ESII ELECTION SYSTEMS INTEGRITY INSTITUTE

A PILOT STUDY

Irreconcilable Differences: Over 200,000 Mail Ballots With Mismatched Signatures Counted Without Being Reviewed ("Cured") in Maricopa

First Study to Calculate Signature Matching Rates to Provide a Quantitative Framework for Assessing Signature Verification of Mail Ballots

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S.M. Visual Studies, M.I.T. Media Laboratory
S.M. Mechanical Engineering, M.I.T.
Ph.D. Biological Engineering, M.I.T.

Study Completed: January 14, 2022
Presented to AZ Senate Liaison: January 16. 2022
Final Report: February 20, 2022
Presentation to Public: February 22, 2022

Delivered to:

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President of the Senate
Arizona State Senate
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AUTHOR'S BIO

Dr. Shiva Ayyadurai, MIT PhD, S.M.M.E., S.M.V.S., S.B.E.E., the inventor of email and polymath, holds four degrees from MIT, is a world-renowned engineer, systems scientist, inventor and entrepreneur. He is a Fulbright Scholar, Lemelson-MIT Awards Finalist, India's First Outstanding Scientist and Technologist of Indian Origin, Westinghouse Science Talent Honors Award recipient, and a nominee for the U.S. National Medal of Technology and Innovation. He holds multiple patents, is the author of twenty books, and has published original research, in leading peer-reviewed high-impact scientific journals including *IEEE, IJPRAI, Nature Neuroscience, CELL Biophysical Journal,* that have received thousands of citations. He has started seven successful high-tech companies, received numerous industry awards, consults for Global 2000 organizations and government, and has been invited to present Keynote and Distinguished lectures at leading institutions such as NSF, NIH, FDA, Harvard, and at MIT, where he delivered the Presidential Fellows Lecture.[1]

In 1978, as a 14-year-old, he was recruited as a Research Fellow by the University of Medicine and Dentistry of New Jersey (UMDNJ), in Newark, NJ after graduating with Honors from a special program in Computer Science at the Courant Institute of Mathematical Science at NYU. At UMDNJ, he invented email – ***the system*** as we know it today – when he was the first to convert the old-fashioned *interoffice paper-based mail system* consisting of the Inbox, Outbox, Memo (To:, From:, Date:, Subject:, Cc:, Bcc:), Attachments, Folders, etc. into its electronic equivalent by writing 50,000 lines of code to create a software system, which he named "Email," – a term never used before in the English language – and went on to be awarded the first U.S. Copyright *TXu 111-775* for "EMAIL, COMPUTER PROGRAM FOR ELECTRONIC MAIL SYSTEM" recognizing him as the inventor of email at a time when Copyright was the only legal mechanism to protect software inventions. Only in 1994 did the Federal Circuit recognize software as a "digital machine" allowing for software patents. Email is not the simple exchange of text messages. Dr. Shiva has never claimed to be the inventor of electronic messaging, which predates email - the system that he created in 1978.[2,3]

Recognizing his talents in software programming, UMDNJ gave him the opportunity to conduct medical research focused on developing pattern recognition classification methods for categorization of sleep signature patterns from babies with Sudden Infant Death Syndrome (SIDS). His research was published in IEEE and presented at the IEEE-EMBS conference in Espoo, Finland. Since that time and for more than forty years, his research and development efforts in academia and industry have been focused in the field of pattern recognition classification systems, systems science, and development of large-scale computational systems for analysis of diverse signals and signatures across a range of industries: biology and medicine, engineering (e.g. aeronautical, civil, mechanical, electrical), banking, finance, and, government, as well as across a diversity of applications including handwriting recognition of courtesy amounts on bank checks, automatic analysis and classification of electronic documents e.g. email, ultrasonic and radar wave signature classification for non-destructive evaluation (NDE), signals analysis of Tadoma

[1]Dr. Shiva Ayyadurai, Biography and Curriculum Vitae, https://vashiva.com/about-va-shiva-ayyadurai/
[2]Facts on the invention of email, https://www.inventorofemail.com/thefacts/
[3]The Man Who Invented Email, TIME, https://techland.time.com/2011/11/15/the-man-who-invented-email/

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AUTHOR'S BIO (CONT.)

feature identification, biomarker analysis for determining signatures of efficacy for multi-combination therapies, image analysis for cardiology, and signal detection of fluid flow anomalies in fluidized bed reactors.

He earned a Bachelors in Electrical Engineering and Computer Science, a Masters in Mechanical Engineering, and another Masters in Visual Studies from the MIT Media Laboratory. In the midst of his PhD research in 1993, where he aimed to create a generalized platform – Information Cybernetics – for pattern recognition, he won an industry-wide competition sponsored by the White House, Executive Office of the President, to automatically analyze and classify President Clinton's email, resulting in his developing EchoMail® - a platform for automatic classification of electronic documents –, and subsequently launching EchoMail, Inc., a company that grew to nearly $200 million in market valuation. EchoMail today applies its technologies across a diversity of applications.

In 2003, he returned to MIT complete his doctoral work in systems biology in the department of Biological Engineering where he developed CytoSolve®, a scalable computational systems biology platform for mathematically modeling the whole cell. Following his PhD, Dr. Shiva was selected for a Fulbright Fellowship returning him to India where he discovered the systems theoretic basis of eastern systems of medicine resulting in Systems Health®, a new educational program that provides a scientific foundation for integrative medicine. In 2012, Dr. Shiva launched CytoSolve, Inc. with the aim of modeling complex diseases and biomolecular processes to discover multi-combination medicines. His efforts led to CytoSolve earning an FDA allowance for a multi-combination therapy for pancreatic cancer in a record eleven months, developing innovative nutraceutical products, and garnering numerous industry and academic partnerships.

As an educator dedicated to the field of systems science and systems thinking, Dr. Shiva pioneered Systems Visualization, a course he taught at MIT to graduate and undergraduate students, which integrated systems theory, narrative story telling, metaphors, and data science to provide a pedagogy for visualization of complex systems. He founded the International Center for Integrative Systems, a research and educational institution and home to Innovation Corps and R.A.W./C.L.E.A.N. Food Certified, for broader applications of systems science.

Dr. Shiva has appeared in The MIT Technology Review, TIME, The Wall Street Journal, New York Times, NBC News, USA Today and other major media. Dr. Shiva was named Top 40 Under 40 in the Improper Bostonian. He continues his passion for entrepreneurialism as Managing Director of General Interactive to incubate, mentor and fund new startups in various areas including healthcare, media, biotechnology, information technology, to name a few.

Dr. Shiva is a member of Sigma-Xi, Eta Kappa Nu, and Tau Beta Pi.

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A Publication of the Election Systems Integrity Institute

The Election Systems Integrity Institute ("ESII") is dedicated to providing independent research and infrastructure to support Election Systems Integrity. This publication documents the work completed by EchoMail, Inc., which was commissioned by the Arizona State Senate to perform the work in this study.

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Executive Summary

Key Items for Attorney General & AZ Senate to Consider

- First study to calculate Signature Matching Rates and to provide a quantitative framework for assessing Signature Verification of early voting mail ballots (EVBs)
- In Maricopa County, 1,911,918 EVBs were received and counted
- The County reported no more than 25,000 of these ballots (1.3%) had signature mismatches and required review ("curing"); and of the 25,000, 2.3% in post-curing – 587 – were confirmed signature mismatches
- A Pilot Study recruited three novices and three experts (forensic document examiners) to calculate signature matching rates on the same sample of 499 EVB envelopes. The purpose of this Pilot Study is to determine if results warrant any further investigation
- All six reviewers who were presented images of EVB envelopes to evaluate if the signatures on those envelopes matched with genuine signatures on file concurred 60 of the 499 (12%) EVBs as signature mismatches
- Based on this Study, over 204,430 early EVBs should have been cured vs. the 25,000 that the County actually cured; and, using the County's 2.3% post-curing rate, 5,277 EVBs should have been disallowed
- Though this Pilot Study is compelling on its own, an expanded study is warranted.

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Background

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What Is Signature Verification?

- Signature verification is a multi-step process aimed to verify a signature based on review of two signatures side-by-side: one being genuine, the other being questionable.

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- Early voting mail ballot envelopes are scanned to produce images

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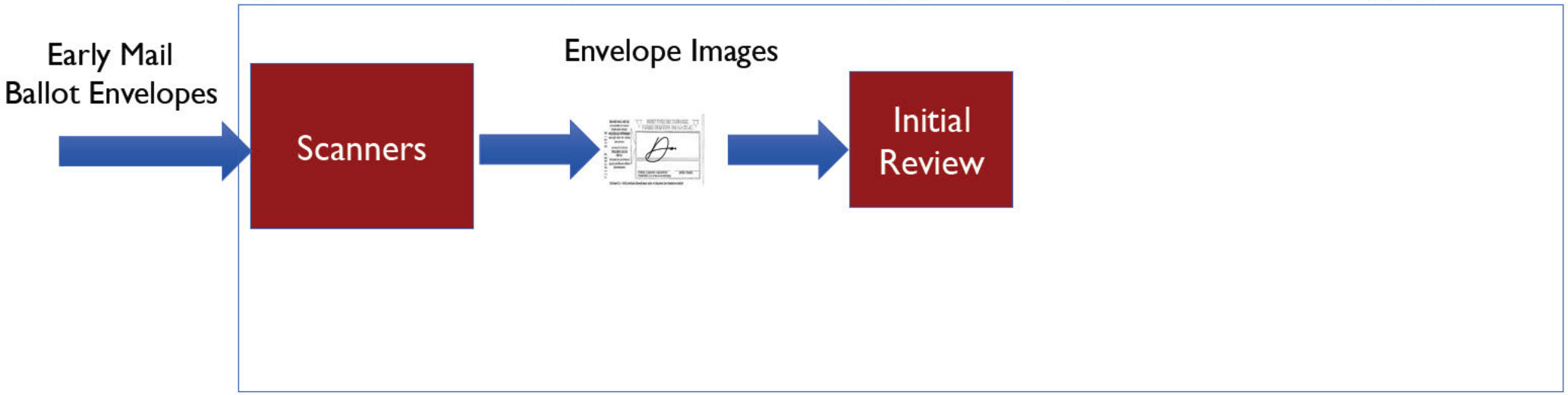

- Early voting mail ballot envelopes are scanned to produce images
- Step 1: Initial Review (4-30 seconds) using County's procedures. Reviewer compares signature on envelope with genuine signature on file to determine: *Match* or *No Match*

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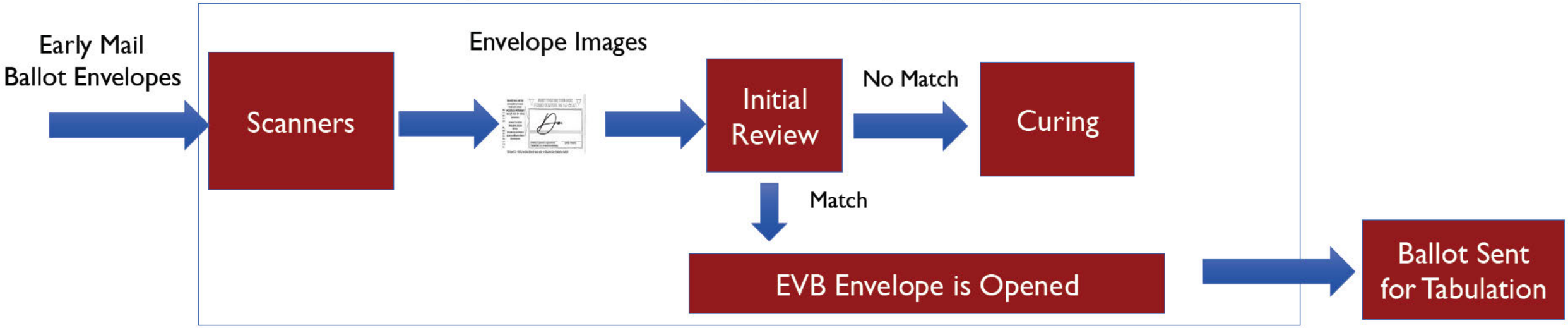

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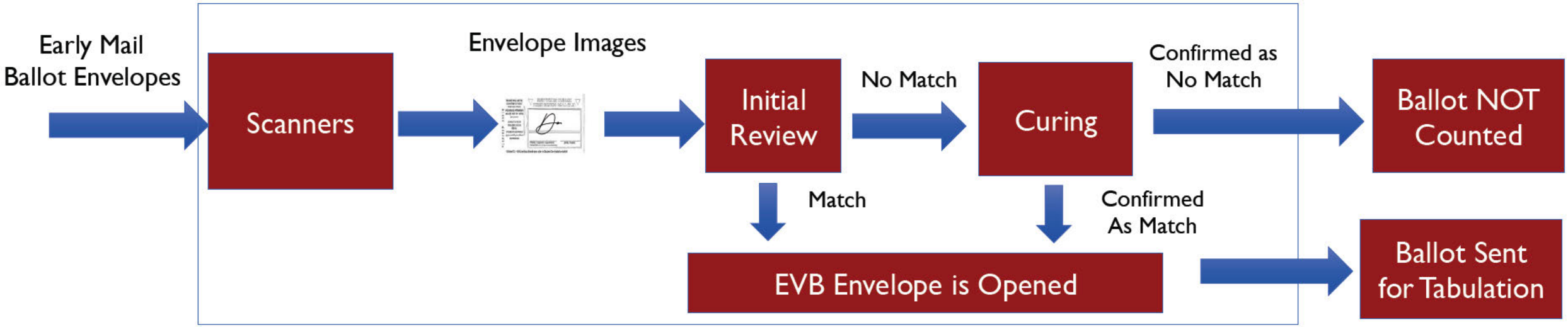

- Early voting mail ballot envelopes are scanned to produce images
- Step 1: Initial Review (4-30 seconds) using County's procedures. Reviewer compares signature on envelope with genuine signature on file to determine: *Match* or *No Match*
- Step 2: Full Review – "Curing" (3+ minutes). Investigation including attempts to contact voter to determine if the signature is indeed a Match or No Match

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Signature Verification In Maricopa County

2020 General Election

Total Number of Early Voting Mail Ballots	**1,911,918**
Maximum Number That Were Cured by Maricopa	**25,000**
Percent of Total Early Voting Mail Ballots	1.31%
Confirmed Signature Mismatches (EVBs NOT Counted)	**587**
Percent of Total Early Voting Mail Ballots	0.031%
Percent of Total Cured	2.3%

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Methodology

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Methodology

- **Step 1**: Select a representative statistical sample from population of 1,911,918 early voting mail ballots (EVBs)
  - Confidence Level: 95%
  - Margin of Error: ±4.4%
  - **Sample size: 499**

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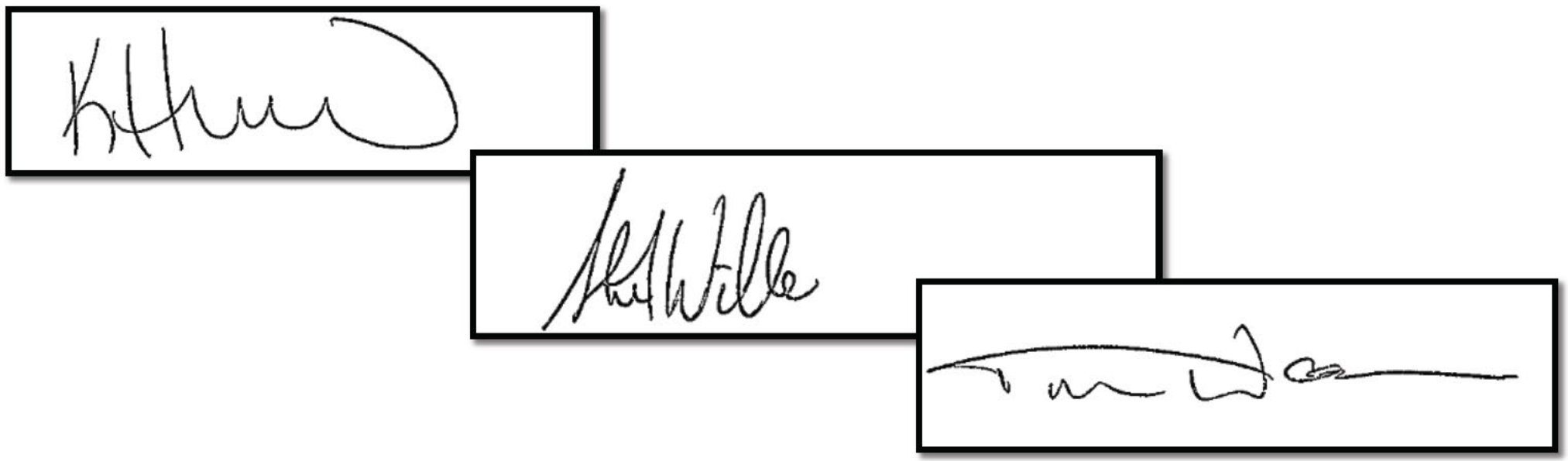
Methodology

- **Step 2**: Organize a data set of 499 envelope signatures by random sampling of Maricopa's 1.9M+ EVB envelope images:



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Methodology

- **Step 3**: Create data set of the 499 genuine signatures that match names and addresses of the 499 envelope signatures:
  - Sourced from Maricopa publicly accessible Deeds repository
  - Extracted 499 Deeds' signatures
  - It should be noted that the source of the genuine signatures used in this study are likely different from the source of genuine signatures used by the County; however, experts in forensic document examination share that signatures from a Deeds repository may likely be more valid given such signatures are Notarized.
    - **If the County wished to provide their genuine signatures for these 499 samples, the Study can be updated.**

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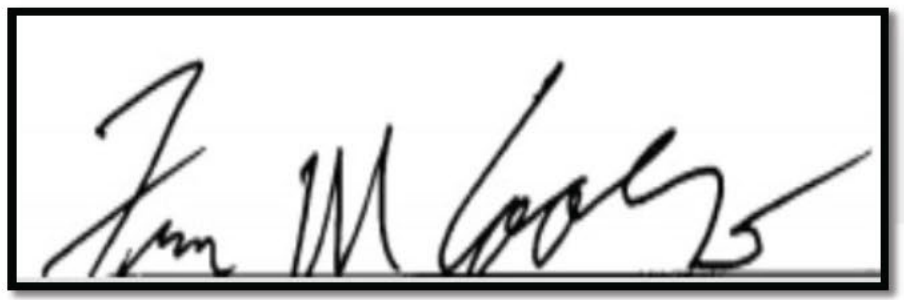
Methodology

- **Step 4**: Create pairwise dataset of 499 envelope signatures and 499 genuine signatures

Signature on Mail Ballot Envelope

Genuine Signature



- Reviewer is given TWO choices: ***Match*** or ***No Match***

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Experiment I

Novices: non-Forensic Document Examiners (non-FDEs)

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Experiment I

Novices: non-FDEs (non-Forensic Document Examiners)

- Three non-FDEs selected and instructed to follow County's guide

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Experiment I

Novices: non-FDEs

- Three non-FDEs selected and instructed to follow County's guide
- Presented 499 pairwise images to review – no more than 30 sec
- Recorded each non-FDE's **Match** and **No Match** selections
- Calculate each non-FDE's **Mismatch** rate
  - Calculate average of all THREE non-FDE's Mismatch rates
- Calculate non-FDE's **Pooled Consensus*** Mismatch rate

*"Pooled Consensus Mismatch" denotes the number of signatures that a set of reviewers agree are mismatched.

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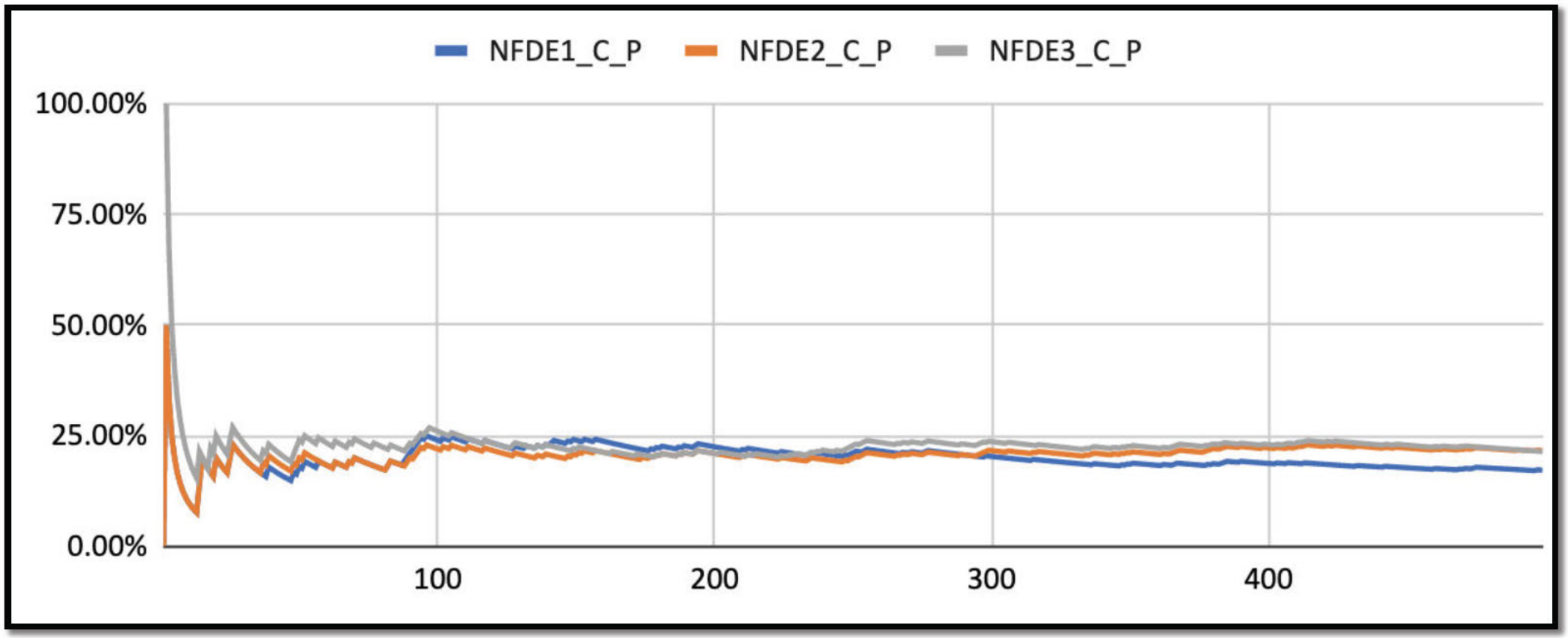
Results of Experiment I

Temporal Mismatch Rate of Individual Non-FDEs



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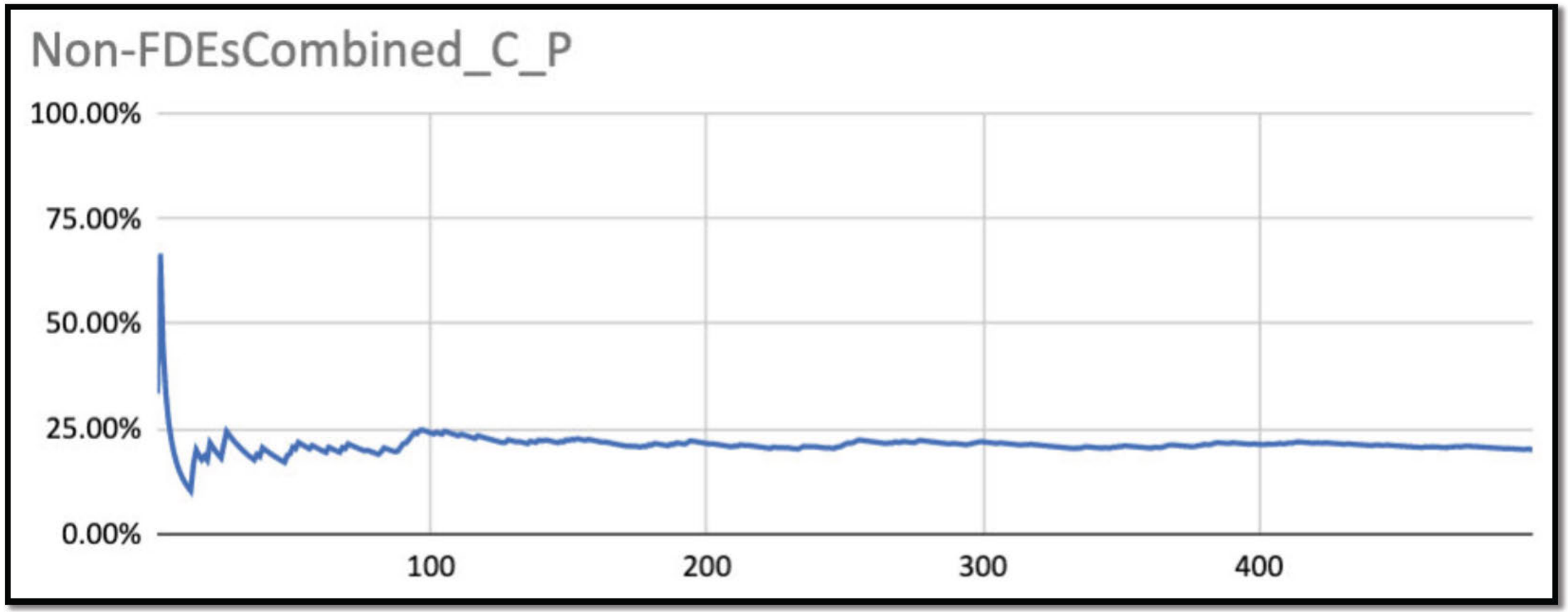
Results of Experiment I

Average Temporal Mismatch Rate of All Three Non-FDEs: 20.1%



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Results of Experiment I

Average Mismatch Rate of All Three Non-FDEs: 20.1%

NON-FDE	Match	No Match	Mismatch Rate (%)
Non-FDE-1	413	86	17.2%
Non-FDE-2	391	108	21.6%
Non-FDE-3	392	107	21.4%
		Average	**20.1%**

20.1% non-FDE Average Signature Mismatch Rate

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Results of Experiment I

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20.1% non-FDE Average Signature Mismatch Rate

1.3% Maricopa Signature Mismatch Rate

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Results of Experiment I

Pooled Consensus of Three Non-FDES

"Pooled Consensus" means how many times did ALL three Non-FDEs, for a pair of signatures, conclude it was a Match, a No Match, or did NOT have agreement.

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Results of Experiment I

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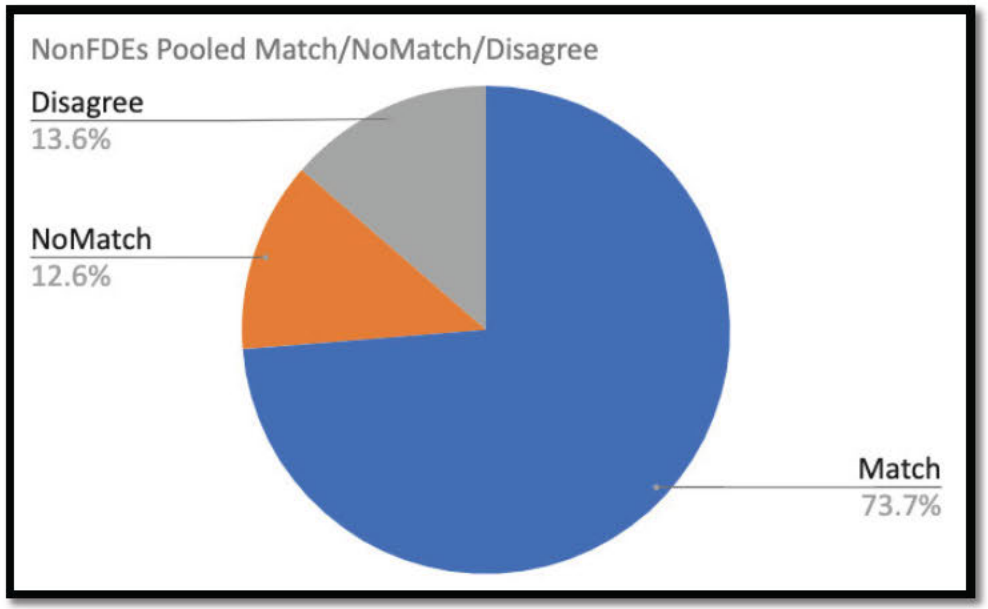

Assessments	Counts	Rate (%)
Match	368	73.7%
No Match	**63**	**12.6%**
Disagree	68	13.6%

12.6% non-FDE Pooled Consensus Signature Mismatch Rate

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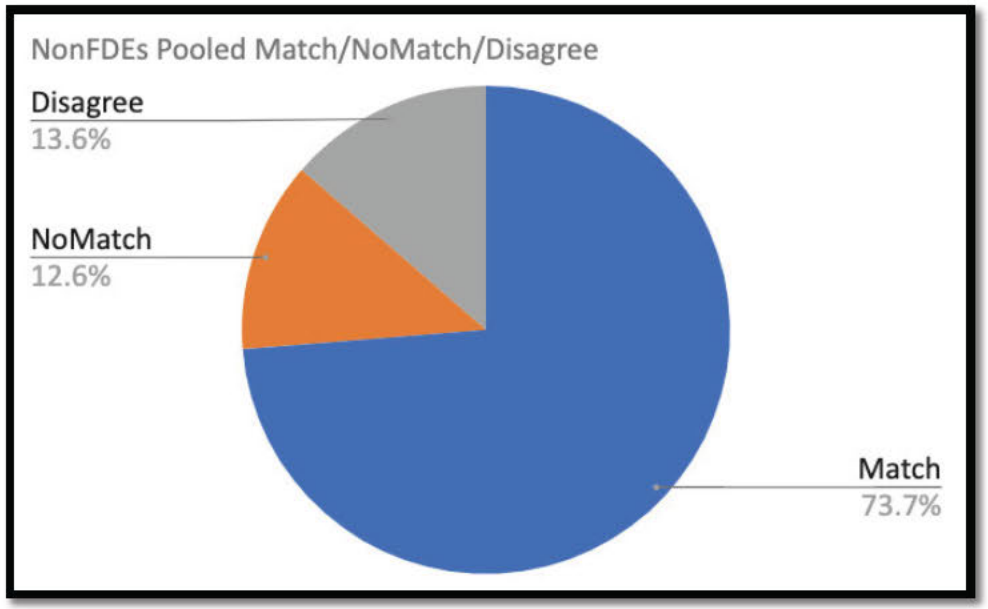
Results of Experiment I

Pooled Consensus of Three Non-FDES



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1.3% Maricopa Signature Mismatch Rate

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Experiment I Summary

Minimum of 240,902 EVBs Should Have Been Cured.

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Experiment I Summary

Minimum of 240,902 EVBs Should Have Been Cured.

Total Number of Early Voting Mail Ballots	**1,911,918**
Maricopa Mismatch Rate Before Curing	**1.31%**
Maximum Number of EVBs Actually Cured	25,000
Non-FDEs Average Mismatch Rate	**20.1%**
Number of EVBs That Should Have Been Cured	384,295
Non-FDEs Pooled Consensus Mismatch Rate	**12.6%**
Number of EVBs That Should Have Been Cured	240,902

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Experiment II

Experts: Forensic Document Examiners (FDEs)

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Experiment II

Experts: Forensic Document Examiners (FDEs)

- Three FDEs were recruited and asked to apply their training
- Presented 499 pairwise images to review – no more than 30 sec
- Recorded each FDE's **Match** and **No Match** selections
- Calculate each FDE's **Mismatch** rate
  - Calculate average of FDE's Mismatch rates
- Calculate FDE's **Pooled Consensus** Mismatch rate

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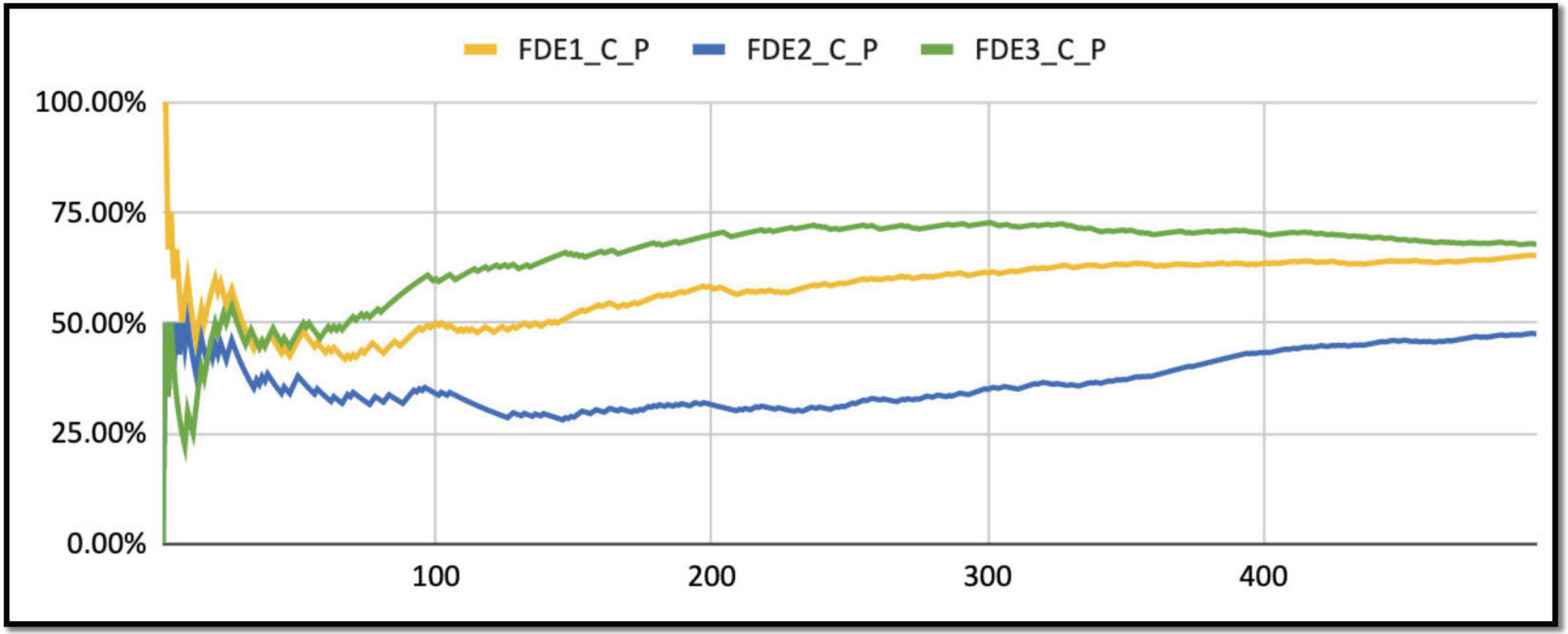
Results of Experiment II

Mismatch Rate of Individual FDEs



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Results of Experiment II

Average Temporal Mismatch Rate of All Three Non-FDEs: 60.3%

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Results of Experiment II

Average Mismatch Rate of All Three Non-FDEs: 60.3%

NON-FDE	Match	No Match	Mis-Match Rate (%)
FDE-1	173	326	65.3%
FDE-2	262	237	47.5%
FDE-3	160	339	67.9%
		Average (FDE)	**60.3%**

60.3% FDEs Average Signature Mismatch Rate

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60.3% FDEs Average Signature Mismatch Rate

1.3% Maricopa Signature Mismatch Rate

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Results of Experiment II

Pooled Consensus of Three FDES

"Pooled Consensus" means how many times did ALL three FDEs, for a pair of signatures, conclude it was a Match, a No Match, or did NOT have agreement.

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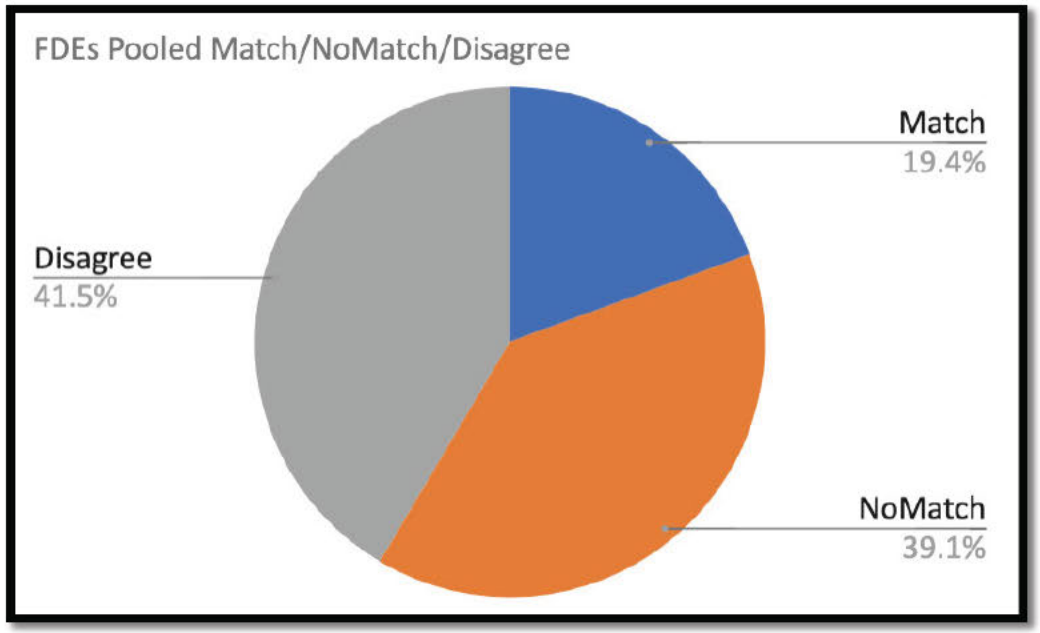
Results of Experiment II

Pooled Consensus of Three FDES



Assessments	Counts	Rate (%)
Match	97	19.4%
No Match	**195**	**39.1%**
Disagree	207	41.5%

39.1% FDEs Pooled Consensus Signature Mismatch Rate

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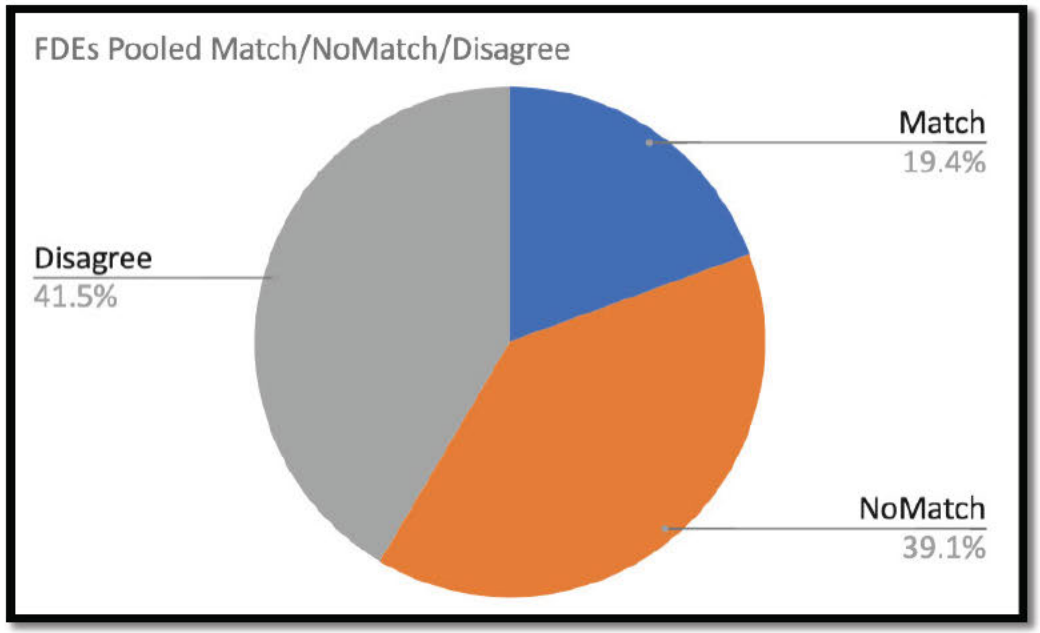
Results of Experiment II

Pooled Consensus of Three FDES



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1.3% Maricopa Signature Mismatch Rate

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Experiment II Summary

Minimum of 747,560 EVBs Should Have Been Cured

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Experiment II Summary

Minimum of 747,560 EVBs Should Have Been Cured

Total Number of Early Voting Mail Ballots	**1,911,918**
Maricopa Mismatch Rate Before Curing	**1.31%**
Maximum Number of EVBs Actually Cured	25,000
FDEs Average Mismatch Rate	**60.3%**
Number of EVBs That Should Have Been Cured	1,152,887
FDEs Pooled Consensus Mismatch Rate	**39.1%**
Number of EVBs That Should Have Been Cured	747,560

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Combined Analysis of Novices & Experts

Novices(non-FDEs) & Experts (FDEs)

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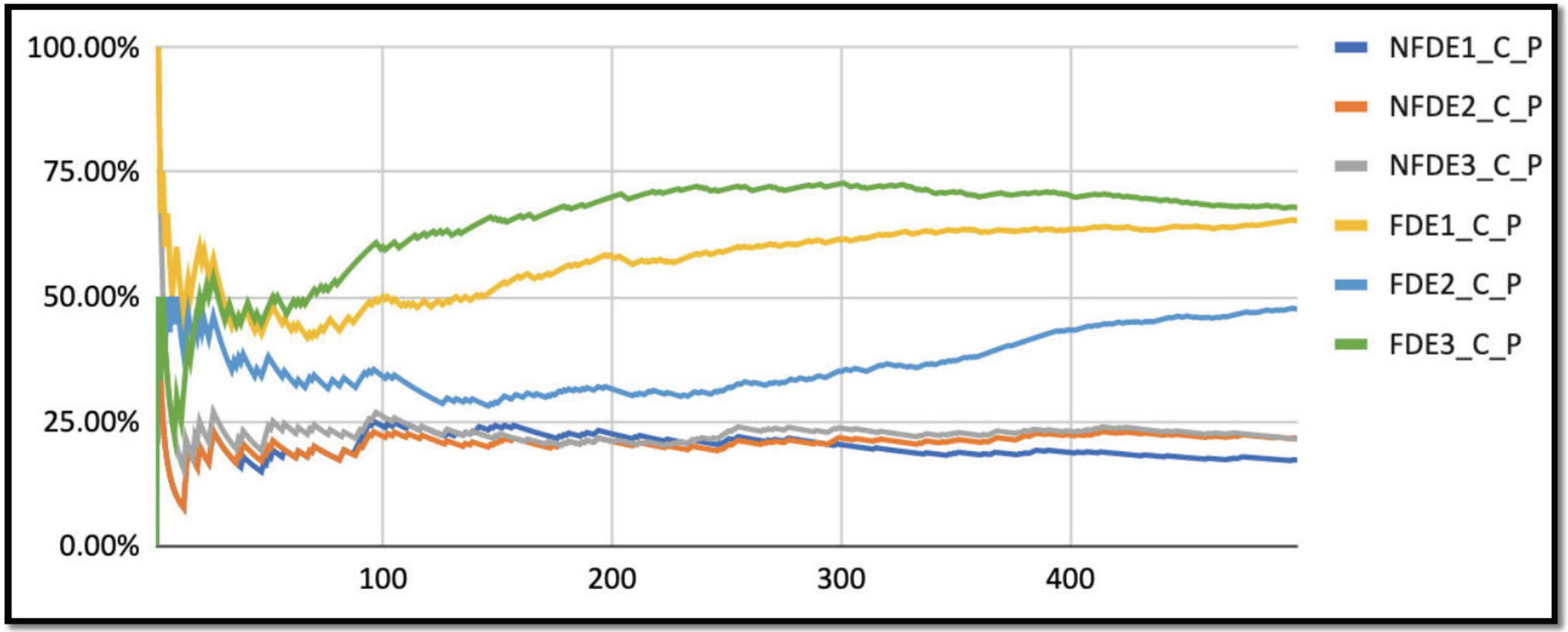
Combined Analysis of Novices & Experts

Temporal Mismatch Rate of Individual non-FDEs and FDEs



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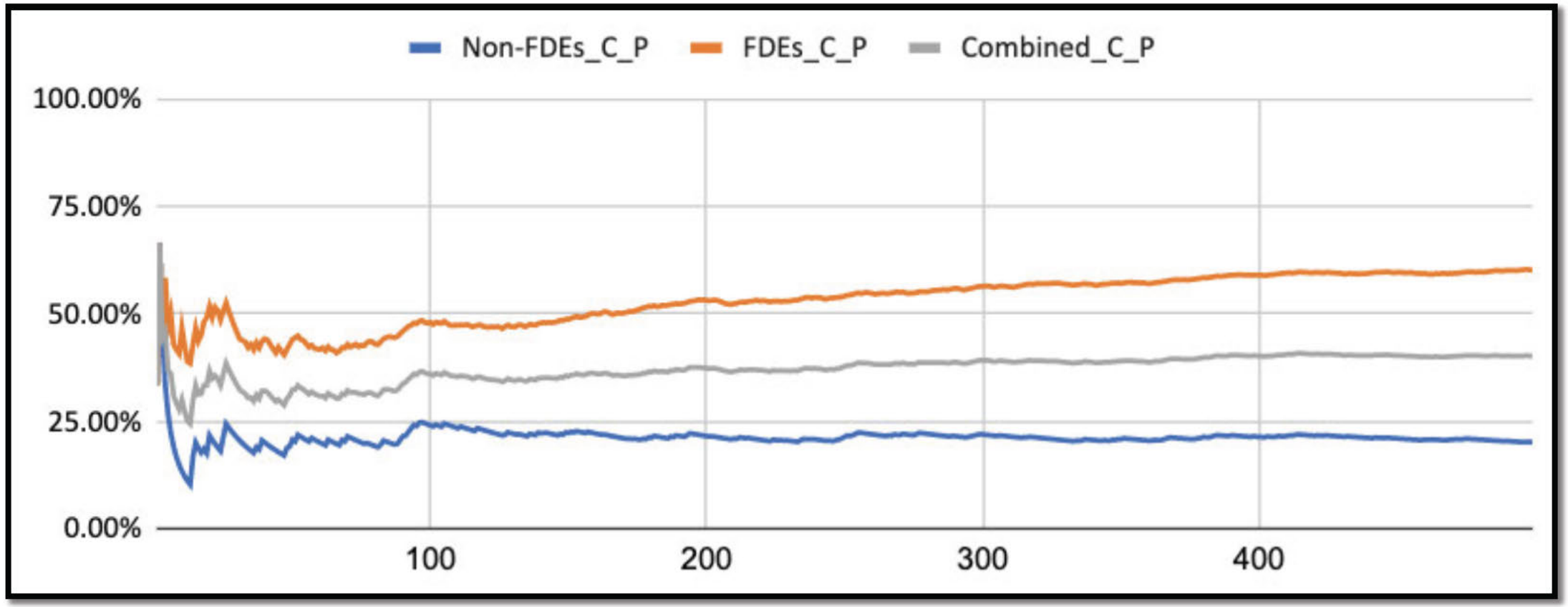
Combined Analysis of Novices & Experts

Temporal Average Mismatch Rate of non-FDEs, FDEs, and All



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Combined Analysis of Novices & Experts

Average Mismatch Rate of All 6 non-FDEs and FDEs: 40.2%

BOTH non-FDEs & FDES	Match	No Match	Mismatch Rate (%)
Non-FDE-1	413	86	17.2%
Non-FDE-2	391	108	21.6%
Non-FDE-3	392	107	21.4%
FDE-1	173	326	65.3%
FDE-2	262	237	47.5%
FDE-3	160	339	67.9%
		Average	**40.2%**

40.2% Average Combined Signature Mismatch Rate

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Combined Analysis of Novices & Experts

Average Mismatch Rate of All 6 non-FDEs and FDEs: 40.2%

BOTH non-FDEs & FDES	Match	No Match	Mismatch Rate (%)
Non-FDE-1	413	86	17.2%
Non-FDE-2	391	108	21.6%
Non-FDE-3	392	107	21.4%
FDE-1	173	326	65.3%
FDE-2	262	237	47.5%
FDE-3	160	339	67.9%
		Average	**40.2%**

40.2% Average Combined Signature Mismatch Rate

1.3% Maricopa Signature Mismatch Rate

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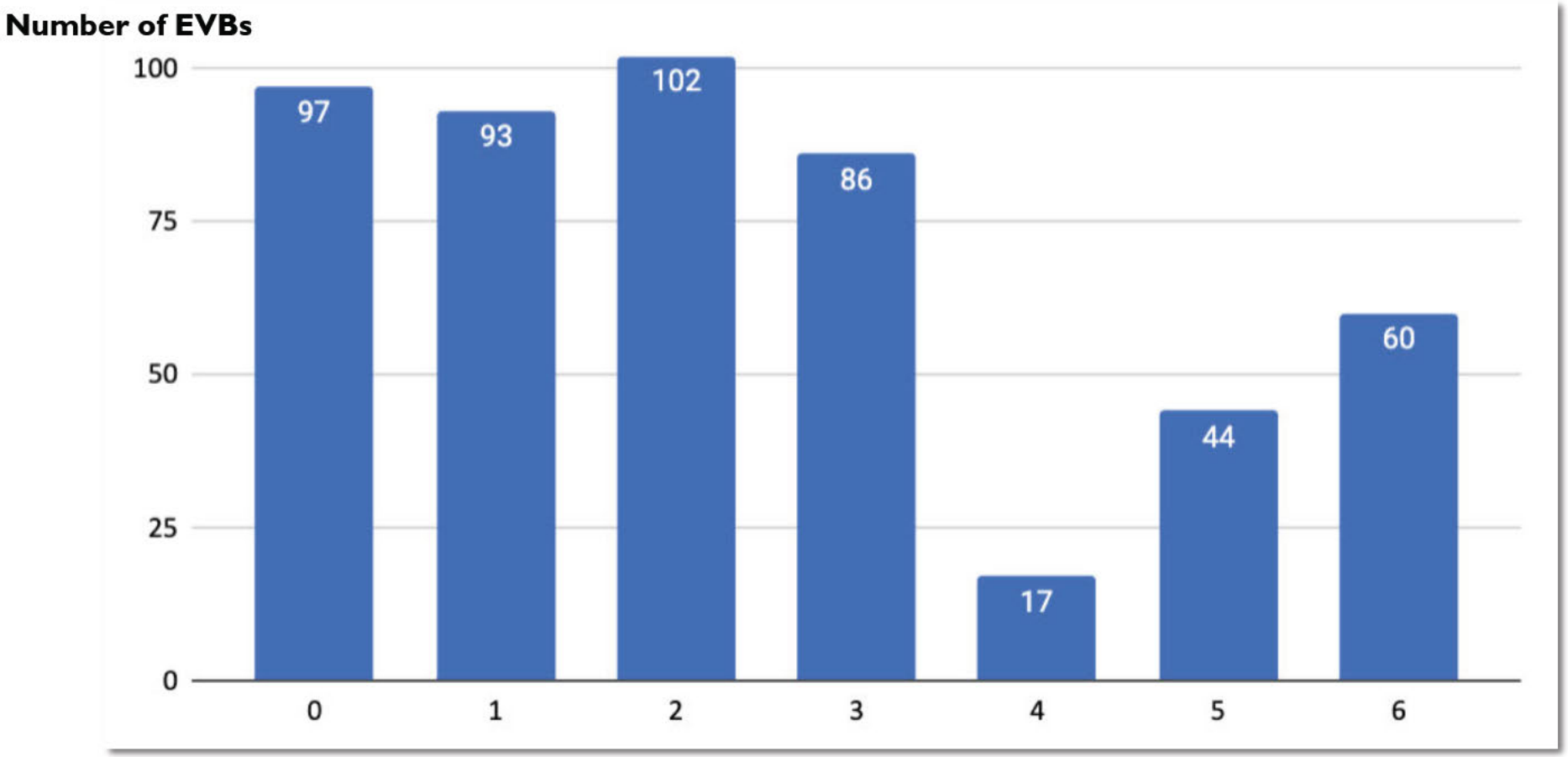
Combined Analysis of Novices & Experts

Determining Pooled Consensus Rates of ALL THREE non-FDEs and THREE FDEs



Reviewers Agreeing on Common Mismatches

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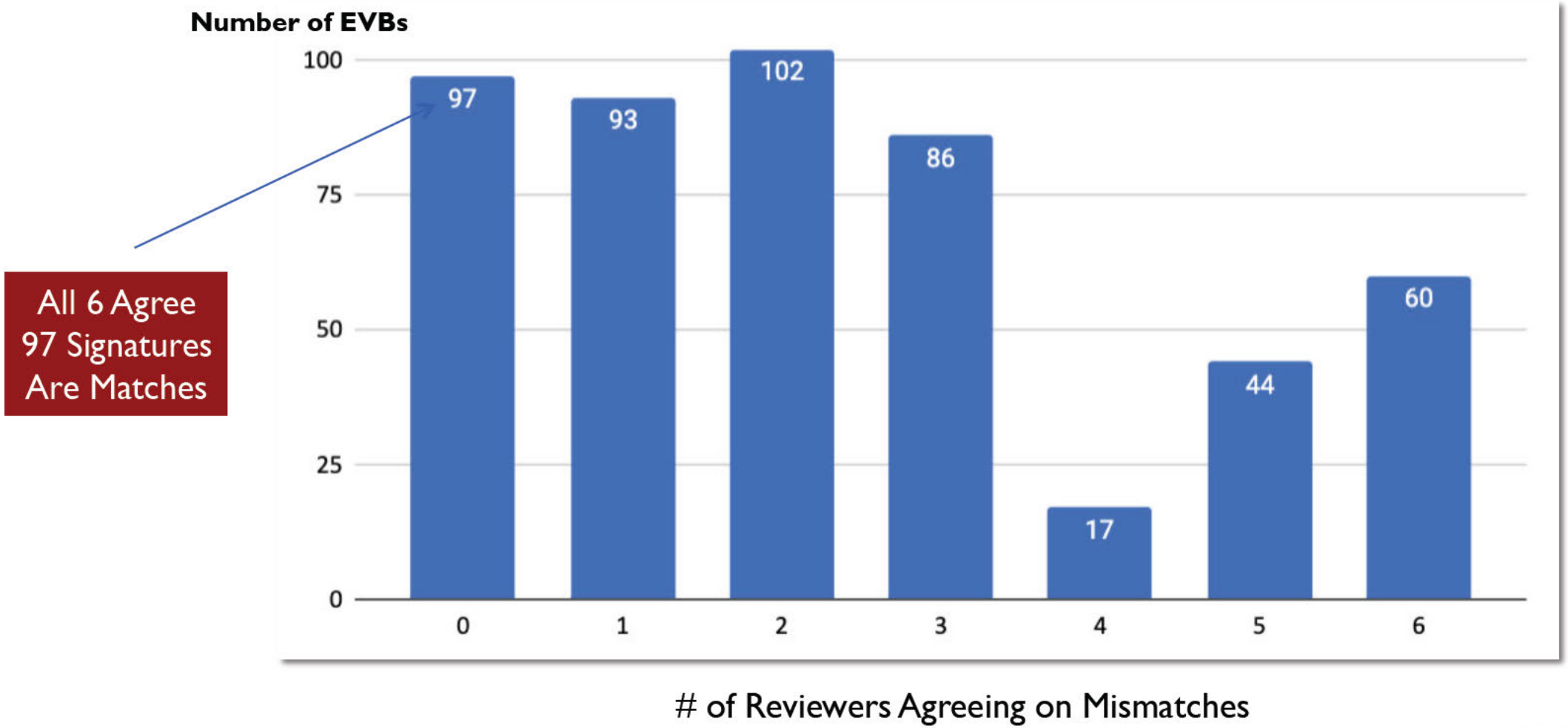
Combined Analysis of Novices & Experts

Determining Pooled Consensus Rates of ALL THREE non-FDEs and THREE FDEs



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Examples of Signature Matches

Agreed Upon by ALL 3 Novices AND 3 Experts

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Signature Matches Agreed Upon By ALL 3 Novices AND 3 Experts

Signature on Mail Ballot Envelope

Genuine Signature

ALL 6 Reviewers Agreed as "MATCH"

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Signature Matches Agreed Upon By ALL 3 Novices AND 3 Experts

Signature on Mail Ballot Envelope

Genuine Signature

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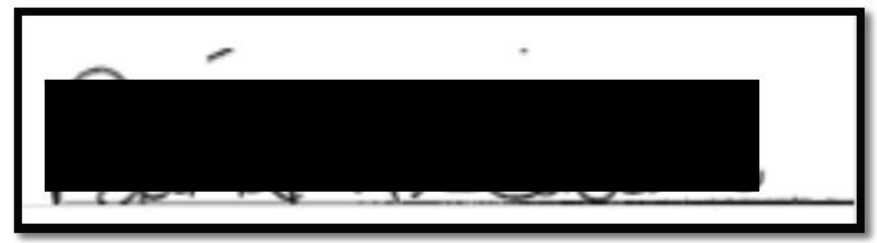

ALL 6 Reviewers Agreed as "MATCH"

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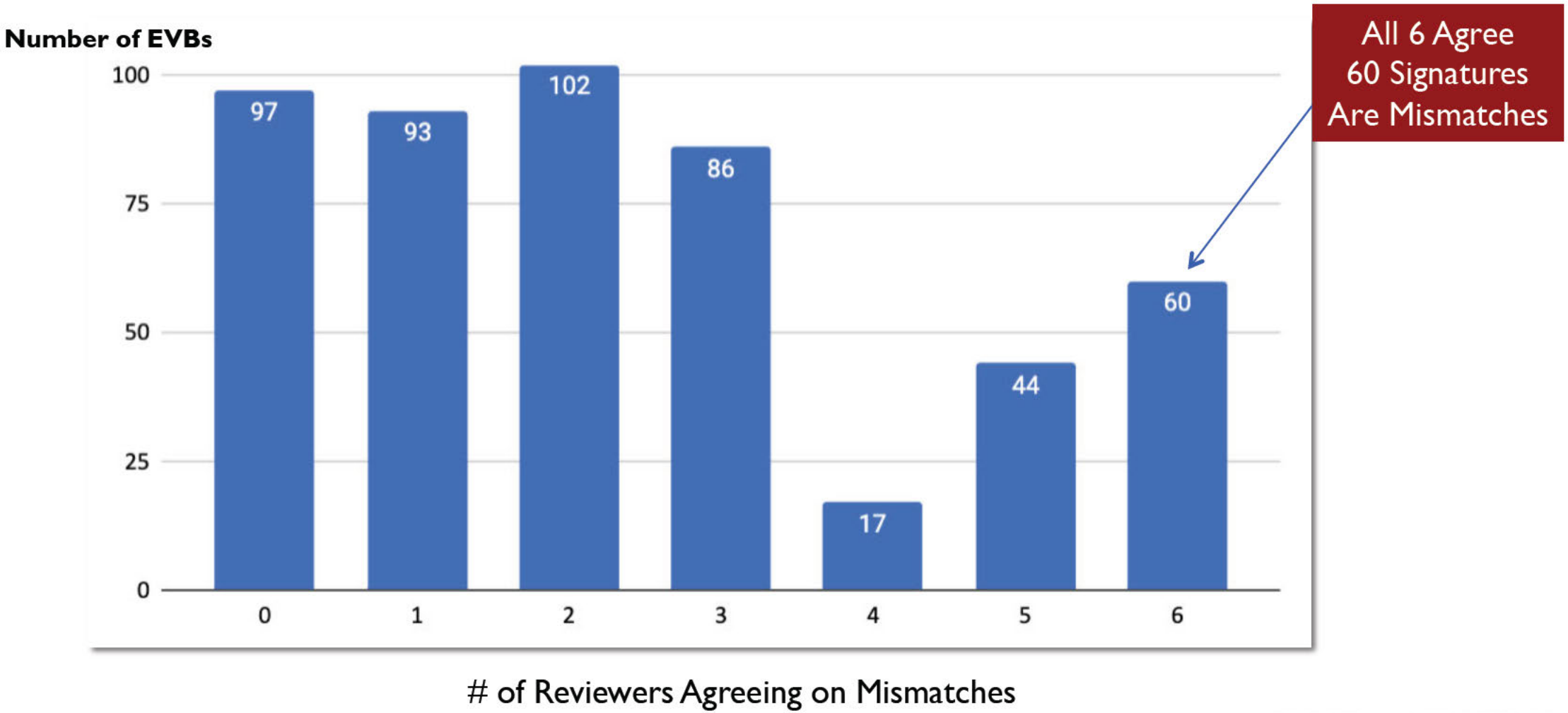

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Examples of Signature Mismatches

Agreed Upon by ALL 3 Novices AND 3 Experts

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Signature Matches Agreed Upon By ALL 3 Novices AND 3 Experts

Signature on Mail Ballot Envelope

Genuine Signature

ALL 6 Reviewers Agreed as "NO MATCH"

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Signature Matches Agreed Upon By ALL 3 Novices AND 3 Experts

Signature on Mail Ballot Envelope

Genuine Signature

ALL 6 Reviewers Agreed as "NO MATCH"

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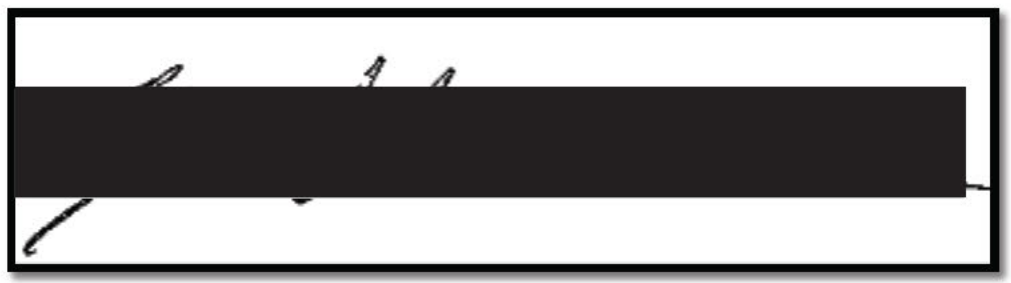
Signature Matches Agreed Upon By ALL 3 Novices AND 3 Experts

Signature on Mail Ballot Envelope



Genuine Signature

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Signature Matches Agreed Upon By ALL 3 Novices AND 3 Experts

Signature on Mail Ballot Envelope

Genuine Signature

ALL 6 Reviewers Agreed as "NO MATCH"

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Signature Matches Agreed Upon By ALL 3 Novices AND 3 Experts

Signature on Mail Ballot Envelope

Genuine Signature

ALL 6 Reviewers Agreed as "NO MATCH"

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Calculating Signature Mismatch Rate

From Common Mismatches of Novices & Experts

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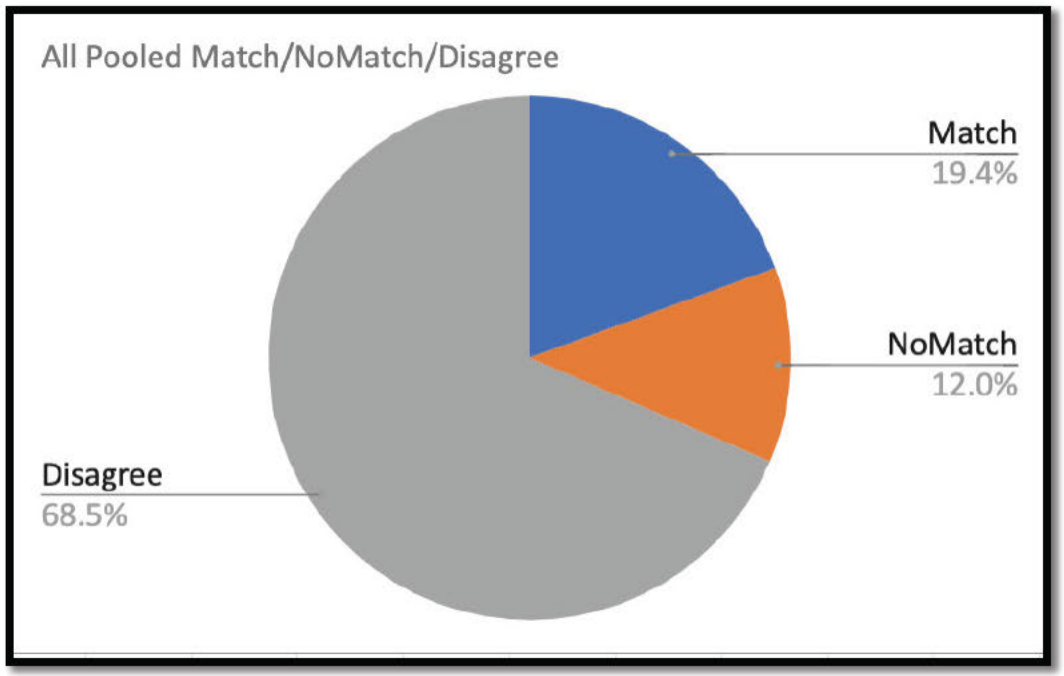
Combined Analysis of Novices & Experts

Determining Pooled Consensus Rates of ALL THREE non-FDEs AND THREE FDEs



Assessments	Counts	Rate (%)
Match	97	19.4%
No Match	**60**	**12.0%**
Disagree	342	68.5%

12.0% Pooled Signature Mismatch Rate

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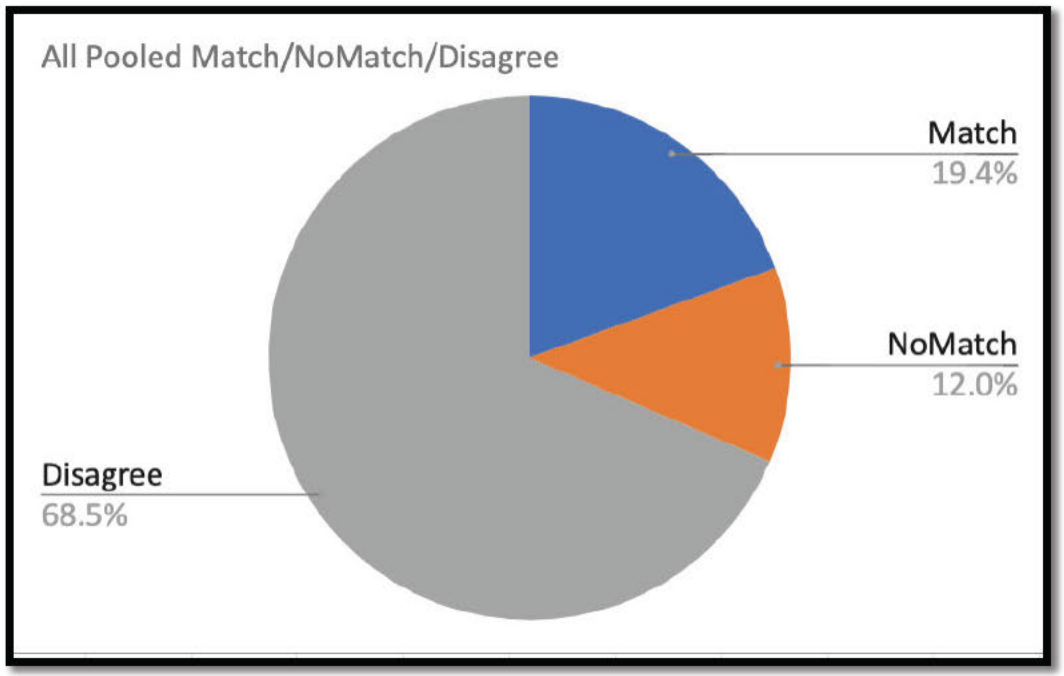
Combined Analysis of Novices & Experts

Determining Pooled Consensus Rates of ALL THREE non-FDEs AND THREE FDEs



Assessments	Counts	Rate (%)
Match	97	19.4%
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12.0% Pooled Signature Mismatch Rate

1.3% Maricopa Signature Mismatch Rate

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Combined Analysis Summary

Minimum of 229,430 EVBs Should Have Been Cured

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Combined Analysis Summary

Minimum of 229,430 EVBs Should Have Been Cured

Total Number of Early Voting Mail Ballots	**1,911,918**
Maricopa Mismatch Rate Before Curing	**1.31%**
Maximum Number of EVBs Actually Cured	25,000
COMBINED Average Mismatch Rate	**40.2%**
Number of EVBs That Should Have Been Cured	768,591
COMBINED Pooled Consensus Mismatch Rate	**12.0%**
Number of EVBs That Should Have Been Cured	229,430

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Discussion

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Discussion

Summary Analysis

- In Maricopa County, 1,911,918 early voting mail ballots (EVBs) were received and counted
- The County reported 1.31% of all EVBs or 25,000 EVBs had signature mismatches requiring curing
- The County reported that 0.031% of all EVBs or 587 EVBs were confirmed mismatches post-curing

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Discussion

Summary Analysis

Measures	Mismatch Rate (%)	EVBs to be Cured	Maximum Cured by Maricopa	EVBs to be Disallowed Post-Curing	Maricopa Disallowed Post-Curing
Non-FDEs Average	20.1%	384,295	25,000	8,839	587
Non-FDEs Pooled Consensus	12.6%	240,902	25,000	5,541	587
FDEs Average	60.3%	1,152,884	25,000	26,516	587
FDEs Pooled Consensus	39.1%	747,560	25,000	17,194	587
ALL Average	40.2%	768,591	25,000	17,678	587
All Pooled Consensus	12.0%	229,430	25,000	5,277	587

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Discussion

Summary Analysis

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Discussion

Summary Analysis

- In Maricopa County, 1,911,918 early voting mail ballots (EVBs) were received and counted
- The County reported 1.31% of all EVBs or 25,000 EVBs had signature mismatches requiring curing
- The County reported that 0.031% of all EVBs or 587 EVBs were confirmed mismatches post-curing
- As the results show, a minimum of 229,430 ±4.4% EVBs should have been cured
- If we subtract the 25,000 the County DID cure, then 204,430 ±4.4% EVBs should have been cured
- Based on this Pilot's minimum signature mismatching rate of 12% and the County's post-curing rate of 2.3%, 5,277 ballots would have been disallowed.

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Conclusion

- First study to quantify the Signature Mismatching Rates during Signature Verification of EVBs
- In Maricopa County, 1,911,918 early voting mail ballots (EVBs) were received and counted
- The County reported no more than 25,000 of these ballots (1.3%) had signature mismatches and required review ("curing"); and of the 25,000, 2.3% in post-curing – 587 – were confirmed signature mismatches
- A Pilot Study recruited three novices and three experts (forensic document examiners) to calculate signature matching rates on the same sample of 499 EVB envelopes
- All six reviewers were presented images of EVB envelopes to evaluate if the signatures on those envelopes matched with genuine signatures on file
- All six reviewers in the Study concurred 60 of the 499 (12%) EVBs as signature mismatches
- Based on this Study, 204,430 EVBs should have been cured vs. 25,000 that the County actually cured; and, using the County's 2.3% post-curing rate, over 5,277 EVBs should have been disallowed
- While the Study is compelling, an expanded study is warranted to confirm the findings of this Study

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A PILOT STUDY

Irreconcilable Differences – Over 200,000 Mail Ballots With Mismatched Signatures Counted Without Being Reviewed ("Cured") in Maricopa:

First Study to Calculate Signature Matching Rates to Provide a Quantitative Framework for Assessing Signature Verification of Mail Ballots

Dr. Shiva Ayyadurai, MIT Ph.D.

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S.M. Visual Studies, M.I.T. Media Laboratory
S.M. Mechanical Engineering, M.I.T.
Ph.D. Biological Engineering, M.I.T.

Study Completed: January 14, 2022
Presented to AZ Senate Liaison: January 16. 2022
Final Report: February 20, 2022
Presentation to Public: February 22, 2022

Delivered to:

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