Reasoning about Forensic Science Evidence

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ABSTRACT
Forensic evidence has become a common tool in police investigations and a familiar form of evidence at trial. Forensic scientists are trained to analyze such evidence (e.g., fingerprints, handwriting, seized drugs, blood spatter, fire debris) and to provide reports and testimony concerning their findings. Despite the prevalence and potential usefulness of this type of information, there is widespread misunderstanding of how accurate and determinative forensic evidence can be. Lawyers and judges often do not have a good understanding of forensic science and its limitations even though they may need to make use of and critique forensic analysts and forensic evidence in the course of their work. This chapter first addresses how and when flawed reasoning, biases, and non-optimal laboratory conditions may affect forensic analysts and their conclusions. Then it describes what people—forensic experts, lawyers, judges, and jury-eligible lay persons—believe about forensic science. Finally, it explains strategies for how lawyers or judges can evaluate and communicate the value of forensic science evidence during trials, such that the ultimate factfinders will understand the evidence, what it means, and how to consider that evidence appropriately in the context of a particular case.

KEYWORDS
forensic science; forensic evidence; legal reasoning; cognitive bias

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Reasoning about Forensic Science Evidence

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Introduction

Forensic science evidence has been both a blessing and a curse to the legal system for the past century. In a "perfect world" for investigators, forensic evidence could be used to quickly and easily determine what happened at a scene (e.g., was there even a crime and, if so, what was its nature?). It would also be ideal if forensic evidence could help rapidly determine who was and was not to blame. This "perfect world" would feature judges who understand the reliability and value of different types of forensic evidence and, as a result, appropriately allow (or disallow) that evidence to be used to apprehend or convict someone. Lawyers would understand the weaknesses of forensic evidence and question expert witnesses in a way that made both the flaws and strengths of the evidence clear to factfinders during trials. Finally, factfinders—professional judges, lay judges, or random citizens—would learn during trial how to evaluate the forensic evidence properly and use it to render a verdict.

Of course, we do not live in the world described in the above story, nor are we perfect reasoners. Some of the faults of forensic evidence (e.g., it may contribute, in several ways, to the arrest and conviction of people who are factually innocent) lie in the science underlying the forensic disciplines. But it is mostly us—the people who collect, analyze, interpret, communicate, question, evaluate, and use such evidence—who are responsible for its misuse (MORGAN 2023). Each of those tasks involves "the human element" (DROR 2015) and, therefore, is a fertile ground for cognitive science study.

This chapter is in three parts. The first explains some of what forensic analysts do, drawing on cognitive science to understand their reasoning processes and how they, or the systems in which they work, can produce faulty judgments. The second part lists some of what people (specifically non-scientists, e.g., judges, lawyers, random jurors) believe—accurately or mistakenly—about forensic science, and how those beliefs arise. The third part describes occasions in which forensic analysts and legal decision makers cross paths in the legal system, such as when judges rule on the admissibility of forensic evidence, when lawyers question forensic experts, and when jurors interpret forensic testimony. Although the chapter is framed in terms of the US jury-based adversarial system, the analyses should be relevant across systems, even when different parties are responsible for the relevant tasks.

1. *The cognitive science underlying forensic science*

To understand how to approach forensic science evidence from a legal perspective, it is important to understand how forensic science evidence is constructed. We don't mean how the evidence is left by a relevant participant or observer involved in the case; rather, we mean how it is found, analyzed, and interpreted by forensic scientists in order to produce evidence that can be used by investigators or at trial. Because forensics analysts are engaged in tasks that involve reasoning, judgment, decision-making, memory, communication, and other cognitive skills, cognitive science can provide insights into how evidence selection and interpretation can go right—or go wrong.

Cognitive science has established that reasoning processes, most of the time, lead us to the right conclusions, but those same processes can also lead us astray. Part 1 of this chapter moves between cognitive science and forensic science, describing the limits of forensic science knowledge, some general characteristics of human reasoning, what forensic analysts do, and, importantly, how general characteristics of human reasoning are not necessarily optimal when reasoning in forensic science, or any science, contexts. This core information will help lawyers and judges to understand, elicit, present, question, and evaluate forensic science.

1.1. *Scientific foundations of the forensic sciences*

In the 1980's, forensic science was a booming business. Law enforcement believed that it provided reliable ways to identify people by analyzing fingerprints, voices, hair, footprints, handwriting, and bitemarks. They believed that they could use fibers and tire tracks to narrow down the list of potential suspects and could determine how and where a fire started by examining fire debris. About the same time, advances in DNA processing allowed defendants to request that their cases be revisited, eventually revealing that mistaken eyewitness testimony, false confessions, and bad forensic science analyses were all implicated in hundreds of wrongful convictions.

But is an error in forensics always the fault of forensic analysts or, sometimes, could it be in the science itself? Forensic scientists have claimed that a sample of DNA, a fingerprint, or a bitemark impression picked up at a crime scene can be compared to a known sample taken from a suspect and if the two "match" it is guaranteed that the samples came from the same person. Disregarding the possibility of human error (e.g., in labeling the samples)—could such a guarantee be made?

In 2009, the National Research Council published a report called *Strengthening Forensic Science in the United States: A Path Forward* (hereafter, "NRC Report"). It investigated the scientific foundations of many forensic techniques and found all lacking, with the exception of single-source DNA evidence. DNA analysis was invented by scientists, not for forensic use, and has fairly robust scientific underpinnings—it is very likely that every person (except for "identical" siblings) has distinct DNA and there are techniques that enable analysts to distinguish between DNA from different people. But what about fingerprints? There is little to guarantee their uniqueness. And even if every fingerprint were unique, it may be that not all similarities and differences would show up when fingerprint impressions are taken; every new impression from the same finger differs at least slightly from prior impressions. So, how can analysts be certain that slightly different fingerprints are similar enough to each other to say they are from the same person or different enough to say they are not?

Yet fingerprint analysis has more empirical support than most other forensic techniques. Consider, for instance, bitemarks—a technique that most people have heard of but that has no scientific foundation. To leave an impression, the bite must be made into something soft, like food or skin, and such things immediately begin to lose the impression and rebound towards their original shape (see SAUERWEIN et al. 2023). Overall, the NRC Report showed that the reliability of the forensic sciences was unknown and was likely substantially lower than anyone wanted to believe.

1.2. *Three important characteristics of human reasoning*[1]

Human reasoning processes are complicated. Sadly, we are so often disappointed in its failures that we forget how well our reasoning processes usually work. We are able to navigate, communicate, and interact within a complex world full of people, objects, and challenges, with few untoward results. The three general characteristics of reasoning described below are common and useful in our complex everyday life, but all can create trouble for forensic analysts.

1.2.1. *Perceptions are shaped by pre-existing knowledge and beliefs*

One ubiquitous characteristic of reasoning is that we believe that our perceptions of the world are direct and accurate representations of what is in the world ("naïve realism"). However, that assumption is incomplete: our perceptions and beliefs are shaped both by what is in the world and by what is in our heads, for example, previous knowledge, experiences, expectations, and desires. (See Figure 1.) Combining information from these two sources is done so automatically that we are not usually aware that our interpretation of what exists depends at all on what we already know or believe.

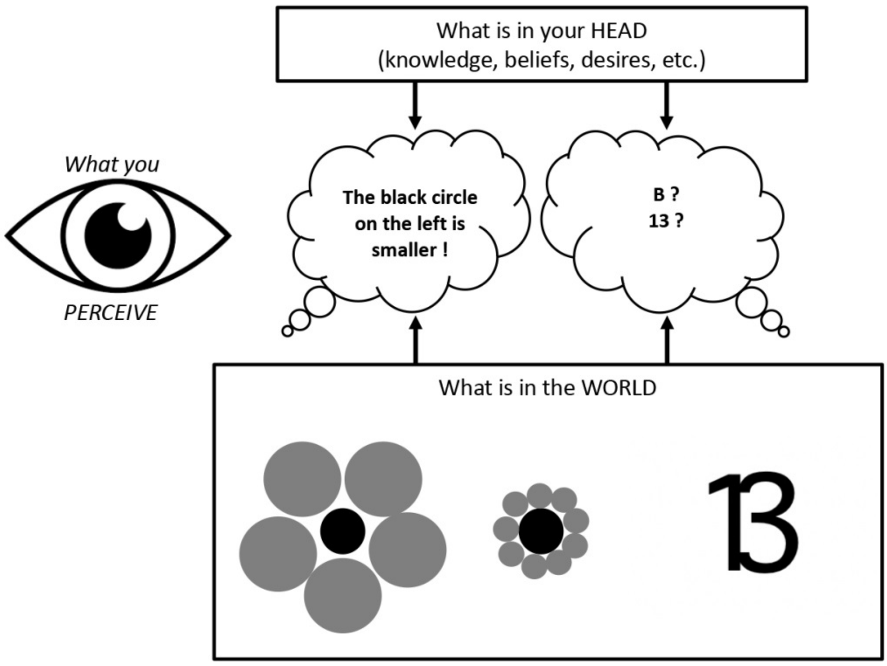

FIGURE 1.

[1] These topics appear in most Cognitive Psychology textbooks. More detail as related to forensic science can be found in SPELLMAN et al. 2022; DROR 2020; EDMONDS et al. 2017.

Consider the familiar visual illusion in the left of Figure 1. Although the two black circles are the same size, our visual system is automatically incorporating the surrounding context and comparing the nearby circles to them it such that the circle surrounded by the smaller ones looks larger than the circle surrounded by the bigger ones. The figure on the right illustrates how motivation or desire might affect perception. Some participants in a study were told to respond when they saw a number, others when they saw a letter; they would be rewarded for each one they got correct. Most of the stimuli were clearly either a number or a letter and participants generally answered correctly. However, participants in both groups responded when this ambiguous figure appeared (BALCETIS & DUNNING 2006).

1.2.2. *People create abstract knowledge structures including causal stories*

A second strong characteristic of human reasoning is that we create abstract knowledge structures: we automatically see patterns in our environment, and we group information into mental structures like categories and causal stories, which help us remember and make sense of the world. A simple example of causal story creation are inferences from one observation based on previous knowledge; for example, if you look outside and see someone carrying an umbrella, you infer that it is likely to rain, because you think that the only reason for the person to carry the umbrella is that they believe it will rain. On the other hand, if the sky were clear and the forecast were for sun, you might revise your hypothesis about whether the covered stick the person carried was actually an umbrella (maybe it's a parasol?), or perhaps consider that the person was traveling to somewhere that the forecast for rain.

Research shows that people tend to create stories with the most parsimonious (i.e., the simplest) explanations (READ & MARCUS-NEWHALL 1993) but also that once people have a story fixed in their mind, they will be likely to ignore or devalue disconfirming information (i.e., "confirmation bias"; see Part 1.4.2 below). Studies using stimuli based on real legal cases show that experimental participants who are pretending to act as jurors (typically from the US) will fit the facts they learn from testimony into a coherent story, and will discount some testimony (e.g., reports about the timing of events, guesses about the motivation of actors) to make their versions of the story more coherent (PENNINGTON & HASTIE 1991).

Creating causal stories turns out to be an important undertaking within the legal system: it is a task for investigators, who are trying to solve how a crime occurred; for lawyers, who are trying to convince others that their version of the story is the correct one; and for the judges or jurors who, after listening to testimony containing inconsistent facts, and arguments containing competing stories, must construct their own story of what did, or did not, happen, in order to come to a verdict.

Note that for amusement, people all over the world watch lots of examples of unrealistic causal story creation in television shows, where for the first 45 minutes the investigators (police or CSI or FBI) find wrong suspect after wrong suspect until, with a minute to spare, everything falls into place.

1.2.3. *Explaining (some) irrationality: "Two systems" of reasoning*

The third characteristic of human reasoning goes by many names. The gist is that people behave as if they have two different ways of learning, processing, and using information. Studies show that people often jump to conclusions that seem "obvious" in light of the available information, only to realize later that, if they had taken more time, they would have come to a different (and correct) answer (FREDERICK 2005).

Qualities that are often attributed to these two different types of processing are shown in Table 1. The Nobel Prize winner Danny Kahneman titled his popular book, *Thinking, Fast and Slow*, after this phenomenon. Part 2 of this chapter describes how people may unintentionally learn information using the non-aware/conscious distinction and how people may be persuaded using the peripheral/central route distinction of PETTY and CACIOPPO (2012).

System 1 (Fast)	System 2 (Slow)
Automatic	Controlled
Non-aware	Conscious
Intuitive	Reflective
Heuristic	Logical
Peripheral Route	Central Route

TABLE 1. Characteristics of the fast and slow systems (adapted from KAHNEMAN 2011.)

Which type of processing people use at any given time depends on both the person and the situation. When people are motivated to think hard about something, they are more likely to use the slow system than if they are not motivated; and when people are under time pressure or stress, they are more likely to use the fast system than if they are not under such pressure.

1.3. *What forensic analysts do and where they do it*[2]

Forensic analysts portrayed in the media are usually collecting the evidence at the crime scene and performing a variety of different analyses in a forensic lab (e.g., deciding whether DNA or fingerprints come from a specific person, or whether a white powder is a certain kind of drug). In some shows, these people are also the arresting officers. In reality, forensic analysts are much more specialized and limited. Most forensic labs are affiliated with a local police department and do not cover all the forensic domains. Labs typically have many of the core "feature comparison" methods such as DNA, fingerprints, and firearms. The PCAST report (2016),[3] following up on the NRC Report (2009), addresses these methods and defines a feature comparison procedure as one in which an examiner «seeks to determine whether an evidentiary sample (e.g., from a crime scene) is or is not associated with a source sample (e.g., from a suspect) based on similar features» (46). Labs also often have analysts who test and identify whether trace evidence is a specific poison ("toxicology") or controlled substance ("seized drugs").

Forensic analyses also occur in medical examiners officers (e.g., an autopsy to determine time and cause of death). Some forensic analyses are even performed at a suspected crime scene itself because the relevant evidence cannot be fully or easily moved to a laboratory environment. For example, forensic analysts who are trying to figure out how a fire started in a building, or what actions created an unusual blood spatter pattern across a floor and wall, will return to a scene after other evidence is catalogued. And, of course, crime scene investigators are responsible for going to the scene of what might, or might not, be a crime, and deciding what is relevant evidence at the scene, so that it can be documented and preserved using photography, collection methods, or *in situ* analysis.

2 Note that the term "forensic psychologist" refers to people with psychological training who evaluate individuals as to their mental abilities, state, and health. These may include competence to stand trial, potential danger to self or others, possibility of prior temporary insanity, experience of long-term mental illness, or other assessments. Forensic psychologists are not usually included as doing "forensic science" (e.g., forensic psychology is not addressed in the NRC Report), but many issues affecting the accuracy of their testimony are similar to issues affecting other forensic scientists and testifying experts generally.

3 The PCAST report was written by the President's Council of Advisors on Science and Technology and entitled: *Forensic Science in Criminal Courts: Ensuring Scientific Validity of Feature-Comparison Methods* (2016).

1.4. *Three dangers to forensic science reasoning*

The characteristics of human reasoning described above are useful in that they usually guide us towards correct or safe outcomes in everyday life. Understanding how these "normal reasoning" processes can also lead people to make bad judgments is important for understanding how forensic science, or forensic analysts, can go wrong.

1.4.1. *Exposure to task-irrelevant biasing influences*

As described in Part 1.2 above, humans take information from different sources and combine it automatically. But that is *not* what a forensic analyst is supposed to do with case information. For example, when deciding whether a fingerprint "matches" the suspect's print, the analyst should not know things like whether the suspect has prior convictions or whether he has confessed. Such information is not relevant to the process of comparing the features in those fingerprints. Yet dozens of studies show that exposure to "task irrelevant" information can improperly influence the decisions of real analysts (GARRETT 2022; KUKUCKA & DROR 2023). Forensic analysts are supposed to provide independent and accurate evaluations of the specific evidence they have been tasked with examining. The task of putting together and evaluating all the different pieces of case information to determine what happened at a crime scene and who was responsible is the job of the factfinder, not the forensic analyst. If an analyst has been biased by some other evidence or information (e.g., knowledge of a confession) (KASSIN et al. 2013), that information will become entwined with the forensic analyst's conclusion and, thus, incorporated into jurors' assessment of the case, even if the jurors have heard the confession and decided it is not believable, or have already considered that evidence (amounting to double counting).

Two techniques that are becoming more common for countering potential bias are *blinding*—keeping task-irrelevant information away from analysts—and *verification*—having a second analyst check the work of the first. Blinding can be done at the lab and case level. Labs can employ "case managers" who keep the paperwork and all other information about a case away from the analysts. Verification means that after an analyst reaches a conclusion, another analyst checks whether they believe that the conclusion is correct. Although these techniques seem simple, they are not free from potential biases, nor are they free from other problems. For example, in small forensic laboratories, it is difficult to keep tasks and information separated across people—for example, a verifier might know who the initial analyst was and be biased by that when verifying, and analysts who must also collect evidence will unintentionally gather task-irrelevant information during that process.

1.4.2. *Closing off hypotheses: Motivated reasoning and confirmation bias*

An important task for analysts, especially, but not only, those who are looking for causal processes (e.g., crime scene investigators, fire analysts; also jurors) is to keep an open mind regarding potential hypotheses for what may have happened. Jumping to conclusions is a consequence of the natural tendency to automatically combine information. People piece information together, try to find a way to explain everything, and once that has been achieved, are satisfied. But reaching a conclusion too quickly can have serious consequences in some settings. For example, in police investigations, sometimes early evidence suggests a particular suspect, then police choose to pursue only that suspect, and they end up ignoring evidence leading to other suspects. This conduct is known as "tunnel vision" and has led to wrongful arrests and wrongful convictions.

In reasoning, humans are motivated to be accurate and consistent but also, sometimes, to arrive at a particular conclusion; together these desires create what is commonly called "motivated reasoning" (KUNDA 1990). One consequence of motivated reasoning is "confirmation bias", the cognitive scientists' name for "tunnel vision". Confirmation bias is when someone has a hypothesis that they believe is true, or that they want to be true, so they are motivated to keep it viable. They might seek out only information that confirms it and interpret any ambiguous evidence in a way that is consistent with their hypothesis. When confronted with disconfirming evidence, they may discount it or explain it away as somehow irrelevant, bad, or corrupted. Similarly, forensic analysts should not jump to conclusions. Rather, it is advisable to keep alternative hypotheses open for investigative purposes and for conveying the appropriate degree of certainty to other persons (e.g., factfinders at trial).

1.4.3. *Failures of metacognition: Overconfidence and bias blind spot*

Metacognition is thinking about the processes of other peoples', or ones' own, cognition. One common metacognitive bias, at least in Western samples, is overconfidence: people are often overconfident about their own abilities and tend to believe that their own arguments are stronger and more persuasive than others. More relevant here is the "bias blind spot," which refers to the finding that people believe that others are more biased than they are themselves (PRONIN 2007). When disagreeing with other people, we might believe that they have been influenced by stray information, or illogical reasoning, or confirmation bias, but people fail to see themselves falling prey to the same errors. However, people are poor introspective investigators—we are not conscious of everything we know or think, or how something might be affecting our decisions. For a forensic analyst, overconfidence in a conclusion, or a failure to recognize that one's judgment may have been improperly influenced, can have unfortunate consequences for justice.

1.5. *General forensic situations*

The accuracy of forensic output depends on the situation in which analysts are working as well as the quality of the forensic analyst's reasoning. Laboratories may be the source of biasing information; for example, analysts working in a "police lab" might be more motivated to support the suspicions of the police than analysts working in an independent lab. Analysts might see biasing information in case logs, on envelopes, or on bags containing evidence. These problems can be ameliorated by having "case managers" who provide a buffer between the analysts' work and task-irrelevant information. In addition to these cognitive bias problems, analysts might be under extra pressure in a high-profile case, generally working in a high-pressure laboratory or a lab with substantial backlog, or dealing with some temporary personal hardship. Such stressors can push people into rushing their decisions rather than carefully analyzing the evidence, which could easily result in more errors (BUSEY et al. 2022).

2. *What factfinders already believe about forensic evidence*

Part 1 of this chapter describes some normal human reasoning processes, how they are involved in forensic science decision making, and what might go wrong when forensic evidence is analyzed and reported. Part 3 below describes whether and how forensic science evidence can be conveyed to factfinders so that the correct amount of weight is given to the information. Because people automatically use their pre-existing knowledge and beliefs to understand and interpret new information, we pause here in Part 2 to describe what ordinary people with no formal scientific or legal education already know and believe about forensic science and forensic analysts.

Through television, movies, the news, social media, and the occasional crime novel, forensic science is now very familiar to the general population—that is, to non-scientists and non-lawyers. But this way of learning exposes people to a plethora of exaggerated, misleading, and incorrect information. Most people do not have the educational background necessary to critique complicated scientific results (KUHN 1989); thus, the general population is not equipped to effectively critique expert forensic testimony at the level required to identify the kinds of issues described in Part 1 above. As a result, the general population holds many misconceptions about forensic science, including believing that forensic evidence is objective, scientific, generally accurate and reliable, readily available at crime scenes, commonly presented in criminal cases, and able to shed light on the truth about what happened during a crime on its own (GARRETT 2022)[4].

2.1. *How people come to "know" about forensic evidence*

2.1.1. *Exposure to media*

As with most topics, people form their beliefs about forensic science using the information that is readily available to them—news media, television shows and movies, and social media platforms (HOUCK 2006). Importantly, legal professionals hold similar misconceptions about forensic science, even though their chosen career increases their likelihood of encountering forensic evidence and associated forensic analyses.

The sources of knowledge through which the public learns about forensic evidence can include accurate information. But, overwhelmingly, television shows, movies, and social media posts are not created to disseminate accurate information. Dramatic fictionalized accounts of how forensic evidence can be found, processed, and used, results in more viewers and more "likes" than descriptions of reality would receive. Yet although many of these productions are clearly fiction, they usually contain elements of truth (e.g., some aspects of legal procedure and the role of law enforcement are accurate, as are some pieces of information about forensics). Thus, it is not surprising that the average, non-expert consumer has trouble distinguishing what is true from what is not with regard to the forensic science in these shows (COLE 2015).

News outlets and documentaries can be misleading as well. News outlets typically do not employ people with advanced scientific backgrounds. Some news outlets research the underlying science so that they can accurately describe the methods and results in their articles and news segments, but this is not the norm. Most are less cautious with their language for various reasons (e.g., attracting viewers is a higher priority than ensuring their reporting accurately represents the science) or are simply unaware that they are portraying the science incorrectly. Furthermore, the stories that are "news-worthy" or entertaining enough to be reported or turned into a film or documentary do not reflect the everyday cases appearing in most trials. For most typical cases, there is no physical evidence at all, which is in stark contrast to what is observed in fictional shows like *CSI*, or some of the real trials that receive the most media exposure.

Thus, the information about forensic science that will typically come to mind when ordinary people call on their knowledge will be based on unreliable, exaggerated sources. Regardless of the exact source of any one person's knowledge about forensic evidence, the available sources are usually designed to prioritize entertainment rather than education.

2.1.2. *Creating "knowledge" through heuristic processes*

People can come to "know" something in two main ways—consciously and without awareness (see Table 1). Conscious learning occurs when a person is motivated to learn about a topic. When a person is motivated, they may purposely try to commit the information to memory and seek to

[4] This book describes the various sources of error that can occur in the forensic sciences, the reasons those errors persist in criminal investigations and trials, and the consequences of these failures for the accused, the criminal justice system, and beyond.

understand the underlying reasons that the information they are learning is correct. This is how people prepare for an exam or gather knowledge that they care about (e.g., researching pre-natal care when trying to get pregnant, reading cookbooks and watching cooking shows when attempting to make tastier food). Most people have not learned what they know about forensic science in this way—they have never been tested on the topic nor intrinsically motivated to ensure that they obtain and remember accurate information about forensic evidence and analysis.

Most learning is incidental. Without knowing it, people accumulate information and notice patterns in their experiences for use in future decisions and judgments. Consider that most people will have a view about global warming, the death penalty, or other controversial topics, but have never actively studied those topics. When people express views that have been formed outside of their awareness, they are drawing on information obtained through heuristic processes (KAHNEMAN 2011). In other words, their view is formed using information obtained from a variety of sources—information they have encountered often, information from people whom they like or respect, and information that is shocking or stood out. However, hearing something frequently, the likeability of the source, or the extreme nature of the information are not good proxies for accuracy. Gathering and using information in this way requires very few cognitive resources, but when inaccurate decisions or judgments have serious consequences, these are not the best sources of information for people to rely on.

2.1.3. *Changing knowledge through persuasion*

Is it possible to change someone's beliefs about forensic evidence? Persuading someone away from their original opinion can be achieved using the same processes that created that opinion in the first place. If people are motivated and paying attention, they can be persuaded by the quality of the information, how well the information is communicated, and the extent to which the reasoning is sound (CHAIKEN & MAHESWARAN 1994; PETTY & CACIOPPO 1981). People can be motivated when the topic is relevant to them, if they believe that they can learn and understand the topic, or if they are generally curious and like to seek out learning and enjoy cognitively engaging tasks.

When people are not motivated, they can be persuaded by more superficial features of the information and how it is communicated. Such features include peripheral or irrelevant information, the perceived level of expertise of the communicator, likeability or attractiveness of the communicator, how easily it feels to process the information, and how consistent the information is with their existing knowledge or beliefs (SPELLMAN & TENNEY 2010). When reading or watching the news, watching crime television shows, or enjoying a movie, most people are not trying to assess the quality of the information and are, instead, influenced by these more superficial aspects of the content that infiltrate our beliefs and opinions largely outside of our awareness.

2.2. *Common misconceptions about forensic evidence*

Given the unreliability of the sources from which most people learn about forensic science, it is no wonder that they have many misconceptions about forensic science processes and conclusions.

2.2.1. *Misconception 1: "Forensic analysis is objective and was created by scientists"*

Ordinary people tend to be impressed with science and scientists and believe that they act in the public interest. Moreover, to some degree, a deep appreciation of many sciences requires some scientific knowledge (FUNK et al. 2019). Because forensic analysis is described as a science, forensic techniques have become synonymous with other sciences to those interpreting the forensic results and opinions. As a result, lay persons perceive forensic science as highly objective—neutral, impartial, and free from the influence of opinions, bias, and emotions.

However, except for DNA evidence, forensic techniques were not developed using scientific testing, methods, and validation; they were not even developed by scientists (NRC 2009). Instead, forensic disciplines were largely created by law enforcement and legal professionals for the purpose of finding suspects and providing evidence to incriminate those individuals. As a result, there are entire disciplines that were built on non-scientific foundations, and remain non-scientific in many ways (GARRETT 2022; see Part 1.1 above).

A related misconception is the belief that there is technology that analysts rely on to draw their conclusions about the evidence. This is true, to an extent. For fingerprints and DNA there are database-search algorithms that can produce candidates in cases where there is no suspect (e.g., Automatic Fingerprint Identification Systems (*AFIS)*, the Combined DNA Index System (*CODIS)*). There is software that helps with DNA analysis—particularly when a DNA mixture is found at a crime scene. There are microscopes and image enhancement software that can improve analysts' ability to look at the details of evidence, and programs designed to digitize their analyses and observations. Ultimately, though, it is a person who makes a subjective judgment to reach a conclusion (DROR & MNOOKIN, 2010)[5].

2.2.2. *Misconception 2: "Forensic results are very rarely inaccurate"*

Many individuals believe that the error rate in forensic analysis is negligible or very low (MARTIRE et al. 2019). However, despite the call for research on error rates in the NRC report, for most forensic techniques there is no known error rate or empirical foundation for establishing accuracy and reliability (GARRETT 2022). Assessing error rates requires knowledge of ground truth, which is unknown in real cases. And analysts will almost never receive feedback about whether they made a correct judgment in real cases. In fact, forensic analysts can become more confident in their abilities because their work results in convictions. When the defendant they identified using their forensic test is convicted, they reason that their analysis must have been correct, not recognizing that their test results helped cause the conviction (i.e., using circular reasoning) (SPELLMAN et al. 2021).

There are a few ways to collect relevant information about accuracy and error rates. Forensic labs can test the accuracy of their output by introducing simulated evidence that mimics real cases, but for which ground truth is known, such as "black box" studies. These studies assess outcomes only, and aggregate error rates within a lab or larger group, but not the processes leading to outcomes (hence, "black box"). Blind proficiency tests are a measure of accuracy focused on the error associated with individual analysts. Such tests involve embedding fake but realistic cases, for which ground truth is known, into analysts' workflow and assessing the accuracy of their determinations.

When done well, "black box" and "blind proficiency" studies produce more precise error rates than classic proficiency tests, when analysts know they are being tested, which are notoriously easy. Understandably, laboratories want to avoid putting analysts in a situation where they must admit to having made errors in the past on the witness stand (ELDRIDGE et al. 2022; see Part 3.3.1 below for further discussion of the impact of providing error rates when giving testimony). However, there are some serious problems associated with "black box" studies and "blind proficiency" tests too.

Setting up such simulations—from evidence receipt through reporting conclusion—is logistically difficult (MEJIA et al. 2020). Analysts can often tell when they receive a simulated

[5] Note that technology can introduce other problems into the decision process. As recent research in many fields shows, big data can introduce biasing effects; see DROR et al. 2012 for a discussion of the biasing effects of AFIS.

case, which leads to more conservative responding that reduces the rate of false positive errors—the kinds of errors that can mistakenly incriminate someone. Plus, the samples are often more pristine than anything typically obtained from a crime scene and, thus, overestimate true performance in casework (GARDNER et al. 2020; KOERTNER & SWOFFORD 2018). There are also issues associated with the analyses and labelling of outcomes in error rate studies (BIEDERMANN & KOTSOGLOU 2021). As a result, when analysts are asked on the witness stand about error rates, they are either providing a subjective judgment about error in the absence of these studies, or they are referring to studies that are not representative of real casework.

2.2.3. *Misconception 3: "Forensic science reliability does not vary much across types of evidence"*

Not all forensic sciences are equal in terms of their reliability. Single source DNA profile comparisons tend to be very accurate, and the error rate for such analyses can be estimated using published empirical research. Other kinds of DNA analyses, such as Mitochondrial DNA analyses and DNA mixture analyses, are far less reliable, more difficult for the analyst, and require more subjective judgments from the analyst. Although forensic scientists and science educated people may understand the different between these two kinds of DNA evidence, lay persons typically do not and, thus, ascribe the high level of accuracy to those less reliable forms of evidence (CHIN & IBAVIOSA 2022; GARRETT 2022). The differences in reliability across forensic domains can be attributed to the foundational science in the field, the methods and procedures used, error rate studies, and studies examining the role of these forensic techniques in wrongful conviction cases (MORGAN 2023). Fingerprint analysis is believed to be fairly reliable and has a stronger research base and rigorous methodology than most other forensic sciences like bitemarks, shoeprints, voice analysis, or canine detection teams.

Regardless of the type of evidence, lay persons tend to overestimate the reliability of the discipline and underestimate the error rate (MARTIRE et al. 2019). Although lay persons can typically understand that some disciplines are relatively more accurate or reliable than others, they do not adequately adjust their perception of the evidence (LIEBERMAN et al. 2008). For instance, highly questionable evidence like bitemarks and hair analysis are considered much more reliable by lay persons than research suggests they are, yielding a larger discrepancy between their views and the actual credibility than seen for more credible evidence types (e.g., DNA, fingerprints).

2.2.4. *Misconception 4: "Forensic evidence is commonly available in criminal cases"*

As forensic evidence became more frequently used in criminal cases, and more frequently reported in the related news and entertainment media, people began to think that it was the norm for criminal cases to involve lots of forensic evidence (i.e., a result of the availability heuristic) (TVERSKY & KAHNEMAN 1974). Lawyers became nervous about a "CSI Effect" (named after the television show)—but they and the researchers who investigated the effect could not agree on the nature of the effect. Some researchers and lawyers (typically prosecutors) believed that jurors would expect every case to include forensic evidence, and if the current case did not, they would decide for the defendant. Other researchers and lawyers (usually defense attorneys) observed the increase in the use of forensic evidence in trials and believed that it would bias jurors to decide in favor of the side with the most forensic evidence (typically the prosecution) regardless of the other facts in the case (CHIN & IBAVIOSA 2022; COLE 2015).

A problem with the supposed CSI-effect is that ordinary people are not aware that evidence collected from a crime scene might not be of high quality to begin with or can become contaminated, thus complicating whether the evidence can be admitted in court and the conclusions that can be drawn from it (GARRETT 2022). Forensic testing is slow and expensive, and not always helpful. Forensic testing is usually reserved for the most serious cases, and is certainly not commonplace.

2.2.5. *Misconception 5: "Forensic evidence can tell you whether a specific person committed a crime"*

Not only do people struggle to understand the forensic evidence and associated conclusions, but they also have trouble determining what can and cannot be "proven" by forensic evidence. For instance, physical evidence is still circumstantial evidence. The presence of someone's DNA or a fingerprint at a crime scene does not, in itself, prove that this person committed the crime. Forensic evidence can lead to an *inference* that a person had been at the scene at some point because they left behind something that is unlikely to be there unless they had been physically present. The condition of the evidence might reveal whether they had been there at about the time of the crime. Then, those facts can be used to further infer that that person was involved in the crime that took place.

Thus, forensic evidence alone can be fairly weak evidence that someone is the actual perpetrator without other corroborating evidence and reasons to believe they would do such a thing. For ordinary people to understand forensic evidence and what it can offer to a criminal investigation or case, they need to understand that it is just one piece of a puzzle and that, alone, forensic evidence is rarely enough to convict an individual. Even when considering DNA in a sexual assault case, generally seen as particularly incriminating, there are ways that the physical evidence can be wrong or misleading. Consider the example of Mr. Jama who was convicted of rape based on solely on DNA evidence taken from a rate kit at a hospital (*Jama* case, detailed in VINCENT 2010). It was later discovered that Mr. Jama could not have committed the crime and the positive test must have been an error. In fact, Mr. Jama's DNA had been tested at the same hospital two days prior. A formal inquiry was unable to conclusively determine how the relevant test sample had been contaminated by Mr. Jama's DNA but, ultimately, decided that must have been what happened in this case. The report suggests that DNA alone should never be sufficient for a conviction.

3. *Forensic science at trial: Using it appropriately and effectively*

The characteristics of human reasoning and how they contribute to errors in forensic science reasoning were described in Part 1, and common preconceptions and misconceptions among factfinders were described in Part 2. Given this factors, how and when should forensic science evidence be introduced and evaluated in trials? Trial procedures vary around the world, and we consider below if and how forensic science should be presented to factfinders—people who may be judges, lay judges, or citizen-jurors, but are neither scientists nor forensic experts. Judges, lawyers, and witnesses can all help ensure that forensic science information is communicated to factfinders in ways that result in an appropriate level of reliance on that information based on the underlying science. We use the language from the US system to label the function of legal actors in this chapter—a judge rules on the admissibility of evidence, lawyers ask questions of witnesses, and jurors determine the facts and the verdict in the case.

3.1. *Deciding whether a type of forensic science should be admitted at all*

In the US, it is the presiding judge's decision whether to admit proffered expert evidence. The US Supreme Court ruled in *Daubert v Merrell Dow Pharmaceuticals, Inc.* (1993)[6] that judges serve as "gatekeepers" and assess «whether the reasoning or methodology underlying the [expert

6 *Daubert v. Merrell Dow Pharmaceuticals, Inc.*, 509 US 579 (1993).

scientific] testimony is scientifically valid». Rule 702 of the Federal Rules of Evidence also supports this approach. Judges are given guidance about what to consider when assessing the admissibility of expert scientific evidence, including whether the theory or technique can be, and has been, tested; whether the methods are standardized; whether the science has been subject to independent peer-review and published; whether there is a known error rate; and whether the findings are accepted in the relevant scientific community.

The *Daubert* opinion states «We are confident that federal judges possess the capacity to undertake this review»[7]. Despite Justice Blackmun's optimism, the lower Appellate Court re-tried the case using the new *Daubert* standard and noted that federal judges, who are "largely untrained in science", face a "daunting task" when ruling on the admissibility of expert scientific testimony[8]. Subsequent surveys of judges have revealed that many do not belive they have the training or knowledge needed to make such decisions about scientific evidence in general. A more recent survey inquired specifically about forensic science evidence, and judges indicated that they wanted more training and wished such training was more easily available (GARRETT et al. 2021).

A small number of judges have taken notice of the warnings in the NRC report (2009) and disallowed some types of forensic evidence. Yet, for the most part, US judges have continued to admit a wide range of forensic evidence, including those that have been heavily criticized by independent agencies (e.g., bitemarks, non-DNA hair comparisons). Why? One reason is that rejecting established precedent is difficult to justify in legal procedure/culture. If other courts have allowed this type of evidence in the past, why should things be changed for this new case? Judge Jed Rakoff, a US Federal Court Judge and longtime proponent of forensic science reform, suggests another reason—that trial judges, who are often past prosecutors, are «very hesitant to deprive the prosecution of evidence that may make the difference between conviction and exoneration» (RAKOFF 2023, 83). Thus, like all decisions made by people, judges' decisions about admissibility may be driven by their own biases.

3.2. *Describing numbers and conclusions*

Forensic science expert witnesses may be asked questions about the methods and procedures used, the reliability of their tests, and their own qualifications, etc. Typically, though, their featured testimony focuses on the results of forensic tests they performed (or written reports of such tests). Communicating the results of forensic tests to jurors so that they correctly understand them and can use them appropriately is complicated (BALI et al. 2020; ELDRIDGE 2019). One way to describe results is by reporting a number and describing the meaning of that number. For instance, when reporting the results of a DNA comparison, an analyst might say, "it is 5,500,000 times more likely that this blood came from the suspect rather than from a random other person" (reporting a likelihood ratio) or "there is only a 1 in a 1,000,000 chance that a random person would have these features" (reporting a random match probability).

There are problems with reporting numeric results. First, for any forensic discipline other than DNA, the science is unlikely to support the use of exact numbers. More importantly, though, people find it challenging to understand probabilities, especially ones that are very small or very large. Probabilities that seem near 0, or near 1 may be interpreted as being no different from 0 or 1, thus corrupting later conclusions. Finally, presenting very small random match probabilities leads some people to entirely misinterpret the very small numbers as the chance that the defendant is innocent.

The other common way to communicate forensic results is using categorical phrases designed to suggest a range of probabilities. For example, "almost completely certain" suggests that there is some

7 *Daubert v. Merrell Dow Pharmaceuticals, Inc.*, 509 US 579 (1993).
8 *Daubert v. Merrell Dow Pharmaceuticals, Inc.*, 43 F.3D 1311 (9TH CIR. 1995).

probability of error, but it is very unlikely. "It's somewhat likely" suggests that whatever conclusion the expert is presenting may be unreliable. Other phrases imply that the results are definitive, such as "It's a match." These kinds of definitive terms are dangerous in the context of communicating with non-experts because what a non-forensic audience takes away from the testimony is something different from the expert's intended meaning (ELDRIDGE 2019). Research suggests there is low correspondence between the value experts intend to communicate with verbal categorical phrases and what jurors understand when hearing that language (e.g., MARTIRE et al. 2013; MARTIRE & WATKINS 2015).

Regardless of how the results are presented, it is a mistake not to clearly communicate the potential error rates to factfinders (KOEHLER 1996). As discussed in Part 1 and Part 2.2.2 above, no matter how good the science is, there is always a non-zero rate of error. In particular, in any discipline that relies on human decision-making, there will be error associated with the performance of an individual practitioner, as well as errors resulting from laboratory procedures. Whatever the nature of those potential errors, factfinders should be made aware of the potential for such errors in addition to whatever errors are possible in the science itself. When this information is disclosed, ordinary people appear to adjust their judgments about the credibility of the findings appropriately (GARRETT et al. 2020).

3.3. *Testimony*

As described in Part 2, factfinders come to court with pre-existing beliefs about the validity and reliability of forensic evidence. Studies of both jurors and judges indicate that when people rate the reliability of different types of forensic evidence, the relative rankings do align with actual reliability (i.e., current scientific belief about reliability of the evidence). However, although the ordering is correct, their beliefs are inflated and not grounded in a solid understanding of the techniques or the reasons they are or are not reliable (KOEHLER 2017; MARTIRE et al. 2019).

Given that people's attitudes and beliefs are very difficult to change, how can the overconfidence ordinary people have in forensic science be remedied? Experimental research has looked at a variety of techniques for recalibrating "mock jurors" (typically jury-eligible Americans who read vignettes or watch videos of simulated trials). These techniques can be implemented during cross-examination of witnesses or by adding additional witnesses. The success of such measures, however, depends on how "invested" a person is in their pre-existing views (see the descriptions of motivated reasoning and confirmation bias in Part 1.4.2 above). Jurors who acknowledge that their understanding of forensic science is limited should be more willing to change their beliefs than those who feel confident in their understanding. In addition, jurors who are strongly invested in the success of a particular outcome and believe that the testimony will threaten that outcome, will be less likely to change their beliefs.

3.3.1. *Cross-examination*

A multi-disciplinary group of research scientists, forensic scientists, and lawyers based in Australia authored: *How to cross-examine forensic scientists: A guide for lawyers* (EDMOND et al. 2014). Their suggestions include asking questions about the foundation of the forensic discipline, such as the validation of the technique, the likelihood of error, the forensic scientist's proficiency, exposure to potentially biasing information, the quality of the evidence in question, and whether the conclusions were verified by an independent analyst. Research with mock jurors shows that receiving this type of information can appropriately modify mock jurors' beliefs.

Attacking the source of information can be useful for debiasing (LEWANDOWSKY et al. 2012). For example, forensic examiners who admit to low performance on required proficiency exams are viewed as less credible and less persuasive than those who have shown high performance

(CROZIER et al. 2020). If the forensic examiner reveals that they were exposed to potentially biasing information (e.g., information about the defendant's prior criminal history or his confession), people justifiably find the expert less credible. However, if the analyst is asked whether they might have been biased in these situations, those who claimed that they were not improperly influenced seemed more credible than those who acknowledged the possibility that they had been influenced (KUKUCKA et al. 2020). This finding goes against existing research. Forensic examiners, like everyone else, tend to be blind to their own biases—they believe that others are biased but they themselves are not (KUKUCKA et al. 2017). In addition, bias occurs outside of a person's awareness and is difficult to prevent, so we know that forensic examiners cannot always "debias themselves". Yet, mock jurors believe experts can do this, perhaps due to the illusion that expertise immunizes people against such errors.

Of course, to do a good job of cross-examination, opposing counsel needs to have a sufficient degree of understanding of forensic science. And depending on how the legal system works, opposing counsel might need to find the time and financial resources to ask and pay for additional alternative testing.

3.3.2. *Experts for better or worse*

The existing research on calling opposing expert witnesses does not provide support for engaging in a game of "battling experts". The research suggests that ordinary people hearing from experts who completely contradict each other (e.g., "the time of death was 7 pm", "no, it was 11 pm") are not inspired to choose one view over the other—rather, it diminishes their view of both witnesses and their testimony and the science (MITCHELL & GARRETT 2021; SCOBIE et al. 2019).

However, rebuttal experts can teach jurors about aspects of forensic science that were not addressed by the initial expert. They can do that at the level of the forensic science generally—for example, explaining that fingerprint identifications can be wrong, especially when the latent prints are unclear—and then applying that information to the specific case (i.e., the print was of poor quality and not suitable for comparison). Given that information some jurors will decrease their confidence in the evidence (MITCHELL & GARRETT 2021). This technique follows the known debiasing technique of "providing an alternative narrative"—supplying information about how something might have happened differently (LEWANDOWSKY et al., 2012)—in this case why the two examiners came to different conclusions.

3.4. *Jury instructions*

Several researchers have suggested that jury instructions might be a good way of telling jurors about the limitations of forensic science, but the current set of forensic studies that use such instructions is limited and inconclusive. That said, jury instructions that target other kinds of evidence for which lay persons have similar, well-ingrained misconceptions, for example, eyewitness identification evidence, do not help jurors sort between good and bad, or reliable and unreliable, examples of such evidence (e.g., JONES et al. 2020; PAPAILIOU et al. 2015). Thus, it is unlikely that a short instruction from the judge, after all evidence has been presented, would be enough to overcome existing beliefs about forensic evidence and their already-formed opinions about the evidence in the case.

4. *Suggestions and conclusions*

No one is an expert in all forensic science disciplines. But judges may be called upon to rule on the admissibility of any forensic discipline—regarding the science itself and the testimony surrounding it. Lawyers (or judges) may need to question or cross-examine forensic practitioners or decide whether to call them as witnesses. Ultimately, it is the factfinder—judges, lay judges, or jurors—who must be able to understand the appropriate probative value of the evidence and use it to evaluate the issue in a particular case. Although they should, not all legal professionals will be motivated to ensure that factfinders interpret and use this information correctly, but here we have provided background information and various techniques for those who do.

This chapter mainly focuses on the use of forensic science evidence in criminal cases; however, it is also relevant to some civil cases (especially for document and handwriting identification, and for experts in accident reconstruction). The cognitive science underlying the interpretation, use, and understanding of forensic science is broadly applicable to other kinds of decisions in legal contexts. For example, trials often involve non-forensic expert testimony, such as physicians who comment on the severity of injuries from a car crash, art dealers who opine on whether a painting is a forgery, real estate agents who judge the value of a piece of property, and even cognitive psychologists who present on the reliability of eyewitness memory. Understanding the general principles of reasoning, and the factors that could lead to forensic errors, is useful for evaluating any type of expert testimony. In the US, every law school has a course on Evidence Law where students learn about the admissibility of experts and expert evidence, but very few law schools offer courses specifically on scientific or forensic evidence (GARRETT et al. 2022). Judges have expressed a view that they would like more training about forensic science, especially early in their legal education, and access relevant continuing education classes or other aides to help them understanding this constantly and quickly evolving scientific field. We have no doubt that many lawyers do so as well.

We leave the reader with the following suggestions for more information about the intersection between cognitive science and forensic science.

Book for general background on how forensics are done and what can go wrong:

GARRETT B.L. 2022. *Autopsy of a crime lab: Exposing the flaws in forensics*, University of California Press.

Articles on forensics generally with a cognitive science approach:

DROR I.E. 2020. *Cognitive and Human Factors in Expert Decision Making: Six Fallacies and the Eight Sources of Bias*, in «Analytical Chemistry», 92, 12, 7998 ff.

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SPELLMAN B.A., ELDRIDGE H., BIEBER P. 2022. *Challenges to Reasoning in Forensic Science Decisions*, «Forensic Science International: Synergy», 4, 100200.

For general interest in forensic science and up-to-date news see:

What the US is doing:
https://www.nist.gov/forensic-science
https://forensiccoe.org

What the UK is doing:
https://www.gov.uk/government/organisations/forensic-science-regulator

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