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Public beliefs about the accuracy and importance of forensic evidence in the United States

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ABSTRACT

Recent advances in forensic science, especially the use of DNA technology, have revealed that faulty forensic analyses may have contributed to miscarriages of justice. In this study we build on recent research on the general public's perceptions of the accuracy of 10 forensic science techniques and of each stage in the investigation process. We find that individuals in the United States hold a pessimistic view of the forensic science investigation process, believing that an error can occur about half of the time at each stage of the process. We find that respondents believe that forensics are far from perfect, with accuracy rates ranging from a low of 55% for voice analysis to a high of 83% for DNA analysis, with most techniques being considered between 65% and 75% accurate. Nevertheless, respondents still believe that forensic evidence is a key part of a criminal case, with nearly 30% of respondents believing that the absence of forensic evidence is sufficient for a prosecutor to drop the case and nearly 40% believing that the presence of forensic evidence – even if other forms of evidence suggest that the defendant is not guilty – is enough to convict the defendant.

1. Introduction

The collection and use of forensic evidence have increasingly become vital to criminal investigations and prosecutions [22]. Forensic evidence has been valuable in establishing key elements of a crime, identifying people who were at the crime scene, exonerating innocent defendants, and corroborating victim testimonies [10]. However, recent advances in forensic science, especially the use of DNA technology, have revealed that faulty forensic analyses have contributed to miscarriages of justice. This has led to calls to strengthen scientific foundations of the analysis and presentation of forensic evidence by identifying the types of errors that could occur, describing key concepts that clarify the sources of error, and developing strategies for how to reduce error in forensic analyses [34,35]). Given the importance of recognizing the limitations of forensic science, and the potential devastating consequences that the misuse of forensic science can yield, research on perceptions of forensic science is an important endeavor.

In the United States (US) criminal justice system, jurors are expected to determine guilt based upon relevant facts of a case. While there are attempts to minimize biases in juries, there remains concern that jurors may still hold preconceptions that influence their decisions. In recent years, one such concern relates to juror perceptions of forensic science. Dubbed the "*CSI* effect", this term refers to how television crime shows may affect juror expectations and perceptions, including creating unreasonable expectations among jurors; elevating forensic evidence over other forms of evidence; and perceiving forensic evidence as infallible, objective and free from human judgement or error [2,25,29]. While there have been multiples studies examining the influence of television crime shows on perceptions of forensic evidence or testimony, to the authors' knowledge, only one study to date [29] has directly examined public beliefs about how accurate various forensic techniques are and the role that human judgements plays in the forensic science investigation process. Ribeiro et al. [29] surveyed 101 members of the public in Australia to measure general perceptions of human judgement and error involved in forensic techniques and did not find support for a *CSI* effect. In fact, their findings suggest that participants believed forensic science was relatively error-prone, involved an appreciable amount of human judgement, and that different forensic techniques yielded different levels of accuracy.

While Ribeiro et al.'s [29] study provides important insights into perceptions of human judgement and error in the context of forensic science, the study was based upon an Australian sample, so it may not immediately translate to the American context. The Australian legal system is similar to that of the US in many ways (e.g., presumption of innocence, requirements to ensure voluntariness of confessions), but there are also crucial differences. These differences include whether

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illegally obtained evidence is excluded from trial, who has the power to determine charges (prosecutors in the United States but police officers and other criminal investigative units in Australia) as well as plea bargaining and sentencing practices [21,37]. Differences between the US and Australian criminal justice system more broadly necessitate an investigation into US perceptions of forensic science. The US serious crime rate, as well as its high rate of incarceration, give the criminal justice system a much broader role in public life in the United States than in Australia because it affects a far greater percent of the population. Moreover, while there have been acknowledgements of national reports outlining forensic science reliability concerns and errors among legal practitioners in the United States, other countries, such as Australia, have been slower to conduct independent inquiries into the validity and reliability of claims made in forensic science [9]. While there is some evidence that this situation is changing [20], there are differences between the two countries in the knowledge of legal practitioners regarding the fallibility of forensic science, and it is unknown whether such differences also exist among in the general public. Differences of opinion between the two populations could also be attributed to cultural differences distinct from institutional differences between the criminal justice systems of each nation. A sociological comparison of attitudes towards forensic science between Australia and the United States would be an interesting contribution to this discussion. However, this article will focus on documenting the differences in opinion rather than on attempting to explain their cause. As such, it is important to understand the extent to which Ribeiro et al.'s [29] findings are generalizable.

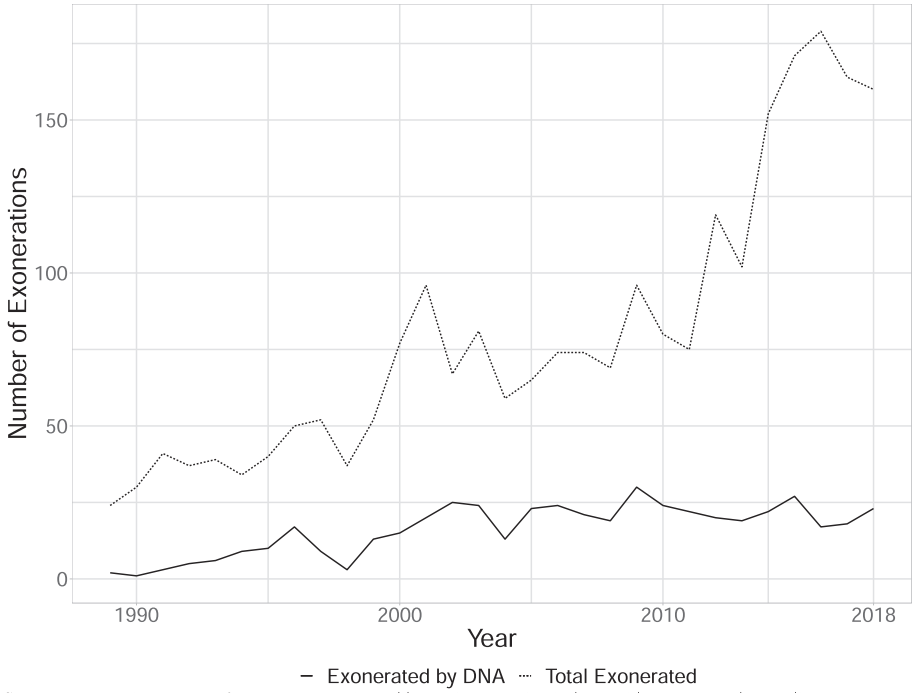
1.1. Miscarriages of justice

1.1.1. Exonerations

With the increased use and application of forensic science over the years come increasing concern over the misuse of forensic evidence. The inappropriate use or application of forensic science has been estimated to contribute to almost a quarter of all wrongful convictions nation-wide [27]. In a study by Garrett and Neufeld [12], 60% of cases involved unsubstantiated or misleading forensic testimonies. There is an increasing trend in the annual number of exonerations in the United States (Fig. 1) and the number of exonerations due, at least in part, to inaccurate or misleading forensic evidence (Fig. 2) over the last two decades. These concerns are especially troubling when considering potential racial disparities in exoneration rates, with evidence that Blacks are exonerated at higher rates than Whites [31]. In an effort to review, rectify, and prevent cases of wrongful convictions, a growing number of prosecutorial offices are establishing conviction integrity units (CIUs). One tool that CIUs use to review cases involves the reexaminiation of forensic evidence. In 2018, CIUs have been responsible for 58 exonerations, some of which involved official misconduct such as falsifying forensic results [23]. Ultimately, flawed interpretations or misrepresentation by forensic analysts may negatively impact jury perceptions. This has augmented concerns about how forensic science may contribute to miscarriages of justice, and how pre-existing and contextual biases may play a role in how forensic evidence is perceived [16].

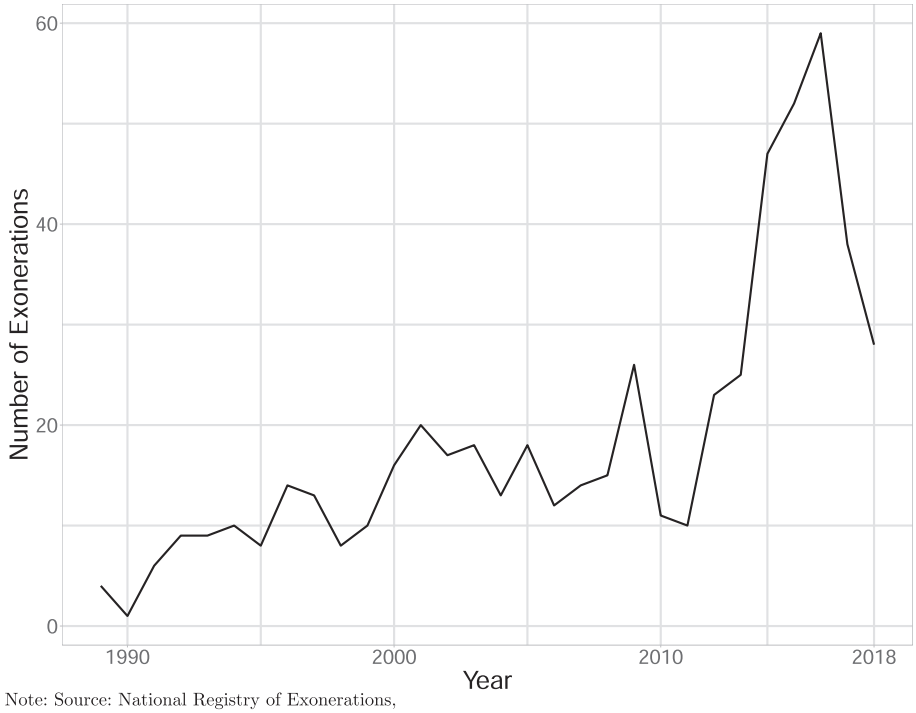
1.1.2. Community relations

The consequences of erroneous use or interpretation of forensic techniques may disproportionately affect racial and ethnic minorities in the US, who have disproportionate contact throughout the criminal justice system. In recent years, there has been a spotlight on compounding racial tensions between criminal justice system and minority community members in particular. This has manifested in several ways, including the establishment and growth of the Black Lives Matters movement as well as the elections of progressive prosecutors. These efforts are part of a growing movement seeking to redress perceived wrongs that certain groups disproportionately experience within the criminal justice system. Indeed, perceptions of injustice or unfair treatment by the criminal justice system can undermine the perception of legitimacy of the system as a whole. This could foster distrust of certain types of evidence during trials, such as police or eyewitness testimony, if they are perceived as biased or subjective. If forensic evidence is seen as more objective than other types of evidence, there may be more reliance on these measures to avoid the flaws of other evidence types. However, there remain ethical concerns over various



Source: National Registry of Exonerations, http://www.law.umich.edu/special/exoneration/Pages/browse.aspx

Fig. 1. Annual Number of People Exonerated in the United States.



Note: Source: National Registry of Exonerations, http://www.law.umich.edu/special/exoneration/Pages/browse.aspx.

Fig. 2. Annual Number of People Exonerated in the United States Whose Conviction Included Inaccurate or Misleading Forensic Evidence.

aspects of forensic evidence. The existence of DNA databases, for example, may be helpful in identifying DNA recovered from a crime scene if the perpetrator has a record in the DNA database already. However, Amankwaa [1] and Machado and Silva [19] identify key risks that may occur with the improper use of these databases, including exacerbating existing stigmas and stereotypes due to the over-representation of certain social and racial groups in criminal DNA databases, as well as mistaken identification resulting from erroneous interpretations of the information provided by DNA profiles that can lead to wrongful convictions.

1.2. How frequently is forensic evidence used?

A study analyzing forensic science collection practices by law enforcement in Denver and San Diego found that in nearly all homicide cases, at lest one type of forensic evidence – primarily DNA, fingerprints, evidence from the weapon used, or hair – was collected [22]. For the crime of sexual assault, over half of cases in Denver and two-thirds of cases in San Diego collected forensic evidence, with the vast majority being DNA or hair. Forensic evidence collection is far less common in other crimes with under one-third of burglaries in San Diego and < 16% of burglaries in Denver having a single type of forensic evidence collected. The cases which do collect evidence primarily collect fingerprints. While forensic evidence is primarily collected in cases of violent crime, there is growing interesting in collecting forensic evidence – in particular DNA evidence - at property crime scenes, vastly expanding the scope of cases in which forensic evidence may play a role [30]. Recent advances in technology have reduced the cost of DNA collection and dramatically increased the speed at which DNA collected at a crime scene can be compared against a DNA registry [14]. This had led to even small police agencies collecting forensic evidence for violent as well as property crimes. As forensic evidence becomes increasingly common in criminal cases, research on how the general public – specifically, jury-eligible members of the public – respond to this evidence is crucial to understanding how they will behave when presented with forensic evidence in a criminal trial.

1.3. Levels of accuracy from literature reports

While differences in public opinion about the validity and reliability of forensic methods are of intrinsic interest to policy makers and other researchers, it is also important to compare public opinion to the findings of scientific experts about the validity and reliability of these methods. At the time of this writing, the authors are not aware of a single standard by which the claims of forensic science can be evaluated. However, a number of studies have been conducted in the US to determine the validity and reliability of forensic methods. In this study, we will compare our survey findings to the expert opinions articulated in one prominent report from the United States, the President's Council of Advisors on Science and Technology (PCAST) report [35]. We use this report because it is a recent, careful analysis by independent scientists of the validity and reliability of a number of forensic methods.

There is no simple score from zero to 100 for the levels of accuracy of forensic methods. However, there are available reviews about whether these methods are valid, meaning accurate and consistent. In the United States, Rule 702 (Fed. R. Evid. 702), from the Federal Rules of Evidence sets the standards of admissibility of scientific evidence in court.[2] Among other sections, it states that the expert may testify if the testimony is "the product of reliable principles and methods" and "the expert has reliably applied the principles and methods to the facts of the case." PCAST called these two standards *foundational validity* and *validity as applied*, respectively. The report reviewed the research about seven forensic disciplines (DNA single-source and simple mixture, DNA complex mixture, bitemarks, fingerprint, firearms, footwear, and hair). The reviewed research consisted of studies of error rates of the methods, and consistency if an analyst performs the analysis at different times and if different analysts perform the same analysis with the same

[2] While Rule 702 establishes federal standards for the admissibility of evidence, the standards within states are somewhat more heterogeneous. States typically adopt the Frye (Frye v. United States, 293F. 1013 (D.C. Cir. 1923)) or Daubert (Daubert v. Merrell Dow Pharmaceuticals, 509 U.S. 579 (1993) at 592) standards, which are based on precedents from case law.

materials. While PCAST is not the only review that could be used for comparison (for instance, The National Research Council [34] could be used as well), we chose it because it is a recent, careful analysis by independent scientists that provides a clear and supported categorization of the validity and reliability of a number of forensic methods. It is left as future work to use other reviews for comparison with our survey responses.

PCAST [35] determined that, out of the seven disciplines reviewed, only DNA analysis of single-source simple mixture (two sources where one source is known) samples and latent fingerprint analysis were foundationally valid. DNA analysis of complex-mixture samples with probabilistic genotyping and firearms analysis were not foundationally valid, but had the potential to be so with current and future research. DNA analysis of complex-mixture samples with combined-probability-of-inclusion (CPI) methods, bitemark analysis, footwear analysis, and microscopic hair comparison were not foundationally valid and/or were missing serious research.

Regarding the techniques from our survey not included in the PCAST report, there is no single review that gives a definitive answer about their foundational validity. The National Research Council [34] concluded that for bloodstain analysis, "some experts extrapolate far beyond what can be supported" and "the uncertainties associated with bloodstain pattern analysis are enormous." For gunshot residue, there are no studies of which the authors are aware that estimate the accuracy or evaluate the validity of the technique, and thus they have not been demonstrated to be foundationally valid. For voice analysis, there is a recent review of the scientific validity of various methods by the Scientific Literature Working Group [36]. The review does not make a final conclusion about the scientific validity, but it does show promising research on the accuracy of various methods. For this study we leave voice analysis unranked in terms of actual accuracy. Toxicology is multidiscplinary since it uses analytical chemistry, pharmacology, and clinical chemistry to aid medical or legal investigation of death, poisoning, and drug use. There are studies of the accuracy of many of the methods used, so it should be considered foundationally valid. However, neither the National Research Council nor the PCAST present a careful review of its methodologies. Finally, while the current study includes brain imaging as a technique, it is not a traditional forensic discipline or a component of crime scene investigation. However, it has been offered as a potential method of gaining insight into individuals' psychological states after a suspect is in custody, and has been used as evidence in multiple phases of criminal trials by prosecutors and defense attorneys [6,7,13].

1.4. Current study

The current study aims to bridge the gap between the increasing importance of forensic evidence in criminal cases and the dearth of knowledge of the US public's view of that evidence. We do so by surveying members of the US public to assess their beliefs on the accuracy of forensic evidence and the process of collecting, analyzing, and reporting of such evidence. We approach this study with four hypotheses:

1. Respondents will have a high level of confidence in the forensic science investigation process as well as for the accuracy of each forensic science technique. Given the relatively high confidence found in Ribeiro et al.'s [29] Australian sample, we expect that our US sample will have a similar high degree of confidence in forensic science.
2. Respondents will overestimate the accuracy of forensic evidence. While determining the objective accuracy of forensic evidence is a difficult and ongoing process, we expect that respondents will perceive the evidence to be of a higher quality than supported by research.
3. Respondents will support the *CSI* effect by believing that what they see on fictional TV shows about forensic science reflects actual forensic science techniques and outcomes.
4. Forensic evidence will be given great weight in criminal trials and be considered a decisive factor in whether a defendant is considered guilty or not guilty. We expect that respondents will prioritize forensic evidence in criminal trials over other types of evidence, and consider its presence to be strong evidence that the defendant is guilty.

2. Method

2.1. Participants

This study utilized Amazon's Mechanical Turk, an online survey platform, to collect information about the general public's perceptions of various forensic science techniques. The survey consisted of 49 questions and took approximately 24 min to complete. Only Mechanical Turk users in the United States were eligible to take the survey. All surveys were collected between June 26th and 27th, 2019. Participants were financially compensated up to $1 for their participation. All study procedures were approved by the University of Pennsylvania's institutional review board. Users who agreed to take the survey were directed to a link on the Mechanical Turk website to the survey which was administered through the Qualtrics survey software.

In total, 180 people completed the survey. Two attention-check questions were used to determine whether responses were reliable. Following the introductory page explaining the purpose and topic of the survey, respondents were asked a multiple-choice question (the first attention-check question) on what the survey was about. Fifteen respondents chose an option other than "Forensic evidence." The second attention-check asked if the respondent had "ever been a victim of murder?" An additional 10 respondents said that they had. In total, 25 respondents failed the attention check and were dropped from the study analyses. Responses from the remaining 155 participants were used for the analyses.

Respondents varied in age from 19 to 70 with most respondents being in their 30s (Mean = 35.6, SD = 10.6). The majority of respondents identified as male (59%), 39% identified as female, and 2% identified as neither male nor female. Over two-thirds (70%) identified as White-only, 10% identified as Black-only, 6.5% identified as Asian or Pacific Islander, and 9% identified as Hispanic. The remaining respondents identified as mixed-race or as American Indians. This is similar to the United States population as a whole where 60.4% of residents are White-only, 13.4% are Black-only, and 5.9% are Asian-only, and 18% are Hispanic. These respondents are more educated than the United States general public. In the present sample, 87.2% have graduated high school, nearly the same as the 87.3% of the general public. However, approximately 52% had earned a four-year degree or higher in the sample compared to 31% in the entire United States. Twenty respondents (12.9% of the sample) had served on a jury, with 65% (13 respondents) of these being involved in a case that included forensic evidence.

The survey utilized in the current study is a modified version of the Ribeiro et al. [29] study (see Ribeiro et al. [29] for how to access their survey).

2.2. Forensic science investigation process

To understand public perceptions of the likelihood of an error occurring during the forensic science investigation process, we asked respondents "how likely is it that an error could occur" at each stage. The six stages of the forensic science investigation process are: collection, storage, testing, analysis, reporting, and presenting. The respondents' answers were on a slider from 0 to 100 with the default position set at 50.[3] Respondents

[3] Analyses were conducted in a separate pilot study to determine whether a default anchor of 0, 50, or 100 would affect participant responses. Results indicated that responses between the three anchors were similar on average, thus suggesting respondents were not influenced by the initial position of the anchor.

were required to select a value to proceed to the next question, even if they selected the value of 50. For each process, respondents were also asked "to what extent does the [process] involve human judgement?" with a 7-point Likert scale answer from N*one at all (1)* to *Entirely (7)*.

2.3. Forensic science techniques

Respondents were then asked how accurate they perceive each of 10 forensic science techniques to be and whether there was significant human judgement involved.[4] As with the forensic science investigation process questions, the accuracy was measured on a slider from 0 to 100 with the default position set to 50. We included 10 techniques or analyses in this survey: bloodstain pattern, brain imaging, DNA, dental, fingerprint, firearm and toolmark, footwear, gunshot residue, toxicology (e.g. urine, drugs), and voice analysis.

Eight of these techniques (all except for brain imaging and footwear analysis) were studied by Ribeiro et al. [29], allowing for a comparison of perceptions between US and Australian populations. In addition to the eight techniques shared with Ribeiro et al. [29], we included footwear analysis, since it is one of the primary methods in feature-comparison and is commonly used in forensic laboratories, and brain imaging because it has been used as evidence during criminal cases as a method of demonstrating defendants' mental states and capabilities. We decided not to include some of the techniques studied in Ribeiro et al. [29] (anthropological, document, faces, fire/explosives, geological materials, image, materials, and wildlife) because they were not included in reports that review the state of forensic science [35] and in the interest of focusing more heavily on feature-comparison methods.

Human judgement was measured by asking whether they believed there to be "key procedures that involve significant human judgement" in that forensic science technique. Respondents could answer *No*, *Yes*, or *Not Sure*.

2.4. CSI effect

The popularity of TV shows depicting forensic science such as *CSI* and *Law & Order* has led to concerns about a "*CSI* effect" where watchers believe that the shows accurately depict forensic science and use standards based on the show's inaccurate depictions as their basis for judging the validity of the techniques [29,5]. These shows often depict forensic science as infallible, nearly instantaneous, and entirely objective. If jurors do indeed base their opinion of forensic science on what is depicted on these shows, they may conclude that a piece of forensic evidence is more powerful than it actually is. Conversely, the lack of forensic evidence - which is found in nearly all crime scenes on these shows - may be seen as evidence that the defendant is not guilty.

Past studies of this topic primarily use TV viewing habits to measure whether watching these shows affects perceptions of forensic evidence [29,32,26]. This method has a number of limitations as it is unclear whether watching more of these shows reflects merely that the respondents watch more TV overall, if they are particularly interested in forensic evidence - and what other material they use to learn about forensic evidence – and only indirectly measures how watching these shows affects perceptions of forensic evidence. In this study we attempt to address the *CSI* effect directly by asking respondents how accurate they believe the "most accurate fictional show" and the "average fictional show" is in depicting forensic science. Respondents could choose from a 4-point Likert-scale from *Not Accurate at all* to *Very Accurate*, as well as *Not Sure*. As these shows are largely fictitious or a gross exaggeration of real forensic evidence techniques, asking respondents directly how accurate they believe these shows to be allows for a better measure of the CSI effect than previously evaluated [15].

[4] We did not define any of the forensic techniques to avoid biasing responses. As such, the results should be interpreted as baseline knowledge.

2.5. Importance of forensic evidence during criminal cases

Jurors may believe that there are substantial flaws in the accuracy of individual techniques or the forensic science investigation process yet may still be willing to accept forensic evidence presented at trial if they believe that only the strongest evidence - that which has avoided the concerns that they have for the evidence - will be presented. To assess this, we asked respondents how strongly they agreed with four statements about the usability and importance of evidence in criminal trials. These questions come from the Forensic Evidence Evaluation Bias Scale (FEEBS), a questionnaire designed and validated by Smith and Bull [32–33], to evaluate people's perceptions of forensic evidence.

1. Forensic evidence always provides a conclusive answer.
2. Forensic evidence always identifies the guilty person.
3. If no forensic evidence is recovered from a crime scene, then the prosecutor should drop the case.
4. If forensic evidence suggests a defendant is guilty, this should be enough to convict even if other evidence (e.g., eyewitness testimony, alibi) suggest otherwise.

3. Results

3.1. Forensic science investigation process

3.1.1. Estimates of error

Table 1 shows how prone to error respondents believe the forensic process to be. Columns (1–2) show the results from the current study with Column (1) showing the percent likelihood of an error occurring and Column (2) showing the cumulative chance of an error occurring at each consecutive stage of the process. Columns (4–5) follow this same pattern and show results from Ribeiro et al.'s [29] study of the general public in Australia. To allow easy comparison between the US and Australian results, the final three columns are the difference between US and Australian values.

At each stage in the forensic science investigation process, respondents believe there to be a high chance of an error occurring. The first stage, collection, was perceived to be the riskiest stage with a 56% chance of an error occurring. The least risky stage, reporting, fared a little better with a perceived 44% chance of an error occurring. The forensic science investigation process is considered to be rife with possibilities for errors, with respondents perceiving that an error could occur about half the time at each stage. The Australian sample believed that an error would occur about 40% of the time on average, approximately 10 percentage points lower than the American sample. For each stage, American respondents believed that an error was more likely to occur - with differences ranging from +2.82 for presenting to +13.26 for collection – than Australian respondents did.

3.1.2. Human judgement

For each stage in the forensic process, respondents were asked how much human judgement was involved in that stage. This question used a seven-point Likert-scale from *None at all* (1) to *Entirely* (7). Column (3) of Table 1 shows the mean respondent score. Respondents believed that there was a high level of human judgement involved at each stage, with all except two stages - storage at 4.65 and testing at 4.78 - having a score above 5. Because variables were nonnormally distributed, Kendall's tau-b correlations were run to examine the association between the likelihood of an error and the level of human judgement involved for each stage of the forensic process. There was a positive correlation between how likely an error could occur and how much human judgement was involved for all six stages: collection ($\tau_\beta = 0.363$, $p < .001$), storage ($\tau_\beta = 0.412$, $p < .001$), testing ($\tau_\beta = 0.289$, $p < .001$), analysis ($\tau_\beta = 0.229$, $p < .001$), reporting ($\tau_\beta = 0.350$, $p < .001$), and presentation ($\tau_\beta = 0.218$, $p < .001$). These correlational results suggest that respondents believe that people involved in

Table 1
Perceived Accuracy and Level of Human Judgement for Each Stage of the Forensic Science Process.

	US Sample			Australian Sample			US – Australian Difference		
Process Stage	Error	Cumulative Error	Human Judgement	Error	Cumulative Error	Human Judgement	Error	Cumulative Error	Human Judgement
Collection	55.74 (27.37)	55.74	5.39 (1.47)	42.48 (27.12)	42.48	5.55 (1.60)	13.26	13.26	−0.16
Storage	48.45 (26.29)	104.19	4.65 (1.67)	39.35 (28.11)	81.83	5.15 (1.66)	9.10	22.36	−0.50
Testing	45.26 (27.07)	149.45	4.78 (1.58)	39.27 (27.77)	121.10	4.94 (1.70)	5.99	28.35	−0.16
Analysis	52.45 (26.28)	201.90	5.57 (1.46)	44.55 (27.60)	165.65	5.25 (1.52)	7.90	36.25	0.32
Reporting	44.25 (27.38)	246.15	5.06 (1.71)	40.69 (26.87)	206.34	5.43 (1.53)	3.56	39.81	−0.37
Presenting	45.04 (26.97)	291.19	5.37 (1.63)	42.22 (29.64)	248.56	5.55 (1.53)	2.82	42.63	−0.18

Note: This table shows the mean and (standard deviation) for the perceived likelihood that an error could occur during each stage in the forensic science process. Error is measured on a scale from 0 to 100. Human judgement is measured on a seven-point scale from 1 to 7. A value of one indicates that no human judgement is involved in the process; a value of seven indicates that the process is entirely based on human judgement. Responses of "Not sure" for the amount of human judgement involved are excluded. The US sample is from the present study, the Australian sample is from Ribeiro et al.'s [29] study of 101 members of the public in Australia.

Table 2
Perceived Accuracy and Level of Human Judgement for Each Forensic Evidence Technique.

	US Sample		Australian Sample	US − Australian *t* value
Type of Forensic Evidence	Accuracy	Human Judgement	Accuracy	Accuracy
DNA	83.09 (17.92)	58% (49%)	89.95 (15.85)	3.13**
Fingerprints	78.62 (17.47)	54% (50%)	88.15 (17.66)	4.25***
Toxicology (e.g. urine, drugs)	76.12 (18.21)	43% (50%)	86.66 (13.75)	4.97***
Dental	75.88 (22.02)	41% (49%)	89.26 (12.04)	5.58***
Firearms and toolmarks	68.15 (19.41)	82% (38%)	79.63 (16.77)	4.87***
Gunshot residue	67.98 (19.66)	65% (48%)	78.87 (17.97)	4.48***
Bloodstain pattern	64.28 (20.50)	85% (36%)	78.53 (19.03)	5.59***
Brain imaging	60.74 (24.92)	58% (50%)	–	–
Footwear	56.98 (23.44)	82% (39%)	–	–
Voice	55.30 (22.25)	86% (35%)	71.47 (19.16)	6.00***

Note: This table shows the mean and (standard deviation) for perceived accuracy of each forensic science technique. Accuracy is measured on a scale from 0 to 100. Human judgement asks respondents whether they believe each technique involves 'key procedures that involve significant human judgement?' Responses shown are the percent the responded 'Yes', excluding those who responded 'Not Sure'. The US sample is from the present study, the Australian sample is from Ribeiro et al.'s [29] study of 101 members of the public in Australia. The final column shows the t-value from a *t*-test comparing US responses to Australian responses from Ribeiro et al. [29].
*p < 0.05.
**p < 0.01.
***p < 0.001.

the forensic science investigation process are liable to make mistakes that reduce the accuracy of the evidence. US respondents believe that there is slightly less human judgement than the general public in Australia (Column 6) do.

3.2. Forensic evidence techniques

3.2.1. Estimates of accuracy

Table 2 assesses how accurate respondents believe each of the 10 forensic techniques examined are. Column (1) shows how accurate respondents believe each technique to be, from 0 to 100. Based on the perceived accuracy, the most accurate to least accurate technique are: DNA, fingerprints, toxicology, dental, firearms/toolmarks, gunshot residue, bloodstain pattern, brain imaging, footwear, and voice.

Respondents believe that DNA analysis is the most accurate forensic technique at 83% accurate, followed by fingerprint analysis at 79%. DNA analysis is the only technique considered above 80% accurate, with most within the range of 65–75% accurate. Two analyses are considered below 60% accurate: voice analysis is considered to be 55% accurate and footwear analysis is considered to be 57% accurate.

For a comparison to Ribeiro et al.'s [29] Australian sample, Column (3) show the accuracy rate among their participants. Column (4) shows the *t*-value from a *t*-test comparing the current study's responses to Ribeiro et al.'s [29] Australian sample. For each type of forensic evidence, there is a statistically significant ($p < 0.01$) difference between each sample's perceptions of accuracy. Relative to the Australian sample studied by Ribeiro et al. [29], American respondents viewed forensic techniques as less accurate. For the eight techniques studied which overlap with Ribeiro et al. [29], US respondents believed that the techniques were on average 12 percentage points less accurate than Australians did.[5] For every comparable technique, US respondents rated it as less accurate than Australian respondents did. In six of the eight comparable techniques, US respondents perceived it to be around 10 percentage points less accurate than Australian respondents.[6] These results may suggest that Americans are less trusting of forensic science overall, though they have relatively similar perceptions of the accuracy of forensic techniques relative to each other.

3.2.2. Comparison between survey responses and levels of accuracy from reports

Table 3 shows the comparison of accuracy rankings between the

[5] Bloodstain pattern, DNA, dental, fingerprints, firearm and toolmarks, gunshot residue, toxicology, and voice analysis overlapped with the Ribeiro et al. [29] study. Brain imaging and footwear analysis were examined in this study but not Ribeiro et al.'s [29] study.

[6] The two exceptions are DNA at 6.86% less accurate and fingerprints at 9.53% less accurate.

Table 3
PCAST report conclusions about foundational validity, which requires a method to be repeatable, reproducible, and accurate, of forensic disciplines [35]. The conclusions derived from the PCAST report have been interpreted and summarized by the authors of this article.

Conclusion by PCAST authors	Discipline
Foundationally valid	DNA Fingerprints
Not foundationally valid yet	Dental*
	Firearms/toolmarks**
	Footwear***
Unranked	Bloodstain pattern
	Voice
	Gunshot residue
	Brain imaging
	Toxicology

* There are low prospects of developing bitemark analysis into a scientifically valid method, according to PCAST.
** There is one appropriate study so far, but more are needed to show the technique is reproducible.
*** Source identification was found to not be foundationally valid, but the validity of class characteristic identification was not evaluated by PCAST.

survey responses and the conclusions from reports (see Section 1.3).[7] It is not possible to make a numerical comparison between these two sources, so instead we analyze the differences in ordering. Other researchers might have different opinions about the ordering of the levels of accuracy of the forensic disciplines.

Toxicology, gunshot residue, bloodstain pattern analysis, brain imaging, and voice analysis were unranked by PCAST, so it is not surprising that they are scattered in the survey responses (they are in places 3, 6, 7, 8, 10, respectively in the survey responses).

Of the techniques that are ranked, the top two disciplines in the survey responses (DNA and fingerprints) are also the only two that are considered foundationally valid by PCAST. It is notable that dental analysis scored high (4 out of 10) in the survey since it is considered not foundationally valid by PCAST. Indeed, PCAST found that "available scientific evidence strongly suggests that examiners not only cannot identify the source of bitemark with reasonable accuracy, they cannot even consistently agree on whether an injury is a human bitemark" [35]. In fact, dental scored higher than firearms and toolmarks, even though PCAST found that firearms and toolmarks was almost shown to be foundationally valid, but it was not yet because there was only one appropriate study of scientific validity instead of multiple, which are required to show reproducibility.

Similar to Ribeiro et al.'s [29] study, we did not separate the DNA analysis into different types (single-source, simple mixture, complex mixture) for the survey, but PCAST did make this important distinction. It would be interesting to study whether the general public is aware of these differences and whether it considers some more accurate than others, but that is left as future work. Thus, for our comparison in Table 3, we refer to any type of DNA evidence as just "DNA". Moreover, the survey asks about firearms/toolmarks, but most of the current research about the accuracy of these methods is about firearms, not toolmarks in general, such as the marks left by screwdrivers or wire cutters. It is common to present firearms and toolmarks as a single category, since imprints on a used bullet or cartridge (considered marks) were made by the firearm (considered a tool). These are issues for future research on forensic techniques to consider.

3.2.3. Human judgement

To judge how objective respondents believed each technique to be, we asked whether they believed there to be "key procedures" in the technique involving human judgement. The percent of respondents who answered *Yes* are shown in Column (3) of Table 2, excluding those who responded *Not sure*.[8] Respondents believe that there is a high level of human judgement involved in each technique. Over 50% of respondents believe that human judgement is involved in the forensic technique for all except for toxicology (43% of respondents) and dental analysis (41% of respondents). Even for the two most trusted analyses, DNA and fingerprints, over half of respondents believe that human judgement is involved in "key procedures" for that analysis with 58% and 54% reporting so, respectively. Because responses were non-normally distributed, Mann-Whitney U tests were conducted to examine differences in perception of accuracy between those who perceived the technique to involve human judgement or not. Individuals who believed no human judgement was involved in brain imaging (mean rank = 71.17) thought that this technique was more accurate than those who believed brain imaging involved human judgement (mean rank = 57.93), $U = 1528$, $p = .044$. Similarly, respondents who believed no human judgement (mean rank = 79.15) was involved in toxicology thought this technique was more accurate than individuals who believed the technique involved with human judgement (mean rank = 62.39), $U = 1914.5$, $p = .017$. For all other techniques, there were no significant differences in perception of accuracy between those who believed human judgement was involved and those who did not.

3.3. CSI effect

Table 4 shows the percent of respondents who chose each answer for the two questions used to measure the *CSI* effect. Column (1) shows the responses for the "most accurate fictional show" while Column (2) shows responses for the "average fictional show" that depicts forensic science. In both cases the vast majority of respondents believe that the shows are between slightly and moderately accurate. For the "most accurate" show, 43% of respondents believe it to be "moderately accurate," more than the 26% who say the "average" show is "moderately accurate." Approximately 10% of respondents believe that these shows are "very accurate." For the "most accurate show," the same number of respondents believe it to be "not at all accurate" as to be "very accurate." For the "average show," however, nearly twice as many (18%) of respondents believe it to be "not at all accurate."

When asked whether watching these shows changed their interest in forensic science, nearly three-quarters of respondents (99 of 135 respondents; 20 respondents in the sample did not watch these shows) claimed they are "Much more interested" or "Somewhat more interested" in forensic science as a result of these shows.

3.4. Importance of forensic evidence during criminal cases

Table 5 shows the responses to the four questions regarding the importance and reliability of forensic evidence during the criminal justice process. Each row is a single question and Columns (1–5) show the percent of respondents who choose each answer. Respondents could select if they strongly or somewhat agree or disagree, or if they are not sure.

Row (1) shows responses to the statement that "forensic evidence always provides a conclusive answer" and the majority of respondents (52%) somewhat or strongly agree. A smaller amount, 41%, agree that "forensic evidence always identifies the guilty person" while the majority of respondents (55%) somewhat or strongly disagreed (Row (2)). These results seem contradictory to previous sections which showed that the forensic science investigation process and many forensic science techniques were perceived to have high levels of human judgement involved and to be relatively inaccurate. It is unclear why

[7] The conclusions from reports are summarized by the authors of this article and are not a consensus that exists in the forensic science community.

[8] Ribeiro et al. [29] also assessed the degree of human judgement for each forensic technique. However, their question was a Likert-scale question, preventing a comparison from our *Yes-No* question.

Table 4
Perceived accuracy of fictional TV shows that depict forensic science.

	Most Accurate Show	Average Show
Very accurate	9.68	9.68
Moderately accurate	43.23	26.45
Slightly accurate	33.55	41.94
Not accurate at all	9.68	18.06
Not sure	3.87	3.87

Note: Respondents were asked "How accurate do you think the [most accurate/average] fictional show is in depicting forensic science?" This table shows the percent of respondents who gave each answer to the questions. Column percentages may not total to 100 due to rounding.

respondents appear to be more supportive of "forensic evidence" abstractly yet hold relatively negative views of each specific technique or stage of the forensic science investigation process.

Row (3) demonstrates the extent to which respondents agree that prosecutors should drop a case if there is no forensic evidence collected at the crime scene. Nearly a third of respondents (29%) somewhat or strongly agreed with this statement while 65% disagreed and 6.5% were not sure. This suggests that, even though overall forensic evidence is considered to be relatively inaccurate, a nontrivial number of respondents would be unwilling to convict a defendant without it. As this study did not assess perceptions of other forms of evidence, such as eyewitness testimony, it is unclear whether this group believes that forensic evidence itself is particularly strong or that other forms of evidence are less valid. Finally, Row (4) reflects how strongly respondents agree that if forensic evidence suggests that the defendant is guilty, they should convict that defendant even if other evidence suggests that the defendant is not guilty. Here, 37% of respondents either somewhat or strongly agreed with this statement. These results indicate that while overall respondents believe there to be serious flaws in forensic evidence, an appreciable portion are willing to make decisions on the defendant's guilt based solely on forensic evidence.

4. Discussion

This study sought to understand public perceptions of forensic science by surveying members of the general public in the United States. Overall, our hypotheses in general were not supported. While we expected respondents to have a high level of confidence in the forensic science investigation process and for the accuracy of each forensic science technique (Hypothesis 1), our results suggest that members of the US public hold significant doubts about the accuracy of forensic techniques and believe that each technique contains high levels of human judgement. The technique perceived to be most accurate was DNA evidence at 83% accuracy, while voice analysis at 55% and footwear analysis at 57% were perceived to be least reliable. Most forensic techniques were considered to be in the range of 65–75% accurate. Our results align with prior work indicating that DNA is often perceived to be among the most accurate forensic techniques, though our study yields lower perceptions of accuracy for DNA than reported elsewhere [18]. Additionally, respondents indicated that they believed there was a substantial risk of error at each stage of the forensic science process, and that each stage involves a large amount of human judgement. Relative to Ribeiro et al.'s [29] study in Australia, our sample reported a higher likelihood of error at every stage, especially in the collection, storage, and analysis stages.

Our second hypothesis reflected our expectation that respondents would overestimate the accuracy of forensic evidence. When comparing the accuracy rankings between the survey responses and the conclusions from reports, it was notable that the top two disciplines in the survey responses (DNA and fingerprints) were also the only two that were considered foundationally valid by the relevant literature [35]. Furthermore, dental analysis ranked 4th most accurate in the survey, although it is considered not foundationally valid by PCAST. In fact, PCAST considers that it is far from being so as examiners "cannot even consistently agree on whether an injury is a human bitemark." In fact, dental analysis scored higher than firearms and toolmarks in the survey, even though PCAST found that firearms and toolmarks was almost shown to be foundationally valid.[9] Several techniques that were ranked in the survey (toxicology, gunshot residue, bloodstain pattern analysis, brain imaging, and voice analysis) were not in the PCAST report, thus, we could not compare their rankings. Overall, there was mixed support for Hypothesis 2.

We also hypothesized that respondents would believe fictional forensic science television shows would be highly accurate (Hypothesis 3). Ribeiro et al. [29] used the number of hours of forensic science-related TV shows that a respondent watched as a measure of their interest in the field and examined the correlations between this measure and respondents' attitudes toward the likelihood of an error in the forensic science investigation process and for individual techniques. They found that there was no significant relationship between the number of hours watched and opinions on the likelihood of an error to occur. In this study we attempted to address the *CSI* effect directly by asking respondents how accurate they believe the "most accurate fictional show" and the "average fictional show" is in depicting forensic science. Our findings indicate that respondents believed that the average forensic science shows were only slightly accurate, and that even the "most accurate fictional show" was only moderately accurate. Arguably, a *CSI* effect would have been contingent on individuals believing what they see in forensic science-related TV shows (i.e., having most people report a *Very Accurate* rating), but the current results suggest that people do not blindly believe the accuracy of these shows. Respondents generally believe that such shows are slightly to moderately accurate at best. These results thus did not seem to indicate a *CSI* effect, and did not support our hypothesis. While this study measured the *CSI* effect in a different way than Ribeiro et al.'s [29] did, our findings are similar as neither study found support for a *CSI* effect.

Finally, we expected that respondents would give great weight to forensic evidence in criminal trials such that the evidence would be considered a decisive factor in whether a defendant is considered guilty or not guilty (Hypothesis 4). Results partially support this hypothesis as nearly 30% of respondents believe that the absence of forensic evidence is sufficient for a prosecutor to drop the case and almost 40% believed that the presence of forensic evidence, even if other forms of evidence suggest the defendant is not guilty, is enough to convict the defendant.

While the current study provides insights into public perceptions of forensic science, the impact of the current study may be limited in scope. In the US criminal justice system, jurors hold immense power during trials, determining whether the defendant is guilty of the crimes they are accused of committing. The Sixth Amendment to the United States Constitution guarantees that defendants the right to be judged by an "impartial jury" consisting of members of the public. In practice, however, juries only impact a small number of criminal cases as in nearly all but the most serious cases, the defendant pleads guilty or the case is dismissed before trial [17,4,28,3]. For the crime of murder, however, nearly 40% of cases do proceed to trial, where jury perceptions of the usefulness and validity of forensic science techniques can play an outsized role in determination of guilt. In the vast majority of murder cases at least one form of forensic evidence was collected by investigators at the scene [22].

However, juries are not presented only with forensic evidence during a trial. Their decision is likely based on other evidence involved in the case, personal biases, and how these factors interact with the forensic evidence presented. Therefore, asking respondents to rate the

[9] Firearms and toolmarks are not considered foundationally valid as there is only one appropriate study of scientific validity instead of multiple, which are required to show reproducibility.

Table 5
Importance of Forensic Evidence in Determining Guilt in a Criminal Trial.

	Strongly Agree	Somewhat Agree	Somewhat Disagree	Strongly Disagree	Not Sure
Forensic evidence always provides a conclusive answer.	16.13	36.13	28.39	16.13	3.23
Forensic evidence always identifies the guilty person.	10.32	30.32	37.42	17.42	4.52
If no forensic evidence is recovered from a crime scene, then the prosecutor should drop the case.	10.32	18.71	29.68	34.84	6.45
If forensic evidence suggests a defendant is guilty, this should be enough to convict even if other evidence (e.g., eyewitness testimony, alibi) suggest otherwise.	10.32	27.10	37.42	19.35	5.81

Note: This table shows the percent of respondents who gave each answer to the questions. Row percentages may not total to 100 due to rounding.

accuracy and degree of human judgement involved in each step on the forensic process or for each type of forensic science technique only captures some of the factors that potential jurors consider when deciding on a verdict. Future research may consider interviewing members of a jury whose case involved forensic science to determine how that piece of evidence influenced their decision. Additional research could use a vignette-design to simulate a juror's experience in a case and vary the forensic science technique involved to measure how much each technique influences their decision and what other variables matter in such a decision.

This study did not define any of the forensic science techniques, allowing the respondent to respond based on what knowledge they already have on the topic. While most of the techniques are self-explanatory, the interpretation of dental analysis may have needed to be clarified. It is unclear whether participants interpreted this as bite mark analysis, as was intended, or if they believed this item to refer to the identification of human remains based on teeth examination. This is a limitation that should be considered and clarified in future studies. In a trial, both the prosecution and the defense would likely explain to the jury what the technique is and argue about its accuracy and relevance. Therefore, this study measures people's baseline beliefs about each forensic technique rather than beliefs at the time that a juror must render a verdict. These results may be useful to attorneys who argue in front of a jury as it provides a guide on the techniques the jurors will expect to be accurate and those that prompt more skepticism. Lawyers may use these results to argue more forcefully for or against certain evidence with the knowledge that jurors already have certain beliefs about these techniques. In addition to its impact on lawyers, these results may be useful to investigative teams who can prioritize techniques that are both based in evidence and have a high degree of support by the public.

This study used data from 155 participants during late June 2019 through Mechanical Turk. Having a larger sample size and utilizing additional recruitment sources may provide more representative responses. The results of the current study may be a reflection of the characteristics of the sample and methods employed, thus replication is needed to assess the ecological validity of the current findings. Moreover, during the past several years the rise of movements such as Black Lives Matters and the election of progressive prosecutors in a number of major cities in the United States reflects a shift in attention towards negative aspects of the criminal justice system such as racial bias and miscarriages of justice. While a majority of those in the US overall remain confident in the police, a growing number − 14% in 2018 – report "very little" confidence [11]. Among Blacks and Hispanics in the US, groups which are over-represented in the criminal justice system, confidence in the police has fallen significantly with fewer than half of Hispanic people and fewer than a third of Black people having a "great deal or quite a lot" of confidence in police [24]. This attention towards negative aspects of the criminal justice system may have affected our results if respondents with low trust of the police cause low trust in the forensic evidence process - or in the people tasked at each stage of the forensic evidence process. A longitudinal study of this topic could detect whether perceptions of forensics change over time and if there is any relationship between trust in the criminal justice system and beliefs towards forensic evidence.

4.1. Implications and future directions

Based on our findings, US respondents believe that there is less human judgement but more errors at each stage of the forensic science process than their counterparts in Australia. It is unclear why this is the case, but this may suggest that US respondents believe that the science itself is more prone to error. Future research should investigate precisely which aspects of each stage is considered at risk of an error occurring. They should also continue to examine perceptions in different countries to better understand how people from different cultures understand and evaluate forensic evidence.

Our results also indicate that while fictional shows depicting forensic science are considered relatively accurate, the vast majority of US respondents do not believe that they are a perfect, or even near-perfect, representation of forensic science practices. The large difference in perceptions of accuracy between the "most accurate" and the "average" shows also indicate that people believe that they have enough knowledge of the field of forensic science to make this distinction between shows. Further studies of this topic should examine this question further, helping to distinguish how accurate these shows truly are and which specific features people believe to be accurate. While the *CSI* effect has been hypothesized to change viewers' opinions on forensic science because they believe that the shows are accurate, it may be that people already interested in forensic science are more likely to watch these shows. Watching shows may also change a person's belief in forensic science if they decide to look up the techniques that they see on the show to read more about them. In the current study, most respondents (99 of 135) acknowledged that their interest in forensic science increased as a result of forensic science-related shows. While this study did not ask if respondents did any research on the forensic science they saw, it does offer avenues for future research to examine if there was a behavioral change as a result of these shows.

5. Conclusion

This study found that US respondents believe that there is a high degree of human judgement involved and high risk of an error occurring at each stage of the forensic science process. When considering forensic science techniques specifically, those in the US hold a skeptical view of the vast majority of techniques, viewing some of them as little more accurate than a coin flip, and no technique more than 84% accurate. When compared to their counterparts in Australia, as studied by Ribeiro et al. [29], members of the US general public have a similar though more negative view of the field of forensic science than Australians.

Inaccurate perceptions of jurors towards forensic techniques likely has a severe and detrimental effect on the criminal justice system as it may influence their decisions of guilt or innocence. As the use of forensic science becomes more common in criminal cases that go before juries, it is increasingly important that we understand preconceptions

that jurors hold towards this field to better reduce biases during trials. Juries during criminal cases, however, are rare in the US justice system. The vast majority of criminal cases, over 90%, are settled through plea bargains, causing an outsized role of prosecutors in the criminal justice system [8]. However, little is known about prosecutors' perceptions of forensic science or how they use the evidence collected during the plea-bargaining process. It is important, therefore, for research in this field to continue to examine perceptions among members of the general public, who decide guilt for a small number of serious cases, and among prosecutors, whose decisions affect nearly all cases in the criminal justice system.

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