COGNITIVE AND HUMAN FACTORS

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Even with major advances in forensic science, the human examiner will continue to play an important role in most forensic decision-making. Forensic work often involves interpretation and subjectivity, and hence cognitive and human factors are important to ensure high-quality forensic decisions. To maximise objectivity and decision quality, forensic examiners should receive cognitive bias training and should evaluate only contextually relevant information.

The human examiner plays a critical role in many forensic domains (often it is the human examiner who is the 'instrument of analysis'). Forensic work often involves human perception, interpretation, evaluation, judgment and decision-making. Therefore forensic work is shaped by, and depends on, cognitive and human factors. These underpin most aspects of forensic work: from the initial collection and evaluation of data (e.g. at the crime scene, in determining where and what to look for, and whether the data is of sufficient value to send to the laboratory); throughout the work in the forensic laboratory, where evidence is interpreted and conclusions are reached; to the presentation in court and to other end users who are the customers of forensic work (e.g. how they understand and integrate the information). Maximising the use and benefit of forensic science, while minimising cognitive bias within forensic work, requires educating practitioners and implementing cognitive best practices.

HUMAN COGNITION

The cognitive system underpins much of what we do. How information is perceived, mentally represented, compared, evaluated, and how we reach decisions are just a few of the cognitive operations carried out in the brain. One of the fundamentals in human cognition is that our brain and cognitive system has limited resources. In simple terms, the amount of information input for processing exceeds the computational recourses of the brain.

The brain and cognitive system have adapted to this challenge by developing a variety of mechanisms, including:

- Selective attention is a fundamental cognitive mechanism that allows the brain to focus on some information while ignoring the rest
- Chunking information together reduces the cognitive load by changing how information is encoded and represented
- The brain is active in processing information: it is not only driven by the data, but uses conceptually-driven information processing. In cognitive terms, 'bottom up' information (what comes in from the world) is driven by 'top down' information (what is already in the brain). Top-down information, such as past experience and expectations, governs what information is processed and how it is processed.

These, and many other cognitive processes[1,2,] enable the brain to function efficiently and effectively even though it has limited resources. The use of such cognitive processes is a characteristic of human intelligence and develops with experience and expertise.

The implications of how the brain processes information are far reaching. We do not 'see' the world as it is (naïve realism): instead, it is mediated by how the brain processes it, which is a function of complex cognitive architecture. Take, for example, Figure 1 – count how many 'F's are in the box (try it).

This illustrates that the human mind is not a camera: it does not passively process information, it uses past experiences and expectations to guide information processing. In other words, it is intelligent. As we learn more and have more experience – as we become experts – we develop, use and rely more and more on such processes[4] (e.g. selective

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Figure 1: Count how many 'F's are in the box above (please try before continuing). Most people see 3 or 4, some 5, but people rarely see all of the Fs: there are actually 6 of them. The reason that many people miss some of the Fs is because we are experts in reading. Our base-rate experience tells us (via our unconscious brain) that words such as 'of', 'the', and 'a' do not carry much meaning and weight, and therefore, based on our expectation, we tend to automatically ignore them[3].

attention, chunking information and reliance on top-down information). It is important to note that these processes occur without awareness: it is a cognitive bias, not an intentional bias.

Although such cognitive processes are effective and efficient, they also can lead us astray. By relying on shortcuts, such as using our expectations and past experiences to selectively attend to some information while ignoring the rest, we are cognitively biased[5]. These biases are widespread and have many forms[5], and only increase with expertise[4]: as we have more experience, we are more driven by top-down, conceptually-driven cognitive processes. These processes and biases are especially powerful when subjective decisions are involved or when the data is low quality, ambiguous, and difficult to determine (as is often the case in forensic evidence).

Another example of bias is base-rate expectation. When experience provides a clear expectation of the outcome, then that base-rate expectancy drives our conclusion, even in the face of contradictory data. If X-ray security screeners in airports do not encounter bombs, then they develop an expectation to not find bombs, and are therefore more likely not to find a bomb even when it is present in the X-ray. Similarly, when medical monitors in intensive care units (ICU) sound false alarms very often, then the medical staff are likely to ignore them[6]. The reason for these biases is that, with experience, the brain has picked up regularities in the information it receives and then uses them to guide future information processing. This is effective, but it biases how new information is processed.

FORENSIC SCIENCE

Forensic science consists of many different domains that utilise different types of evidence. However, in many forensic domains it is the human examiner that is central to the forensic work (this is true in the UK, the US, as well as anywhere else that forensic work is carried out). The main reason for this is that there are many subjective judgements that underpin forensic work.

During initial evidence gathering at the crime scene, the crime scene investigation (CSI) examiner is required to make many decisions, most of which are subjective. First, they need to decide where to look for evidence, and what kind of evidence they will look for. The CSI is guided by their experience and expectation. Second, as they look for evidence, they need to determine whether what they have found is actual data (a 'signal' such as blood) or just an artefact ('noise' such as dirt). Third, if what they find is actual data, then they need to subjectively assess the quality and quantity of the evidence to determine if there is sufficient information to warrant its collection and sending it to the forensic laboratory (e.g. shoe prints found at the crime scene can be of such low quality and quantity of information that they do not merit collection, documentation, and having the forensic laboratory examine them further). Such decisions are critical, as evidence not collected and sent to the forensic laboratory is often lost forever.

Once evidence is received in the forensic laboratory, then examiners have to analyse it. Often that process is subjective. Fingerprints, for example, are defined mainly by their minutia – the characteristics in the flow of the friction ridge (see Figure 2).

Figure 2: Different characteristics (minutia) present in the friction ridge of fingerprints (e.g. when a ridge divides or ends).

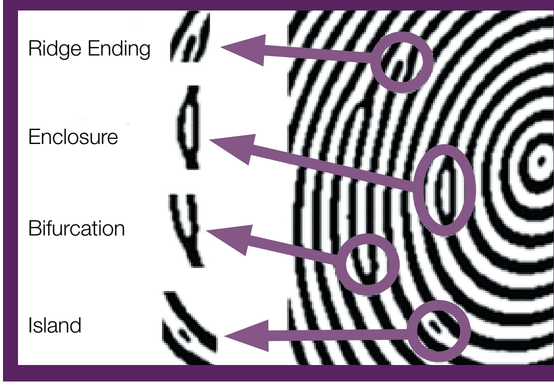


Table 1: The inter-reliability of fingerprinting. Different latent fingerprint examiners looking at the same fingerprints (A to J) lack consistency in the number of minutia they observe[7].

	Latent Fingerprint									
	A	B	C	D	E	F	G	H	I	J
Examiner 1	22	9	15	8	9	3	22	11	7	10
Examiner 2	21	11	25	7	10	9	9	10	6	5
Examiner 3	19	9	18	10	7	9	15	19	6	6
Examiner 4	21	21	29	14	12	9	8	9	4	8
Examiner 5	17	16	15	11	16	9	7	12	5	5
Examiner 6	20	14	22	9	10	7	13	18	7	9
Examiner 7	22	17	15	10	10	8	11	24	8	11
Examiner 8	9	9	19	6	9	8	18	16	9	10
Examiner 9	30	15	25	10	12	12	19	22	12	17
Examiner 10	25	13	18	13	12	10	13	15	7	10
MIN	9	9	15	6	7	3	7	9	4	5
MAX	30	21	29	14	16	12	19	24	12	17
SD	5.49	4.01	4.93	2.49	2.45	2.32	4.25	5.15	2.23	3.54
range	21	12	14	8	9	9	12	15	8	12

These minutiae play a critical role in forensic fingerprinting. However, their presence is subjectively determined. This is evident by the lack of reliability and consistency among fingerprint examiners (see Table 1)[7].

The subjectivity in determining the fingerprint characteristic is further apparent when examining the lack of consistency of expert's judgements with themselves, i.e. their intra-reliability. Not only are examiners not consistent with one another, but the same forensic fingerprint examiner looking at the same print is not always consistent with their own judgment (see Table 2)[7].

The subjectivity underpinning forensic work is not limited to the perception of the evidence, but also to the actual forensic conclusions. In many forensic domains, forensic examiners need to decide whether two patterns are 'sufficiently similar' to conclude that they originate from the same source[8]: for example, whether two handwriting patterns are 'sufficiently similar' to conclude that they were written by the same person, or whether two bullet cartridges are 'sufficiently similar' to conclude that they were fired from the same gun, or whether two fingerprints are 'sufficiently similar' to conclude that they are from the same person, etc. The subjective nature of such forensic decisions arises from the lack of criteria or definition of what constitutes 'sufficiently similar'.

With such subjective decision-making, it is not surprising that different forensic examiners can reach different conclusions. This pertains to many forensic domains, including mixture DNA (even when identical procedures are used)[9], and even when statistical tools are used[10]. In fact, in about 10% of the time, the same fingerprint expert, examining the same pair of fingerprints, will reach different conclusions[11].

Subjective decisions do not only underpin the comparative forensic domains (where evidence from the crime scene is compared to a suspect), but also include many forensic domains, such as blood spatter analysis, forensic anthropology and fire investigations. The subjective decision-making even sometimes pertains to domains such as drug analysis (when one needs to determine if a new designer drug is 'sufficiently similar' to an established illegal drug).

A PROBLEMATIC CONCOCTION

Taken together, the natures of human cognition and of forensic work produce a problematic concoction. Humans are prone to cognitive bias, and that is especially pronounced when information is of low quality and open to different interpretations (as is often the case in forensic evidence) and even more so when subjectivity is involved. That makes cognitive bias a real issue in forensic science, as outlined in a recent briefing to the Houses of Parliament[12]. It is important to note that this relates to cognitive biases that occur without intention or awareness, and that these issues pertain to most aspects involved in forensic work[13]. Below I discuss the potential of biases to affect different aspects and stages of forensic work.

1. At the crime scene

Before the CSI even arrives at the crime scene, before they actually see any evidence, they are briefed. This biases their examination and decisions at the crime scene. Take, for example, a CSI who arrives at a crime scene and has to determine the source of a blood pattern, a highly complex and subjective cognitive process. A briefing that it was caused by a gunshot, or a briefing that it was caused by a knife stabbing, influences how they perceive and evaluate the blood spatter. Similarly, if they come to a crime scene expecting it to be a real burglary, or expecting it to be an attempt at insurance fraud, also affects what evidence is collected and how.

2. At the forensic laboratory

The human examiner at the forensic laboratory, making subjective evaluations and decisions, is often aware of potentially biasing contextual irrelevant information (such as whether the suspect confessed to the crime, if eyewitnesses identified the suspect, whether the detective believes the suspect is guilty etc). Such information is irrelevant to the actual forensic work, but it is nevertheless highly biasing.

The cognitive biases at the forensic laboratory also arise in many forensic procedures, such as verification. Often forensic conclusions are verified, but they suffer from a number of cognitive weaknesses. First, the verifications are not blind: the verifier often knows who did the initial examination, what

Table 2: The intra-reliability of fingerprinting. The table presents the difference between the number of minutia that each expert observes while examining the same fingerprint (A to J) on two separate occasions, i.e. zero indicates consistency[7].

	Latent Fingerprint									
	A	B	C	D	E	F	G	H	I	J
Examiner 1	1	1	4	1	1	2	3	2	0	1
Examiner 2	8	3	5	1	1	2	2	5	2	2
Examiner 3	1	3	3	3	6	4	9	9	1	2
Examiner 4	2	3	2	5	0	1	1	0	0	1
Examiner 5	6	2	2	3	4	1	3	3	0	3
Examiner 6	9	4	2	1	4	6	0	5	1	1
Examiner 7	0	4	5	2	4	3	3	7	0	0
Examiner 8	3	1	4	0	6	2	1	4	2	0
Examiner 9	4	3	9	0	4	4	3	1	1	3
Examiner 10	1	0	0	1	4	1	4	1	0	0
Mean	3.5	2.4	3.6	1.7	3.4	2.6	2.9	3.7	0.7	1.3

TAKEN TOGETHER, THE NATURES OF HUMAN COGNITION AND OF FORENSIC WORK PRODUCE A PROBLEMATIC CONCOCTION.

they decided and why. Second, identification decisions are almost always verified, and hence introduce a base-rate bias (see above).

3. At court

The presentation of evidence in an adversarial legal system is inherently problematic. Although the court wants to rely on and use science, science is often misused and abused in the court. Science within the adversarial system is used by the prosecution to make a case that the suspect is guilty, and by the defence to make the case that the suspect is innocent. Although prosecutors' duty is to do justice, not merely to obtain a conviction (see, for example, the US Supreme Court)[14], "There is reason to doubt that prosecutors comply with these obligations fully" (this statement was made by a US federal appellate judge on the Ninth Circuit[15]). The forensic examiners are often recruited to help make these cases, and that biases the presentation of the evidence.[16,17]

The implications for court and the criminal justice system (regardless if it is in the UK, US, or any other country) are that the forensic evidence may be overstated, and its uncertainties and limitations concealed. Although this should come out in cross-examination, in my view that rarely occurs. First, both sides are rarely equal, because the prosecution often has far more resources than the defence, as well as has better access to the investigative team. Second, many cases enter a plea-bargain or a situation whereby suspects confess to the crime and enter an early guilty plea, and hence the forensic (and other) evidence is never really questioned.

The implications of this bias are corrosive and affect prosecution decisions, plea-bargaining, the actual trial, as well as subsequent appeals[18]. Furthermore, at court, there are cognitive issues that affect how the juries understand the forensic evidence, and how they integrate it within other lines of evidence (see case study, p50).

RESEARCH ABOUT COGNITIVE BIAS IN FORENSIC SCIENCE

Until about a decade ago, there was very little research into the performance of human forensic examiners. The issue of whether they can be biased by irrelevant context, as well as their inter – and intra-reliability, had basically not been studied in any depth. However, in the past few years we have seen a big increase in researching this area (both within forensic science as well as in other scientific domains[19]).

The growing literature includes meta-analytically quantifying the reliability and biasability of forensic experts[20], as well as specific research studies showing that irrelevant contextual information can bias forensic examination most often. This research includes areas such as face comparisons[21], forensic anthropology[22], bite-marks[23], shoe prints[24], firearms[25], fingerprinting[26], DNA[9], blood spatter analysis[27], and fire investigations[28]. There has even been research into forensic bias in the courtroom, showing an 'allegiance effect' whereby forensic experts' conclusions depend on which side hired them[29].

It is worth noting that the research on cognitive bias is complex. First, when participants in the studies are aware that they are taking part in research and that this is not real casework, then the contrived contextual information is not as powerful as when they really believe it. Second, when participating forensic experts think it is real casework, then it is not practically possible to run many examiners on a fully-controlled study with all conditions counterbalanced and good control groups. Third, fully-controlled studies are possible, but then they are mostly done with students. Fourth, contextual information affects perception and cognitive processing, but it does not necessarily determine the decision outcome. This is dependent on the difficulty of the decision (i.e. how close it is to the decision threshold), and the strength and direction of the bias. Only when the decision is within the 'bias danger zone'[3] can bias shift the decision across the threshold and actually determine the decision outcome. Fifth, a null finding that no bias was found does not mean that bias was not there – it could have been there but was not detected, or it may have been absent because of ineffective experimental bias manipulations.

Therefore, although the research literature most often finds biasing effects in studies across the different forensic domains, the effects are not always straightforward and present in terms of decision outcomes. It is not an easy area to study, and there are a number of inherent obstacles in researching it.

Research in this area has also investigated the effects of using technology in forensic science. It has shown that technology does not necessarily solve bias, and may even introduce new forms of biases. For example, the use of computerised fingerprint databases has introduced clear base-rate expectations about a match[30]. This base-rate biasing expectation affects forensic examiners in a number of ways. First, they tend to spend less time comparing suspects that they do not expect to match. Second, they are more likely to make false-positive decisions (i.e. erroneous identifications) when they expect a suspect to match. And third, they are more likely to make false-negative decisions (i.e. not make correct identifications) when they expect a suspect not to match[31].

COGNITIVE BIAS IN FORENSIC CASEWORK

Do these theoretical analyses and research findings apply to actual forensic casework? The answer is clearly yes, as revealed by cases with erroneous forensic identifications and miscarriages of justice. For example, in the US Brandon Mayfield was linked with the 2004 Madrid train bombings after being misidentified by a number of independent forensic examiners, who all concluded with 100% certainty that he was the match. However, because of unusual circumstances the erroneous identification was revealed and prompted an investigation that concluded that confirmation bias was a factor in the mistake[32].

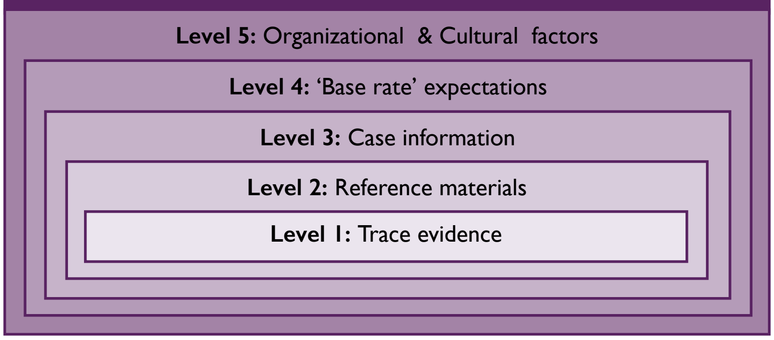
The biasing effects on forensic casework were also revealed in the UK by the public judicial inquiry by the Rt Hon Sir Anthony Campbell, who examined the Shirely McKie case[33]. Other cases include the UK High Court of Justice Court of Appeal (Criminal Division) quashing a conviction that was based on biasing forensic work[34]. In this case, the forensic expert initially examining the evidence "concluded that there was insufficient detail to be able to make a meaningful comparison", but after a suspect had been charged the expert made a comparison and an identification. This type of bias is derived from backward and circular reasoning, whereby the forensic expert is biased by the known reference material (i.e. the suspect who is the target for comparison). Working backwards from the suspect to the evidence in this way is a problem that can be addresses by the Linear Sequential Unmasking method (see below).

We must remember that forensic evidence is not always challenged in court because of the limited resources of the defence as well as the prevalent use of plea-bargaining and early guilty pleas. Furthermore, because we never know the ground truth in casework, it is hard to determine the extent of forensic error. Nevertheless, there is sufficient data to show that forensic bias and error do occur within the criminal justice system. From known miscarriages of justice in the US, 60% included flawed forensic evidence[35].

SOURCES OF CONTEXTUAL BIASING INFORMATION

Bias comes in many forms and guises[5], and it can derive from very different sources. It is important to classify the different sources of contextual biasing information, as this will enable a better understanding of bias in forensic work as well as help to

Figure 3: A taxonomy of the different levels at which task-irrelevant and potentially biasing contextual information may reach a forensic scientist[13, 36].



THE SOLUTIONS ALL SHARE A COMMON GOAL: TO INCREASE THE INDEPENDENCE OF MIND OF THE FORENSIC EXAMINERS, SO THAT THEY CAN ACHIEVE THE HIGHEST POSSIBLE QUALITY DECISIONS.

devise solutions. Clearly, some context and information is needed for forensic examiners to do their job, but other contextual information is extraneous and irrelevant to their forensic work.

I organise the different sources into a 5-level taxonomy[13, 36] (see Figure 3). First is the actual evidence, which may include irrelevant biasing context. For example, handwriting analysis may involve text that includes irrelevant biasing information, voice recognition may include tone and content that includes irrelevant biasing information, and bite-marks may reveal irrelevant information about the nature of the crime.

The second level is the reference material, the known 'target' that the evidence from the crime scene is compared against. This information is relevant and essential: the forensic examiners cannot do their work without it. However, it may cause backward and circular reasoning that can bias the perception and evaluation of the actual evidence. This often occurs when the forensic examiner works from the target suspect to the evidence, rather than from the evidence to the suspect. When examining and analysing the evidence from the crime scene, the target suspect is irrelevant.

The third level is the case information. There is a whole array of case information that is not relevant to the forensic examination in question, but can bias perception, interpretation, judgement and decision-making. Knowing whether eyewitnesses identified the suspect, whether the suspect has previous convictions, and whether the detective believes the suspect is guilty, are all examples of case information that is irrelevant to any forensic examination.

Level four pertains to the base-rate expectations derived from pervious work. The forensic examiner has an expectation of what they will find and what they will conclude before they even see or examine the actual evidence – a clear source of bias. Finally, the fifth level relates to larger contextual sources of bias: the organisational and cultural factors, such as the adversarial legal system and being part of the police service (see the allegiance effect discussed earlier).

SOLUTIONS

Many of the solutions to the problems raised in this chapter do not require additional funds and are practical. In fact, some solutions will enhance forensic decision quality and increase efficiency at the same time. This is because the solutions are derived from understanding human cognition as it applies to forensic work. These solutions are detailed in a number of publications[3, 36-38], and many are included in the Forensic Regulator Codes of Practice and Conduct guidance on "Cognitive bias effects relevant to forensic science examinations"[39].

The solutions all share a common goal: to increase the independence of mind of the forensic examiners, so that they can do their work without interference and bias, and thus achieve the highest possible quality decisions.

1. Context management

Many of the solutions focus on how to manage context, providing what I often call the "Context Management Toolbox"[36]. These tools and procedures consider what the forensic examiner needs and when.

The first and most basic step is **masking irrelevant information** from the forensic examiners. Hence, information that they do not need and that is extraneous to their work should be masked from them (see the Linear Sequential Unmasking method below). This will not only make sure they focus on the information relevant to their forensic expertise, but will also increase efficiency because they will not waste time on irrelevant information.

In some cases, regardless of the forensic domain, it is easy to determine that some case information (see level 3 in Figure 3) is not relevant (e.g. whether the suspect confessed to the crime). At other times it is not so clear cut: for example, the location of where a gun is found may be relevant if it was hidden for a long time in a wet gutter, because that may impact the patterns of bullet cartridges fired from it.

Sometimes irrelevant biasing information is not easily masked, such as those originating from within the evidence itself (see level 1 in Figure 3). In such cases (e.g. handwriting and voice analysis) the context is engrained within the actual evidence and cannot be (easily) removed. However, in other cases (e.g. fingerprints) much of the context is irrelevant, so the forensic examiner must focus their decision on the actual fingerprint patterns. Although some contextual information is still needed – such as the material from which the prints were lifted, or the method used to develop the print off the surface – such information is mostly not biasing.

The second step is **sequencing the information**. In cases where biasing information is necessary to conduct the forensic examination, it is recommended that such information will be provided to the forensic examiner only when it is needed. For example, the 'target' reference material (see level 2 in Figure 3) should only be provided after the analysis of the evidence from the crime scene, hence ensuring that the forensic examiner works from the evidence to the 'target' suspect, rather than from the suspect to the evidence. The US Federal Bureau of Investigation (FBI) recognised that backward and circular reasoning from the evidence is a source of bias and have implemented a sequencing of information approach[36]. (It is not clear to what extent this, and other anti-biasing procedures, are currently in use in the UK.)

The Linear Sequential Unmasking (LSU) approach specifies that an examination of the actual evidence takes place first; that this analysis is documented; and only then is the forensic examiner exposed to the suspect. It further restricts changes that can be made to the evidence post-exposure to the reference materials[36]. For example, in DNA analysis, the forensic examiners must first characterise the profile from the biological material found at the crime scene before seeing the DNA profile of the suspect.

Some aspects of applying LSU are simple and straightforward across forensic domains. For example, requiring forensic examiners to first examine the actual evidence from the crime scene without being exposed to the 'target' suspect is very easy to implement without cost or effort, and will enhance forensic decision making by minimising backward and circular reasoning.

Other aspects of applying LSU are dependent on the specific forensic domain. For example, the analysis and documentation of the evidence is different in DNA analysis (e.g. peaks) than in fingerprinting (e.g. minutiae). The complexity and effort in documenting the analysis will therefore also vary. Some forensic domains and certain aspects may be very easy to document, whereas other may be more challenging.

The final aspect of LSU that needs to be considered before implementation is the restriction on changes to the evidence post-exposure to the target suspect. LSU suggests a number of approaches to achieve a balance between not allowing any such changes versus permitting unrestricted changes. For example, changes may be allowed as a function of confidence during the initial analysis, so that things which were clear during the initial analysis cannot be changed later, whereas things that were ambiguous can be changed (but these changes should be documented). Each forensic domain can determine how and to what extent such changes are permitted.

The LSU involves (sometimes temporary) **blinding** to information in the forensic comparative process, but other types of forensic work should also involve blinding of

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information. For example, when one forensic examiner verifies a forensic conclusion of another examiner, the verifying examiner should be blind to various aspects of the first examiner's decision (e.g. what they decided, why, who made the first decision, etc).

Who will do the masking and sequencing of information? Often, one must know a lot of context in order to determine what forensic tests need to be done, what information is relevant, etc. This could be carried out by a **Case Manager**[3], who will initially communicate with the investigative detective, and know all of the available information about the case. The case manager will then determine what tests to run, and what forensic work needs to be done. They will assign those forensic tasks to other examiners who will only be provided with the relevant information they need for those tasks, thus masking the irrelevant information.

Furthermore, the case manager will also communicate with the police and provide them with the forensic results, explaining what they mean and how they may bear on the case. The forensic examiners doing the actual forensic tests and comparisons will not be part of those communications, and will focus on their specific forensic analysis. Since the case manager role is most interesting, it may be a rotating role among the examiners.

2. Triage

Another set of solutions involves matching resources and effort to the complexity of the forensic work, and depending on whether it is within the 'bias danger zone'[3]. For example, some forensic decisions are complex and hence more prone to errors than others. In such cases one may go to the trouble of fully blinding the verifier to all potentially biasing information, whereas one may not need to use such blind-verifying procedures for simple, self-evident forensic decisions[3].

Similarly, some cases involve highly-emotionally biasing information and a variety of pressures that may influence the forensic examiner, whereas other cases may have very limited (if any) biasing information. The need to have a case manager and to blind case information (level 3 in Figure 3) may depend on the existence of biasing information. Hence, a triage approach can determine if and what measures are appropriate[3]. The triage approach makes implementing the bias countermeasures much simpler and cost-effective.

3. Countering base-rate expectations

This is quite easy to achieve by introducing a few examples that change the base rate. In airport security, for example, this may involve introducing fake bombs into the X-ray screening procedure, a tactic known as Threat Image Projection (TIP). In the forensic domain such measures can be implemented in a variety of processes. For example, the base rate for verifying identifications is very high, and this can be countered by including a few 'similar non-matches' as identifications within the verification stream[3].

Another example is countering the technology base-rate expectation, by including matches in locations that they rarely appear, or by randomising the positions so that there are no regularities of where the technology presents the most likely match[3, 30, 31]. All of these measures aim to make sure that the forensic examiner is cognitively engaged and bases their decision on the actual evidence rather than base-rate expectations.

4. Training

The best procedures and forensic practices will not help if the forensic examiners do not accept the need to have them and understand their utility. Since cognitive bias in forensic science is a relatively new topic, most forensic examiners have never received training in this area and have very little (if any) understanding of the underlying cognitive issues. Even the forensic trainers themselves – those who instruct and teach the forensic examiners

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HOPEFULLY WE WILL WITNESS THE INCREASED POWER OF FORENSIC SCIENCE TO CONTRIBUTE TO THE CRIMINAL JUSTICE SYSTEM AND TO SOCIETY AT LARGE.

about these issues – are predominately forensic scientists, not cognitive scientists, and therefore have little-to-no understanding of the human cognitive system to address the issues of cognitive bias (e.g. they often mistake them as ethical issues).

Therefore, it is paramount that all forensic and CSI examiners receive proper training on the bias and cognitive factors involved in making forensic decisions. This has started to take place: for example, Hertfordshire, Bedfordshire and Cambridgeshire Police are providing such training to their CSI and forensic examiners. Such training has already had a practical impact on the way they carry out forensic work: by removing possible irrelevant contextual information, for example, thereby ensuring that forensic decisions are based on the relevant forensic evidence and are not contaminated and biased by extraneous information (an aspect of the LSU method). Such higher-quality forensic decisions benefit the Criminal Justice System and save costs in the long run.

It is also important to provide training to judges, lawyers and jurors, so that they understand the strengths of forensic evidence, but also its limitations and vulnerabilities to cognitive bias. Such training should include the Forensic Regulator Codes of Practice and Conduct guidance on "Cognitive bias effects relevant to forensic science examinations"[39].

With education in this area, along with cognitive best practices, forensic science can increase its contribution to the Criminal Justice System and beyond. However, without acknowledging these issues and implementing training and solutions, forensic work may suffer from a variety of biases. A number of police forces in a variety of countries are undergoing such training (e.g. in the United States, the FBI and Police Departments including those in New York City, Los Angeles, San Francisco, and Kansas), have all provided cognitive training to their forensic/CSI examiners. It is suggested that such training also be provided to a variety of police forces in the United Kingdom.

CONCLUSIONS

In most forensic domains – from the work at the crime scene to forensic comparisons at the laboratory – it is the human examiner who perceives information, interprets it, makes judgments and reaches a decision. Often it is the human examiner who is the 'instrument of analysis'. However, until recently the role of the human examiner has been relatively neglected.

For forensic science to increase its positive impact on the Criminal Justice System and beyond, it must ensure that cognitive bias in forensic work is minimised. Understanding human cognition helps to identify the weak points and vulnerabilities inherent in forensic science, and also to develop and implement biasing countermeasures. Without such measures, forensic examiners and CSIs will be cognitively contaminated and biased in their work. These biases affect others and ultimately create a 'bias snowball effect'[37, 38].

Taking on board the cognitive and human factors involved in forensic science is long overdue, but recent years have seen very fruitful progress in advancing these issues within forensic science. Hopefully this trend will continue and increase, and we will witness the increased power of forensic science to contribute to the Criminal Justice System and to society at large.

CASE STUDY

STATISTICS IN COURT

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Imagine you are a juror in a criminal trial, in which the defendant is charged with assault. A key piece of evidence is that the defendant's footprint matches a print found at the crime scene. The prosecution calls a forensic expert, who testifies that the probability of seeing such a match if the defendant was not the source of the footprint is 1 in 1,000. Based on this information alone, what is your estimate of the probability that the defendant left the print?

Many people would be tempted to give a high probability, perhaps even quantifying it as 999 in 1,000. But this line of reasoning is logically flawed – it is an example of the notorious 'prosecutor's fallacy', so called because it usually overstates the prosecution's case.

The prosecutor's fallacy is not just a reasoning error made by lay people. Legal experts such as prosecutors, judges, barristers, and forensic scientists are also susceptible, and the error often crops up in media coverage of legal cases. The fallacy has figured in several high profile cases, with convictions being quashed due to the misrepresentation of the evidence. The seriousness of the error has been recognised by courts, and instructions have been formulated to avoid the mistake. Nevertheless it still seems to be a pernicious problem, and it arises in many other areas with probabilistic evidence, such as medical diagnosis and psychological testing.

WHY IS THIS A FALLACY?

The expert has told you the probability that the footprints would match, based on the hypothesis that someone else left the footprint. This is calculated from an estimate of how rare the footprint is in some relevant population.

But this is entirely different to the probability that someone else left the footprint, based on the evidence that the footprints match.

The former is a statement about the probability of the evidence, whereas the latter is about the probability of the hypothesis of interest.

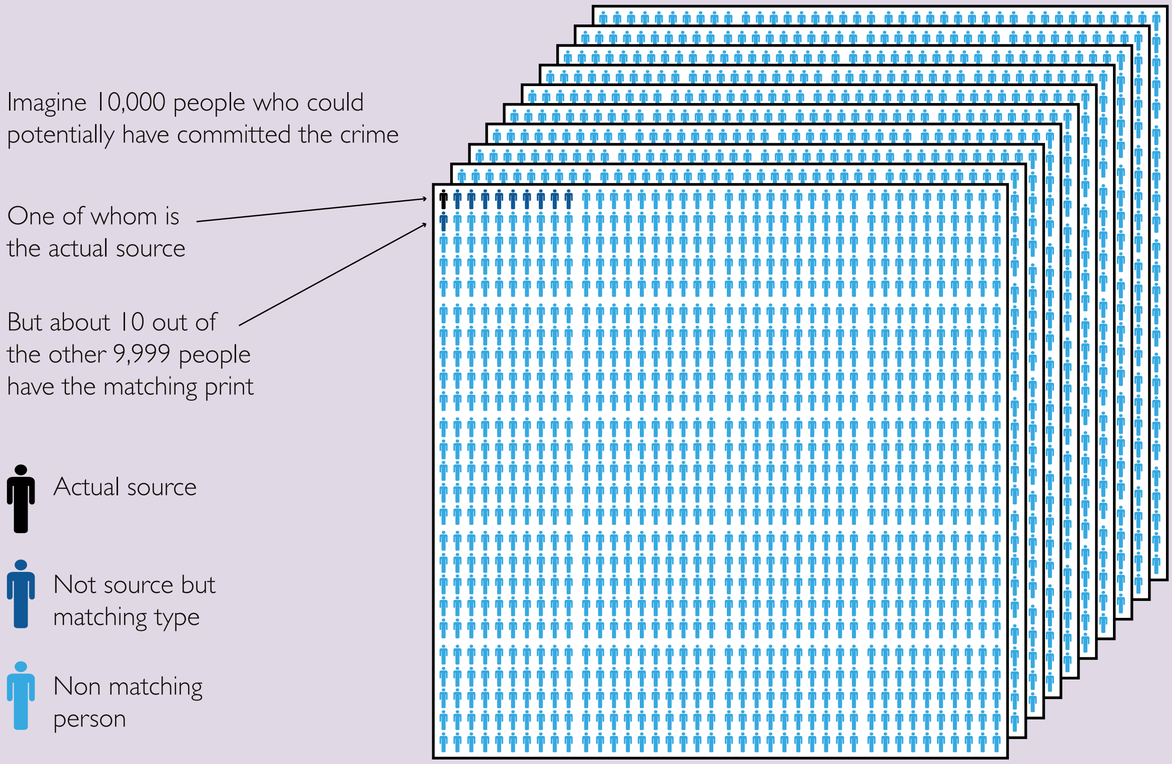
The logically correct method for incorporating the expert's evidence into a judgment about the probability of the hypothesis is to use Bayes' theorem, an approach that depends on an estimate of the probability of the hypothesis before considering the footprint evidence – a concept called 'prior probability'.

An intuitive way to understand the problem is by casting it in terms of frequencies. Suppose that in the absence of the footprint evidence there are 10,000 men, including the defendant, in the local area that could have committed the crime. Given the expert's statement that the match probability is 1 in 1,000, we would expect about 10 of these men to match the print. So the footprint evidence has narrowed the number of possible suspects from 10,000 to about 11 (10 plus the defendant); this increases the probability that the defendant left the print from 1 in 10,000 to about 1 in 11 (see Figure 1).

This is a substantial increase, but it is still relatively unlikely that the defendant left the print, given that about 10 other men would also be expected to match. The prosecutor's fallacy implies that the probability the defendant left the print is 999 in 1,000, whereas the correct calculation, incorporating the prior probability, gives a figure closer to 1 in 11.

Note that footprints are used here for illustrative purposes, and are rarely used in forensic investigations. However, exactly the same logic applies to DNA profiles, fingerprints, and other kinds of trace evidence that are routinely used in court. Also, in the forensic context a 'match' often amounts to the claim of a correspondence between two items (to within a specified tolerance), but not to a claim that they are identical. Indeed, even two footprints from the same individual will not be identical.

Figure 1. Visual depiction of the suspect population (adapted from ref. 1).



WHY IS THE FALLACY HARD TO AVOID?

Forensic experts can only tell us how well the evidence supports a hypothesis. This leaves us with the task of using that information to reach a judgment about the probability of the hypotheses – something that is difficult if left to commonsense and intuition alone.

Extensive psychological research[2,3] reveals that when people face difficult probability problems they use 'cognitive heuristics' – shortcut solutions that can lead to systematic biases. The prosecutor's fallacy is especially tempting because it incorporates several interrelated heuristics and biases.

Attribute substitution: Faced with a difficult question, people often respond with a readily available but incorrect answer. Thus the expert's statement – the probability that the footprint evidence would match if someone other than the defendant had left the print (1 in 1,000) – is readily taken as the answer to the ultimate question of interest i.e. the probability that someone else left the print, given the evidence that the footprints match.

Base rate neglect: When updating their beliefs, people often ignore information about how common something is in the general population – known as base-rate information – and give too much weight to case-specific evidence. In our case, this is tantamount to ignoring the prior probability that the defendant left the print, and focusing just on the match evidence.

Belief bias: People are more likely to accept a fallacious argument if its conclusion fits with what else they know or assume. This means that the prosecutor's fallacy can seem more acceptable when there are other reasons to believe the defendant is guilty.

Defaults: People often use default values to simplify their reasoning. In the legal case, people often assume a 50/50 prior probability, but this assumption is usually unjustified and prejudicial.

CASE STUDY

Explanatory scenarios: People usually reason in terms of scenarios and stories rather than probabilities, and often prefer scenarios that best explain the evidence, even if these are not the most likely explanations. Thus the fallacy is promoted because the hypothesis that the defendant left the print is clearly the best explanation for the match, and yields a more satisfying story.

WHAT CAN WE DO TO ALLEVIATE THIS FALLACY?

Ideally, everyone involved in a trial should receive proper training in the probabilistic evaluation of evidence. But psychological studies have highlighted various approaches that can also help people to reach better judgments and avoid errors like the prosecutor's fallacy.

Frequency formats: Framing the problem in terms of frequencies (as we did in the example above) helps people reach more accurate judgments and avoid the fallacy.

Exemplar cueing: Framing the evidence in terms of how many other matches are expected, rather than just giving a match probability, makes people evaluate the evidence more accurately.

Visual aids: Using diagrams to represent the relevant populations and show the expected numbers of matches (as in Figure 1) also improves reasoning.

Verbal scales: We can calculate a likelihood ratio (LR), which compares the probability of the evidence under the prosecution and defence hypotheses (see Annexe 1). These LR values can then be converted into a verbal scale[4]. For example, an LR of 100–1,000 can be expressed as providing "moderately strong support" for the prosecution rather than the defence hypothesis; an LR of 10,000–1,000,000 as providing "very strong support"; and so on. This enables evidential interpretation to satisfy the key characteristics of balance, logic, transparency and robustness.

THE INCREASING USE OF FORENSIC EVIDENCE AND QUANTITATIVE PROBABILISTIC ANALYSES MAKES IT ESSENTIAL THAT PROFESSIONAL USERS OF EVIDENCE UNDERSTAND HOW TO INTERPRET AND PRESENT THIS INFORMATION.

However, these approaches are harder to scale-up to more complex problems, especially those with multiple pieces of evidence and issues of evidence reliability. One promising solution is to use Bayesian networks[5], which build on likelihood ratios and Bayesian reasoning. These networks provide a graphical representation of the interrelations between hypotheses and evidence, and can capture issues of evidence reliability and credibility.[6]

A key question is whether non-experts need to engage with Bayesian computations from first principles, or whether they can be trained on simpler examples and then learn to trust and understand an expert's explanations in more complicated cases.

What is clear is that the increasing use of forensic evidence and quantitative probabilistic analyses makes it essential that professional users of evidence understand how to interpret and present this information.