenotyping, Ancestry Testing in Germany Raises Discrimination Concerns*, GENOMEWEB (MAY 4, 2018), https://www.genomeweb.com/policy-legislation/push-forensic-dna-phenotyping-ancestry-testing-germany-raises-discrimination [https://perma.cc/WR2N-5S4K] (describing how German police went to Austria to obtain biogeographic ancestry analysis that was at the time illegal); *see also* GABRIELLE SAMUEL & BARBARA PRAINSACK, SOCIETAL, ETHICAL, AND REGULATORY DIMENSIONS OF FORENSIC DNA PHENOTYPING 32 (2019) (discussing the case of the "Phantom of Heilbronn"); Peter M. Schneider, Barbara Prainsack & Manfred Kayser, *The Use of Forensic DNA Phenotyping in Predicting Appearance and Biogeographic Ancestry*, 116 DEUTSCHES ÄRZTEBLATT INT'L 873, 876 (2019) ("In Germany, in November 2019, the Bundestag (Parliament) and Bundesrat (Federal Council) approved a change in the law to permit forensic DNA phenotyping (with the exception of the DNA-based inference of biogeographic ancestry)." (citation omitted)).

11. By contrast, DNA collected directly from an individual person of interest (e.g., via a swab of one's cheek) is subject to federal and state statutory laws and constitutional law. *See generally* Maryland v. King, 569 U.S. 435 (2013).

12. Verified Complaint ¶ 3, N.J. Off. of the Pub. Def. v. N.J. Dep't of Health, Div. of Pub. Health & Env't Lab'ys, No. MER-L-001210-22 (N.J. Super. Ct. Law Div. July 11, 2022); Dana DiFilippo, *Judge Orders State to Release Information About Police Use of Baby Blood Spots*, N.J. MONITOR (Jan. 4, 2023, 11:41 AM), https://newjerseymonitor.com/2023/01/04/judge-orders-state-to-release-information-about-police-use-of-baby-blood-spots [https://perma.cc/62SR-ASN4]. *See generally* Natalie Ram, *America's Hidden National DNA Database*, 100 TEX. L. REV. 1253 (2022) (analyzing law enforcement use of newborn genetic screening data nationally).

13. *See* Associated Press, *A Woman Whose Rape DNA Led to Her Arrest Sues the City of San Francisco*, NPR (Sept. 13, 2022, 10:56 AM), https://www.npr.org/2022/09/13/1122670742/rape-dna-san-francisco-lawsuit [https://perma.cc/9LPW-HL7H].

14. *See* Marisa Gerber, *The Controversial DNA Search That Helped Nab the 'Grim Sleeper' Is Winning over Skeptics*, L.A. TIMES (Oct. 25, 2016, 3:00 AM), https://www.latimes.com/local/lanow/la-me-familial-dna-20161023-snap-story.html [https://perma.cc/QP68-E8DV].

and surreptitiously gathered items such as a child's McDonald's soda,[15] licked envelopes,[16] and face masks,[17] to investigate the persons who used the objects. While these measures can produce extraordinary benefits, sometimes solving crimes decades after they occurred, they also come with societal risks, such as privacy intrusions and wrongful identifications.

Some developers of the genetic tools available to law enforcement have received critique for reliance on genetic data from inappropriate sources. For illustration, forensic researchers have relied on genetic data from: research participants, stored in databases intended for health research such as UK Biobank;[18] the Uyghur population in China, collected pursuant to an alleged health check;[19] public ancestry websites;[20] convicted and arrested community members' DNA in the United States and abroad;[21] and DNA

15. *See, e.g.*, Jan Ransom & Ashley Southall, *N.Y.P.D. Detectives Gave a Boy, 12, a Soda. He Landed in a DNA Database.*, N.Y. TIMES (Aug. 15, 2019), https://www.nytimes.com/2019/08/15/nyregion/nypd-dna-database.html [https://perma.cc/HRP4-8QAZ].

16. *See, e.g.*, State v. Athan, 158 P.3d 27, 37 (Wash. 2007).

17. *See, e.g.*, Colin Freeze, *Toronto Police Solve Decades-Old Murder of Two Women Using Modern Genetic Genealogy*, GLOBE & MAIL (Dec. 25, 2023), https://www.theglobeandmail.com/canada/article-two-women-were-murdered-in-1983-years-later-toronto-police-used [https://perma.cc/DY9C-QWSS] (to determine which sibling committed the crime, "[u]ndercover officers shadowed several of the brothers so they could gather DNA from their discarded items, which included pop cans and a COVID-19 mask"); Kelly Taylor Hayes, *DNA from Coronavirus Face Mask Leads to Arrest in Child Molestation Case, Police Say*, FOX10 PHOENIX (June 3, 2020, 9:10 AM), https://www.fox10phoenix.com/news/dna-from-coronavirus-face-mask-leads-to-arrest-in-child-molestation-case-police-say [https://perma.cc/YL6P-4BT2].

18. *E.g.*, *Learn More About UK Biobank*, UK BIOBANK (June 9, 2023), https://www.ukbiobank.ac.uk/learn-more-about-uk-biobank [https://perma.cc/TQM9-A7ES] ("Who can use UK Biobank? UK Biobank's aim is to encourage as many bona fide researchers as possible to use the research resource to perform health research that's in the public interest . . . ."); *see also* Vilius Dranseika, Jan Piasecki & Marcin Waligora, *Forensic Uses of Research Biobanks: Should Donors Be Informed?*, 19 MED., HEALTH CARE & PHIL. 141, 141 (2016).

19. *See* Sui-Lee Wee, *Two Scientific Journals Retract Articles Involving Chinese DNA Research*, N.Y. TIMES (Sept. 9, 2021), https://www.nytimes.com/2021/09/09/business/china-dna-retraction-uyghurs.html [https://perma.cc/FJ9K-RFPU]; Sui-Lee Wee & Paul Mozur, *China Uses DNA to Map Faces, with Help from the West*, N.Y. TIMES (Oct. 22, 2021), https://www.nytimes.com/2019/12/03/business/china-dna-uighurs-xinjiang.html [https://perma.cc/RK5L-KPWY]; Dennis Normile, *Genetic Papers Containing Data from China's Ethnic Minorities Draw Fire*, SCIENCE (Aug. 10, 2021, 5:00 PM), https://www.science.org/content/article/genetic-papers-containing-data-china-s-ethnic-minorities-draw-fire [https://perma.cc/V5VQ-MWBN].

20. *See* Daniel Kling, Christopher Phillips, Debbie Kennett & Andreas Tillmar, *Investigative Genetic Genealogy: Current Methods, Knowledge and Practice*, 52 FORENSIC SCI. INT'L: GENETICS 102474, 102477 (2021).

21. *See, e.g.*, Victor Toom, *Bodies of Science and Law: Forensic DNA Profiling, Biological Bodies, and Biopower*, 39 J.L. & SOC'Y 150, 163–65 (2012) (discussing research on DNA of convicted individuals in the Netherlands); N.Y. EXEC. LAW § 995-c(6)(c) (McKinney 2021) (stating that DNA records may be released only "after personally identifiable information has been removed by the division, to an entity authorized by the division for the purpose of . . . identification research and protocol development for forensic DNA analysis or quality control purposes").

databases that may contain genetic profiles obtained without informed consent.[22]

Unlike in the early years of forensic DNA testing in the United States, when national and state legislation accompanied the expanding use of genetic testing in the legal system, federal legislative architecture has yet to emerge to guide or curb these myriad genetic practices. While there has been robust reporting and discussion amongst scholars about the ethics of these practices,[23] nearly all of these techniques and tools remain available to law enforcement and forensic researchers in the United States. These practices are not always disclosed in affidavits or in discovery, so their use may not be visible to defendants, judges, or juries.[24]

This Article advocates for deliberative bodies at the federal, state, and local levels to regulate investigative genetic techniques—and examines genetic appearance estimation as an illustrative example. Also described as "molecular photofitting," forensic DNA phenotyping technologies purport

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22. *See* Quirin Schiermeier, *Forensic Database Challenged over Ethics of DNA Holdings*, 594 NATURE 320 (2021) (discussing ethical concerns pertaining to the Y-chromosome Haplotype Reference Database (YHRD), which both forensic researchers and law enforcement utilize); Veronika Lipphardt et al., *Europe's Roma People Are Vulnerable to Poor Practice in Genetics*, 599 NATURE 368, 369–70 (2021) ("In many cases, especially in the late twentieth century, samples have been collected from people (including prisoners) without adequate consent or any record of consent, then shared across research groups or deposited in public databases. In others, participants seem to have given some kind of consent, but it is unclear whether they understood exactly what their DNA would be used for. . . . Participants, who in some cases gave only their spoken consent, were told that their data would reveal whether they were carriers of genetic diseases—but not that their genetic information would end up in public databases (such as EMPOP and YHRD) that can also be accessed by law-enforcement agencies, which is what happened in some cases. . . . The problems we have identified with respect to Roma people are highly likely to apply to other groups.").

23. One perhaps under-explored consideration for clinicians and genetic research participants is how forensic developers are utilizing medical data from patients who participate in clinical research to develop tools for law enforcement. *See* Francesca Forzano, Maurizio Genuardi & Yves Moreau, *ESHG Warns Against Misuses of Genetic Tests and Biobanks for Discrimination Purposes*, 29 EUR. J. HUM. GENETICS 894, 894 (2021). Researchers (including forensic researchers) regularly utilize data which they had no hand in collecting, gathered in databanks like the UK Biobank, 23andMe, and the U.S. National Institute of Health's dbGAP. This practice facilitates meaningful research, but it is not always clear that the purposes the consent forms describe (e.g., to study the causes of health outcomes) align with the purposes of forensic research (e.g., to estimate phenotypes for law enforcement technology). *See* Elizabeth Bromley & Dmitry Khodyakov, *The Value of Consent for Biobanking*, 5 NATURE HUM. BEHAV. 1125, 1125 (2021). For example, the consent form for 23andMe explains that independent researchers may use the data to investigate "simple traits such as hair color or freckles," but does not explain that an application of this research may be to law enforcement. *Research Consent Document*, 23ANDME, https://www.23andme.com/about/consent [https://perma.cc/DE33-JP97].

24. *See, e.g.*, Steve Busch & Steve Kramer, *Forensic Genetic Genealogy Webinar Series: An Inside Look at the Facts and Fiction Surrounding Genetic Genealogy*, INT'L SYMP. ON HUM. IDENTIFICATION, at 32:30–40:30 (Apr. 13, 2022), https://event.on24.com/wcc/r/3685341/21735EBF362195FB6C5843DE15AFEFB0?partnerref=ishiwebsite [https://perma.cc/HD3A-ED6C] (stating that information about genetic genealogy need not be disclosed in an affidavit articulating probable cause for arrest nor during discovery); Heather Tal Murphy, *How Police Actually Cracked the Idaho Killings Case*, SLATE (Jan. 10, 2023, 6:19 PM), https://slate.com/technology/2023/01/bryan-kohberger-university-idaho-murders-forensic-genealogy.html [https://perma.cc/V5JE-SVRA].

to predict externally visible characteristics (eye color, hair color, skin color, hair texture, and face shape) from DNA.[25] Put another way, these tools predict or estimate an individual's looks (one's "phenotype") solely from one's genetic information (called one's "genotype").[26]

Appearance prediction tools include forensic DNA phenotyping, biogeographic ancestry estimation, and age estimation. Forensic researchers are working to expand these predictive categories further to include behavioral characteristics like smoking habits. Researchers in the field often refer to biogeographic ancestry and age estimation as distinct from forensic DNA phenotyping because age and ancestry are not necessarily apparent from one's physical appearance. For the reader's ease, this Article uses the terms forensic DNA phenotyping and genetic appearance estimation as inclusive of biogeographic ancestry and age estimation.

Like many law enforcement investigative techniques in the United States, forensic DNA phenotyping lacks statutory authorization in most states even while it has been used in most states.[27] Like the research of other forensic tools, studies in the field have sometimes relied upon genetic data from controversial sources. In certain countries, legislative bodies have chosen to regulate forensic DNA phenotyping,[28] offering lessons for the United States.

Forensic DNA phenotyping goes to the heart of key legal questions, which this Article discusses, regarding the use of genetics in the criminal legal system and whether the nature of the genetic analysis matters for the Fourth Amendment. These questions include whether there are limits to government analysis of DNA when it reveals complex and sometimes intimate genetic traits;[29] and whether, if law enforcement does not need a warrant to collect discarded items,[30] it ever requires judicial approval to test involuntarily shed DNA.

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25. *See* discussion *infra* Part II.

26. This Article uses the terms "predict" and "estimate" when discussing forensic DNA phenotyping tools. Although phenotyping tools may not "predict" appearance in the lay sense of the word, this Article frequently uses the term because researchers in the field employ it. In certain contexts, forensic researchers may use the terms "estimate" (e.g., estimate age) and "infer" (e.g. infer biogeographic ancestry). I stray from technical terminology when it would improve clarity for the general reader.

27. Law enforcement have used forensic DNA phenotyping in at least forty-one states in the United States and sixteen countries. Use of the technology in eight states and in the District of Columbia is unknown. *See infra* Sections IV.A–B.

28. *See infra* Section IV.B.

29. For context, law enforcement does not require a warrant to conduct traditional DNA identity testing on an arrestee, in part because this analysis examines non-coding DNA, once considered "junk" DNA relevant only to identity. *See* Maryland v. King, 569 U.S. 435, 442–43 (2013).

30. *See* Elizabeth E. Joh, *Reclaiming "Abandoned" DNA: The Fourth Amendment and Genetic Privacy*, 100 NW. U. L. REV. 857, 859 (2006).

The science of phenotyping and the legal landscape of forensic DNA testing have meaningfully evolved since the publication of other legal analyses of the technology's use in the United States.[31] This Article builds upon and benefits from prior discussions of the technology. It is based on reviews of the relevant scientific and legal literatures, conversations with stakeholders, as well as original freedom of information requests. This Article has a U.S. focus, but provides international context when instructive.

Part I introduces readers to forensic DNA testing. Part II contrasts traditional forensic DNA testing with genetic appearance estimation. Because stakeholders' views with respect to forensic DNA phenotyping vary, Part III identifies the scientific and ethical concerns associated with forensic DNA phenotyping. Part IV considers the legality of these tools internationally and domestically. Although other countries have passed laws to regulate the use of genetic appearance estimation tools, the United States has no federal law that governs the technology. Emblemizing the limited oversight of police investigatory practices nationally, forensic DNA phenotyping is in use even in the few states that appear to prohibit the technology. This Part discusses how forensic DNA phenotyping relates to constitutional issues that scholars have debated in the wake of the Supreme Court's decisions in *Maryland v. King*[32] and *Carpenter v. United States*.[33] Finally, the Article concludes in Part V by proposing legislative regulation.

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31. The most in-depth discussions of forensic DNA phenotyping were published during or prior to 2015. Most authors to examine the technology, with the notable exceptions of Professor Erin Murphy and Natalie Quan, argued in favor of wider adoption of forensic DNA phenotyping. *See* Bert-Japp Koops & Maurice Schellekens, *Forensic DNA Phenotyping: Regulatory Issues*, 9 COLUM. SCI. & TECH. L. REV. 158 (2008); Dov Fox, *The Second Generation of Racial Profiling*, 38 AM. J. CRIM. L. 49 (2010); Natalie Quan, Note, *Black and White or Red All Over? The Impropriety of Using Crime Scene DNA to Construct Racial Profiles of Suspects*, 84 S. CAL. L. REV. 1403 (2011); Charles E. MacLean, *Creating a Wanted Poster from a Drop of Blood: Using DNA Phenotyping to Generate an Artist's Rendering of an Offender Based Only on DNA Shed at the Crime Scene*, 36 HAMLINE L. REV. 357 (2013); Charles E. MacLean & Adam Lamparello, *Forensic DNA Phenotyping in Criminal Investigations and Criminal Courts: Assessing and Mitigating the Dilemmas Inherent in the Science*, 8 RECENT ADVANCES DNA & GENE SEQUENCES 104 (2014); Erin Murphy, *Legal and Ethical Issues in Forensic DNA Phenotyping* (N.Y.U. Sch. of L. Pub. L. & Legal Theory Working Paper, Paper No. 13-46, 2013) [hereinafter Murphy, *Phenotyping*], https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2288204 [https://perma.cc/D72E-FXQ6]; ERIN E. MURPHY, INSIDE THE CELL: THE DARK SIDE OF FORENSIC DNA (2015) [hereinafter MURPHY, INSIDE THE CELL]. Three review articles that examine emergent DNA technologies also discuss forensic DNA phenotyping in brief. Jessica Gabel Cino, *Tackling Technical Debt: Managing Advances in DNA Technology that Outpace the Evolution of Law*, 54 AM. CRIM. L. REV. 373 (2017); Murphy, *Forensic DNA Typing*, *supra* note 9; Samuel D. Hodge, Jr., *Current Controversies in the Use of DNA in Forensic Investigations*, 48 U. BALT. L. REV. 39 (2018).

32. 569 U.S. 435 (2013).

33. 138 S. Ct. 2206 (2018); *see, e.g.*, Matthew Tokson, *The Aftermath of* Carpenter*: An Empirical Study of Fourth Amendment Law, 2018–2021*, 135 HARV. L. REV. 1790 (2022).

I. AN OVERVIEW OF FORENSIC DNA TESTING

Reliance on flawed forensic disciplines has placed innocent people in prison with alarming frequency.[34] In the past thirty years, forensic science has contributed to half of all the wrongful convictions that the Innocence Project has exposed, and one-quarter of all known wrongful convictions nationally.[35] One of the few forensic disciplines not developed for courtrooms but for life sciences research, DNA identity testing has helped to expose the inaccuracies of other, flawed forensic disciplines.[36] To place appearance estimation techniques in context, this Part provides an overview of forensic DNA identity testing.

Human DNA is organized into twenty-three sets of chromosomes, with each person receiving one set of chromosomes from each genetic parent.[37] Within chromosomes, DNA forms a double-stranded helix, akin to a twisting ladder. The rungs of the ladder are comprised of base pairs of just four nucleotides known as adenine (A), cytosine (C), guanine (G), and thymine (T). The ordering of these base pairs is what makes individuals, with the exception of identical twins, genetically unique.[38]

Sequences of base pairs code the genetic information to make proteins: these portions of the genetic code are referred to as exons or coding DNA. Non-coding regions are the object of traditional DNA analysis. Because

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34. For a historical overview of the growth of the forensics field in the United States, see Maneka Sinha, *Radically Reimagining Forensic Evidence*, 73 ALA. L. REV. 879, 894–98 (2022). *See also* Meehan Crist & Tim Requarth, *Forensic Science Put Jimmy Genrich in Prison for 24 Years. What if It Wasn't Science?*, NATION (Feb. 1, 2018), https://www.thenation.com/article/archive/the-crisis-of-american-forensics [https://perma.cc/TTM5-V2DA].

35. *Misapplication of Forensic Science*, INNOCENCE PROJECT, https://innocenceproject.org/misapplication-of-forensic-science/ [https://perma.cc/9C7Y-NGQC].

36. *See* NAT'L RSCH. COUNCIL NAT'L ACADS., STRENGTHENING FORENSIC SCIENCE IN THE UNITED STATES: A PATH FORWARD 41 (2009), https://www.ncjrs.gov/pdffiles1/nij/grants/228091.pdf [https://perma.cc/ERW7-33Q2] ("Thus, DNA analysis—originally developed in research laboratories in the context of life sciences research—has received heightened scrutiny and funding support. That, combined with its well-defined precision and accuracy, has set the bar higher for other forensic science methodologies, because it has provided a tool with a higher degree of reliability and relevance than any other forensic technique.").

37. JOHN M. BUTLER, FORENSIC DNA TYPING: BIOLOGY, TECHNOLOGY, AND GENETICS OF STR MARKERS 20, 23 (2d ed. 2005). This Section discusses the genetic makeup that is most common in typically developing individuals. But one's genetic makeup can differ from the typical. *See, e.g.*, Erin E. Murphy, *DNA at the Fringes: Twins, Chimerism, and Synthetic DNA*, DAILY BEAST (Apr. 13, 2017, 6:27 PM), https://www.thedailybeast.com/dna-at-the-fringes-twins-chimerism-and-synthetic-dna [https://perma.cc/6HAE-9BSK] (discussing how blood transfusions, transplants, pregnancy, and atypical cell development prior to birth can cause "more than one genetic profile [to] be present in an individual," a result that is "loosely labeled 'chimerism'").

38. BUTLER, *supra* note 37, at 18, 26–27; *see also id.* at 26 ("A vast majority of our DNA molecules (over 99.7%) is the same between people. Only a small fraction of our DNA (0.3% or ~10 million nucleotides) differs between people and makes us unique individuals. These variable regions of DNA provide the capability of using DNA information for human identity purposes. Methods have been developed to locate and characterize this genetic variation at specific sites in the human genome.").

non-coding regions do not code for proteins, scientists previously thought of these regions as "junk" DNA.[39] As we will return to in Part II, forensic DNA phenotyping relies upon examination of both coding and non-coding regions.

In 1985, Dr. Alec Jeffreys described how particular non-coding regions of DNA contain sequences of base pairs that repeat regularly but have lengths that tend to differ between individuals.[40] The discovery of these highly variable ("polymorphic") base pair sequences formed the basis for traditional human identity testing, called DNA profiling. Today, scientists in the United States primarily conduct a type of DNA profiling known as short tandem repeat (STR) profiling. The STR markers employed for casework consist of four base pairs that repeat a certain number of times. The variable number of repeats are alleles—variants of a gene.[41] Currently, STR profiling is the U.S. standard.[42]

STR profiles display specific genetic locations ("loci") on each chromosome. The same locus on each chromosome can be identical ("homozygous," e.g., AA) or different ("heterozygous," e.g., Aa). When a person is homozygous this means that they received the same gene variant, or allele, from each parent (for instance, two genes for face freckling). Together, the two alleles comprise one's genotype.

In 1997, the FBI selected the thirteen core STR loci to serve as a consistent way to compare DNA profiles across the country.[43] The FBI also launched the Combined DNA Index System software (CODIS) to store and compare STR profiles.[44] This is a three-tiered system that consists of a single, nationwide index known as the National DNA Index System (NDIS); state-level indices, each of which is known as a State DNA Index System (SDIS); and local-level indices, each of which is known as a Local DNA Index System (LDIS).[45] Law enforcement continues to employ CODIS to store and compare DNA profiles within and between states.[46]

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39. Modern research has upended the notion that these regions have no genetic importance. *See, e.g.*, *id.* at 22 ("Because these regions are not related directly to making proteins they are sometimes referred to as 'junk' DNA," although recent research suggests that these regions may have other essential functions).

40. *Id.* at 4–5; Peter Gill, Alec J. Jeffreys & David J. Werrett, *Forensic Application of DNA 'Fingerprints*,*'* 318 NATURE 577, 577 (1985) (introducing a forensic application for DNA testing).

41. Erin Murphy, *Relative Doubt: Familial Searches of DNA Databases*, 109 MICH. L. REV. 291, 295 (2010).

42. *Id.*

43. Over time, the number of loci has expanded. BUTLER, *supra* note 37, at 60, 155.

44. *Id.* at 16.

45. Eligible profiles may be uploaded from LDIS to SDIS, and from SDIS to NDIS. *Id.* at 266–67.

46. *Frequently Asked Questions on CODIS and NDIS*, FBI, https://www.fbi.gov/services/laboratory/biometric-analysis/codis/codis-and-ndis-fact-sheet [https://perma.cc/A494-ZEKG].

Over time, the FBI has expanded to require twenty core STR loci for upload to NDIS.[47]

When forensic DNA testing is employed in the same quality conditions as those in which it was tested (historically, high-quality, high-quantity samples from a single unknown person), its results are generally straightforward and highly accurate. However, unlike in laboratory or medical settings, conditions at crime scenes are rarely ideal. DNA at crime scenes may be degraded, contaminated, or of very low quantity—factors which can impact the reliability of DNA analyses.[48] In the past, crime labs could do little with these types of samples.

Even with an ideal sample, human, random, and systematic errors may occur. Investigators or laboratories can accidentally contaminate samples with their own DNA or that from another case.[49] DNA testing can only reveal that a person's DNA is on an object but not when their DNA was deposited or why.[50] Individuals can unknowingly transfer DNA to the crime scene from an unrelated location, as naturally occurs when an individual touches several objects (known as "indirect transfer").[51]

In an attempt to bring genetic solutions to more cases, forensic researchers have pushed the boundaries of genetic testing. Certain recently developed genetic tools, like forensic DNA phenotyping technologies, rely on complex computer algorithms to draw conclusions from forensic DNA

47. EMILY J. HANSON, CONG. RSCH. SERV., R41800, THE USE OF DNA BY THE CRIMINAL JUSTICE SYSTEM AND THE FEDERAL ROLE: BACKGROUND, CURRENT LAW, AND GRANTS 4 (2022), https://crsreports.congress.gov/product/pdf/R/R41800/23 [https://perma.cc/M4A5-ZRZ2] ("In 2017, the number of required loci was increased from 13 to 20 to enhance discriminatory power, facilitate international cooperation via the collection of more common loci, and aid in missing person investigations.").

48. In prior cases, these circumstances have contributed to wrongful arrests, prosecutions, and convictions. *See, e.g.*, EUR. FORENSIC GENETICS NETWORK OF EXCELLENCE, MAKING SENSE OF FORENSIC GENETICS 22 (2017) [hereinafter MAKING SENSE OF FORENSIC GENETICS], https://senseaboutscience.org/wp-content/uploads/2017/01/making-sense-of-forensic-genetics.pdf [https://perma.cc/Z3BU-R8N3]; MURPHY, INSIDE THE CELL, *supra* note 31, at 22, 56; *see also* Eli Rosenberg, *Can DNA Evidence Be Too Convincing? An Acquitted Man Thinks So*, N.Y. TIMES (May 16, 2017), https://www.nytimes.com/2017/05/16/nyregion/can-dna-evidence-be-too-convincing-an-acquitted-man-thinks-so.html [https://perma.cc/FVK6-KZSR]; Katie Worth, *Framed for Murder by His Own DNA*, MARSHALL PROJECT (Apr. 19, 2018, 7:00 AM), https://www.themarshallproject.org/2018/04/19/framed-for-murder-by-his-own-dna [https://perma.cc/CB2D-4NQT]; Naomi Elster, *How Forensic DNA Evidence Can Lead to Wrongful Convictions*, JSTOR DAILY (Dec. 6, 2017), https://daily.jstor.org/forensic-dna-evidence-can-lead-wrongful-convictions [https://perma.cc/KMS4-MX5B]. *See generally* JOHN M. BUTLER ET AL., NAT'L INST. OF STANDARDS & TECH., DNA MIXTURE INTERPRETATION: A NIST SCIENTIFIC FOUNDATION REVIEW (2021) [hereinafter DNA MIXTURE INTERPRETATION], https://doi.org/10.6028/NIST.IR.8351-draft [https://perma.cc/T94Y-P32A] (providing a description of the limitations of DNA mixture interpretation).

49. MURPHY, INSIDE THE CELL, *supra* note 31, at 44, 56.

50. Worth, *supra* note 48.

51. *See generally* Roland A.H. van Oorschot, Bianca Szkuta, Georgina E. Meakin & Bas Kokshoorn, *DNA Transfer in Forensic Science: A Review*, 38 FORENSIC SCI. INT'L: GENETICS 140 (2019).

samples where humans cannot.[52] Genetic appearance estimation tools differ in important ways from forensic STR testing, the methodology that earned DNA its reputation as a truth-finding mechanism.

II. THE SCIENCE OF GENETIC APPEARANCE ESTIMATION

Scientific understanding of the relationships between genotype, phenotype, and disease has expanded considerably since the early 2000s, in part a product of collaborative scientific projects such as the Human Genome Project,[53] which generated the first sequence of the human genome.[54] Forensic biological research has benefited from and attempted to expand upon these advances.[55] While forensic DNA phenotyping is a relatively new field of research, it is enmeshed in a long and troubling history of attempts to scientifically predict criminal activity and categorize human difference.[56]

When traditional DNA identity testing produces no matches, forensic DNA phenotyping tools promise law enforcement an alternative route to identification: an estimate of what the unknown person looks like. Forensic DNA phenotyping takes advantage of the fact that human phenotypes are, to a degree, a visual representation of their genotypes, meaning that externally visible characteristics (also known as EVCs) like eye color are in part a product of expressed genes.[57] Forensic DNA phenotyping tools

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52. Algorithmic forensic tools are vulnerable to the same limitations as algorithms in other fields—most notably, miscodes and bias. Hindering opportunities to identify these vulnerabilities, developers of forensic algorithmic tools, particularly the developers of commercial tools, do not always disclose their code and are commonly critiqued for a lack of transparency. *See generally* REVA SCHWARTZ ET AL., NAT'L INST. OF STANDARDS & TECH., SPECIAL PUBLICATION 1270: TOWARDS A STANDARD FOR IDENTIFYING AND MANAGING BIAS IN ARTIFICIAL INTELLIGENCE (2022), https://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.1270.pdf [https://perma.cc/P39W-THWT]; Christian Chessman, *A "Source" of Error: Computer Code, Criminal Defendants, and the Constitution*, 105 CALIF. L. REV. 179, 186–95 (2017) (discussing structural sources of error); Rebecca Wexler, *Life, Liberty, and Trade Secrets: Intellectual Property in the Criminal Justice System*, 70 STAN. L. REV. 1343 (2018).

53. *See generally* Melina Claussnitzer et al., *A Brief History of Human Disease Genetics*, 577 NATURE 179 (2020).

54. *See The Human Genome Project*, NIH, https://www.genome.gov/human-genome-project [https://perma.cc/Q5DW-QKTK].

55. *See generally* TONY N. FRUDAKIS, MOLECULAR PHOTOFITTING: PREDICTING ANCESTRY AND PHENOTYPE USING DNA (2008); Runa Daniel & Simon J. Walsh, *The Continuing Evolution of Forensic DNA Profiling–From STRS to SNPs*, 38 AUSTL. J. FORENSIC SCIS. 59, 59 (2006).

56. *See* MURPHY, INSIDE THE CELL, *supra* note 31, at 215–17; Troy Duster, *A Post-Genomic Surprise. The Molecular Reinscription of Race in Science, Law and Medicine*, 66 BRIT. J. SOCIO. 1, 20–24 (2015); Koops & Schellekens, *supra* note 31, at 161; Robin Williams & Matthias Wienroth, *Social and Ethical Aspects of Forensic Genetics: A Critical Review*, 29 FORENSIC SCI. REV. 145, 161 (2017).

57. *See* Manfred Kayser, *Forensic DNA Phenotyping: Predicting Human Appearance from Crime Scene Material for Investigative Purposes*, 18 FORENSIC SCI. INT'L: GENETICS 33 (2015) [hereinafter Kayser, *Forensic DNA Phenotyping*].

attempt to estimate how an individual looks (their "phenotype") solely from their genetic information (called their "genotype").[58]

Genetic appearance tools cannot identify individuals. Law enforcement stress that they use forensic DNA phenotyping tools for investigative leads, meaning that they use phenotyping estimations to shape whom they investigate.[59]

Government priorities have driven biogeographic ancestry and forensic DNA phenotyping research.[60] In the United States, the Department of Defense and the National Institute of Justice are key funders of the academics and for-profit companies who conduct phenotype research.[61] In Europe, police and justice institutions are among thirteen partners in the prominent Visible Attributes through Genomics (VISAGE) consortium.[62] By contrast, medical studies have focused on understanding appearance in relation to disease-causing genes and inheritance.[63]

To better understand genetic appearance estimation, an overview of the science behind these technologies is useful. This Part overviews how such tools are developed and how they function. Section A describes how entities develop forensic DNA phenotyping and related tools; Section B explains what factors impact the accuracy of these tools; Section C overviews some of the current forensic DNA phenotyping and biogeographic ancestry tools

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58. For some stakeholders, forensic DNA phenotyping does "not merely denote an attempt to infer observable traits from DNA, but it signifie[s] the technical ability to do so at a certain level of validity and reliability." Gabrielle Samuel & Barbara Prainsack, *Forensic DNA Phenotyping in Europe: Views "on the Ground" from Those Who Have a Professional Stake in the Technology*, 38 NEW GENETICS & SOC'Y 119, 127 (2019) [hereinafter *Views "on the Ground"*].

59. *Id.*

60. *See, e.g.*, *About the VISAGE Consortium*, VISAGE CONSORTIUM, https://www.visage-h2020.eu [https://perma.cc/RXJ2-XPQK].

61. *See* MURPHY, INSIDE THE CELL, *supra* note 31, at 227; *see also, e.g.*, *Predictive Genes for Human Physical Appearance*, IUPUI, https://walshlab.sitehost.iu.edu/pages/study.html [https://perma.cc/4PP5-B5WY] ("The study is funded in part by the National Institute of Justice."); *Advanced DNA Phenotyping for Superior Tactical Intelligence*, SBIR STTR, https://www.sbir.gov/sbirsearch/detail/1485903 [https://perma.cc/7TT4-72HY]; *SNAPSHOT: A System for Predicting Human Physical Traits from Sample DNA*, SBIR STTR, https://www.sbir.gov/sbirsearch/detail/397947 [https://perma.cc/5D7Q-9QBB]; *SNAPSHOT: A System for Predicting Human Physical Traits from Sample DNA*, SBIR STTR, https://www.sbir.gov/sbirsearch/detail/379719 [https://perma.cc/NSJ7-6MSL]; *Parabon Awarded Government Contract to Develop Next-Generation Forensic DNA Analysis Platform*, PARABON (Nov. 16, 2016), https://www.parabon-nanolabs.com/news-events/2016/11/keystone-next-generation-dna-forensic-platform-award.html [https://perma.cc/LF45-B97X]; *Snapshot Genetic Genealogy (GG) Analysis*, SAM.GOV, https://sam.gov/opp/816511a2439180cfdc429005c05c9df0/view#general [https://perma.cc/4VUG-84BE].

62. The EU funds the VISAGE Consortium, comprised of eight EU member states, in order to advance forensic DNA phenotyping research. *About the VISAGE Consortium*, *supra* note 60; John M. Butler & Sheila Willis, *Interpol Review of Forensic Biology and Forensic DNA Typing 2016-2019*, 2 FORENSIC SCI. INT'L: SYNERGY 352, 358 (2020).

63. *E.g.*, Tess Levy et al., *Strong Evidence for Genotype–Phenotype Correlations in Phelan-McDermid Syndrome: Results from the Developmental Synaptopathies Consortium*, 31 HUM. MOLECULAR GENETICS 625 (2022); Claussnitzer et al., *supra* note 53.

available; Section D reviews the state of the field by characteristic; and Section E previews developing trends in the field.

Two contextual considerations are worth noting. First, this Part relies primarily on published research. Little information is available regarding commercial forensic DNA phenotyping tools that private, for-profit companies produce. Readers should hesitate to assume that unpublished techniques obtain the same degree of accuracy as published techniques, particularly when applied to forensic samples. Second, this Part does not address what utility forensic DNA phenotyping tools offer to law enforcement in practice. Regardless of how accurate a tool is during development, it can only provide probabilistic estimations, which law enforcement must decide how to interpret and apply. Statistical accuracy cannot capture a tool's efficacy or utility in practice, or its overall contribution to the public interest.[64]

A. Developing Tools

The first step in forensic DNA phenotyping research is the discovery of genes related to specific phenotypes. One common way that researchers learn which genes contribute to phenotypes is to conduct genome-wide association studies known as "GWAS" on large datasets.[65] In this approach, researchers analyze groups of genotypic markers and evaluate their connection to target characteristics, like eye color.[66] The quality of the datasets researchers rely upon is important: the output of any test is only as good as the input data from which it was developed—emblemized by the phrase "garbage in, garbage out."

The genetic datasets contain information-rich genetic data known as single-nucleotide polymorphisms (also called SNPs and pronounced like "snips").[67] As the name suggests, SNPs result from a solo-nucleotide variation. Unlike traditional identity testing, forensic DNA phenotyping examines single-nucleotide polymorphisms in both "coding" and "non-

64. OSCE Office for Democratic Institutions and Human Rights, *Opinion on Draft Amendments to the DNA Profiles Act of Switzerland*, Op. No. CRIM-CHE/418/2021 (Aug. 3, 2021) ("The output of phenotyping . . . can often have little probative value, given that, at the most, such analyses may lead to conclusions with a 90% probability; . . . investigators thus need to be mindful that a perpetrator may in fact look very different from the predicted appearance.").

65. Kayser, *Forensic DNA Phenotyping*, *supra* note 57, at 34.

66. More specifically, genome-wide association studies look for differences in the allele frequencies of genetic variants among those who share similar ancestries but do not share the target phenotypes. Emil Uffelmann et al., *Genome-Wide Association Studies*, 1 NATURE REVS. METHODS PRIMERS 1 (2021).

67. *See generally* Anthony J. Brookes, *The Essence of SNPs*, 234 GENE 177 (1999).

coding" regions of DNA.[68] Groups of SNPs are more information-rich than STRs.[69]

From genome-wide association studies, researchers create a model reference dataset (a panel of SNPs) or test system that consists of genotypes and associated phenotypes. Researchers use these test systems to create predictive models.[70] These models undergo statistical validation to assess their test accuracy along different parameters. Test accuracy values reveal how well the prediction model performs.[71] Before application to casework, the best practice is for models to undergo forensic validation to assess their test accuracy on casework samples, which are often of much poorer quality than research samples.

Genome-wide association studies can more easily identify SNPs that have larger effects on appearance traits, known as major gene effects.[72] To estimate traits for which there are no major gene effects, researchers must identify a much larger number of genes that each have a small phenotypic effect.

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68. *See* GABRIELLE SAMUEL & BARBARA PRAINSACK, VISAGE, THE REGULATORY LANDSCAPE OF FORENSIC DNA PHENOTYPING IN EUROPE 9–11 (2018) [hereinafter THE REGULATORY LANDSCAPE]. The forensic research field is moving toward the use of massive parallel sequencing, also known as next-generation sequencing, a more recent method of DNA analysis. Although its cost currently limits its uptake in forensic cases, massive parallel sequencing has the advantage of improved sensitivity on samples with less input DNA. Murphy, *Forensic DNA Typing*, *supra* note 9, at 500; Maria de la Puente et al., *Development and Evaluation of the Ancestry Informative Marker Panel of the VISAGE Basic Tool*, 12 GENES 1284, 1285 (2021) ("[T]he emergence of massively parallel sequencing (massive parallel sequencing) now provides major enhancements for forensic DNA analysis, including improved sensitivity to analyse minimal amounts of evidential material.").

69. Groups of SNPs can reveal more sensitive information than STRs. The use of SNPs is a primary reason that forensic DNA phenotyping raises concerns for privacy and legal advocates. Key legal decisions approving forensic DNA testing have relied on the assumption that forensic genetic testing is informative only of identity. *See infra* Part IV.

70. *See, e.g.*, Schneider et al., *supra* note 10, at 875–76; Kayser, *Forensic DNA Phenotyping*, *supra* note 57, at 35. Researchers are also investigating the spacial distribution, meaning the geographic prevalence, of traits across countries. Enhancing knowledge about prior distribution may improve prediction accuracy. On the other hand, some experts recommend against incorporating evidence about priors such as spacial distribution into prediction models. Maria-Alexandra Katsara & Michael Nothnagel, *True Colors: A Literature Review on the Spatial Distribution of Eye and Hair Pigmentation*, 39 FORENSIC SCI. INT'L: GENETICS 109 (2019).

71. *See* Schneider et al., *supra* note 10, at 876 ("Test accuracy *(Table 1)* should not be confused with the accuracy of individual test results *(eFigure)*.").

72. Fan Liu et al., *Update on the Predictability of Tall Stature from DNA Markers in Europeans*, 42 FORENSIC SCI. INT'L: GENETICS 8 (2019).

B. Assessing (In)accuracy

This Section discusses factors that impact the accuracy of phenotyping tools. During validation of a prediction model, researchers assess test accuracy across multiple parameters.[73]

Test accuracy differs from the individual test results that law enforcement receive. Individual test results reflect the probability that an unknown person has a certain phenotypic trait, like eye color. Understanding a test's accuracy is critical to determining the weight to afford its individual results. If a test estimates that an individual is most likely to have green eyes, but that test's accuracy is generally poor, law enforcement should hesitate to rely on that prediction. No matter how accurate a test is in general, it cannot estimate an individual's appearance with absolute certainty.

Best practice is for developers to share information about test accuracy with the scientific community and with law enforcement.[74] Despite the importance of test accuracy data, not all commercial test systems release or publish these data.[75] Without this information, law enforcement lack important data relevant to making an informed evaluation about the weight to place on a test's result.

Several factors impact test accuracy. These factors include the sufficiency of the input data during test development, the quality of the samples being tested, and the degree of genetic admixture (meaning the individual has ancestors from multiple locations, for instance, Europe and Asia) of the samples. This Section briefly discusses each factor that influences test accuracy. Note that forensic DNA phenotyping tests cannot account for, and test accuracy does not reflect, inaccuracies due to appearance changes that result from cosmetic procedures, hormones, diet, makeup, or other bodily choices.

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73. Most common are the area under the receiver operating characteristic (ROC) curves (AUC), positive predictive value (PPV), and negative predictive value (NPV). *See generally* Christopher M. Florkowski, *Sensitivity, Specificity, Receiver-Operating Characteristic (ROC) Curves and Likelihood Ratios: Communicating the Performance of Diagnostic Tests*, 29 CLINICAL BIOCHEMIST REV. S83 (2008); Amke Caliebe, Susan Walsh, Fan Liu, Manfred Kayser & Michael Krawczak, *Likelihood Ratio and Posterior Odds in Forensic Genetics: Two Sides of the Same Coin*, 28 FORENSIC SCI. INT'L: GENETICS 203 (2017); Ana-Maria Šimundić, *Measures of Diagnostic Accuracy: Basic Definitions*, 19 J. INT'L FED'N CLINICAL CHEMISTRY & LAB'Y MED. 203 (2009).

74. GABRIELLE SAMUEL & BARBARA PRAINSACK, VISAGE, REPORT ON RECOMMENDATIONS TO ADDRESS THE ETHICAL AND SOCIETAL CHALLENGES OF FDP 29 (2020) [hereinafter RECOMMENDATIONS TO ADDRESS FDP] (discussing recommendations for validation and transparency).

75. *See, e.g.*, Schneider et al., *supra* note 10, at 874–75 (summarizing available test accuracy data as of 2019).

1. Insufficient Data

The accuracy and generalizability of output data depends on the input data. Limitations in a genome-wide association study will result if the study includes too few people, too few people who display the phenotype of interest (e.g., red hair), or too little information about the phenotype (e.g., a database where individuals are coded as having blue, brown, or intermediate eye color, rather than containing quantitative data about individuals' eye color).

Frequently, non-Europeans and those not primarily of European ancestry are not well represented in forensic DNA phenotyping research.[76] People of color, who are vastly overrepresented in the U.S. criminal legal system, tend to be underrepresented in genomics research generally[77] and forensic DNA phenotyping studies in particular.[78] The under-inclusion of populations in genome-wide association studies can limit the performance of existing models and be a source of systemic bias.[79] For commercial phenotyping tools especially, it is often unclear how they perform on non-European populations.[80]

2. Low-Quality Samples

The scientific limitations that apply to traditional DNA testing on crime scene samples can also impact the test accuracy of genetic appearance estimation. Forensic DNA phenotyping tests require a minimum amount of DNA to proceed and each test comes with a trade-off between accuracy and practicability.[81] Certain forensic DNA phenotyping tests cannot reliably use mixed-source samples that contain DNA from more than two contributors.[82] While analyzing a greater number of SNPs can make a test more sensitive

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76. *See* Katsara & Nothnagel, *supra* note 70, at 109, 112 ("[W]e conducted a detailed literature review . . . . A strong limitation was the quite low amount of available data, especially outside Europe. . . . A number of human genetic studies have been published in recent years. Perhaps not surprising given the higher levels of variety in Europe compared to other continents, most of these publications used European samples or those of European descent.").

77. Lucia A. Hindorff et al., *Prioritizing Diversity in Human Genomics Research*, 19 NATURE REVS. GENETICS 175 (2018).

78. Mark Simcoe et al., *Genome-Wide Association Study in Almost 195,000 Individuals Identifies 50 Previously Unidentified Genetic Loci for Eye Color*, 7 SCI. ADVANCES eabd1239, eabd1244 (2021).

79. RECOMMENDATIONS TO ADDRESS FDP, *supra* note 74, at 29 (discussing recommendations for transparency).

80. TE AKA MATUA O TE TURE L. COMM'N, THE USE OF DNA IN CRIMINAL INVESTIGATIONS 326 (2020).

81. *See* Kayser, *Forensic DNA Phenotyping*, *supra* note 57, at 37.

82. Some scientists speculate that in the future researchers may use single-cell separation to deconvolute mixtures prior to single-cell sequencing for phenotyping. *See generally* Marta Diepenbroek, Birgit Bayer & Katja Anslinger, *Pushing the Boundaries: Forensic DNA Phenotyping Challenged by Single-Cell Sequencing*, 12 GENES 1362 (2021).

and therefore boost accuracy, more sensitive SNP tests require higher-quantity and higher-quality DNA samples, which are often unavailable in real-world forensic cases.[83]

In casework, low-quality samples and mixtures are commonplace. Environmental factors can degrade DNA. This is to say nothing of the consequences of human error.

Best practice is for forensic DNA phenotyping tools to undergo forensic validations, to assess how tools perform in circumstances that approximate those that occur during casework.[84] Forensic tools should not be used in live casework on samples that are meaningfully worse than those for which the tool was validated.

3. Genetic Admixture

Forensic DNA phenotyping tests tend to have lower accuracy for individuals with genetic admixture, a term geneticists use to describe when an individual's ancestors are from multiple locations in the world, such as Europe and Asia, rather than just one location. Genetic admixture refers to the exchange of genes from previously isolated populations.[85]

Individuals with genetic admixture present with intermediate phenotypes at a higher frequency (e.g., hazel rather than blue or brown eyes).[86] The estimation of intermediate phenotypes is often less accurate than the estimation of traits at opposing ends of a phenotypic spectrum. Accordingly, the estimation of externally visible characteristics is typically more challenging, and the prediction models are sometimes less accurate, for individuals with genetic admixture.[87]

The global distribution of phenotypes is a challenge to improving test accuracy. Genome-wide association studies are most appropriate for so-called genetically homogenous populations, which may not display the full range of phenotypes (such as for skin color or hair texture) that is important

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83. *See* Butler & Willis, *supra* note 62, at 354.

84. DNA MIXTURE INTERPRETATION, *supra* note 48, at 60–62 (discussing factor space).

85. *See* Garrett Hellenthal et al., *A Genetic Atlas of Human Admixture History*, 343 SCIENCE 747 (2014).

86. Thássia Mayra Telles Carratto et al., *Prediction of Eye and Hair Pigmentation Phenotypes Using the HIrisPlex System in a Brazilian Admixed Population Sample*, 135 INT'L J. LEGAL MED. 1329, 1329 (2021).

87. *Id.*; Olalla Maroñas et al., *Development of a Forensic Skin Colour Predictive Test*, 13 FORENSIC SCI. INT'L: GENETICS 34, 42–43 (2014); Naomi A. Weisz, Katherine A. Roberts & W. Reef Hardy, *Reliability of Phenotype Estimation and Extended Classification of Ancestry Using Decedent Samples*, 135 INT'L J. LEGAL MED. 2221, 2222, 2230 (2021); Prashita Dabas, Sonal Jain, Himanshu Khajuria & Biswa Prakash Nayak, *Forensic DNA Phenotyping: Inferring Phenotypic Traits from Crime Scene DNA*, 88 J. FORENSIC & LEGAL MED. 102351, 102359 (2022); Kayser, *Forensic DNA Phenotyping*, *supra* note 57, at 36.

for genome-wide association studies.[88] Rather, for some phenotypes, most variation is observed between continental groups.

Emphasis on the study of genetically isolated populations can lead to restrictive sampling strategies. These strategies can contribute to under-sampling of populations that tend to have genetic admixture.[89] Even among sampled individuals, researchers may exclude data samples that display too great a degree of genetic admixture in the eyes of the study authors. These practices can lead to biased and unrepresentative results.[90]

Some scholars have leveled pointed critiques at the assumptions underlying genetic admixture research. In practice, every person displays some degree of genetic admixture.[91] Admixture studies can depend on socially constructed notions of race,[92] and a notion of population groups with little evidence of reproductive isolation.[93] When these groups also coincide with social definitions of race, this can reinforce the false notion that race is genetically created.[94]

C. Current Tools

Law enforcement have a variety of commercial and non-commercial appearance estimation tools available to them.[95] Popular in Europe are IrisPlex (for eye pigmentation);[96] HIrisPlex (for hair and eye pigmentation); HIrisPlex-S (for hair, eye, and skin pigmentation); and the VISAGE basic and enhanced tools (for eye, hair, and skin pigmentation; continental

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88. Kayser, *Forensic DNA Phenotyping*, *supra* note 57, at 41.

89. Katharine L. Korunes & Amy Goldberg, *Human Genetic Admixture*, 17 PLOS GENETICS e1009374 (2021).

90. *See* Veronika Lipphardt, Gudrun A. Rappold & Mihai Surdu, *Representing Vulnerable Populations in Genetic Studies: The Case of the Roma*, 34 SCI. CONTEXT 69, 80–83 (2021).

91. *See* Shyamalika Gopalan et al., *Human Genetic Admixture Through the Lens of Population Genomics*, 377 PHIL. TRANSACTIONS ROYAL SOC'Y 20200410, at *3 (2022) ("Many population genetics methods and analytical results are based on assumptions about populations that do not hold under recent admixture.").

92. Duster, *supra* note 56.

93. *See* Deborah A. Bolnick et al., *The Science and Business of Genetic Ancestry Testing*, 318 SCIENCE 399, 400 (2007).

94. Troy Duster, *Race and Reification in Science*, 307 SCIENCE 1050, 1050–51 (2005).

95. For a scientific review of existing forensic DNA phenotyping test systems and their accuracy in lab settings, see generally Schneider et al., *supra* note 10; Manfred Kayser, Wojciech Branicki, Walther Parson & Christopher Phillips, *Recent Advances in Forensic DNA Phenotyping of Appearance, Ancestry and Age*, 65 FORENSIC SCI. INT'L: GENETICS 102870, at *1, *10–11 (2023); Daniele Podini & Katherine B. Gettings, *Forensic Analysis of Externally Visible Characteristics: Phenotyping*, *in* FORENSIC DNA ANALYSIS: TECHNOLOGICAL DEVELOPMENT AND INNOVATIVE APPLICATIONS 201 (Elena Pilli & Andrea Berti eds., 2021); and Weisz et al., *supra* note 87.

96. Leonardo Arduino Marano & Cintia Fridman, *DNA Phenotyping: Current Application in Forensic Science*, 9 RSCH. & REPS. FORENSIC MED. SCI. 1, 3 (2019).

biogeographic ancestry; and age).[97] Other non-commercial programs are also available.[98]

There are several commercial forensic DNA phenotyping and biogeographic ancestry prediction systems available, which U.S. companies have developed.[99] Most prominent in the United States is Snapshot® by Parabon NanoLabs ("Parabon"), the private company that the Edmonton Police Service and the NYPD each hired. Parabon purports to create a rendering of individuals from their DNA, including their facial morphology.[100] In 2021, the company Corsight AI announced plans to introduce a technology called DNA to FACE that will construct a physical profile from DNA.[101]

Because test systems can rely upon distinct SNP markers, reference data, and prediction models, different test systems can produce different prediction values. Disclosure of how test systems work and the data upon which they rely is important to the robust evaluation and appropriate interpretation of results.[102]

Evaluation of the accuracy, utility, or ethics of any tool requires attention to the traits that the tool purports to estimate. Section D provides a more detailed examination of the state of the field for each characteristic and its application to casework.

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97. Leire Palencia-Madrid et al., *Evaluation of the VISAGE Basic Tool for Appearance and Ancestry Prediction Using PowerSeq Chemistry on the MiSeq FGx System*, 11 GENES 708 (2020).

98. *See, e.g.*, *Classification of Individuals Using AIMs*, UNIVERSIDADE SANTIAGO COMPOSTELA, http://mathgene.usc.es/snipper [https://perma.cc/F94H-TGKR]; Structure *Software*, PRITCHARD LAB STANFORD UNIV., https://web.stanford.edu/group/pritchardlab/structure.html [https://perma.cc/775N-P8HM]; Torben Tvedebrink, Poul Svante Eriksen, Helle Smidt Mogensen & Niels Morling, *GenoGeographer – A Tool for Genogeographic Inference*, 6 FORENSIC SCI. INT'L: GENETICS SUPPLEMENT SERIES e463 (2017).

99. *See, e.g.*, *ForenSeq DNA Signature Prep Kit*, VEROGEN, https://verogen.com/products/forenseq-dna-signature-prep-kit [https://perma.cc/K45S-FTX5]; *Increasing Investigatory Efficiency, Saving Time and Money*, IDENTITAS, https://www.identitascorp.com [https://perma.cc/U5Z7-7848]; *Precision ID Ancestry Panel*, THERMOFISHER SCI., https://www.thermofisher.com/order/catalog/product/A25642 [https://perma.cc/4SY7-LJE4]. Some for-profit companies integrate non-commercial forensic DNA phenotyping technologies into their products. *E.g.*, *ForenSeq Imagen Kit*, VEROGEN, https://verogen.com/products/forenseq-imagen-kit [https://perma.cc/A6J8-LAUQ] ("Additionally, seamless report integration with 3rd party software such as HIrisPlex-S allows users to access enhanced lead generation insights.").

100. *Parabon Snapshot Advanced DNA Analysis*, PARABON NANOLABS, https://snapshot.parabon-nanolabs.com [https://perma.cc/WM7F-LK4C].

101. Tate Ryan-Mosley, *This Company Says It's Developing a System that Can Recognize Your Face from Just Your DNA*, MIT TECH. REV. (Jan. 31, 2022), https://www.technologyreview.com/2022/01/31/1044576/corsight-face-recognition-from-dna [https://perma.cc/8J66-8VVH].

102. Certain forensic for-profit companies have elected not to publish evidence of how their tools function and have fought defense efforts to obtain such evidence at trial, citing intellectual property protections. *See generally* Wexler, *supra* note 52.

D. Estimating Phenotypic Traits for Casework

Before turning to the scientific and ethical concerns that attend the application of forensic DNA phenotyping tools to casework, a closer examination of the traits that phenotyping tools target is merited. As this Section illustrates, distinct limitations pertain to the study and estimation of each phenotypic trait.

1. Biogeographic Ancestry

Law enforcement reliance on biogeographic ancestry to identify suspects traces back to 2006. Biogeographic ancestry (abbreviated as BGA in the literature) refers to the broad geographic region or regions from which an individual's ancestors originated.[103] Biogeographic ancestry tools purport to reveal whether a person's ancestors are likely to have originated from Europe, sub-Saharan Africa, East Asia, South Asia, Oceania, or the Americas. Non-commercial ancestry tests report test accuracies above 99% for those without genetic admixture, while commercial tests do not always report their test accuracies.[104]

Biogeographic ancestry results are inherently probabilistic and subject to important limitations. Biogeographic ancestry tests tend to be poorer at inferring the geographic ancestries of individuals whose ancestors were from multiple geographic origins. More specific inferences about subcontinental regions of origin tend to have lower accuracy because human migration lessens the informativeness of DNA markers for distinguishing more proximate regions.[105]

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103. Troy Duster encourages critical evaluation of the assumptions that underlie this research:

> [T]he . . . technology [of] Ancestry-Informative Markers (AIMS) examines a group's relative share of genetic markers found on the autosomes—the non-gender chromosomes inherited from both parents. As noted, AIMS are overwhelmingly shared across all human populations, it is therefore not their absolute presence or absence, but their rate of incidence, or frequency, that is usually being analysed. . . . This procedure generates the baseline for the statistically-based notion of a 100 per cent pure European (or African, etc.), so that when you send in your DNA from the saliva swab, and it turns out that you have one-third of the markers that have been designated as 'European'—you are told that you are 33 per cent European. . . . There are a number of deeply problematic, even flawed assumptions behind that percentage claim. What is this 'reference population' that has become the measuring stick by which we inform people of their 'per cent ancestry to a putatively pure continental population' (read 'race' here)?

Duster, *supra* note 56, at 9–10.

104. Schneider et al., *supra* note 10, at 876.

105. *Id.* at 878; *see* M. Eduardoff et al., *Inter-Laboratory Evaluation of the EUROFORGEN Global Ancestry-Informative SNP Panel by Massively Parallel Sequencing Using the Ion PGM™*, 23 FORENSIC SCI. INT'L: GENETICS 178, 188 (2016). But researchers report that their accuracy at reporting subcontinental regions has meaningfully improved in recent years. Manfred Kayser et al., *supra* note 95, at *10–11.

Genetic ancestry research relies on the premise that individuals from distant geographic origins display greater genetic differences than those whose ancestors were from closer geographic origins. These differences, revealed through ancestry-informative markers (also called AIMs), are theoretically a product of factors such as mutations, local selection, and human migration.[106]

Biogeographic ancestry inferences depend on the assumptions that populations have been geographically isolated and that certain markers are diagnostic of population ancestry. In fact, genetic diversity can occur within populations and particular genetic markers may be present in multiple populations.[107] Biogeographic ancestry developers rely on databases that may not represent the full array of genetic diversity of a population group. As explored *supra*, restrictive sampling strategies and data filtering to remove samples that display significant genetic admixture can lead to biased and unrepresentative results.[108]

Researchers emphasize that biogeographic ancestry is distinct from the socially constructed concepts of race and ethnicity,[109] which correlate only partially with geography.[110] However, as this Article will return to, recipients of biogeographic ancestry estimations may not interpret these concepts as distinct.

In addition to interrogating the accuracy of biogeographic ancestry tools in a laboratory, one should consider their impacts and effectiveness in practice. In 2006, police in the United Kingdom hired a now bankrupt company to predict the biogeographic ancestry of a person of interest in multiple serious crimes, who became known in the press as the "Night Stalker."[111] The company reported to law enforcement that the biogeographic ancestry of their person of interest was a male, whose biogeographic ancestry was 82% sub-Saharan African, 12% Native American, and 6% European.[112]

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106. *See* Chris Phillips, *Forensic Genetic Analysis of Bio-Geographical Ancestry*, 18 FORENSIC SCI. INT'L: GENETICS 49, 61–62 (2015).

107. Bolnick et al., *supra* note 93, at 400.

108. *See* Lipphardt et al., *supra* note 90, at 80–83.

109. *See, e.g.*, Schneider et al., *supra* note 10, at 877.

110. Bolnick et al., *supra* note 93 ("Consumers often purchase these tests to learn about their race or ethnicity, but there is no clear-cut connection between an individual's DNA and his or her racial or ethnic affiliation. Worldwide patterns of human genetic diversity are weakly correlated with racial and ethnic categories because both are partially correlated with geography. Current understandings of race and ethnicity reflect more than genetic relatedness, though, having been defined in particular sociohistorical contexts (i.e., European and American colonialism). In addition, social relationships and life experiences have been as important as biological ancestry in shaping individual identity and group membership." (footnote omitted)).

111. Amade M'charek & Peter Wade, *Doing the Individual and the Collective in Forensic Genetics: Governance, Race and Restitution*, 15 BIOSOCIETIES 317, 319–20 (2020).

112. *Id.* at 320.

To optimize the DNA kit, which had been developed using DNA samples from the United States, U.K. law enforcement requested DNA from hundreds of police officers who had a Caribbean background.[113] Law enforcement subsequently reported to the press that additional advanced DNA analysis had revealed that the suspect was a Black Caribbean man, probably from the Windward Islands, a part of the West Indies.[114] Law enforcement then collected DNA from thousands of Black men residing in the London area who had a Caribbean background.[115] Men who elected not to comply reported receiving threatening letters from law enforcement.[116] Eight officers even traveled to Caribbean islands to investigate.[117] The individual eventually arrested was not identified from the genetic hunt but through CCTV footage.[118] As a legacy of the ineffective use of biogeographic ancestry in the Night Stalker case, the U.K. rarely employs forensic DNA phenotyping and biogeographic ancestry predictive tools to this day.

2. *Facial Morphology*

Facial morphology is a complex polygenic trait of great interest in the forensics field.[119] Despite being applied to casework, robust estimation of facial morphology is not scientifically supported in publicly available research.[120] Academic researchers investigating facial morphology are engaged in early stage research.[121]

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113. *Id.* ("Given the specific colonial history of the UK and the effect thereof on post-colonial migration patterns, the profile based on the probabilistic results was squarely translated by the investigating police into the suspect was a [B]lack Caribbean man.").

114. *Id.*

115. Chris Greenwood, *2,000 DNA Tests in Hunt for 'Night Stalker*,*'* INDEPENDENT (Nov. 6, 2009, 12:12 PM), https://www.independent.co.uk/news/uk/crime/2000-dna-tests-in-huntfor-night-stalker-1816140.html [https://perma.cc/SD9V-ZZ9Z].

116. *Id.*

117. *Id.*

118. M'charek & Wade, *supra* note 111, at 320. As it happens, the suspect was from London and had a Jamaican background. *Id.*

119. *See, e.g.*, Julie D. White et al., *Insights into the Genetic Architecture of the Human Face*, 53 NATURE GENETICS 45 (2021); Peter Claes et al., *Genome-Wide Mapping of Global-to-Local Genetic Effects on Human Facial Shape*, 50 NATURE GENETICS 414 (2018); Stephen Richmond, Laurence J. Howe, Sarah Lewis, Evie Stergiakouli & Alexei Zhurov, *Facial Genetics: A Brief Overview*, 9 FRONTIERS GENETICS 462 (2018); Peter Claes, Harold Hill & Mark D. Shriver, *Toward DNA-Based Facial Composites: Preliminary Results and Validation*, 13 FORENSIC SCI. INT'L: GENETICS 208 (2014); Jens Fagertun et al., *Predicting Facial Characteristics from Complex Polygenic Variations*, 19 FORENSIC SCI. INT'L: GENETICS 263 (2015).

120. *See* Carrie Arnold, *The Controversial Company Using DNA to Sketch the Faces of Criminals*, NATURE (Sept. 23, 2020), https://www.nature.com/articles/d41586-020-02545-5 [https://perma.cc/VTN6-JTKU]; Southall, *supra* note 7.

121. *E.g.*, Ziyi Xiong et al., *Novel Genetic Loci Affecting Facial Shape Variation in Humans*, 8 ELIFE e49898 (2019); Christoph Lippert et al., *Identification of Individuals by Trait Prediction Using Whole-Genome Sequencing Data*, 114 PROC. NAT'L ACAD. SCIS. 10166 (2017).

Because facial morphology involves a great many genes interacting together (genome-wide association studies have identified nearly 500 genomic variants associated with face shape),[122] a substantial hurdle for the prediction of faces is the need to collect both DNA and detailed phenotypic data from a great number of individuals.[123] To date, genome-wide association studies have primarily been conducted on European populations, while other populations are underrepresented in many studies.[124] In sum, facial morphology estimation is a sought-after but currently low-accuracy technology.

The sole company to provide a facial morphology estimation tool to law enforcement, to harsh reception from the scientific community,[125] is the for-profit company Parabon. Parabon sells its DNA analysis service Snapshot®, a suite of tools that includes the production of virtual portraits from unknown DNA. A forensic artist incorporates predictions of eye, hair, and skin color; freckling; biogeographic ancestry; and facial morphology into a composite profile akin to a virtual mugshot. Parabon can also incorporate forensic art enhancements (hairstyle adjustments and accessorization) based on information from cognitive interviews with witnesses.[126] Some of these adjustments—the addition of a hood, a gapped front tooth, a new hairstyle—are visible on their website.[127]

Little is known about how Parabon's Snapshot tool works due to Parabon's decision not to publish their methodologies, statistical models, validations, DNA markers, code, and reference data. Their work has not been subject to peer review. No other company or research group provides law enforcement with the purported facial morphology of persons of interest in casework.

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122. Dabas et al., *supra* note 87, at *9.

123. "There are also other physical characteristics that [are] commonly used to describe a person: craniofacial features, height, male balding, and hair structure. These traits though are not yet accurately predictable either due to a lack of knowledge of their specific genetic cause or due to the fact that they are highly complex traits. In particular, traits such as height and craniofacial features are a consequence of a large number of genes interacting together where each one contributes a very small proportion of the phenotypic variance." Podini & Gettings, *supra* note 95, at 203.

124. *See* Dabas et al., *supra* note 87, at *9.

125. *See* Arnold, *supra* note 120; Matthias Wienroth, *Socio-Technical Disagreements as Ethical Fora: Parabon NanoLab's Forensic DNA Snapshot™ Service at the Intersection of Discourses Around Robust Science, Technology Validation, and Commerce*, 15 BIOSOCIETIES 28, 29 (2020); *cf.* Gabrielle Samuel & Barbara Prainsack, *Civil Society Stakeholder Views on Forensic DNA Phenotyping: Balancing Risks and Benefits*, 43 FORENSIC SCI. INT'L: GENETICS 102157, at *2 (2019) [hereinafter *Civil Society Stakeholder Views*].

126. PARABON NANOLABS, SNAPSHOT REPORT GUIDE vii–viii, https://pub.parabon.com/Parabon_Snapshot_Report_Guide.pdf [https://perma.cc/5Y43-FHKK].

127. *The Snapshot DNA Phenotyping Service*, PARABON NANOLABS, https://snapshot.parabon-nanolabs.com/phenotyping [https://perma.cc/XDE8-9THR]; *Published Police Investigations*, PARABON NANOLABS, https://snapshot.parabon-nanolabs.com/posters [https://perma.cc/JBR2-MBZF].

Nevertheless, Snapshot is in wide usage. At least ninety-seven jurisdictions in the United States have used Parabon's Snapshot technology to date,[128] and additional jurisdictions have used Parabon internationally.[129] Parabon stated that law enforcement used its products for forensic DNA phenotyping, investigative genetic genealogy, and kinship testing to identify over 260 persons of interest between May 2018 and January 2022.[130]

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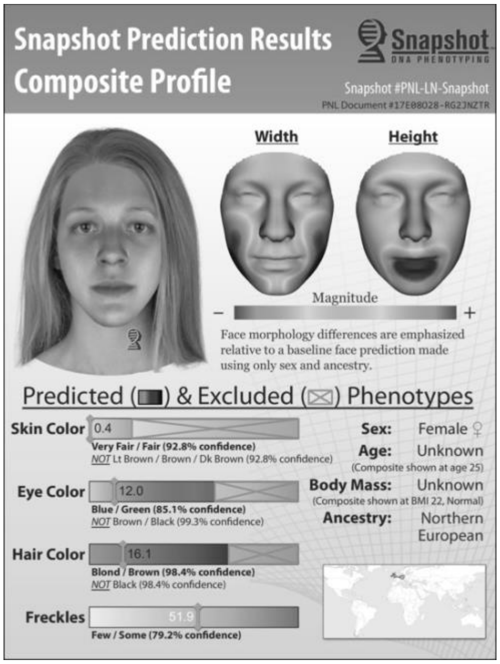
128. *Published Police Investigations*, *supra* note 127; *Snapshot Testimonials*, PARABON NANOLABS, https://snapshot.parabon-nanolabs.com/testimonials [https://perma.cc/RA6G-VK8U]; William Thornton, *DNA Shows Us What a Headless 1997 Alabama Murder Victim Looked Like in Life*, AL.COM (May 19, 2021, 10:27 AM), https://www.al.com/news/2021/05/dna-shows-us-what-a-headless-1997-alabama-murder-victim-looked-like-in-life.html [https://perma.cc/2FHL-3CS3]; Helena Wegner, *Woman Vanished from Oregon Home in 1959, Cops Say. Her Remains Were Just Identified*, KAN. CITY STAR (Feb. 17, 2023, 5:50 PM), https://www.kansascity.com/news/nation-world/national/article272539115.html#storylink=cpy [https://perma.cc/2SMN-36EJ]; Tom Olsen, *Chisholm Cold-Case Suspect Alleges Constitutional Violations in DNA Database Search*, DELUTH NEWS TRIB. (June 30, 2021, 9:02 AM), https://www.duluthnewstribune.com/news/chisholm-cold-case-suspect-alleges-constitutional-violations-in-dna-database-search [https://perma.cc/V2T2-R42S]; Michael Vogen, *Missouri State Highway Patrol Has Partnered with Othram and Southeast Anthropology to Identify Vernon County John Doe*, DNASOLVES.COM (Mar. 11, 2021), https://dnasolves.com/articles/vernon-county-john-doe [https://perma.cc/24UW-CBKG]; Chris Welch, *DNA-Based Imaging Technology Creates Images of Victims, Suspects in Decades-Old Cases*, KMTV 3 NEWS NOW (Apr. 30, 2018, 3:49 PM), https://www.3newsnow.com/news/national/dna-based-imaging-now-leading-to-answers-in-decades-old-cases [https://perma.cc/GH99-ULLL]; Fleming Smith, *SC Police Using DNA to Sketch Cold-Case Suspects, but Some Say It's Not Accurate Enough*, POST & COURIER (Sept. 14, 2020), https://www.postandcourier.com/news/sc-police-using-dna-to-sketch-cold-case-suspects-but-some-say-its-not-accurate/article_141a74c2-e9cf-11e9-b977-3b5c5dd94bff.html [https://perma.cc/UC5J-VL93]; Defendant's Brief in Support of Motion to Suppress at 19, State v. Bentaas, No. 49CRI19-001657 (S.D. 2020), https://www.eff.org/files/2020/06/10/2020-02-14_brief_in_support_of_motion_to_suppress.pdf [https://perma.cc/78YP-JQRS]; Eric Levenson, *Scientists Sketched Out a Suspect's Face Using DNA from a 42-Year-Old Cold Case*, CNN (July 24, 2018, 2:59 PM), https://www.cnn.com/2018/07/24/us/cold-case-marinette-camping-trnd [https://perma.cc/PZT7-4YVA]; Amanda Milkovits, *How DNA, a Tattoo Led to Charges in Cold Murder Case*, PROVIDENCE J. (July 27, 2018, 6:44 PM), https://www.providencejournal.com/story/news/courts/2018/07/27/how-dna-and-tattoo-led-to-charges-in-cold-ri-murder-case/11202328007 [https://perma.cc/HYP9-MVZH]; Ashleigh Fox, *Wyoming DCI Continues Work on 26-Year-Old Murder Case*, CASPER STAR TRIBUNE (May 6, 2020), https://trib.com/news/state-regional/wyoming-dci-continues-work-on-26-year-old-murder-case/article_881c3e12-e08c-5115-9acae8eb5544e3e0.html [https://perma.cc/DKK9-YSSP]; Brief of Amicus Curiae ACLU, ACLU of Iowa, and Electric Frontier Foundation in Support of Defendant-Appellant, State v. Burns, No. 20-1150 (Iowa 2021), https://www.eff.org/files/2021/04/09/20-1150_famc_362171_amicus_brief.pdf [https://perma.cc/D8XM-8MKG]; Southall, *supra* note 7.

129. *Published Police Investigations*, *supra* note 127 (describing Snapshot's application in cases in Australia, Canada, and Sweden).

130. *Parabon® Tops 200 Solved Cases*, PARABON, https://parabon-nanolabs.com/news-events/2022/01/parabon-tops-200-solved-cases.html [https://perma.cc/SGC8-THZ5]. Investigative genetic genealogy, also known as forensic genetic genealogy, involves using commercial direct-to-consumer databases, such as FamilyTreeDNA and GEDMatch, to identify genetic relatives of persons of interest. When genealogy investigations lead to dead ends in the family tree or even multiple potential suspects, investigators may use forensic DNA phenotyping to narrow down the familial suspects or decide branch of a family tree to pursue; it may also provide an internal check on the outcome of genealogy investigations. *See Parabon Snapshot Advanced DNA Analysis*, *supra* note 100 ("Starting with extracted DNA or biological evidence from your case, we will predict the unknown person's

FIGURE 1. EXAMPLE RESULTS OF PARABON'S SNAPSHOT.[131]



3. Skin Pigmentation

The first assay and model to include skin pigmentation prediction emerged in 2013.[132] In 2018, HIrisPlex-S became the first skin prediction tool to be forensically validated.[133] Genetic forensic tests for skin color

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ancestry and pigmentation, then perform a genetic genealogy screening to determine if such analysis would be helpful. If more information is needed, we can optionally produce a detailed phenotyping report and composite sketch and/or perform kinship analysis to advance the investigation.").

Law enforcement use of investigative genetic genealogy has escalated rapidly in the United States since 2018, when the FBI announced that they used the technique to solve the case of the so-called Golden State Killer. Parabon employs CeCe Moore, probably the most well-known genealogist in the country, to conduct investigative genetic genealogy for law enforcement.

It is hard to determine whether law enforcement's growing use of investigative genetic genealogy has led to a corresponding increase in the use of forensic DNA phenotyping, since Parabon appears to employ these techniques in combination, or a decrease, because genetic genealogy has served as a market replacement. *See* Natalie Ram, Christi J. Guerrini & Amy L. McGuire, *Genealogy Databases and the Future of Criminal Investigation*, 360 SCIENCE 1078 (2018).

131. *Parabon Snapshot Advanced DNA Analysis*, *supra* note 100.

132. This system targeted ten DNA markers based on a small model dataset.

133. This system uses two assays that target forty-one SNPs (twenty-four predictive of eye and hair color; thirty-six predictive of skin color). Lakshmi Chaitanya et al., *The HIrisPlex-S System for Eye,*

prediction are less accurate than those for eye and hair pigmentation. As previewed in Section II.B, predictions for those with intermediate pigmentations tend to have lower test accuracies.

For models of skin pigmentation, it is important to know who is included and excluded from the reference and test data sets. Some studies of skin pigmentation do not incorporate data from multiple populations or limit the inclusion of individuals with a certain degree of genetic admixture. These study design choices are important to consider when applying a pigmentation prediction tool in forensic contexts, particularly when the crime scene sample being analyzed would not have met the criteria for inclusion in the studies underlying the tool's development.

As with most models, accuracies are inherently a product of the scale one uses (i.e., where one divides a phenotypic continuum). Current predictive models tend to use categorical models of just three to five categories of skin tone (e.g., very pale, pale, intermediate, dark, dark-to-black). These categories may not capture the pigmentation with the degree of detail that may be meaningful within a community, particularly communities in which many share similar eye, hair, and skin colors.

Moreover, environment influences skin color in ways that predictive models may not fully capture. For instance, how tan one's skin becomes is a product of both genes (that contribute to one's ease of skin tanning) and environment (specifically, exposure to ultraviolet radiation, which stimulates production of melanin).[134] As with skin pigmentation, its full genetic basis is not understood.[135] It can also be a product of individual choices (e.g., whether and how often one wears sunscreen). Depending on where one lives, these effects may not be understood in a lay sense as tanning at all.

These considerations are typically absent from the information law enforcement receives from Parabon. A concern with Parabon's Snapshot tool from critics' perspective, a consideration to which this Article will return, is that law enforcement may rely upon an estimation of a person of interest that contains no particularized or individualized information, yet

Hair and Skin Colour Prediction from DNA: Introduction and Forensic Developmental Validation, 35 FORENSIC SCI. INT'L: GENETICS 123, 123 (2018) ("The HIrisPlex-S DNA test represents the first forensically validated tool for skin colour prediction, and reflects the first forensically validated tool for simultaneous eye, hair and skin colour prediction from DNA."); Susan Walsh et al., *Global Skin Colour Prediction from DNA*, 136 HUM. GENETICS 847, 847, 860 (2017). In 2019, the AUCs of skin pigmentation tests varied from 0.72 to 0.96 depending on the test system and the categories of pigmentation the model employed (i.e., three or five categories). Schneider et al., *supra* note 10, at 873.

134. *See generally* Alessia Visconti et al., *Genome-Wide Association Study in 176,678 Europeans Reveals Genetic Loci for Tanning Response to Sun Exposure*, 9 NATURE COMMC'NS 1684 (2018).

135. Researchers have hypothesized that skin color is an evolutionary response to ultraviolet radiation, with darker skin colors developing in regions with stronger ultraviolet intensity. Dabas et al., *supra* note 87, at *8; Chaitanya et al., *supra* note 133.

bears the imprimatur of science, to form the basis for enhancing surveillance of community members en masse.[136]

4. Hair Pigmentation and Texture

The estimation of hair color is regularly applied to casework. Like eye color, hair color is a complex phenotype involving many genes. Despite the identification of hundreds of genes associated with hair color, known variants explain just over 20% of hair color variation.[137]

The first DNA test to predict hair color emerged in the early 2000s and was limited to red hair.[138] In 2013, HIrisPlex was introduced as the first forensic tool for prediction of all categorical hair colors and eye color; its forensic validation was published in 2014.[139]

Currently hair color prediction tends to be most accurate for red hair,[140] followed by black hair, with the lowest predictive accuracies for brown and blond.[141] One reason why models struggle to predict brown and blond hair colors may be their failure to differentiate individuals who have brown hair in childhood from individuals whose hair turns from blond to brown with age.[142]

Hair pigmentation prediction faces notable limitations. First, studies tend to incorporate categorical data about hair color (e.g., "brown") rather than quantitative data.[143] Second, pigmentation is changeable—whether due to the sun, cosmetic procedures, or time (like hair that turns from blond to brown to gray). Current phenotyping models tend not to incorporate information about age-dependent hair color phenomena. Third, some studies limit the inclusion of individuals with admixture,[144] and accuracy tends to be poorer in studies of individuals with genetic admixture.[145]

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136. *See, e.g.*, Jay Stanley, *Forensic DNA Phenotyping*, ACLU (Nov. 29, 2016), https://www.aclu.org/news/privacy-technology/forensic-dna-phenotyping [https://perma.cc/7XMX-P3RK].

137. Pirro G. Hysi et al., *Genome-Wide Association Meta-Analysis of Individuals of European Ancestry Identifies New Loci Explaining a Substantial Fraction of Hair Color Variation and Heritability*, 50 NATURE GENETICS 652 (2018).

138. Susan Walsh et al., *The HIrisPlex System for Simultaneous Prediction of Hair and Eye Colour from DNA*, 7 FORENSIC SCI. INT'L: GENETICS 98, 99 (2013).

139. *See generally* Susan Walsh et al., *Developmental Validation of the HIrisPlex System: DNA-Based Eye and Hair Colour Prediction for Forensic and Anthropological Usage*, 9 FORENSIC SCI. INT'L: GENETICS 150, 151 (2014). The tool uses a single multiplex genotyping assay for twenty-four SNPs. *Id.* at 151.

140. Because it is tied to the mutation of a specific known gene, color prediction is most accurate for those with red hair. Kayser, *Forensic DNA Phenotyping*, *supra* note 57, at 39.

141. In a 2018 study of the HIrisPlex model for hair and eye inference, AUCs ranged from .64 to .91, with differences observed based on hair color and population cohort. Hysi et al., *supra* note 137, at 654.

142. *See* Schneider et al., *supra* note 10, at 876.

143. *See* Kayser, *Forensic DNA Phenotyping*, *supra* note 57, at 39, 41.

144. *E.g.*, Hysi et al., *supra* note 137.

145. *See* Carratto et al., *supra* note 86, at 1337.

Two characteristics related to hair pigmentation are eyebrow color and hair texture.[146] Eyebrow pigmentation features correlate with hair color, but imperfectly.[147] Hair texture, also known as hair form, shape, type, or morphology, is the product of the shape of one's embedded hair follicles.[148] Models of hair texture to date have had moderate predictive accuracy.[149] However, studies assessing hair texture have analyzed datasets consisting primarily of white European populations and individuals without significant genetic admixture. These studies frequently employ discrete categories (e.g., straight or wavy) rather than continuous, quantitative methods. Terminology and methodology to characterize the phenotype are underdeveloped in the field and do not tend to capture the full range of diversity in hair texture.[150]

In sum, knowledge of the genetic underpinnings of hair texture is limited. Like other traits, forensic DNA phenotyping tests do not account for how cosmetic procedures and age can alter hair texture.

5. Eye Pigmentation

Prediction of eye color tends to be the most accurate form of phenotype prediction. Once, scientists thought human eye color was a genetically simple trait.[151] Readers may be familiar with Punnett squares, which children in science classes once drew to represent a simple model of Mendelian inheritance.[152] In this model, children could only have blue eyes, a recessive trait, if they inherited a blue eye gene from each parent; a child

146. VISAGE incorporates each into its prediction tool. *See* Kayser et al., *supra* note 95, at *4.

147. *Id.* at *5; Fuduan Peng et al., *Genome-Wide Association Studies Identify Multiple Genetic Loci Influencing Eyebrow Color Variation in Europeans*, 139 J. INVESTIGATIVE DERMATOLOGY 1601, 1601 (2019).

148. For a review, see Dabas et al., *supra* note 87, at *9. *See also* Suraj Kataria, Prashita Dabas, K.N. Saraswathy, M.P. Sachdeva & Sonal Jain, *Investigating the Morphology and Genetics of Scalp and Facial Hair Characteristics for Phenotype Prediction*, 63 SCI. & JUST. 135, 141–42 (2023).

149. *See* Fan Liu et al., *Meta-Analysis of Genome-Wide Association Studies Identifies 8 Novel Loci Involved in Shape Variation of Human Head Hair*, 27 HUM. MOLECULAR GENETICS 559, 560 (2018). *See generally* Ewelina Pośpiech et al., *Evaluation of the Predictive Capacity of DNA Variants Associated with Straight Hair in Europeans*, 19 FORENSIC SCI. INT'L: GENETICS 280 (2015); Ewelina Pośpiech et al., *Towards Broadening Forensic DNA Phenotyping Beyond Pigmentation: Improving the Prediction of Head Hair Shape from DNA*, 37 FORENSIC SCI. INT'L: GENETICS 241 (2018).

150. Tina Lasisi et al., *High-Throughput Phenotyping Methods for Quantifying Hair Fiber Morphology*, 11 SCI. REPS. 1, 1 (2021) ("[F]ocus on investigating the underlying causes of the perceived macroscopic variation has come at the expense of developing language and methodology for describing the phenotype itself. This need is illustrated by the multitude of subjective and, at times, race-based classification systems used across disciplines interested in the variability of this trait despite criticism."); *see also* Tina Lasisi, *The Constraints of Racialization: How Classification and Valuation Hinder Scientific Research on Human Variation*, 175 AM. J. PHYSICAL ANTHROPOLOGY 376 (2021).

151. *See, e.g.*, Gertrude C. Davenport & Charles B. Davenport, *Heredity of Eye-Color in Man*, 26 SCIENCE 589 (1907).

152. MURPHY, INSIDE THE CELL, *supra* note 31, at 221–22.

with even one brown eye gene, a dominant trait, could only have brown eyes.

Today, researchers understand eye color to be a genetically complex trait, influenced by multiple factors including the form and amount of melanin in the iris, the density and distribution of certain cells, and extracellular components that influence light absorption and scattering.[153] Research on this trait has advanced through studies that involve greater numbers of participants across distinct populations and the collection of high-resolution photographs of participants, which provide more detailed and precise phenotypic data than was previously available.[154]

Known genetic loci only explain a little over half of all eye color variation.[155] But because certain genes have a great impact on eye color, forensic tools to predict eye color are designed to test far fewer genetic loci than the sixty-plus that researchers have found to be associated with eye color. For instance, IrisPlex, first introduced in 2010, utilizes just six DNA markers by relying on genes that have the largest effect on eye color.[156]

Currently, test accuracy is much greater for the estimation of blue and brown eye colors than for any other color, referred to within the field as intermediate colors.[157] As with other domains of forensic DNA phenotyping research, genetic admixture and low-quality input DNA also impact the accuracy of eye color prediction tools.[158]

6. Body Height

The study of height puts a fine point on the influence that environment, health, and other lifestyle factors can have on appearance. Adult height is a genetically complex trait[159] that is a product of both genetic factors and the

153. Simcoe et al., *supra* note 78, at *1.

154. Fan Liu et al., *Digital Quantification of Human Eye Color Highlights Genetic Association of Three New Loci*, 6 PLOS GENETICS e1000934 (2010).

155. Simcoe et al., *supra* note 78, at *7.

156. Susan Walsh et al., *IrisPlex: A Sensitive DNA Tool for Accurate Prediction of Blue and Brown Eye Colour in the Absence of Ancestry Information*, 5 FORENSIC SCI. INT'L: GENETICS 170, 171 (2011); *HIrisPlex-S Eye, Hair and Skin Colour DNA Phenotyping Webtool*, ERASMUS MC, https://hirisplex.erasmusmc.nl [https://perma.cc/EZW3-8DYT]; Fan Liu et al., *Eye Color and the Prediction of Complex Phenotypes from Genotypes*, 19 CURRENT BIOLOGY R192, R192 (2009).

157. Walsh et al., *supra* note 139, at 151; Harvard Chan School Department of Epidemiology, *Manfred Kayser Seminar*, YOUTUBE (Oct. 7, 2021), https://www.youtube.com/watch?v=Uq3cHvh4Uq4&list=PLkt0Sm-85E-JnWdnXQnExMoLHEnyoJ7aF&index=27 [https://perma.cc/44JC-28MZ]; *see also* Kayser et al., *supra* note 95, at *3–5 (summarizing recent advances in eye color estimation).

158. *See* Kayser, *Forensic DNA Phenotyping*, *supra* note 57, at 36.

159. Fan Liu et al., *supra* note 72, at 9.

environment.[160] Like the study of certain other externally visible characteristics, early research in the field is tied to the dark history of eugenics and other attempts to scientifically categorize human difference.[161] Despite the long history of stature research, the availability of stature data, and the existence of large genome-wide association studies, prediction of continuous stature is in its early stages and is not yet applied in a forensic context.[162]

Thousands of genetic variants likely contribute to height.[163] Researchers have estimated that inherited genes explain an estimated 80% of human phenotypes,[164] while environment explains an estimated 20%.[165] External factors such as nutrition and childhood diseases, particularly during infancy, are influential. Because of these factors' association with social and economic conditions, predicting height may reveal more than purely genetics.[166]

7. Age

As with height, factors such as lifestyle habits and health have a meaningful influence on the age one appears to be. Researchers use DNA methylation patterns, which alter over time, to estimate age.[167] While not neatly meeting the definition of an externally visible characteristic because it is not external, age is associated with externally visible characteristics such as wrinkles and balding.[168] In recent years, forensically suitable age

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160. *See, e.g.*, Aline Jelenkovic et al., *Genetic and Environmental Influences on Height from Infancy to Early Adulthood: An Individual-Based Pooled Analysis of 45 Twin Cohorts*, 6 SCI. REPS. 28496, at *2–3 (2016).

161. Francis Galton, *Regression* Towards *Mediocrity* in *Hereditary Stature*, 15 J. ANTHROPOLOGICAL MISCELLANEA 246 (1886); R.A. Fisher, *The Correlation Between Relatives on the Supposition of Mendelian Inheritance*, 52 TRANSACTIONS ROYAL SOC'Y EDINBURGH 399 (1918); Walter Bodmer et al., *The Outstanding Scientist, R.A. Fisher: His Views on Eugenics and Race*, 126 HEREDITY 565 (2021); *see also* MURPHY, INSIDE THE CELL, *supra* note 31, at 215–17.

162. Athina Vidaki & Manfred Kayser, *From Forensic Epigenetics to Forensic Epigenomics: Broadening DNA Investigative Intelligence*, 18 GENOME BIOLOGY 238, *1 (2017) [hereinafter *Epigenomics*]; Dabas et al., *supra* note 87, at *9. While predicting continuous stature from crime scene samples is "expected to be challenging," forensic prediction of tall versus non-tall stature is much more promising. Kayser et al., *supra* note 95, at *7.

163. Michael H. Guo, Joel N. Hirschhorn & Andrew Dauber, *Insights and Implications of Genome-Wide Association Studies of Height*, 103 J. CLINICAL ENDOCRINOLOGY & METABOLISM 3155, 3158 (2018).

164. Crista M. Carmichael & Matt McGue, *A Cross-Sectional Examination of Height, Weight, and Body Mass Index in Adult Twins*, 50 J. GERONTOLOGY: BIOLOGICAL SCIS. B237, B237 (1995).

165. *Epigenomics*, *supra* note 162, at *7.

166. Jelenkovic et al., *supra* note 160, at *3.

167. A. Heidegger et al., *Development and Optimization of the VISAGE Basic Prototype Tool for Forensic Age Estimation*, 48 FORENSIC SCI. INT'L: GENETICS 102322, 102322 (2020); Walther Parson, *Age Estimation with DNA: From Forensic DNA Fingerprinting to Forensic (Epi)Genomics: A Mini Review*, 64 GERONTOLOGY 326, 330 (2018).

168. Kayser, *Forensic DNA Phenotyping*, *supra* note 57, at 43–44.

prediction tools have emerged.[169] Existing tools purport to provide epigenetic age prediction from blood, saliva, bones, and semen.[170] Accuracy of these tests tends to be reduced among more elderly individuals, likely due to the inherent variability of aging between individuals.[171] Accuracy can depend upon the substrate analyzed and the quantity of DNA that is available for testing.[172]

Age estimation can reveal particularly sensitive information. The methylation patterns that reveal age result from epigenetic changes. Epigenetics—the study of functionally relevant, heritable changes to gene expression that do not alter the DNA—is a growing field of research across scientific domains.[173] Epigenetic markers of age do not necessarily correspond to chronological age; they may depend, for example, on disease status or lifestyle.[174] Correspondingly, analysis of methylation may reveal lifestyle habits, such as alcohol use.[175] That is to say that someone may appear physically older than they are due to habits such as smoking, substance use disorder, or prolonged sun exposure. Analysis of methylation could also reveal that one appears at the epigenetic level to be older than they are because of habits that harm their health.

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169. Kayser et al., *supra* note 95, at *15–16; Parson, *supra* note 167, at 326. Researchers have also suggested using age prediction tools to estimate the age of refugees, and others who lack legal identification documents but for whom their age is in contest. Kayser et al., *supra* note 95, at *20.

170. Kayser et al., *supra* note 95, at *15–16; *see also* Aleksandra Pisarek et al., *Epigenetic Age Prediction in Semen – Marker Selection and Model Development*, 13 AGING 19145 (2021).

171. Kayser et al., *supra* note 95, at *15.

172. *Id.* at *16.

173. *See generally* Adrian Bird, *Perceptions of Epigenetics*, 447 NATURE 396 (2007).

174. Kayser, *Forensic DNA Phenotyping*, *supra* note 57, at 44.

175. *E.g.*, Danuta Piniewska-Róg et al., *Impact of Excessive Alcohol Abuse on Age Prediction Using the VISAGE Enhanced Tool for Epigenetic Age Estimation in Blood*, 135 INT'L J. LEGAL MED. 2209 (2021); Pisarek et al., *supra* note 170, at 19146; Anna Woźniak et al., *Development of the VISAGE Enhanced Tool and Statistical Models for Epigenetic Age Estimation in Blood, Buccal Cells and Bones*, 13 AGING 6459 (2021).

E. Looking to the Future

Research is underway for many other externally visible characteristics. These include facial pigmented spots associated with age, facial hair thickness, hair greying,[176] freckling,[177] and balding.[178]

Experts in the field anticipate that forensic DNA phenotyping will move toward the estimation of forensically informative lifestyle and environmental information about unknown trace donors. Already, researchers use DNA methylation patterns to estimate age.[179] The study of a variety of other epigenomic factors is underway, including epigenetic evidence of diet, physical activity, and body mass index.[180]

As we will return to in Parts III and IV, the government's use of genetic information to reveal intimate information other than identity presents ethical and legal questions. The application of epigenetics in criminal law raises ethical queries because it can expose sensitive information about lifestyle habits (e.g., smoking, alcohol abuse), environmental exposure, and health.[181] Epigenetics can provide clues to a person's socioeconomic status, where they live, how active they are, whether they are on a diet, their body size and shape, how much alcohol they consume, whether they smoke, their historical or habitual use of illicit drugs, what types of cell tissue a sample contains, and from which twin a sample derives. Examination of epigenetic changes might present novel legal considerations because Supreme Court

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176. *See* Kayser et al., *supra* note 95, at *6; Dabas et al., *supra* note 87, at *10; Kayser, *Forensic DNA Phenotyping*, *supra* note 57, at 41; Manfred Kayser, *Forensic Use of Y-Chromosome DNA: A General Overview*, 136 HUM. GENETICS 621 (2017); Leonie C. Jacobs et al., *A Genome-Wide Association Study Identifies the Skin Color Genes IRF4, MC1R, ASIP, and BNC2 Influencing Facial Pigmented Spots*, 135 J. INVESTIGATIVE DERMATOLOGY 1735 (2015).

177. VISAGE has incorporated freckling into its appearance prediction tool. Kayser et al., *supra* note 95, at *4. A 2018 study of a Spanish cohort developed the first genetic prediction model for freckling, *id.* at *5, a seven-gene eight-SNP prediction model that obtained AUC ~0.74. Incorporating the sex of the individual moderately improved prediction accuracy to AUC 0.76. Barbara Hernando et al., *Genetic Determinants of Freckle Occurrence in the Spanish Population: Towards Ephelides Prediction from Human DNA Samples*, 33 FORENSIC SCI. INT'L: GENETICS 38, 41 (2018). A 2019 study of a Polish cohort developed a model to predict presence of freckles or not and reached AUC 0.752, while a model to predict three categories (non-freckled, medium freckled, and heavily freckled) obtained AUC 0.754, 0.657, and 0.792, respectively. Magdalena Kukla-Bartoszek et al., *DNA-Based Predictive Models for the Presence of Freckles*, 42 FORENSIC SCI. INT'L: GENETICS 252, 256 (2019).

178. VISAGE has incorporated male hair loss into its appearance prediction tool. Kayser et al., *supra* note 95, at *4; *see also* Saskia P. Hagenaars et al., *Genetic Prediction of Male Pattern Baldness*, 13 PLOS GENETICS e1006594 (2017); Magdalena Marcińska et al., *Evaluation of DNA Variants Associated with Androgenetic Alopecia and Their Potential to Predict Male Pattern Baldness*, 10 PLOS ONE e0127852 (2015).

179. Heidegger et al., *supra* note 167, at 102322; Parson, *supra* note 167, at 326.

180. *Epigenomics*, *supra* note 162, at *6–7.

181. *Id.* at *1 ("We also expect that in the near future novel technologies will be developed to allow . . . for many more forensic purposes—that is, forensic epigenomics will emerge. These purposes are likely to include the prediction of forensically informative lifestyle and environmental information of an unknown trace donor . . . .").

precedent tethers the justification of the government's analysis of DNA in part to the limited nature of the information that forensic DNA testing could historically reveal.

In sum, prediction of pigmentation, biogeographic ancestry, age, and facial morphology are in use in casework. Forensic studies characterize pigmentation prediction and biogeographic ancestry estimation as being the highest accuracy techniques, although these tools have notable scientific limitations.[182] Even assuming their efficacy, application of these prediction techniques to casework merits careful consideration for legal and ethical reasons this Article examines in Parts III and IV.

III. SCIENTIFIC AND ETHICAL CONCERNS

In 2019, an anonymous whistleblower revealed that the NYPD had hired a private company to predict the biogeographic ancestry of a person of interest in a 2016 case solely from DNA.[183] According to the whistleblower, the ancestry prediction shifted the entire course of an investigation: after receiving the prediction that the suspect was of African ancestry,[184] the NYPD stopped seeking two white male suspects and began seeking DNA from Black men who lived in the Howard Beach neighborhood of New York.[185] The NYPD ultimately collected, compared, and stored DNA from over 360 Black and Latinx community members. Some reported feeling

182. MAKING SENSE OF FORENSIC GENETICS, *supra* note 48, at 33, 35 ("[K]nowledge about the genetic basis of any other physical traits [beyond eye, hair, and skin color] is not yet advanced enough for them to be predicted from a DNA sequence. In particular, the genetics of human facial structure is highly complex, and the scientific studies that have been published in this area have identified only a few out of the hundreds or possibly thousands of genes that scientists expect to be involved—each with a very small effect. . . . All in all, predicting physical appearance from DNA is still in its infancy.").

183. Ransom & Southall, *supra* note 6 ("The person with knowledge of the investigation said investigators were searching for two white men for nearly two weeks until Deputy Chief Emanuel J. Katranakis, the commander of the Forensic Investigation Division, received phenotype results suggesting the DNA collected from Ms. Vetrano's neck and from her telephone belonged to a [B]lack man."); Rivlin-Nadler, *supra* note 5. In 2017, the NYPD additionally revealed a Snapshot sketch to the public in order to solicit help in identifying human remains from a case in 2005. Rocco Parascandola, *New DNA Testing Method Helps NYPD Get Closer to Identifying Man Found Dismembered in 2005*, DAILY NEWS (Apr. 7, 2018, 5:45 PM), https://www.nydailynews.com/new-york/brooklyn/dna-helps-nypd-closer-id-man-found-dismembered-2005-article-1.3471933 [https://perma.cc/R32F-LL7A].

184. "'The report says "African,"' Greytak [who works at the forensic DNA phenotyping company,] said. 'I think the focus was mostly of African . . . . Most people of African descent are also of European descent. I'm trying to remember. I remember he was of African descent. So that's the extent of it. I don't know if we also said "and European."'" Barshad, *supra* note 4; Southall, *supra* note 7.

185. The whistleblower reported that an NYPD Chief directed officers to take DNA samples from all Black men in custody in Brooklyn and Queens, and to collect DNA from Black men in the community who had previously been arrested. *See* Rivlin-Nadler, *supra* note 5. The NYPD ultimately arrested and a jury convicted Mr. Chanel Lewis, a Black man, who still maintains his innocence and seeks to have his conviction overturned. Vertuccio, *supra* note 8.

embarrassed, intimidated, and stigmatized by the experience of officers appearing at their homes to request their DNA.[186]

While advocates have fairly praised the investigative potential of forensic DNA phenotyping for law enforcement, this example surfaces the risks associated with the technology, including discriminatory DNA dragnets, wrongful convictions, and lack of transparency. This Part examines the scientific and ethical critiques of the technology.[187]

Researchers Samuel and Prainsack interviewed professional and civil society stakeholders, who identified the following concerns associated with forensic DNA phenotyping: (1) potential for discrimination, (2) infringement on privacy rights, (3) uncertainty of findings, (4) possibility for over-interpretation of findings, (5) loss of trust in technology if predictions are wrong, (6) potential for stigma, (7) cost of technology, (8) lack of evidence of usefulness, and (9) consideration of suspect population's rights. This Part discusses and expands upon their work.

A. Risks Discrimination, Stigma, and Racial Profiling

Forensic DNA phenotyping and biogeographic ancestry predictions risk contributing to discrimination and racial profiling.[188] Consistent with critiques in the Edmonton case, scholars have identified how forensic DNA phenotyping probabilistically identifies externally visible characteristics that correspond to sets of people rather than individuals, which may result in the production of an overly broad suspect class of people.[189] Due to their lack of specificity, forensic DNA phenotyping and biogeographic ancestry estimations may, in some instances, serve to justify mass surveillance of communities, risking wrongful convictions and diminished community trust.[190] As scholars Samuel and Prainsack explain: "These risks relate to the context of structural racism, which does not require intent but is rather embodied by, and inscribed in, our societal and political institutions and

186. *See* Rivlin-Nadler, *supra* note 5; Rayman, *supra* note 5.

187. *See Civil Society Stakeholder Views*, *supra* note 125, at *7 tbl.3 (summarizing and categorizing the scientific and ethical critiques of phenotyping tools that interviewees identified).

188. "If it were not to lead to discriminatory policing, then there would be no reason for undertaking the process, that is its very purpose—to target resources and police attention." Carole McCartney, Expert's Preliminary Comments on Legislation: Analysis of the Amendments to the Federal Act on the Use of DNA Profiles in Criminal Proceedings and for Identifying Unidentified or Missing Persons 9–10 (2021) (examining proposed amendments in Switzerland) (on file with author).

189. *See* M'charek & Wade, *supra* note 111, at 320–21; *see also* Toom, *supra* note 21, at 162; Rafaela Granja, Helena Machado & Filipa Queirós, *The (De)materialization of Criminal Bodies in Forensic DNA Phenotyping*, 27 BODY & SOC'Y 60, 62 (2021).

190. *See, e.g.*, *Edmonton Police Issue Apology for Controversial Use of DNA Phenotyping*, *supra* note 3.

shared practices."[191] Discrimination may result from (a) "bias inherent in the algorithms and data sets;"[192] (b) "police misinterpretations of [forensic DNA phenotyping] findings which could lead to racial profiling,"[193] or (c), as the Edmonton example surfaces, inappropriate communication of the results to the public.[194]

Proponents of forensic DNA phenotyping emphasize that forensic DNA phenotyping prevents discrimination rather than perpetuating it by accurately narrowing the investigation to an appropriate range of individuals.[195] They argue that forensic DNA phenotyping is also more accurate, precise, and quantifiable than eyewitness identification.[196] Under these theories, forensic DNA phenotyping has the advantage of avoiding undue surveillance for innocent individuals. A few cases demonstrate the potential of biogeographic ancestry to refocus an investigation appropriately, as in the investigation of a series of homicides in Louisiana,[197] and reduce rather than stoke tensions toward an ethnic minority population, as in the Marianne Vaatstra case in the Netherlands.

Marianne Vaatstra was a sixteen-year-old Dutch girl who was murdered in the Netherlands in 1999.[198] Shortly after, residents of Marianne's town began to insinuate that the murderer was a resident of an asylum center near

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191. RECOMMENDATIONS TO ADDRESS FDP, *supra* note 74, at 15; *see also id.* at 15–16 ("Discrimination could happen at a number of levels, including police misinterpretations of [phenotyping] findings which could lead to racial profiling; if [phenotyping] findings are released to the public it could upset community and social relations; bias inherent in the algorithms and data sets used in [phenotyping]; and in leading to reification of the mistaken belief of a biological basis of race, which might, in turn, deepen the social divide between different groups or individuals, and lead to stigmatisation.").

192. *Id.* at 15. When populations are overrepresented or underrepresented in the data on which a program is trained, biased estimations may result for these populations. *Id.* at 15–16, 29; *see also* Victor Toom et al., *Approaching Ethical, Legal and Social Issues of Emerging Forensic DNA Phenotyping (FDP) Technologies Comprehensively: Reply to 'Forensic DNA Phenotyping: Predicting Human Appearance from Crime Scene Material for Investigative Purposes' by Manfred Kayser*, 22 FORENSIC SCI. INT'L: GENETICS e1 (2016); SAMUEL & PRAINSACK, *supra* note 10, at 25–39.

193. RECOMMENDATIONS TO ADDRESS FDP, *supra* note 74, at 15.

194. *Id.* at 14–15.

195. Some scholars argue that the risk of discrimination is mitigated because investigators receive data about biogeographic ancestry and skin color in combination with predictive data for other externally visible characteristics. *See, e.g.*, MacLean & Lamparello, *supra* note 31, at 105; Cino, *supra* note 31, at 378.

196. *See, e.g.*, Cino, *supra* note 31, at 373–74. Unfortunately, eyewitness testimony is well known to be flawed. However, unlike forensic DNA phenotyping, eyewitnesses can offer contextual information to investigators. *See* Kayser, *Forensic DNA Phenotyping*, *supra* note 57, at 34; MacLean & Lamparello, *supra* note 31, at 109; Manfred Kayser & Peter M. Schneider, *DNA-Based Prediction of Human Externally Visible Characteristics in Forensics: Motivations, Scientific Challenges, and Ethical Considerations*, 3 FORENSIC SCI. INT'L: GENETICS 154, 158–59 (2009).

197. MURPHY, INSIDE THE CELL, *supra* note 31, at 221–22.

198. *See generally* Lisette Jong & Amade M'charek, *The High-Profile Case As 'Fire Object': Following the Marianne Vaatstra Murder Case Through the Media*, 14 CRIME, MEDIA, CULTURE 347 (2018); Amade M'charek, Victor Toom & Lisette Jong, *The Trouble with Race in Forensic Identification*, 45 SCI., TECH. & HUM. VALUES 804 (2020).

the town, resulting in hostility toward the residents of the center, who were primarily migrants from Iraq and Afghanistan. But in 2000, the government released a phenotyping analysis of the DNA that suggested that the person of interest was a man of northwestern European descent, unlike the expected biogeographic ancestry of many asylum seekers. Papers quickly reported that Marianne's murderer was white. In 2012, law enforcement began a campaign to collect DNA from men in the local area; law enforcement eventually asked nearly ten thousand men to "volunteer." Later that year, law enforcement arrested Jasper S., a white Dutch man.

On the other hand, genetic analyses have a history of provoking undue government surveillance premised on race and ethnicity, outcomes which Marianne Vaatstra's case also illustrates.[199] Although forensic researchers emphasize that externally visible characteristics such as biogeographic ancestry and skin color are distinct from the concept of race, scholars critical of forensic DNA phenotyping contend that genetic appearance estimation tools inherently emphasize and reify racial categories.[200] Law enforcement may translate biogeographic ancestry and forensic DNA phenotyping findings into signals and stereotypes pertaining to race and ethnicity. In the New York City case discussed *supra*, law enforcement relied on biogeographic ancestry results to engage in a mass genetic screening of individuals who were Black and resided in a geographic area proximate to the crime. In the case of the "Night Stalker" investigation in the United Kingdom, biogeographic ancestry results led law enforcement to collect DNA from Black men of Caribbean descent near London.[201]

Using forensic DNA phenotyping findings to target investigations can lead to cognitive biases, including tunnel vision, wherein a person concentrates on evidence that supports one hypothesis while devaluing evidence to the contrary.[202] For instance, an officer may learn that forensic DNA phenotyping estimated that an individual was most likely to have dark skin color to justify placing Black residents under suspicion, despite the uncertainty associated with the forensic DNA phenotyping estimation and the lack of individualizing information that the estimation provides.

Forensic DNA phenotyping predictions are more likely to negatively impact a region's minority population than its majority population. This is because forensic DNA phenotyping results have greater "tactical utility" for casework when the estimated features are associated with a smaller number

199. *See* M'charek et al., *supra* note 198, at 818–20.
200. SAMUEL & PRAINSACK, *supra* note 10, at 35–49.
201. M'charek & Wade, *supra* note 111, at 319–20.
202. *See* Koops & Schellekens, *supra* note 31, at 194–96.

of individuals.[203] For instance, a Munich Police Headquarters received a phenotyping report that predicted a suspect was most likely to be of European ancestry and have brown hair, brown eyes, and a medium complexion.[204] Police reported that the results were helpful but not groundbreaking, considering that the results were consistent with tens of millions of individuals in the region. Prior research has found that law enforcement may be more willing to tolerate lower standards of accuracy from techniques that officers perceive as having high utility.[205]

Understanding that race is socially constituted, and science's historical role in justifying racial categories, is important context for understanding the risks associated with use of forensic DNA phenotyping technology.[206] Scholars have urged that relying on race in research, even as a temporary proxy, can lead to a "misplaced [genetic] concreteness."[207] Employing a notion of population groups that coincides with social definitions of race can reinforce racial categorizations[208] and the false notion that race is genetically created.[209]

Forensic DNA phenotyping may promote false theories about the relationships between biological categories or biomarkers and criminality.[210] In the 1960s and 1970s, the U.S. government screened newborns for XYY syndrome, thought to be a biomarker of propensity for crime, and followed positively identified individuals into adulthood. Law enforcement was a key funder of research into the syndrome.[211] Although

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203. WALTER L. PERRY, BRIAN MCINNIS, CARTER C. PRICE, SUSAN SMITH & JOHN S. HOLLYWOOD, PREDICTIVE POLICING: THE ROLE OF CRIME FORECASTING IN LAW ENFORCEMENT OPERATIONS 119 (2013) ("Declaring most of the city a hot spot for robbery is highly accurate but has almost no tactical utility. To ensure that predicted hot spots that are small enough to be actionable, we must accept some limits on 'accuracy' as measured by the proportion of crimes in the hot spots. . . . When performing tactical analysis, practitioners should generally focus on producing results with tactical utility. This means that the scale of the analysis should fit the scale of the possible responses. For example, a beat officer can likely manage a few hot spots the size of a city block but would not find it practical to focus on a strip a few miles in length.").

204. Julian Hans, *Österreicher Erstellen Neues Gutachten zum Isarmörder* [*Austrians Prepare New Report on the Isarmörder*], SÜDDEUTSCHE ZEITUNG (Mar. 5, 2020, 5:06 PM), https://www.sueddeutsche.de/muenchen/muenchen-isarmord-gutachten-1.4832679 [https://perma.cc/WV4M-KMZ5] (translated).

205. *See Views "on the Ground"*, *supra* note 58, at 136 ("[Q]uestions still remain about what constitutes a 'valid' and 'reliable' phenotypic test, and what threshold of probabilistic accuracy must be reached to classify a test as [forensic DNA phenotyping]. Our findings indicate differences in views about this, at least some of which can be attributed to professional background, with police officers more willing to accept lower standards of reliability and validity in exchange for an increased perceived utility.").

206. *See* Quan, *supra* note 31, at 1428–29.

207. Duster, *supra* note 94, at 1050.

208. *See id.*

209. Quan, *supra* note 31, at 1428–29.

210. Murphy, *Phenotyping*, *supra* note 31, at 24–25; Quan, *supra* note 31, at 1438.

211. Koops & Schellekens, *supra* note 31, at 196.

this association has since been debunked, attempts to identify predictive markers for criminality remain.[212]

B. Reveals Sensitive Genetic, Lifestyle, and Health Information

Prediction of externally visible characteristics, biogeographic ancestry, and age present numerous risks to privacy.[213] Because forensic DNA phenotyping technology analyzes groups of SNPs, it can reveal sensitive traits related to appearance, health risks, ancestry, and parentage.[214] In the future, epigenomics (the study of epigenetics changes in DNA) promises to reveal age, lifestyle habits, environmental exposure, and health.[215] This information may be private, sensitive, or even unknown to an individual DNA donor.

For instance, the discovery that one who has left DNA at the scene of a crime has a genetic predilection for a certain disease (e.g., sickle cell anemia or breast cancer) may give law enforcement reason to inspect private medical records in order to narrow suspect pools.[216] Some fear that legal actors may search for supposed genetic evidence of behavioral traits, such as predispositions for violence.[217]

Because individuals may be unaware that they carry certain genetic risk factors, forensic DNA phenotyping presents a corresponding risk to the right not to know, meaning the right for individuals not to know their own genetic health information.[218] The right not to know is an ethical principle grounded in patients' autonomy. For instance, a person with a family history of breast cancer may not want to know whether they carry the BRCA mutation that predisposes them to developing breast cancer.[219] On the other hand, once the government discovers that an individual has a genetic risk factor, the DNA donor may have a right to know this information. Law enforcement do not receive the training a physician or a genetic counselor does to determine whether and how to deliver sensitive genetic information.

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212. *See* MURPHY, INSIDE THE CELL, *supra* note 31, at 217–19.

213. *Id.*

214. *See* Murphy, *Phenotyping*, *supra* note 31, at 19–21.

215. *See, e.g.*, Athina Vidaki & Manfred Kayser, *Recent Progress, Methods and Perspectives in Forensic Epigenetics*, 37 FORENSIC SCI. INT'L: GENETICS 180 (2018); *Epigenomics*, *supra* note 162, at *1 ("We also expect that in the near future novel technologies will be developed to allow . . . for many more forensic purposes—that is, forensic epigenomics will emerge. These purposes are likely to include the prediction of forensically informative lifestyle and environmental information of an unknown trace donor . . . .").

216. Toom et al., *supra* note 192.

217. See *supra* notes 211–12 and accompanying text for a discussion of XYY syndrome.

218. *See* Murphy, *Phenotyping*, *supra* note 31, at 29.

219. *See* R. Andorno, *The Right Not to Know: An Autonomy Based Approach*, 30 J. MED. ETHICS 435, 435–36 (2004).

Phenotyping presents privacy risks not only for the donors of unidentified DNA at crime scenes but also those who have donated DNA to research databanks. Individuals who have donated their DNA for research purposes on the condition that it be deidentified may not have the promise of long-term anonymity,[220] in part due to forensic DNA phenotyping.[221]

However, some do not consider externally visible characteristics to be private data because they are linked to an unknown person[222] or are already visible to the public.[223] Dr. Kayser, head of the Erasmus Department of Genetic Identification and member of the VISAGE consortium who advocates this view, admits exceptions to this principle: namely, ancestry information (because ancestry information is not necessarily visibly apparent) and disease-linked appearance.[224]

Complicating the perspective that genetic phenotyping does not reveal private information is the unique nature of DNA. Stored DNA data is both "usable and losable."[225] In contrast to the one-off examinations of others' visages that occur daily between strangers, DNA-linked appearance data is "usable" in the sense that it can be aggregated, stored, continually reexamined, and continually compared to other data sources.[226] DNA data may also be stolen or lost. In countries without applicable regulations for appearance estimation, genetic data may not be subject to requirements for data privacy. These factors present long-term privacy risks to individuals. Moreover, because of the nature of DNA persistence and transfer, these risks pertain to anyone whose DNA lingers at a crime scene and not solely to the perpetrators of crimes.[227]

C. Risks Wrongful Arrests and Convictions

The criminal legal system has a "long and storied history of using underdeveloped science in aid of serious criminal justice decisions."[228] DNA findings have a tendency to be over-interpreted and trusted, known as

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220. *See, e.g.*, Gamze Gürsoy et al., *Data Sanitization to Reduce Private Information Leakage from Functional Genomics*, 183 CELL 905, 905–06 (2020).

221. Researchers are attempting to link the photographs of known individuals with genetic profiles based on phenotypic information derived from DNA. Soha Sadat Mahdi et al., *Matching 3D Facial Shape to Demographic Properties by Geometric Metric Learning: A Part-Based Approach*, 4 IEEE TRANSACTIONS ON BIOMETRICS, BEHAV. & IDENTITY SCI. 163 (2022); Dzemila Sero et al., *Facial Recognition from DNA Using Face-to-DNA Classifiers*, 10 NATURE COMMC'NS 2557 (2019).

222. *See, e.g.*, Kayser & Schneider, *supra* note 196, at 159.

223. *See* Kayser, *Forensic DNA Phenotyping*, *supra* note 57, at 45; *see also* Marano & Fridman, *supra* note 96, at 2.

224. Kayser, *Forensic DNA Phenotyping*, *supra* note 57, at 45.

225. Toom et al., *supra* note 192, at 2.

226. *See* TE AKA MATUA O TE TURE L. COMM'N, *supra* note 80, at 333.

227. *See id.*

228. Murphy, *Forensic DNA Typing*, *supra* note 9, at 510.

the CSI effect.[229] Genetic appearance estimation results, like all statistical estimations, are uncertain, which makes the appropriate interpretation of DNA results paramount.[230] Unlike certain forensic technologies, phenotyping technologies lack established industry standards and, in most countries, legal regulations.[231] Phenotyping tools may present heightened risks if used in combination with other technologies, such as facial recognition software,[232] that present their own risk of algorithmic bias.[233]

Proponents of phenotyping reasonably point out that forensic DNA phenotyping is one tool among many that investigators may use and that they use it only for investigations. Acting appropriately, investigators should recognize that forensic DNA phenotyping is premised on probabilities and use it to generate new leads, which are particularly valuable in cold cases. However, when phenotyping tools are used inappropriately, they can be counterproductive. Over-reliance on probabilistic findings may lead to wasted resource allocation and misinterpretation, thus contributing to wrongful arrests, confessions, and prosecutions.

D. Lack of Transparency or Oversight

Like certain other investigative tools, application of forensic DNA phenotyping tools rarely receives judicial or public oversight in the United States. For instance, in warrant applications, police need not rely explicitly on information gleaned from tools such as forensic DNA phenotyping if they can point to other independent sources. With respect to investigative genetic genealogy, former FBI agents have advised that this is best practice in order to "protect the technique."[234]

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229. *See Civil Society Stakeholder Views*, *supra* note 125, at *2.

230. "Statistics borrow from mathematics an air of precision and certainty but also call on human judgment and so are subject to bias and imprecision[.]" ROSEMARY A. BAILEY ET AL., SENSE ABOUT SCI., MAKING SENSE OF STATISTICS 3 (2010), https://senseaboutscience.org/wp-content/uploads/2016/11/Makingsenseofstatistics.pdf [https://perma.cc/7XJ2-NHY7].

231. *See Civil Society Stakeholder Views*, *supra* note 125, at *2.

232. The NYPD appears to have compared a Snapshot portrait against a database of photographs using facial recognition software. *See* Break in the Case, *Who is Monique?*, N.Y.C. POLICE DEP'T., at 33:30 (Dec. 10, 2019), https://megaphone.link/NYCPF5726666881 [https://perma.cc/2EU2-5DT] (discussing running a photograph of a Snapshot report through databases of historical photographs).

233. For example, Professor Murphy describes how one outdated method that produces minimal errors can cause significant errors when combined with other outdated approaches. *See* Murphy, *Forensic DNA Typing*, *supra* note 9, at 502, 510 (regarding the combined probability of inclusion, or CPI).

234. *See* Busch & Kramer, *supra* note 24, at 32:25–40:30 (stating that information about genetic genealogy need not be disclosed in the affidavit articulating probable cause for arrest or during discovery). This practice bears similarities to parallel construction. *See Dark Side: Secret Origins of Evidence in US Criminal Cases*, HUM. RTS. WATCH (Jan. 9, 2018), https://www.hrw.org/report/2018/01/09/dark-side/secret-origins-evidence-us-criminal-cases [https://perma.cc/J8GM-ZXVA].

Without knowledge that a technique has been used, defendants and civil society advocates are unable to challenge its application. From their perspectives, freedom of information requests are poor substitutes for laws that mandate disclosure. Freedom of information laws often contain statutory exceptions for public safety or non-routine police procedures, which permit police organizations to keep the details of investigative tools confidential.[235]

Parabon's Snapshot tool is an informative example of how this occurs in practice. Despite being publicly funded, the methods behind Snapshot are unknown. The company has not disclosed how the technology works in scientific journals, as is standard in scientific fields.[236] Parabon's practice of offering "'complete solutions[,]' namely DNA-based photofit pictures to police," concerns some experts, who worry this practice risks making forensics genetics "untrustworthy at long sight."[237] Secrecy prevents independent researchers and the accused from inspecting and validating its methodology.

From the perspective of law enforcement, discretion provides a tactical advantage that advances public safety. To the defense, these practices compromise the rights of defendants and undermine public trust.

E. Costly to the Public Without Clear and Corresponding Benefits

Decisionmakers in legislatures, local government, and in law enforcement must decide how to allocate their budgets. In so doing, they may weigh monetary and social costs against the benefits of forensic DNA phenotyping and related tools. Policing costs across the United States are extraordinary.[238] In 2020, state and local governments spent 129 billion dollars on policing.[239] In 2020, the budget for the NYPD alone was approximately 6 billion dollars.[240] Many of the details about how the NYPD and other police departments spend their budgets are not public.

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235. *See* Nate Jones, *Public Records Laws Shield Police from Scrutiny – and Accountability*, WASH. POST (July 30, 2021), https://www.washingtonpost.com/investigations/public-records-laws-shield-police-from-scrutiny--and-accountability/2021/07/29/be401388-a794-11eb-bca5-048b2759a489_story.html [https://perma.cc/E4M7-7N4M].

236. *See* Schneider et al., *supra* note 10, at 875.

237. *Views "on the Ground"*, *supra* note 58, at 127.

238. *See What Policing Costs: A Look at Spending in America's Biggest Cities*, VERA, https://www.vera.org/publications/what-policing-costs-in-americas-biggest-cities [https://perma.cc/Z477-6TGZ].

239. State and Local Backgrounders, *Criminal Justice Expenditures: Police, Corrections, and Courts*, URBAN INST. (Feb. 27, 2023), https://www.urban.org/policy-centers/cross-center-initiatives/state-and-local-finance-initiative/state-and-local-backgrounders/criminal-justice-police-corrections-courts-expenditures#Question1Police [https://perma.cc/3NWA-MJRJ].

240. *Id.*

The federal government has paid millions to fund forensic DNA phenotyping research. In addition, local governments have frequently paid Parabon to apply forensic DNA phenotyping tools in their cases, even though free, peer-reviewed options are available.

When deciding whether to use, or how to regulate, forensic DNA phenotyping, decisionmakers may wish to consider a technique's known cost, accuracy, tactical utility, benefits, and risks to society.[241] Policymakers may wish to evaluate a tool's contributions to solving crimes and weigh this societal benefit against its risks and monetary costs, to decide what degree of public investment it merits.

IV. LEGALITY

This Part reviews the current regulatory landscape for forensic DNA phenotyping in the United States. Section A discusses relevant domestic statutes; Section B overviews international regulation as a potential model for domestic regulation; and Section C considers the constitutionality of forensic DNA phenotyping in the United States.

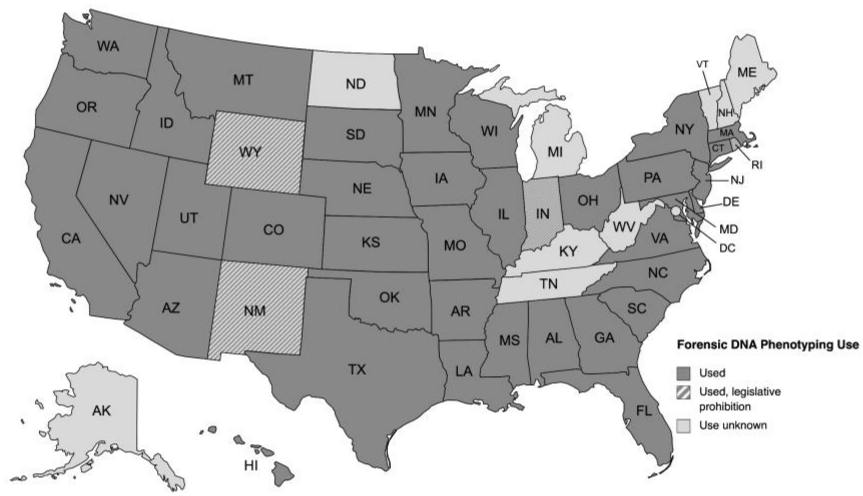
A. In the United States, Regulation Gaps and Deficiencies

In the United States, law enforcement use of forensic DNA phenotyping resides in a regulation gap. No federal laws address forensic DNA phenotyping and few states have laws that address the technology.[242] This Section discusses the domestic statutes that pertain to forensic DNA phenotyping, the texts of which are provided in the Appendix. As we will see, law enforcement have used forensic DNA phenotyping even in the few states that appear to prohibit the technology.

241. For instance, a surveillance technique may prove invaluable in solving a particular case, but have powerful, negative risks associated with its use. *See* Carole McCartney, Preliminary Comments on Review of the DNA and Forensic Procedure Powers in the Crimes Act 1958, at 13 (2022) (unpublished manuscript) (on file with author) (quoting Matthias Wienroth, Rafaela Granja, Veronika Lipphardt, Emmanuel Nsiah Amoako & Carole McCartney, *Ethics as Lived Practice. Anticipatory Capacity and Ethical Decision-Making in Forensic Genetics*, 12 GENES 1868 (2021)).

242. MURPHY, INSIDE THE CELL, *supra* note 31; *See* Murphy, *Forensic DNA Typing*, *supra* note 9, at 510.

FIGURE 2. STATES THAT HAVE EMPLOYED FORENSIC DNA PHENOTYPING.



Law enforcement agencies have used forensic DNA phenotypic tools in at least forty-one states.[243] Four states in which law enforcement have used phenotyping tools have statutes that arguably prohibit application of the technology. They are Rhode Island, Indiana, New Mexico, and Wyoming. In Rhode Island, a provision of criminal procedure state law prohibits DNA sampling "for the purpose of obtaining information about physical characteristics, traits or predispositions for disease."[244] Similarly, Indiana and Wyoming laws both prohibit the collection or storage of information in the state databases "to obtain information about human physical traits or

243. *See supra* Figure 2. These states are: Alabama, Arizona, Arkansas, California, Colorado, Connecticut, Delaware, Florida, Georgia, Hawaii, Idaho, Illinois, Indiana, Iowa, Kansas, Louisiana, Maryland, Massachusetts, Minnesota, Mississippi, Missouri, Montana, Nebraska, Nevada, New Jersey, New Mexico, New York, North Carolina, Ohio, Oklahoma, Oregon, Pennsylvania, Rhode Island, South Carolina, South Dakota, Texas, Utah, Virginia, Washington, Wisconsin, and Wyoming. *See supra* note 130. In nine states and the District of Columbia, this author is not aware of any instances of the technology's application. (Alaska, Kentucky, Maine, Michigan, New Hampshire, North Dakota, Tennessee, Vermont, West Virginia, and Washington, D.C.). But limited evidence suggests that law enforcement in a few of these states may be considering application of forensic DNA phenotyping. *See, e.g.*, Commonwealth of Kentucky, Contract No. PON2 040 2200002764 (May 20, 2022), https://www.ag.ky.gov/Contracts/PON2_040_2200002764_1.PDF [https://perma.cc/D63L-6GWW] ("Sexual Assault Kit Initiative (SAKI) Project scope includes review of cases, . . . to determine which, . . . , would be appropriate candidates for consideration of genealogy searches and/or phenotyping/ancestral analysis.").

244. 12 R.I. GEN. LAWS § 12-1.5-10(5) (2023).

predisposition for disease."[245] New Mexico law prohibits the "collect[ion], stor[age], or release[]" of information in its state DNA database to "obtain[] information about physical characteristics, traits, or predisposition for a disease or mental illness or behavior."[246]

While none of these laws use the term "forensic DNA phenotyping" or "molecular photofitting," each state statute prohibits using certain genetic samples to obtain information about physical characteristics or predispositions for diseases. Additionally, seven states—Florida, Michigan, Nevada, Vermont, South Dakota, Utah, and Washington[247] —prohibit collection or storage of samples in the state database for identification of any medical or genetic disorders.

Texas is an exception. Although Texas generally provides that "information contained in the DNA database may not be collected, analyzed, or stored to obtain information about human physical traits or predisposition for disease," it has a statutory exception for criminal investigations.[248] This provision appears to authorize the use of forensic DNA phenotyping in certain instances.

In practice, law enforcement agencies have used forensic DNA phenotyping even in jurisdictions with statutes that appear to disallow its application.[249] These jurisdictions include Warwick, Rhode Island; Vincennes, Indiana; Fort Wayne, Indiana; and Albuquerque, New Mexico.[250] While a law enforcement agency in each jurisdiction hired Parabon to produce a Snapshot report, the Indiana State Police previously announced a pilot project to use HIrisPlex technology.[251] In the absence of external oversight, existing statutory laws have yet to pose a barrier to government use of forensic DNA phenotyping.

B. International Regulations Offer Lessons

Other sovereign states offer lessons for how to regulate forensic DNA phenotyping. Internationally, five countries legislatively authorize phenotyping: Austria, Germany (including the German Land of Bavaria),

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245. IND. CODE § 10-13-6-16 (2023); WYO. STAT. ANN. § 7-19-404(c) (2023).

246. N.M. Stat. Ann. § 10.14.200.11(F) (2023).

247. *See infra* Appendix.

248. TEX. GOV'T CODE ANN. § 411.143(d) (West 2023) (effective Sept. 1, 2005); *see also* TEX. GOV'T CODE ANN. § 411.143(a)–(c) (West 2023) (creating exception for criminal investigations).

249. One could argue these laws apply only to samples that are eligible for or collected for inclusion in the FBI's CODIS database. If law enforcement may subvert statutory prohibitions applicable to CODIS-eligible samples by simply collecting duplicate samples, such statutory prohibitions would have quite limited applications.

250. *Published Police Investigations*, *supra* note 127.

251. *See* Susan Matheson, *DNA Phenotyping: Snapshot of a Criminal*, 166 CELL 1061, 1062 (2016).

the Netherlands, Slovakia, and Switzerland.[252] Each takes a different approach to regulation.

In 2003, the Netherlands became the first country to legislatively authorize forensic DNA phenotyping.[253] The Netherlands presently permits forensic DNA phenotyping to predict sex, biogeographic ancestry, hair color, eye color, and skin color in serious offenses, but only if all other investigative tools have failed.[254] Since 2018, Slovakia has permitted use of forensic DNA phenotyping for the prediction of visible phenotypic traits (i.e., hair color, eye color, skin color) in limited circumstances, namely for the investigation of severe crimes.[255] Until 2019, Germany prohibited forensic DNA phenotyping to predict externally visible characteristics other than sex.[256] Today, Germany permits forensic DNA phenotyping for estimation of pigmentation of the eyes, hair, and skin, and for age, but not for biogeographic ancestry.[257] The German Land of Bavaria additionally permits the inference of biogeographic ancestry, as it has since 2018, in order to preempt immediate threats.[258] In Austria, since the revision of the Security Police Act in 2018, international scholars interpret Austrian law to permit use of forensic DNA phenotyping.[259] In 2023, Switzerland passed legislation to permit the use of forensic DNA phenotyping for estimation of eye, skin, and hair colors; biogeographic ancestry; and age.[260]

In certain countries, forensic DNA phenotyping rests on less sure footing. At least eleven sovereign states practice forensic DNA phenotyping

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252. For an early review of the field, see generally Koops & Schellekens, *supra* note 31. The VISAGE Consortium has catalogued and produced a thorough review of the regulatory landscape in EU member states. THE REGULATORY LANDSCAPE, *supra* note 68, at 1–2. The Swiss Confederation legislatively authorized phenotyping in 2023. 363 Federal Act of 20 June 2003 on the Use of DNA Profiles in Criminal Proceedings and for Identifying Unidentified or Missing Persons § 1 (Switz. Sept. 1, 2023), https://www.fedlex.admin.ch/eli/cc/2004/811/en [https://perma.cc/NRD3-2KPR]; *Switzerland Adopts DNA Phenotyping to Nab Crime Suspects*, SWI SWISSINFO.CH (Aug. 3, 2023, 10:50 AM), https://www.swissinfo.ch/eng/business/switzerland-adopts-dna-phenotyping-to-nab-crime-suspects/48708794 [https://perma.cc/9D5M-AYV2].

253. *See* Amade M'charek, *Silent Witness, Articulate Collective: DNA Evidence and the Inference of Visible Traits*, 22 BIOETHICS 519, 521–23 (2008).

254. A Royal Decree is necessary in order to investigate additional externally visible characteristics. THE REGULATORY LANDSCAPE, *supra* note 68, at 60–63; Koops & Shellekens, *supra* note 31, at 200; Murphy, *Phenotyping*, *supra* note 31, at 19.

255. THE REGULATORY LANDSCAPE, *supra* note 68, at 2–3.

256. *Id.* at 1 ("[Forensic DNA phenotyping] is considered forbidden because legal provisions state that forensic DNA analyses using coding markers is forbidden.").

257. Schneider et al., *supra* note 10, at II supp. etbl.

258. THE REGULATORY LANDSCAPE, *supra* note 68, at 40.

259. *Id.* at 74; *see also* Schneider et al., *supra* note 10, at II supp. etbl. (describing as implicit regulation).

260. 363 Federal Act of 20 June 2003 on the Use of DNA Profiles in Criminal Proceedings and for Identifying Unidentified or Missing Persons § 1 (Switz. Sept. 1, 2023), https://www.fedlex.admin.ch/eli/cc/2004/811/en [https://perma.cc/NRD3-2KPR]; *see also* OSCE Office for Democratic Institutions and Human Rights, *supra* note 64.

without clear statutory authorization (Australia, Belgium, Canada, France, Hungary, Italy, the United Kingdom, Poland, the Czech Republic, Sweden, and Spain); in some countries use of the technology to date appears limited to biogeographic ancestry only (e.g., Belgium, Italy).[261] A few sovereign states have independent commissions that provide moderate regulatory oversight, although they operate with varying degrees of effectiveness. For instance, the United Kingdom has a forensic science regulator and a Biometrics and Surveillance Camera Commissioner,[262] and the New Zealand Law Commission researches forensic issues to advance law reform.[263]

By way of comparison, in the United States several states have forensic science commissions, although they may not regulate forensic DNA phenotyping. The U.S. Department of Justice established a national forensic commission in 2013, but it has been dissolved.[264]

In a few countries, international scholars have interpreted existing laws and legal norms to forbid forensic DNA phenotyping, even though explicit legislation does not prohibit it.[265] One such example is Ireland, which limits analyses of DNA profiles in the national database to non-coding regions.[266] Belgium prohibits use of DNA coding markers for identification purposes, and debate is ongoing as to whether this provision prohibits phenotyping.[267] In France, some legal experts interpret statutory law to forbid forensic DNA phenotyping. The highest constitutional authority in France, the Constitutional Council, pronounced forensic DNA phenotyping

261. *See* Schneider et al., *supra* note 10, at II supp. etbl.

262. Carole McCartney & Emmanuel Amoako, *The UK Forensic Science Regulator: A Model for Forensic Science Regulation?*, 34 GA. ST. U. L. REV. 945, 945 (2018); *About Us: Biometrics and Surveillance Camera Commissioner*, https://www.gov.uk/government/organisations/biometrics-and-surveillance-camera-commissioner/about [https://perma.cc/S7WC-XWP3].

263. *See Our Role in Law Reform*, TE AKA MATUA O TE TURE L. COMM'N, https://www.lawcom.govt.nz/our-role-law-reform [https://perma.cc/2KDY-X66Z].

264. *See National Commission on Forensic Science (Archive)*, NIST, https://www.nist.gov/forensic-science/interdisciplinary-topics/national-commission-forensic-science#:~:text=National%2520Commission%2520on%2520Forensic%2520Science%2520%2528archive%2529%2520In%25202013%252C,practice%2520and%2520improve%2520the%2520reliability%2520of%2520forensic%2520science [https://perma.cc/SX5R-6GF2].

265. *See* Schneider et al., *supra* note 10, at II supp. etbl. (describing legal norms as forbidding use of forensic DNA phenotyping in Ireland, Luxembourg, and Greece).

266. THE REGULATORY LANDSCAPE, *supra* note 68, at 1; *see also* FORENSIC GENETICS POL'Y INITIATIVE, ESTABLISHING BEST PRACTICES FOR FORENSIC DNA DATABASES 83–84 (2017), http://dnapolicyinitiative.org/wp-content/uploads/2017/08/BestPractice-Report-plus-cover-final.pdf [https://perma.cc/2U6E-D7L7] (discussing legal provisions in various countries that restrict DNA profiles to non-coding regions).

267. THE REGULATORY LANDSCAPE, *supra* note 68, at 1 ("Current law forbids using coding markers for identification purposes, though there is dispute regarding whether [forensic DNA phenotyping] is practiced for 'identification purposes' and therefore whether it is actually forbidden."). *But see* Koops & Shellekens, *supra* note 31, at 173 ("Belgium . . . prohibit[s] forensic DNA phenotyping across the board.").

impermissible in 2011; but, in 2014, France's Court of Cassation, the nation's highest court for civil and criminal matters, determined forensic DNA phenotyping to be permissible for prediction of externally visible "morphological characteristics."[268]

In any nation, whether the government can use forensic DNA phenotyping often depends on who forms the stopgap for use of forensic DNA tools in the country. Certain countries require positive legislation for law enforcement to use new investigatory technologies, or require law enforcement to seek approval from an investigatory judge. For example, in France, an order from a public prosecutor or Magistrate was necessary in order to conduct forensic DNA phenotyping. To this day, the frequency and type of forensic DNA phenotyping analyses that French laboratories conduct are public.[269] By contrast, in countries like the United Kingdom and the United States, a regulation-gap can afford law enforcement broad discretion over investigative procedures, including forensic DNA phenotyping.[270] To understand the scope of forensic DNA phenotyping internationally, policymakers should consider both existing legislation and investigators' practices in the absence of it.

As this Section illustrates, sovereign states vary in their approaches toward forensic DNA phenotyping and few have passed laws that squarely address the technology. The countries that do explicitly regulate use of forensic DNA phenotyping may offer a model for legislators in the United States.

C. Constitutionality

This Section addresses whether, in the United States, the government's collection and analysis of DNA in order to reveal phenotypic information constitutes a Fourth Amendment search requiring a court-ordered warrant supported by probable cause. A key issue in this analysis is whether the collection and testing of DNA for forensic DNA phenotyping involves a search.

To be subject to the Fourth Amendment, a court must first find that a search has taken place. The Fourth Amendment, incorporated to the states through the Fourteenth Amendment, protects "[t]he right of the people to be secure in their persons, houses, papers, and effects, against unreasonable

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268. THE REGULATORY LANDSCAPE, *supra* note 68, at 28–33.

269. *See id.* at 32.

270. *See* Koops & Shellekens, *supra* note 31, at 173–74 ("It would, however, be a mistake to interpret such silence as an implicit prohibition of DNA phenotyping.").

searches and seizures . . . ."[271] As the Supreme Court announced in *Katz v. United States*, "the Fourth Amendment protects people, not places."[272] Thus, "[w]hen an individual 'seeks to preserve something as private,' and his expectation of privacy is 'one that society is prepared to recognize as reasonable' [the Court has] held that official intrusion into that private sphere generally qualifies as a search and requires a warrant supported by probable cause."[273] Were forensic DNA phenotyping to be conducted on a *known* person, and law enforcement collected DNA directly from an individual, the DNA collection and analysis would certainly constitute a search,[274] as "[v]irtually any 'intrusio[n] into the human body'" does.[275] But forensic DNA phenotyping is typically conducted on unknown forensic samples collected not from a person but from a crime scene.

Courts do not typically afford constitutional scrutiny to law enforcement collection and analysis of DNA recovered from a crime scene under the theory that DNA at a crime scene is abandoned. This reasoning finds its origins in the Supreme Court case *California v. Greenwood*.[276]

In *Greenwood*, the Court held that an individual does not retain a reasonable expectation of privacy in garbage that one discards to the public outside the curtilage of his home—for Fourth Amendment purposes, it is abandoned. The Court reasoned that abandonment ends one's possessory

271. U.S. CONST. amend. IV.

272. 389 U.S. 347, 351 (1967).

273. Carpenter v. United States, 138 S. Ct. 2206, 2213 (2018) (quoting Smith v. Maryland, 442 U.S. 735, 740 (1979)). In addition to the *Katz* test, there remains a property-rights-based test for a Fourth Amendment search. *See* United States v. Jones, 565 U.S. 400, 408–09 (2012) ("[O]ur very definition of 'reasonable expectation of privacy' . . . [involves] 'reference to concepts of real or personal property law or to understandings that are recognized and permitted by society.' . . . [T]he Katz reasonable-expectation-of-privacy test has been *added to*, not *substituted for*, the common-law trespassory test." (quoting Minnesota v. Carter, 525 U.S. 83, 88 (1998))); *see also* Grady v. North Carolina, 575 U.S. 306, 309 (2015) ("[A] State also conducts a search when it attaches a device to a person's body, without consent, for the purpose of tracking that individual's movements. . . . [A]nd the government's purpose in collecting information does not control whether the method of collection constitutes a search."); *Carpenter*, 138 S. Ct. at 2272 (Gorsuch, J., dissenting) ("I would look to a more traditional Fourth Amendment approach. Even if *Katz* may still supply one way to prove a Fourth Amendment interest, it has never been the only way."). This may have implication for states that would define DNA as one's property. *See* Joh, *supra* note 30, at 868 n.61 (reviewing statutes that define genetic information as property). Professor Natalie Ram has explored how property law could provide a legal basis to challenge the government's analysis of a relative's DNA. Natalie Ram, *DNA by the Entirety*, 115 COLUM. L. REV. 873, 891 n.105 (2015) (discussing whether human biological material may be the subject of personal property rights).

274. *See* MURPHY, INSIDE THE CELL, *supra* note 31, at 226–28 (discussing testing of samples on known persons).

275. Maryland v. King, 569 U.S. 435, 446 (2013) (quoting Schmerber v. California, 384 U.S. 757, 770 (1966) (second alteration in original)). Virtually any "intrusion[] into the human body," *id.*, will work an invasion of "'cherished personal security' that is subject to constitutional scrutiny," Cupp v. Murphy, 412 U.S. 291, 295 (1973) (quoting Terry v. Ohio, 392 U.S. 1, 24–25 (1968)).

276. California v. Greenwood, 486 U.S. 35 (1988).

interest and thus one's expectation of privacy in the abandoned property.[277] Only a few states have departed from federal jurisprudence and found, pursuant to their state constitutions, that one maintains a reasonable expectation of privacy in garbage that is placed out for collection.[278] The *Greenwood* argument is perhaps the greatest hurdle that a constitutional challenge to forensic DNA phenotyping would have to overcome.

Since the Supreme Court's decision in *Greenwood*, lower courts have frequently reasoned that DNA one leaves outside of one's home is, like trash, abandoned for Fourth Amendment purposes.[279] Scholars and practitioners taking the contrary position have reasonably pointed out that abandonment is not a neat doctrinal fit for DNA. Unlike in *Greenwood*, DNA left outside one's home is unlikely to have been "observed by any member of the public," nor could any member of the public reasonably conduct a search of one's DNA,[280] nor is DNA voluntarily left behind. Each day, we shed hundreds of thousands of DNA cells unwittingly and involuntarily, suggesting that its disposal lacks voluntariness in a meaningful sense. While one might reasonably be said to forfeit any reasonable expectation of privacy in DNA one discards in the commission of a crime, because DNA can transfer between people or objects and persist over time, the mere presence of DNA at a crime scene does not indicate that it was necessarily discarded in the conduct of a crime.[281]

The Supreme Court has made way for preservation of Fourth Amendment rights in the wake of certain new, invasive technologies. In *Kyllo v. United States*, the Court held that using thermal imaging, then a new technology not in general public use, which law enforcement used to detect heat radiating from inside a person's home, constituted a search. Even without a physical intrusion, the Court reasoned that permitting police reliance on sense-enhancing technology not in general public use without a warrant would allow new technology to erode the Fourth Amendment's protections.[282]

277. *Id.* at 41–42; *see also* Abel v. United States, 362 U.S. 217, 241 (1960) (reasoning that that the government's appropriation of contents the petitioner had thrown away was not unlawful, because petitioner had abandoned his interest in these items).

278. *See, e.g.*, State v. Crane, 329 P.3d 689, 699 (N.M. 2014); State v. Wright, 961 N.W.2d 396, 419 (Iowa 2021).

279. Joh, *supra* note 30, at 875.

280. *Greenwood*, 486 U.S. at 41 (citing California v. Ciraolo, 476 U.S. 207 (1986)) (holding that surveillance of a suspect's backyard from an airplane that was flying at an altitude of 1,000 feet did not require warrant because a member of the public could do the same); *see also* Kyllo v. United States, 533 U.S. 27 (2001) (holding that the use of thermal imaging glasses to inspect the interior of a home constituted a search requiring a warrant).

281. *See, e.g.*, Rosenberg, *supra* note 48; Worth, *supra* note 48.

282. *Kyllo*, 533 U.S. at 34–35 ("We think that obtaining by sense-enhancing technology any information regarding the interior of the home that could not otherwise have been obtained without

More recently, the Supreme Court narrowed an exception to the Fourth Amendment known as the third-party doctrine in response to changes in cellphone technology. Previously, law enforcement did not generally need to seek a warrant in order to request and access information that one voluntarily discloses to a third party, because these actions did not constitute a search subject to Fourth Amendment scrutiny.[283] But, in *Carpenter v. United States*, the Court found that government acquisition of cell-site location information must constitute a search because of the nature of cellphone usage in the modern world; this decision narrowed the third-party doctrine.[284]

Kyllo and *Carpenter* are instances in which the Court found that the government's application of investigatory technologies constituted a search subject to Fourth Amendment scrutiny and required the government to seek a warrant prior to use. However, one may readily argue that both cases are distinguishable from the circumstances in which investigators might use forensic DNA phenotyping. *Kyllo* concerned the government's search of one's home, where one's expectation of privacy is at its strongest ebb. *Carpenter* was addressed to one's expectation of privacy in physical location and movement and in information one provides to a third party; neither is at issue where one leaves DNA in a public space. Furthermore, by its own language, *Carpenter* was a "narrow" decision addressed only to the facts of its case.[285]

If the government's collection of DNA that one leaves in a public space does not receive Fourth Amendment scrutiny, the government's breaking open of the cell and analysis of the content within it might receive constitutional scrutiny. Under this reasoning, the DNA analysis could constitute a search distinct from the DNA collection.

In *Maryland v. King*, the Court separately analyzed the reasonableness of the genetic collection and of the genetic analysis, arguably leaving undecided whether genetic analysis, in addition to genetic collection, may

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physical 'intrusion into a constitutionally protected area,' constitutes a search—at least where (as here) the technology in question is not in general public use. This assures preservation of that degree of privacy against government that existed when the Fourth Amendment was adopted. On the basis of this criterion, the information obtained by the thermal imager in this case was the product of a search." (quoting Silverman v. United States, 365 U.S. 505, 512 (1961))).

283. "What a person knowingly exposes to the public, even in his own home or office, is not a subject of Fourth Amendment protection." Katz v. United States, 389 U.S. 347, 351 (1967); *see also* Smith v. Maryland, 442 U.S. 735, 743–44 (1979) ("[A] person has no legitimate expectation of privacy in information he voluntarily turns over to third parties."). *But see* Carpenter v. United States, 138 S. Ct. 2206 (2018) (declining to extend the third-party doctrine to cell site location information).

284. *Carpenter*, 138 S. Ct. at 2217.

285. *Id.* at 2220.

merit constitutional analysis.[286] This is either because the genetic analysis itself constitutes a distinct search, as Professor Natalie Ram has suggested,[287] or because it speaks to whether the Fourth Amendment search at issue is, as it must be, "reasonable in its scope and manner of execution."[288] The former view is consonant with Fourth Amendment jurisprudence pertaining to cellphones and containers. For cellphones, the collection and the analysis of cellphone content each merit distinct constitutional analyses. While a cellphone may be collected without a warrant when it is incident to arrest or abandoned at the crime scene, analyzing the content of the phone is a separate search requiring a warrant.[289]

If either the DNA collection or its analysis constitutes a search, the next inquiry pertinent to the Fourth Amendment is whether this search is reasonable without a warrant supported by probable cause. A warrant's purpose is to protect the public from "arbitrary acts of government agents,"[290] and to "ensure[] that the inferences to support a search are drawn by a neutral and detached magistrate instead of being judged by the officer engaged in the often competitive enterprise of ferreting out crime."[291] In evaluating the legality of a search pursuant to the Fourth Amendment, the Supreme Court has repeatedly emphasized that reasonableness is key. "As the text of the Fourth Amendment indicates, the ultimate measure of the constitutionality of a governmental search is 'reasonableness.'"[292] The nature of the analysis may inform whether the DNA contributor maintains

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286. "In light of the scientific and statutory safeguards, once respondent's DNA was lawfully collected the STR analysis of respondent's DNA pursuant to CODIS procedures did not amount to a significant invasion of privacy that would render the DNA identification impermissible under the Fourth Amendment." Maryland v. King, 569 U.S. 435, 465 (2013).

287. Natalie Ram, *Genetic Privacy After* Carpenter, 105 VA. L. REV. 1357, 1381 (2019) ("The Supreme Court has already recognized that genetic data can carry with it reasonable expectations of privacy. In *Maryland v. King*, . . . the Court considered the analysis of a compelled genetic sample to be a separate Fourth Amendment event from the acquisition of the sample itself. . . . [T]he separate consideration of genetic analysis indicates that genetic data carries with it an enduring privacy interest of constitutional magnitude.").

288. *King*, 569 U.S. at 448; *see also* United States v. Davis, 690 F.3d 226, 246 (4th Cir. 2012) (reasoning in dicta that "the extraction of DNA and the creation of a DNA profile result in a sufficiently separate invasion of privacy [from the collection of bloody clothing] that such acts must be considered a separate search under the Fourth Amendment even when there is no issue concerning the collection of the DNA sample").

289. Riley v. California, 573 U.S. 373, 403 (2014) (prohibiting warrantless search of cellphone collected incident to arrest); Commonwealth v. Fulton, 179 A.3d 475, 479 (Pa. 2018) (holding that a warrantless search of a cellphone collected from a crime scene where the suspect was unknown contravened *Riley*).

290. Skinner v. Ry. Lab. Execs.' Ass'n, 489 U.S. 602, 621–22 (1989).

291. *Riley*, 573 U.S. at 382 (internal quotation marks and citation omitted).

292. *King*, 569 U.S. at 447 (quoting Vernonia Sch. Dist. 47J v. Acton, 515 U.S. 646, 652 (1995) (internal quotation marks in original)).

an "expectation of privacy . . . 'that society is prepared to recognize as reasonable.'"[293]

The expansive scope of intimate information that forensic DNA phenotyping can reveal weighs against the reasonableness of conducting phenotype estimations without a warrant, if there is a predicate search. In *Maryland v. King*, the Court concluded that traditional STR analysis, on a swab collected pursuant to state law and as a part of a routine booking procedure, was reasonable.[294] Unlike *King*, forensic DNA phenotyping in the United States is not typically conducted in a government laboratory pursuant to the national uniform standards of CODIS, and the nature of the genetic analysis at issue is far more revealing.[295]

The *Carpenter* Court laid out several factors that were relevant to its analysis of whether a government search of a person's cell-site location information was reasonable and could proceed without a warrant. Each of the *Carpenter* factors is implicated here: the revealing nature of the information collected, the amount of data at issue, the automatic nature of data disclosure, the inescapability of the data collection, the low cost to the government, and the number of people affected by the surveillance.[296] An empirical study has suggested that the first three factors have most often informed lower courts' analyses of novel Fourth Amendment surveillance issues, and the first two factors were most strongly correlated with case outcomes.[297] With respect to forensic DNA phenotyping, evaluation of the *Carpenter* factors weighs against the reasonableness of the search (if there is one): forensic DNA phenotyping relies on SNP testing, which can reveal deeply intimate information; DNA contains an extraordinary amount of data; DNA is shed constantly and automatically; a great number of people

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293. Carpenter v. United States, 138 S. Ct. 2206, 2213 (2018) (alteration in original) (quoting Smith v. Maryland, 442 U.S. 735, 740 (1979)). Reasonableness may be tied to individualized suspicion and a lack of government discretion. While not a requirement, "the Court has preferred 'some quantum of individualized suspicion . . . [as] a prerequisite to a constitutional search or seizure.'" *King*, 569 U.S. at 447 (omission and alteration in original) (quoting United States v. Martinez-Fuerte, 428 U.S. 543, 560–61 (1976)). Indeed, in *Maryland v. King*, the Court upheld a warrantless search and seizure where the search was conducted according to a standardized procedure which lacked government discretion of the kind that may benefit from the review of a magistrate. *Id.* at 447–48. Even where a warrant is not required, a court should apply "'traditional standards of reasonableness' . . . to weigh 'the promotion of legitimate governmental interests' against 'the degree to which [the search] intrudes upon an individual's privacy.'" *Id.* at 448 (alteration in original) (quoting Wyoming v. Houghton, 526 U.S. 295, 300 (1999)); *Carpenter*, 138 S. Ct. 2206, 2221 (2018); Katz v. United States, 389 U.S. 347, 350–51 (1967).

294. *King*, 569 U.S. at 445, 465–66.

295. *See id.* at 465.

296. Tokson, *supra* note 33, at 1801 ("The key doctrinal language from *Carpenter*, according to most scholars, is this: 'In light of the deeply revealing nature of [cell phone location data], its depth, breadth, and comprehensive reach, and the inescapable and automatic nature of its collection, the fact that such information is gathered by a third party does not make it any less deserving of Fourth Amendment protection.'" (alteration in original) (quoting *Carpenter*, 138 S. Ct. at 2223)).

297. *Id.* at 1823, 1825.

could be impacted, particularly given the ease with which DNA is transferred; and the costs of genetic analyses continue to decrease.

Before *Carpenter*, the *King* Court suggested its analysis of the reasonableness of forensic genetic testing might differ if the testing could reveal additional, intimate information: "If in the future police analyze samples to determine, for instance, an arrestee's predisposition for a particular disease or other hereditary factors not relevant to identity, that case would present additional privacy concerns not present here."[298] In responding to the Justices' questions on this point at oral argument, the government agreed that "mak[ing] use of the rest of the genome" may indeed require additional Fourth Amendment scrutiny.[299] Forensic DNA phenotyping and other forms of DNA analysis present privacy concerns that were not at issue in *King*.[300] The attendant privacy concerns implicate not only those arrested, accused, or convicted, but also their family members.[301]

If forensic DNA phenotyping analysis and related tools fall within the scope of the Fourth Amendment, the government may still conduct the genetic analyses but must seek a warrant first. Law enforcement may disfavor this practice because it can slow investigations or limit officers' flexibility. A warrant requirement, while imperfect from the perspective of both law enforcement and defense advocates, may nevertheless advance the privacy interests of individuals.

The foregoing analysis depends on the question of the constitutionality of forensic DNA phenotyping reaching a court. As a threshold matter, to challenge the constitutionality of the technology, a petitioner must have standing.[302] If the government sought to introduce evidence of a phenotyping analysis during a criminal prosecution, the defendant would have standing to seek to suppress the evidence.

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298. *King*, 569 U.S. at 464–65.

299. *See* MURPHY, INSIDE THE CELL, *supra* note 31, at 229 (quoting Transcript of Oral Argument at 16, *King*, 569 U.S. 435 (No. 12-207)).

300. *See* discussion *supra* Section III.B; *see also* Michael D. Edge, Bridget F.B. Algee-Hewitt, Trevor J. Pemberton, Jun Z. Li & Noah A. Rosenberg, *Linkage Disequilibrium Matches Forensic Genetic Records to Disjoint Genomic Marker Sets*, 114 PROC. NAT'L ACAD. SCIS. 5671 (2017) (finding that 90–98% of a database of anonymized STR profiles can be accurately connected to anonymized SNP records and vice versa, meaning that known STR and SNP profiles have the potential to deidentify anonymized genetic data and reveal evidence of predisposition for disease).

301. *See generally* Jaehee Kim, Michael D. Edge, Bridget F.B. Algee-Hewitt, Jun Z. Li & Noah A. Rosenberg, *Statistical Detection of Relatives Typed with Disjoint Forensic and Biomedical Loci*, 175 CELL 848 (2018) (describing how one can identify relatives of SNP-profile donors among a database of anonymized STR profiles); Murphy, *Relative Doubt: Familial Searches of DNA Databases*, *supra* note 41 (discussing law enforcement use of individuals' forensic samples to investigate their family members).

302. *See, e.g.*, Rakas v. Illinois, 439 U.S. 128, 133 n.2 (1978) ("[A] person whose Fourth Amendment rights were violated by a search or seizure, but who is not a defendant in a criminal action in which the illegally seized evidence is sought to be introduced, would not have standing to invoke the exclusionary rule to prevent use of that evidence in that action.").

The standing analysis may prove more challenging if the government does not seek to introduce phenotyping results to a court. Because forensic DNA phenotyping is an investigatory tool, the government is unlikely to rely upon its results at trial. A prosecutor is more likely to introduce the results of STR testing, conducted after the application of genetic investigatory measures. Unless forensic DNA phenotyping was the sole evidence leading to the identification of an individual and to the subsequent STR analysis, a defendant would be hard pressed to succeed on a claim to exclude STR analysis as fruit of the poisonous tree.[303]

To reach a court, a person must first be aware of the technique's application in his case. This fact underscores the importance of state and local governments passing transparency-enhancing measures for the criminal legal system.

V. AVENUES FOR LEGISLATIVE REFORM

This Part presents avenues for legislators to regulate forensic DNA phenotyping and other genetic investigatory tools in the United States. Legislative action could improve the transparency of investigatory technologies, encourage the public to debate the merits of investigatory tools,[304] and curb risks associated with the technologies.[305] This Part draws lessons from proposed and enacted laws internationally and domestically pertaining to forensic DNA phenotyping and also from scholarship regarding the regulation of algorithmic systems.

A. Moratoria and Prohibitions

Lawmakers may institute prohibitions on the use of forensic DNA phenotyping just as jurisdictions have placed bans on several other investigative technologies. Since 2019, at least thirteen cities and counties

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303. After other investigatory measures have led to a suspect, law enforcement officers typically collect DNA, sometimes surreptitiously, from the suspect for STR testing and introduce the results of this DNA testing to a court. A defendant may move to exclude the results of STR testing as fruit of the poisonous tree, but he must overcome exceptions to the exclusionary rule: for example, that the initial unconstitutional analysis was too remote and attenuated by the application of an intervening, constitutional investigative technique. *See* Utah v. Strieff, 579 U.S. 232, 238 (2016) (explaining that suppression of evidence is a "last resort" and detailing exceptions to the fruit of the poisonous tree rule).

304. Part of the role of policymakers is to determine which values to prioritize. To this end, policymakers may benefit from hearing robust public debate as to the benefits and harms of various tools. *See* Helena Machado & Susana Silva, *What Influences Public Views on Forensic DNA Testing in the Criminal Field? A Scoping Review of Quantitative Evidence*, 13 HUM. GENOMICS 23, *9–10 (2019).

305. When considering avenues for reform, stakeholders may wish to consider whether a potential regulation would promote meaningful change or serve as a symbolic one. *See generally* Sinha, *supra* note 34.

in the United States have banned use of facial recognition technology.[306] Neither Maryland nor D.C. permits the use of familial DNA searching,[307] and Maryland severely circumscribes the use of investigative genetic genealogy.[308] As discussed *supra* in Part IV, Austria and France prohibited the use of forensic DNA phenotyping for many years. Germany still prohibits estimation of biogeographic ancestry.

Moratoria offer an avenue to temporarily halt use of a technology in order to study whether to implement it, develop best practices, and institute appropriate guardrails. Algorithmic impact assessments, for instance, are one mechanism to investigate the risks and suitability for use of algorithmic tools prior to use.[309] The Canadian Directive on Automated Decision-Making requires federal public agencies to conduct algorithmic impact assessments prior to producing an automated decision-making system.[310]

Lawmakers may establish a timeline when use may begin again or establish particular conditions that must be met before use can begin. Without explicit conditions, moratoria may end without the implementation of guardrails. In Morocco, national regulators established a time-limited moratorium on facial recognition technology.[311] When the moratorium ended, no facial recognition technology accountability mechanisms had actually been implemented.

Prior enacted laws demonstrate that prohibitions and moratoria on the use of forensic DNA phenotyping are feasible. The precise statutory language of the prohibition—for instance, whether it is time-limited or condition-dependent, and whether it includes a private right of action where there is a violation of the prohibition—can impact the effectiveness of the prohibitions in accomplishing lawmakers' objectives.

B. Limitations on Permissible Uses

Alternatively, lawmakers may elect to curtail government use of predictive phenotype tools through explicit limitations on their applications. *First*, lawmakers can limit the applications of forensic DNA phenotyping based on the characteristics that the tool predicts. Internationally, some

306. ADA LOVELACE INST., AI NOW INST. & OPEN GOV'T P'SHIP, ALGORITHMIC ACCOUNTABILITY FOR THE PUBLIC SECTOR 16–17 (2021) [hereinafter ALGORITHMIC ACCOUNTABILITY FOR THE PUBLIC SECTOR], https://www.opengovpartnership.org/wp-content/uploads/2021/08/algorithmic-accountability-public-sector.pdf [https://perma.cc/3MJ7-BRAN].

307. MD. CODE ANN., PUB. SAFETY § 2-506(d) (West 2009); D.C. CODE. § 22-4151(b) (2023).

308. MD. CODE ANN., CRIM. PROC. § 17-104 (West 2022) (regarding "licensing and training programs for laboratories and individuals performing genetic genealogy").

309. ALGORITHMIC ACCOUNTABILITY FOR THE PUBLIC SECTOR, *supra* note 306, at 21–23 (discussing and noting the challenges of algorithmic impact assessments).

310. *Id.* at 23.

311. *Id.* at 16–17.

countries have limited genetic appearance prediction to statutorily identified characteristics (e.g., age, biogeographic ancestry, appearance); characteristics that are immutable (i.e., present from birth); or externally visible characteristics.[312]

Lawmakers may consider whether analysis of a characteristic would reveal sensitive information and how reliable tools are to predict the characteristic. The Netherlands, for instance, requires publication of a scientifically validated test prior to approval of an investigative method.[313] Given the lack of scientific support for prediction of facial morphology, U.S. lawmakers could permit forensic DNA phenotyping for prediction only of particular appearance traits.

Second, lawmakers could limit the application of forensic DNA phenotyping to particular categories of crimes. In a study of the attitudes of the Swiss public, a majority of those who supported forensic DNA phenotyping testing preferred to employ it selectively, dependent upon the severity of the underlying crime.[314] Such a measure would be consistent with laws in Austria, the Netherlands, and Slovakia.[315]

Third, lawmakers could limit the purposes for which law enforcement may employ phenotyping tools. As in Bavaria, its use could be limited to preemption of imminent threats. In the United States, lawmakers may wish to establish a neutral arbiter to oversee such determinations. Alternatively, lawmakers could limit application of forensic DNA phenotyping to the identification of missing persons, unknown victims, or human remains—contexts in which the attendant ethical concerns may be diminished relative to the identification of unknown persons of interest.[316] Lawmakers could also provide that phenotyping and related techniques should not form the basis for a DNA dragnet or be sufficient grounds for probable cause for a warrant or for a subpoena, such as to investigate medical records.

The foregoing measures would balance law enforcement's interest in promoting public safety against the individual interests at stake. The first category of laws would account for law enforcement interests while diminishing the scientific and privacy concerns that phenotyping tools present. The second and third categories of laws would narrow the instances in which law enforcement may rely on forensic DNA phenotyping in order

312. *See* Murphy, *Phenotyping*, *supra* note 31, at 19; THE REGULATORY LANDSCAPE, *supra* note 68, at 1–3.

313. THE REGULATORY LANDSCAPE, *supra* note 68, at 43.

314. Martin Zieger & Silvia Utz, *About DNA Databasing and Investigative Genetic Analysis of Externally Visible Characteristics: A Public Survey*, 17 FORENSIC SCI. INT'L: GENETICS 163, 166 (2015).

315. THE REGULATORY LANDSCAPE, *supra* note 68, at 1–2.

316. *See* Murphy, *Phenotyping*, *supra* note 31, at 31; MacLean & Lamparello, *supra* note 31, at 110. However, ethical concerns are not absent with respect to the identification of missing persons or unknown victims.

to promote proportionality between the nature of the crime and the techniques law enforcement may employ.

C. Judicial Oversight

While judicial oversight is a requirement for many government searches and for the introduction of forensic evidence into courts, it is a rarity for investigatory technologies in the United States. By contrast, judicial oversight of investigations is commonplace in countries that utilize investigatory judges. In forensic DNA phenotyping cases in France and the Netherlands, investigative judges have the power to order or deny use of phenotyping.[317] This system results not only in enhanced transparency regarding the application of forensic DNA phenotyping in criminal cases but also in an opportunity for judges to rule on the legality of the technology.

Lawmakers in the United States could require law enforcement to make an application to the judicial branch before using certain investigatory technologies. In 2021, the Maryland legislature required judicial authorization for law enforcement to employ a controversial investigatory tool known as genetic genealogy. To receive judicial authorization, law enforcement must submit an affidavit certifying compliance with statutory requirements.[318] This process should be familiar to law enforcement, because they regularly submit applications for warrants to the judiciary prior to conducting searches.

Implementation of this legislative proposal may require dedication of funding. Maryland's law demonstrates the possible perils of passing a law without approving the funding the law requires to be implemented.[319] Even were such a bill to pass, a reasonable critique of this proposal is that judges are ill-equipped to, and the warrant process is not designed to, weed out law enforcement reliance on underdeveloped technologies.

D. Communication of Results

Critics of appearance estimation have expressed concerns about how individual test results are communicated to law enforcement and to the public. Lawmakers may introduce measures addressed to these twin concerns.

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317. THE REGULATORY LANDSCAPE, *supra* note 68, at 32, 64.

318. MD. CODE ANN., CRIM. PROC. § 17-104 (West 2022) (regarding "licensing and training programs for laboratories and individuals performing genetic genealogy").

319. Patrick Terpstra, *Maryland Quietly Shelves Parts of Genealogy Privacy Law*, 2ABC WMAR BALT. (Sept. 21, 2022, 11:39 AM), https://www.wmar2news.com/infocus/maryland-quietly-shelves-parts-of-genealogy-privacy-law [https://perma.cc/2YT7-XY3C].

Critics fear that law enforcement will interpret and communicate forensic DNA phenotyping or biogeographic ancestry data in ways that are inaccurate or reproduce racial and gender stereotyping.[320] Evidence suggests that judicial actors are typically poor at discriminating between different forms of DNA testing.[321] To reduce the risk that law enforcement misinterprets results, some scholars have proposed disclosing limited results to law enforcement[322] and training them as to what these results do and do not mean. To reduce the risk of unconscious bias and limit its negative effects, policymakers may require law enforcement to document contemporaneously how they utilize forensic DNA phenotyping findings during investigations.

Lawmakers could mandate the disclosure of certain data, which informs the interpretation of individual test results, to law enforcement and to judicial actors who request it. For instance, access to population genetic reference data informs interpretation of biogeographic ancestry estimations. Disclosure of reference data, training data, and test accuracy statistics are just a few of the metrics that may merit disclosure along with phenotyping results.

Policymakers may also wish to establish best practices for accurate and appropriate communication with the public.[323] Except in extraordinary cases, policymakers or police departments may determine it is inappropriate to communicate any form of biogeographic ancestry, age, or forensic DNA phenotyping results to the public because doing so could contribute to the othering of communities,[324] as well as diminished trust in law enforcement.

E. Public Disclosure

While state and federal freedom of information laws provide important avenues for the public to seek information in the government's hands, these laws have received significant critiques. For instance, the federal Freedom of Information Act places the burden on the public to request records, to identify with some specificity the records they seek, and—in some cases—to advocate or litigate for access to the records.[325]

To promote transparency, lawmakers may consider implementing measures that instead place the burden of public disclosure on governmental

320. *See, e.g.*, *Civil Society Stakeholder Views*, *supra* note 125, at *14; SAMUEL & PRAINSACK, *supra* note 10, at 25–47.

321. *See* Murphy, *Forensic DNA Typing*, *supra* note 9, at 500–02.

322. *See* Toom et al., *supra* note 192, at 2.

323. SAMUEL & PRAINSACK, *supra* note 10, at 31–35.

324. *See* M'charek & Wade, *supra* note 111, at 321–24.

325. *See generally* Seth F. Kreimer, *The Freedom of Information Act and the Ecology of Transparency*, 10 U. PA. J. CONST. L. 1011 (2008) (analyzing criticisms of the Freedom of Information Act).

bodies or contractors. Consolidated public registries of investigatory, surveillance, and algorithmic technologies can be valuable transparency measures.[326] Artificial intelligence registries are a "standardised, searchable and archivable way to document the decisions and assumptions that were made in the process of developing, implementing, managing and," if necessary, "dismantling an algorithm."[327] Several cities have implemented algorithm registers, including Amsterdam, Helsinki, Ontario, and several cities in France.[328]

Jurisdictions such as France and Canada have established publication requirements for source code, meaning the human-readable computer programming instructions that inform the operating logic of any algorithm.[329] The United Kingdom and New Zealand have introduced transparency requirements for technical, organizational, and administrative aspects of algorithms.

Disclosure requirements can be agency-specific. For instance, the New York City Council enacted the Public Oversight of Surveillance Technology (POST) Act to require the NYPD to disclose information about surveillance technology—defined as "equipment, software, or systems capable of, or used or designed for, collecting, retaining, processing, or sharing . . . biometric, or similar information, that is operated by or at the direction of the department."[330] Despite the passage of this local law, the NYPD has not disclosed any information about their use of genetic technologies,[331] perhaps considering them to be outside the scope of the law's definition of biometric surveillance. This example illustrates how statutory language—specifically, the description of the technologies that lawmakers designate for disclosure—can impact the implementation of public registries and publication requirements.

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326. ALGORITHMIC ACCOUNTABILITY FOR THE PUBLIC SECTOR, *supra* note 306, at 18.

327. MEERI HAATAJA, LINDA VAN DE FLIERT & PASI RAUTIO, PUBLIC AI REGISTERS 3 (2020), https://ai.hel.fi/wp-content/uploads/White-Paper.pdf [https://perma.cc/K2Q6-29XH].

328. ALGORITHMIC ACCOUNTABILITY FOR THE PUBLIC SECTOR, *supra* note 306, at 19–20, 50.

329. *Id.* at 18–19, 47.

330. N.Y.C. ADMIN. CODE § 14-188 (2020), https://legistar.council.nyc.gov/LegislationDetail.aspx?ID=3343878&GUID=996ABB2A-9F4C-4A32-B081-D6F24AB954A0 [https://perma.cc/77JH-P3L9] (establishing a local law to require reporting and create oversight of NYPD technologies, known to proponents of the bill as the Public Oversight of Surveillance Technology (POST) Act); *The Public Oversight of Surveillance Technology (POST) Act: A Resource Page*, BRENNAN CTR. FOR JUST. (Mar. 5, 2021), https://www.brennancenter.org/our-work/research-reports/public-oversight-surveillance-technology-post-act-resource-page [https://perma.cc/3HA6-43G8].

331. *See Public Oversight of Surveillance Technology (POST) Act Impact and Use Policies*, NYPD, https://www1.nyc.gov/site/nypd/about/about-nypd/policy/post-act.page [https://perma.cc/KZN5-G6LV].

F. Procurement and Funding Conditions

Law enforcement are increasingly relying on technology from private companies, whose research is often undisclosed to the public or to purchasers. Procurement conditions are conditions that companies must satisfy in order for governments to contract with them. For algorithmic technologies, the City of Amsterdam has instituted procurement conditions that mandate the inclusion of particular contractual terms regarding transparency, explainability, and scientific accuracy.[332] Canada maintains a list of authorized vendors for whom they expedite procurement; a condition for authorization is the vendor's "demonstrated competence in AI ethics."[333]

Funding conditions may also be tied to government grants. Medical researchers who rely on federal funding for clinical studies must publish certain data on clinicaltrials.gov.[334] As a condition for funding of forensic research, government entities could require companies to publish their validation studies, training data, models, and source code. Procurement and funding provisions could allow U.S. government actors to institute standards for scientific accuracy, ethical implementation, and meaningful transparency for forensic DNA phenotyping and related technologies.

G. External Oversight Bodies

Lawmakers may establish executive oversight of investigatory technologies through local, state, or national commissions and task forces to ensure transparent and independent reviews of technologies. Independent review is a hallmark of scientific fields. External oversight bodies can offer valuable pre-implementation oversight as well as post-implementation reviews of systemic failures. Several U.S. jurisdictions have established

332. ALGORITHMIC ACCOUNTABILITY FOR THE PUBLIC SECTOR, *supra* note 306, at 35 ("These conditions include, among other things: reviews of 'data quality' to ensure the avoidance of distortions, inaccuracies and biases; establishing that the rights to the data used or collected through the use of the algorithmic system will lie with the municipality; quality assurance about compliance of the algorithmic system with laws, and assurances of accuracy; transparency into the functioning of the algorithmic system, including a mandate to make the working of the system auditable and explainable to the municipality or to an external auditor; and risk identification and management requirements for the contractor.").

333. *Id.* at 34.

334. *See About ClinicalTrials.gov*, NAT'L LIBR. MED., https://clinicaltrials.gov/ct2/about-site/background [https://perma.cc/N3PH-PYPX].

commissions, comprised of government workers and scientific experts, to review forensic technologies[335] and automated decision systems.[336]

Regulatory bodies could oversee forensic DNA phenotyping and biogeographic ancestry tests akin to how the U.S. Food and Drug Administration reviews medical devices and certain health-related genomic tests to evaluate their safety and efficacy.[337] A regulator of forensic DNA phenotyping and biogeographic ancestry tests could review, for instance, the positive and negative predictive values of these and provide the regulator with evidence sufficient to support their claims. Currently, there is no independent oversight of predictive values.

Particular existing commissions have received critiques for their lack of transparency, limited statutory authority, and lack of independence.[338] To have meaningful oversight authority and perceived legitimacy, commissions may benefit from a membership with broad expertise (e.g., from impacted individuals, bioethicists, practitioners, racial justice experts, statisticians, and experts in forensic DNA analysis). The success of an oversight body depends not only on the statutory text but on how the membership wields its statutory authority.[339] The Texas Commission on Forensic Science, for instance, has leveraged its statutory authority to investigate forensic technologies that have contributed significantly to wrongful convictions.[340]

Additionally, commissions and task forces can oversee algorithmic auditing, another mechanism to evaluate forensic algorithmic technologies. Audits and regulatory inspections are independent reviews to assess

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335. JERI D. ROPERO-MILLER & NICOLE JONES, FORENSIC TECH. CTR. OF EXCELLENCE, FORENSIC SCIENCE STATE COMMISSIONS AND OVERSIGHT BODIES—A 2022 UPDATE 6 (2022), https://forensiccoe.org/private/654825e11c28b [https://perma.cc/K2S3-AB6S].

336. KATE CRAWFORD ET AL., AI NOW INST., 2019 REPORT 34–35 (2019), https://ainowinstitute.org/publication/ai-now-2019-report-2 [https://perma.cc/J6U2-CZUP] (discussing automated decision systems task forces).

337. But note that these processes have loopholes. *See Regulation of Genetic Tests*, NAT'L HUM. GENOME RSCH. INST., https://www.genome.gov/about-genomics/policy-issues/Regulation-of-Genetic-Tests [https://perma.cc/WR22-4B2T].

338. *E.g.*, AI NOW INST., CONFRONTING BLACK BOXES: A SHADOW REPORT OF THE NEW YORK CITY AUTOMATED DECISION SYSTEM TASK FORCE 11–19 (Rashida Richardson ed., 2019), https://ainowinstitute.org/publication/confronting-black-boxes-a-shadow-report-of-the-new-york-city-automated [https://perma.cc/DB7X-J7H4].

339. *See* Mark Bovens & Anchrit Wille, *Indexing Watchdog Accountability Powers a Framework for Assessing the Accountability Capacity of Independent Oversight Institutions*, 15 REGUL. & GOVERNANCE 856, 858–60 (2021).

340. *E.g.*, TEX. FORENSIC SCI. COMM'N, FORENSIC BITEMARK COMPARISON COMPLAINT FILED BY NATIONAL INNOCENCE PROJECT ON BEHALF OF STEVEN MARK CHANEY - FINAL REPORT 2–5 (2016), https://www.txcourts.gov/media/1454500/finalbitemarkreport.pdf [https://perma.cc/AQF8-39MS].

performance and compliance with technical and normative standards.[341] Audits are a common tool for accountability including in forensic and research laboratories.[342] The ANSI National Accreditation Board (ANAB), for instance, assesses forensic laboratories' compliance with international standards and issues accreditation certificates.[343] Independent verification and validation (IV&V), a type of third-party inspection, is a process on which the engineering field relies to ensure products as significant as Department of Defense nuclear weapons systems are "correctly built for [their] intended use."[344] Researchers and governments have proposed myriad frameworks for auditing algorithms.[345] Government agencies in the United Kingdom, Sweden, and the Netherlands have each conducted audits of public-sector algorithmic systems.[346]

External oversight bodies may have the power to conduct or solicit impact assessments, audits, and regulatory inspections. Impact assessments are policy mechanisms to identify and evaluate the potential unintended effects of tools in practice. Civil society stakeholders have proposed impact assessment frameworks for racial equity,[347] automated decision systems,[348] the environment,[349] and data protection.[350] Ideally, assessments take place

341. ALGORITHMIC ACCOUNTABILITY FOR THE PUBLIC SECTOR, *supra* note 306, at 24–25; Inioluwa Deborah Raji et al., *Closing the AI Accountability Gap: Defining an End-to-End Framework for Internal Algorithmic Auditing*, 2020 PROC. ACM CONF. ON FAIRNESS, ACCOUNTABILITY & TRANSPARENCY 33.

342. *See* SUPREME AUDIT INSTS. OF FIN., GER., THE NETH., NOR. & THE UK, AUDITING MACHINE LEARNING ALGORITHMS: A WHITE PAPER FOR PUBLIC AUDITORS 9 (2023), https://www.auditingalgorithms.net [https://perma.cc/7ATH-9VN6].

343. *Forensic Service Provider Accreditations*, ANAB: ANSI NAT'L ACCREDITATION BD., https://anab.ansi.org/en/forensic-accreditation [https://perma.cc/QJ6Z-84BY].

344. Letter from IEEE-USA to the National Institute of Standards & Technology (July 11, 2022) (responding to request for comments on NISTIR 8354-DRAFT Digital Investigation Techniques: A NIST Scientific Foundation Review).

345. Raji et al., *supra* note 341.

346. ALGORITHMIC ACCOUNTABILITY FOR THE PUBLIC SECTOR, *supra* note 306, at 26–27.

347. *See, e.g.*, *REIA Database*, COUNCIL OFF. RACIAL EQUITY, https://www.dcracialequity.org/reia-database [https://perma.cc/9EJM-4QGC]; ANNIE E. CASEY FOUND., TOOLS FOR THOUGHT: USING RACIAL EQUITY IMPACT ASSESSMENTS FOR EFFECTIVE POLICYMAKING (2016), https://assets.aecf.org/m/resourcedoc/aecf-ToolsforThoughtCaseStudy-2016.pdf [https://perma.cc/BJ9Q-8974].

348. *See, e.g.*, DILLON REISMAN, JASON SCHULTZ, KATE CRAWFORD & MEREDITH WHITTAKER, ALGORITHMIC IMPACT ASSESSMENTS: A PRACTICAL FRAMEWORK FOR PUBLIC AGENCY ACCOUNTABILITY 3–4 (2018), https://openresearch.amsterdam/image/2018/6/12/aiareport2018.pdf [https://perma.cc/L4A9-98HG]; ALGORITHMIC ACCOUNTABILITY FOR THE PUBLIC SECTOR, *supra* note 307, at 21–24.

349. *See, e.g.*, Stephen Jay, Carys Jones, Paul Slinn & Christopher Wood, *Environmental Impact Assessment: Retrospect and Prospect*, 27 ENV'T IMPACT ASSESSMENT REV. 287, 287–88 (2007).

350. *See* Margot E. Kaminski & Gianclaudio Malgieri, *Multi-Layered Explanations from Algorithmic Impact Assessments in the GDPR*, 2019 PROC. CONF. ON FAIRNESS, ACCOUNTABILITY & TRANSPARENCY 68.

before the government's utilization of a technology in order to identify and prevent unwarranted effects.[351]

Only one U.S. executive agency, to this author's knowledge, has reviewed forensic DNA phenotyping. The New York Department of Health, which oversees private laboratories that conduct DNA testing in the state, granted Parabon a permit to conduct forensic DNA phenotyping in New York State in 2020. Their review process and their basis for approval are not public.

H. Enhanced Protection of Genetic Data in Non-Forensic Databases

Ethicists have questioned whether those who donate their genetic data to medical biobanks have really provided meaningful consent, particularly for forensic research,[352] as noted *supra*.[353] Lawmakers may wish to establish restrictions on the collection and distribution of biometric data that forensic researchers derive from non-forensic sources. For instance, lawmakers could require medical biobanks to notify patients before disclosing data for non-medical research purposes or require reconsent.[354]

Medical researchers and hospitals may also wish to inform their patients about or limit the possibility that their data will be used for forensic research. Medical researchers and institutional review boards may revise their consent forms to account for and inform their patients of the possible applications of their data for forensic purposes. When medical researchers and hospitals contract with third parties, such as drug developers, they may wish to contractually limit the purposes for which third parties may use the data and to whom they may resell it.

Lawmakers may take measures to limit warrantless law enforcement searches of genetic data stored in non-forensic databases. For instance, Professor Natalie Ram and colleagues have suggested enacting a statute akin to the Stored Communications Act, in order to introduce judicial oversight and limit law enforcement searches to instances when the government can describe a "specific and articulable" connection between a database record and a crime.[355] Such a law could reduce fishing expeditions for investigative leads, while balancing the government's weighty interest in solving crimes.

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351. *See* Nicole D. Porter, *Racial Impact Statements*, SENT'G PROJECT (June 16, 2021), https://www.sentencingproject.org/publications/racial-impact-statements [https://perma.cc/N3Y4-9Q55].

352. *See* Dranseika et al., *supra* note 18, at 142–43.

353. *See supra* notes 18–22 and accompanying text.

354. *See* Jennifer Kulynych & Henry T. Greely, *Clinical Genomics, Big Data, and Electronic Medical Records: Reconciling Patient Rights with Research when Privacy and Science Collide*, 4 J.L. & BIOSCIENCES 94, 124–28 (2017).

355. Ram et al., *supra* note 130, at 1079.

Additionally, lawmakers could require individuals' consent for the collection and analysis of their biometric data and could provide a statutory remedy where there is a violation. A few states, including New York,[356] statutorily require consent for DNA collection and testing. However, like New York, states may not create a remedy for violation of the statute, or may exempt DNA testing without consent when it is in furtherance of a criminal investigation or prosecution, as Florida's statute does.[357] A few jurisdictions have passed biometric privacy laws that afford individuals greater control over their own data.[358] The most robust law of this kind is Illinois's Biometric Information Privacy Act (BIPA), which requires consent for collection and disclosure of biometric data[359] and creates a private right of action for individuals to sue for violation of this law.[360]

CONCLUSION

Genetic appearance estimation is a controversial investigatory technique which has been subject to significant scientific and ethical critiques. In the United States, where commercial companies are invested in the utilization of these techniques and regulation is notably absent, the concerns attendant to forensic DNA phenotyping are heightened. This Article examined potential legislative responses to the proliferation of forensic DNA phenotyping in the United States. Regulation—to establish a threshold for scientific accuracy, enhance transparency, provide guidance to law enforcement, and promote community trust—is overdue.

356. N.Y. CIV. RIGHTS LAW § 79-1(2)(a) (McKinney 2022) (requiring written informed consent for genetic testing).

357. *Id.*; FLA. STAT. § 817.5655(3), (7)(a) (2023) (making it unlawful for a person to conduct, or submit a sample for, genetic analysis of another person's DNA, but excepting DNA analysis for the purpose of a criminal investigation or prosecution); ALASKA STAT. § 18.13.010 (2023) (making DNA collection and analysis of another unlawful without their written consent, but excepting this practice "for a law enforcement purpose").

358. *See* 6 R.C.N.Y. § 8-01 (2021), https://rules.cityofnewyork.us/wp-content/uploads/2021/07/NOA_DCWP-Rule-re-Biometric-Data-Collection.pdf [https://perma.cc/JUP2-MF2L]; TEX. BUS. & COM. CODE ANN. § 503.001 (West 2023) (regarding capture or use of a biometric identifier); WASH. REV. CODE § 19.375.010 (2023).

359. 740 ILL. COMP. STAT. 14/15(b)(3), (d) (2023) (effective Oct. 3, 2008).

360. 740 ILL. COMP. STAT. 14/20 (2023) (effective Oct. 3, 2008).

APPENDIX

TABLE 1. STATE STATUTES THAT REGULATE FORENSIC DNA PHENOTYPING (AS OF JANUARY 1, 2023).

State	**Statute Text**	**Forensic DNA phenotyping practiced?**
Prohibit obtaining information about physical traits or predisposition for disease		
Indiana	"The information contained in the Indiana DNA data base may not be collected or stored to obtain information about human physical traits or predisposition for disease." IND. CODE § 10-13-6-16 (2023).	Yes
New Mexico	"The information contained in the DNA identification system **database** shall not be collected, stored, or released for the purpose of obtaining information about physical characteristics, traits, or predisposition for a disease or mental illness or behavior and shall not serve any purpose other than those specifically allowed by the DNA Identification Act." N.M. STAT. ANN. § 10.14.200.11(F) (2023).	Yes
Rhode Island	"DNA samples and DNA records collected under this chapter shall never be used under the provisions of this chapter for the purpose of obtaining information about physical characteristics, traits or predispositions for disease." 12 R.I. GEN. LAWS § 12-1.5-10(5) (2023).	Yes
Wyoming	"Only DNA records which directly relate to the identification characteristics of individuals shall be collected and stored in the state DNA database. The information contained in the state DNA database shall not	Yes

	be collected or stored for the purpose of obtaining information about physical characteristics, traits or predisposition for disease and shall not serve any purpose other than those stated in W.S. 7-19-402(a). The submitting agency may maintain control of the DNA records it develops." WYO. STAT. ANN. § 7-19-404(c) (2023).	
Prohibit identification of medical or genetic conditions		
Florida	"The analyses of DNA samples collected under this section shall be used only for law enforcement identification purposes or to assist in the recovery or identification of human remains or missing persons and may not be used for identification of any medical or genetic condition." FLA. STAT. § 943.325(13)(b) (2023).	Yes
Louisiana	"Except as otherwise provided in R.S. 15:612(C), the tests to be performed on each DNA sample shall be used only for law enforcement identification purposes or to assist in the recovery or identification of human remains from disasters or for other humanitarian identification purposes, including identification of missing persons." LA. STAT. ANN. § 15:611(C) (2023).	Yes
Michigan	"DNA samples provided under this act shall not be analyzed for identification of any medical or genetic disorder." MICH. COMP. LAWS § 28.175a(2) (2023).	Unknown
Nevada	"A forensic laboratory shall not use any biological specimen, DNA profile or DNA record for the purpose of identification of any medical or genetic disorder." NEV. REV. STAT. § 176.09173(3) (2023).	Yes

South Dakota	"Analyses of DNA samples obtained pursuant to this chapter are not authorized for identification of any medical or genetic disorder." S.D. CODIFIED LAWS § 23-5A-17 (2023).	Unknown
Utah	"(1) The bureau shall: . . . (e) ensure that the DNA identification system does not provide information allowing prediction of genetic disease or predisposition to illness." UTAH CODE ANN. § 53-10-406(1)(e) (West 2023) (effective May 4, 2022).	Yes
Vermont	"Analysis of DNA samples obtained pursuant to this subchapter is not authorized for identification of any medical or genetic disorder." VT. STAT. ANN. tit. 20, § 1937(b) (2023) (effective Apr. 29, 1998).	Unknown
Permits identification of physical traits or predisposition for disease for criminal investigations		
Texas	"The information contained in the DNA database may not be collected, analyzed, or stored to obtain information about human physical traits or predisposition for disease unless the purpose for obtaining the information is related to a purpose described by this section." TEX. GOV'T CODE ANN. § 411.143(d) (West 2023) (effective Sept. 1, 2005). One permitted purpose is for criminal investigations. TEX. GOV'T CODE ANN. § 411.143(a)–(c) (West 2023).	Yes