PHILOSOPHICAL TRANSACTIONS B

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Review

Cite this article: Dror IE. 2015 Cognitive neuroscience in forensic science: understanding and utilizing the human element. *Phil. Trans. R. Soc. B* **370**: 20140255.
http://dx.doi.org/10.1098/rstb.2014.0255

Accepted: 16 March 2015

Subject Areas:
cognition, behaviour

Keywords:
forensic science, bias, human factors, decision-making, expertise, cognitive forensics

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Cognitive neuroscience in forensic science: understanding and utilizing the human element

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The human element plays a critical role in forensic science. It is not limited only to issues relating to forensic decision-making, such as bias, but also relates to most aspects of forensic work (some of which even take place before a crime is ever committed or long after the verification of the forensic conclusion). In this paper, I explicate many aspects of forensic work that involve the human element and therefore show the relevance (and potential contribution) of cognitive neuroscience to forensic science. The 10 aspects covered in this paper are proactive forensic science, selection during recruitment, training, crime scene investigation, forensic decision-making, verification and conflict resolution, reporting, the role of the forensic examiner, presentation in court and judicial decisions. As the forensic community is taking on the challenges introduced by the realization that the human element is critical for forensic work, new opportunities emerge that allow for considerable improvement and enhancement of the forensic science endeavour.

1. Introduction

Forensic evidence does not merely play 'a' role in administering justice, it has an increasing and often decisive power in the judicial system. This is partially because many other lines of the evidence (such as eyewitnesses) are inherently weak and problematic. Their inaccuracy has not only been demonstrated by cognitive scientists, but of equal importance, the courts for the most part are aware of these vulnerabilities [1]. In contrast, forensic evidence is accepted by the courts because it offers testimony from experts who provide supposedly objective and impartial scientific input to the legal proceedings. This type of evidence is therefore very powerful and heavily relied on by courts in determining what happened and administering justice. The court's reliance on forensic evidence is likely to increase with advances in science and as new technologies are developed.

Forensic science has flourished for decades with minimal scrutiny. However, this has dramatically changed over the past few years, with questions now being raised about the very foundation and underpinning of forensic science. The debates and controversies have centred around two themes:

(1) *The science behind forensic evidence*. What is the research foundation that supports forensic science? What is the basis for forensic reasoning and inference? What statistics or other sources are used to determine performance data and error rates? Such questions have different answers when examining different domains of forensic science.
(2) *The human element*. Since forensic science emerged about 100 years ago, there has been a systematic neglect in considering the role of the human examiner in forensic science. This is despite the fact that the human examiner plays a critical role in forensic science. Indeed, in many forensic domains, it is the human who is the main instrument of analysis. Even in the domains that rely more on objective quantification and instrumentation, the human still plays an important role, from the initial stages of sampling, determining what is noise and what should be used as input, to the final stages of communicating the results.

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The importance of the human element and its critical role in forensic science is very broad. It is not limited only to issues relating to forensic decision-making, such as bias, but relates to most stages of forensic work, from challenges in selection and recruitment of the best people for this profession, to optimizing training, to presentation of the evidence in court [2–4]. Given such a wide range of issues surrounding the human element, it should not be a surprise that cognitive neuroscience is very relevant to forensic science—the topic of this paper.

I would like to point out that the debates and controversies in forensic science on these two themes can (and should, and hopefully will) have a positive impact, and lead to the strengthening of forensic science [2]. Indeed, we have recently witnessed a variety of actions that reflect that the forensic community is starting to take on these new challenges (e.g. the work by the UK Forensic Regulator, the establishment of the US National Commission on Forensic Science (NCFS) and the Forensic Science Standard Board (FSSB)).

Using the human element perspective to dissect forensic science is not a simple task. In fact, it is a momentous task and requires a full book (or more), with each chapter dedicated to a specific topic. This may come in the future, but is definitely beyond the scope of this paper, which can sketch out only the main elements of such a project. In addition, it must be kept in mind that this area, now often called *cognitive forensics* [2–4], is relatively new, and therefore contains only relatively few studies. Indeed, when I started research in this area about a decade ago, there were practically no studies at all. Although this has now changed, with over 50 papers by over 35 different researchers published in the past 5 years alone, nevertheless, there is still a lot of work to do in understanding and properly using the human element in forensic science.

2. The human element in the various aspects of forensic work

In this paper, I discuss the human element in the various aspects of forensic work. Within the scope of this paper, I can give only an overview of 10 such aspects. Many of these aspects involve things that arise after the actual forensic conclusions have been made, or long before a crime is even committed. I present these aspects in somewhat of a reverse order, starting off with the decision of a case in court, working backwards to the crime and beyond.

(a) Judicial case decisions

Forensic science's contribution to administering justice in fair and accurate judicial case decisions is its pivotal role in legal proceedings. However, judicial case decisions, whether they are made by judges or juries, are determined by humans who are governed and limited by the workings of the brain and cognitive architecture.

If forensic evidence is not properly understood, evaluated, weighted and integrated with other evidence, then it has not appropriately contributed to the criminal justice system (as a result, forensic evidence may have not sufficiently impacted the judicial case decision, or, alternatively, it may have over-influenced it).

Even when forensic evidence has been accurately and appropriately presented in court (see §2(b), below), if those who make the judicial case decision do not take it on board correctly, then the entire forensic contribution is distorted, if not corrupted altogether. The forensic evidence in theory and in practice can be flawless, but de facto, its contribution and effect on the legal proceedings (and the judicial system in general) can be considerably damaged and degraded (if not made totally inappropriate). This, although indirectly, is a concern for forensic science.

Cognitive neuroscience has many insights into how humans function as trier of fact, and can (and should) be used to improve these processes [5]. For example, understanding human memory and cognitive load gives insights into what forms of information are well encoded, well remembered and well used. For instance, the primacy and recency effects demonstrate how order and sequencing of information influences what actually is most remembered [6], as do anchoring effects [7]. Other examples would be how judicial case decisions on length of sentencing are affected by whether crime photos are in black and white or in colour [8], and how attractiveness of suspects also influences judicial decisions [9,10].

Such examples well illustrate that an understanding of cognitive neuroscience can be both relevant and important to any effort to optimize the use of forensic science from the initial to the final stages of the judicial process. The forensic evidence that is put before the factfinder is going to be used by humans making legal and factual decisions, and therefore it is critical to understand what factors affect those decisions. It is not sufficient to create an ideal forensic science in an isolated vacuum. For forensic science to work, it must take into account the human element, and therefore consider the cognitive neuroscience that will help use that human element as optimally as possible. Although the above-mentioned issues are mainly not under the forensic expert's control, they, nevertheless, are relevant to the forensic contribution to the courts, and therefore, an issue for the forensic community to consider. Section 2 deals with elements that are more under the control of the expert appearing in court.

(b) Presentation in court

The information and terminology presented in forensic testimony plays a critical role in determining the impact of forensic evidence on court proceedings. There is an ongoing debate on how forensic examiners should best express their conclusions. The key issues involve not only what constitutes the most accurate way to present the findings, but also how the manner of presentation and how it is presented affects what is actually understood by the trier of fact when hearing expert opinions [11], and these problems are compounded if those opinions involve decision scales [12], or statistics and probabilities [13,14].

These are important issues. How forensic evidence is presented is at least as important as what is presented, because the 'packaging' determines to a large extent if and how the trier of fact takes on board the content. Of course, the presentation of forensic evidence has to be effective and accurate. However, beyond that there are many other factors at play. For example, the confidence with which the forensic expert delivers their presentation clearly can affect what weight is given to the testimony [15,16], which means that it is not only what they say, but how they say it that must be considered. Whether they use statistics, decision scales or categorical determinations, the presentation delivery plays an important role in what is conveyed by the forensic examiners, or more accurately, what is actually heard and understood by the trier of fact. Cognitive neuroscience has a large literature on these affects, which needs to be used when considering standards for presentation of forensic evidence in the court.

The adversarial legal system in my opinion presents great challenges for the proper communication of forensic science results. Although an expert scientist is in theory impartial and committed to the truth (indeed, Rule 33.2(1)(a) of The Criminal Procedures clearly and explicitly states that the expert's duty is to the court and to being 'objective and unbiased'), in practice, the exact opposite is nurtured by the very nature of the adversarial system.

Theory aside, the practical reality that forensic experts are situated within 'a side', as part of a team, influences their ability to be impartial and to be 'objective and unbiased'. This not only influences how they present their evidence in court, but also affects how they conduct their forensic analysis and their decision-making. Recent research demonstrates an effect of *adversarial allegiance*, in which experts tend to reach conclusions that support the 'side' they are on [17]. In this study, identical evidence was given to experts who either believed they were working for the defence or for the prosecution. Their forensic work and conclusions were affected by adversarial allegiance, i.e. their conclusions tended to support the side they were on.

(c) Reporting

Reporting has three main issues. The first is disclosure, that is, what is actually reported, and how it is expressed within the forensic report. Again, this is affected by the adversarial system within which the forensic scientist works. Unless effective protocols require otherwise, the tendency is to write a report as evidence within the supporting documents of one side. Second, the scientific accountability and transparency of the forensic examiner's work is dependent on the thoroughness of documentation in the report. Third, there are the cognitive effects that result from the very act of writing a report. I will elaborate on this third point (the other points are well discussed in a variety of sources, whereas this point has been overlooked).

Most people view reporting in a cognitively naive way, i.e. that the report simply reflects the working of the forensic examiner. However, the writing of a report (and its structure and requirements) not only reflects the work, but it also actually influences the work itself [18]. This is similar to language, where language does not simply reflect thought (i.e. the naive idea that we first have a thought, and then language is a mere vehicle to communicate it), but rather language plays a constitutive role in creating and forming thought itself.

Therefore, forensic reports are not mere documents that give account of the forensic work (which is important by itself), but they influence and guide the actual work carried out by the forensic examiner. As such, they are important tools in a proper process for obtaining high-quality forensic results, and their requirements need to be carefully considered in this light.

(d) The role of the forensic examiner

Much progress can be made if the role of the forensic examiner is clear. To achieve maximum impartiality, objectivity and unbiased work, forensic examiners should be viewed as laboratory scientists examining forensic evidence. In this view, their role as scientists requires that their work focuses on the science and be isolated as much as possible from the adversarial judicial system and the criminal investigation. In this view, their role should mimic that of administrators of laboratory tests in the medical domain: the doctor (i.e. the investigator) requests tests, and these are carried out in isolation of the doctor's motivations and hypothesis (e.g. the laboratory examiner counting red blood cells).

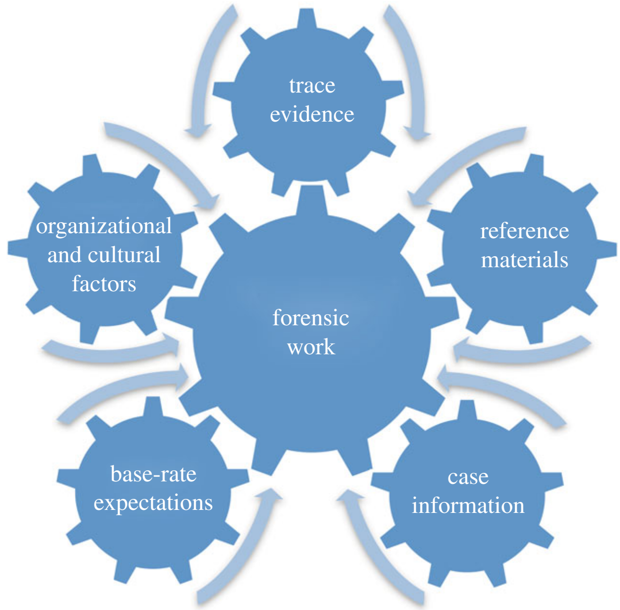

Figure 1. Different sources of information that influence and shape the work of the human forensic examiner.

Such an approach maximizes scientific rigour, and gives the forensic examiner a clear scientific role. However, this view has had four main objections. The first objection is that some examiners see themselves as 'investigators' rather than scientists (indeed, some forensic domains label the examiners in such a role, e.g. 'fire investigators'). This Sherlock Holmes role [19] introduces confusion as per the role of the forensic scientist. They are not investigating detectives (as portrayed by CSI TV shows), but scientists who contribute to investigations.

The second objection is that examiners do not want the limited role of scientists because it is—to put it plainly—boring. As detailed by a leading forensic examiner, who explains that "... examiners want to read investigative reports or talk to investigators before or while they examine a case ... such interest merely provides some personal satisfaction which allows them to enjoy their jobs ... admittedly, many tasks performed by forensic examiners can be tedious, mundane, and to many people just not interesting or diverse enough to interest them in doing it" [20].

The third objection is a practical and pragmatic objection, i.e. that the forensic examiner cannot be isolated. The practicalities involved in achieving the focused scientific role of forensic examiners are complex and may not be fully achievable. This may be true, however, first we need to define and agree what the role of the forensic examiner should be and what that entails. Then, we can try to find, as much as practically possible and reasonable, ways to fulfil this role of scientific focus. The diagram in figure 1 shows a variety of sources that contain irrelevant information that can effect and shape forensic examiners in ways that undermines their scientific work.

Information irrelevant to the forensic examiner as a scientist may be within the trace evidence itself (e.g. bitemarks,

Figure 2. Different levels which may contain irrelevant information for the forensic scientist.

handwriting and voice may contain such information within the evidence); such information may also be in the known reference samples (which if not used correctly can cause circular or backward reasoning, i.e. from the suspect to the evidence, rather than from the evidence to the suspect); it may also be in irrelevant information relating to the case; it may even be related to expectations based on previously experienced base rate or it may be related to wider organizational and cultural factors. These different sources can be organized within five 'levels' (based on a four-level taxonomy originally suggested by Stoel *et al.* [21]), starting with the deepest level where the information is ingrained and within the actual trace evidence, all the way to the wider level of organizational and cultural factors (figure 2).

Just as forensic examiners are well aware and take great steps to minimize *physical contamination* of the evidence, they also must be aware and take steps to minimize *cognitive contamination*. By focusing on the scientific data they need, and isolating themselves as much as possible from everything else, they minimize cognitive contamination and help achieve their role as scientists.

The fourth objection to adopting a purely scientific role is that forensic examiners needs to contribute to the investigation, and to do so they need to interact and work with the investigative team, from the initial stages of investigation (e.g. to determine what tests to run), to the very end of the investigation (e.g. to explain the forensic findings). I think this objection is valid and appropriate. Some forensic examiners must play a collaborative role with the investigative team [22]. However, the forensic examiner working and interacting as a collaborator with the investigative team should not be the one carrying out the actual forensic scientific work. An examiner in the collaborative role should act as a 'case manager' who assigns the actual forensic work to other 'isolated' examiners, so as to preserve the scientific integrity of the forensic work [2,23].

(e) Verification and handling disagreement and error

Some topics discussed so far relate to aspects of forensic work that take place after a forensic conclusion has been reached (e.g. presentation in court, judicial decisions). The next few topics pertain to specific stages in the actual forensic decision-making process. One such important topic is verification of forensic conclusions.

Verification is an essential part of forensic work, aimed at verifying the correctness of forensic conclusions. However, this aspect of forensic work is plagued by practices that ignore the human cognitive element, as I briefly outline below.

First, in many forensic laboratories, the verifier is chosen by the examiner whose work is being verified. Thus, after an examiner makes a decision, they choose their verifier and approach them. Clearly, this introduces many interpersonal issues that pertain to how the examiner decides who they choose, what position it places the verifier in, and a whole set of human element issues that in most cases could be easily avoided by proper protocols and standard operating procedures (SOPs) [2,24].

Second, the verifier not only often knows who the examiner is, but also what the examiner decided. This creates an expectation that affects the strength of the verification process. Furthermore, the expectation is very strong, because, in many forensic laboratories, in general, only identifications are verified, and the rate of verification is extremely high—very rarely is an identification decision found to be incorrect by the verifier. This introduces base-rate expectation bias, which will be discussed in the next section in the paper devoted to decision-making.

Third, compounding the expectancy problem, there is often great pressure for the verifier and examiner to agree. In most forensic laboratories, if the verifier does not agree with the examiner (a rare occurrence, see above), then there is strong pressure to reach agreement among themselves, for two main reasons: (i) the verifier, if and when there is a disagreement, goes to the examiner in an effort to discuss the case. They meet together with a view to mutually agreeing (remember that often it is the examiner who chose the verifier). (ii) If they cannot agree among themselves, then the issue escalates, it grows into an official conflict with the risk of one of them being found and recorded to be 'in error'—which brings me to the next issue.

Conflict resolution and error management are key areas in which forensic science can make great strides if laboratory managers take into account and use what is known about the human element. When disagreements occur, like errors, they are seen in a very negative way. Procedures are in place to 'find the guilty' and take 'corrective action'. Rather than adopting a more open culture that accepts disagreements and errors, and embraces them as opportunities for learning, they are viewed very negatively (it should come as no surprise, then, that with such pressures the verifiers and examiners rarely disagree, in order to avoid escalating a disagreement to a point that might be threatening to both).

Furthermore, when conflict resolution does occur, it is often not handled in an effective way, taking into account the nature of the human element and what is known about group dynamics. Rather than employing well-tested procedures from other expert domains, forensic disagreements are most often resolved hierarchically, or according to the personalities involved.

(f) Forensic decision-making, subjectivity and technology

The heart of forensic science work is the forensic conclusion. In most forensic domains, including fingerprinting and DNA mixture interpretation, subjectivity is involved. There is no objective quantification or instrumentation; it is the human examiner who is the main 'instrument' of analysis [25,26].

Such cognitive processes are vulnerable to a variety of contextual influences and biases [24,26]. These aspects of forensic work have been highly neglected until recent years when

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I and others have published a number of studies demonstrating the potential of such cognitive biases [27–29]. Now, the effects of these cognitive biases have been studied and demonstrated by a variety of researchers across a number of forensic domains [30–32].

With potential contextual biases, the precursors of which we can call 'cognitive contamination', it is important that forensic examiners focus on the relevant scientific data, isolating and blinding them from information that they do not need and that can bias their forensic work. This is to establish their role as scientist (see previous discussion on this issue in §2(d)).

It needs to be stated that such blinding steps may not be needed in each and every case, but can also be applied selectively by using triage to identify the 'bias danger zone' (where the effects of bias are most likely to be pronounced, which is a function of the difficulty of the decision and the biasing context [2]). Hence, 'for forensic science to successfully take on the issue of contextual bias, it is important that one correctly considers the risks, that measures are taken when needed, and that they are proportionate and appropriate' [33, p. 276].

The case information can definitely include a variety of biasing contextual information (e.g. other forensic evidence, statements from witnesses, whether the suspect confessed to the crime, etc.). However, the cognitive effects on forensic decision-making are not limited to the case information (figure 2), the human examiner can be influenced by a variety of other factors. I will elaborate on two of these.

The known reference samples (figure 2) provide the examiner with a 'target' for comparison. This target can affect perception and interpretation of the actual evidence from the crime scene, and can cause circular or backward reasoning (working from the suspect to the evidence, rather than from the evidence to the suspect). A linear approach (implemented through documentation and the reporting—see §2(c)) will cause the examiner to first analyse and characterize the evidence from the crime scene before being exposed to the reference material. Some advocate a strict linear 'sequential unmasking' approach whereby there is no 'going back'. Others would allow an analyst to go back without restrictions (as long as the changes were documented) [34]. However, I suggest a more balanced linear approach which allows the flexibility of 'going back', but limits when and how this can be done (e.g. guided by confidence levels of the initial analysis) [2].

Another source of biased forensic decision-making can arise from base-rate expectations (figure 1). Such biases arise from regularities that bias the brain to process information differently. An example of such a bias is the use of database search technology in forensic science. Automated fingerprint identification systems (AFIS) allow technology to search large databases for similar prints, which provides a ranked list of potential matches for the human forensic scientists to examine. These technologies are very efficient, and in most cases, if there is a match, it will be to the print on the top of the list. This base rate regularity causes an expectation which affects the examiner's work: they are more likely to make a false identification decision on the print on the top of the list (where they expect a match), and are more likely to make a false non-match decision on prints further down the list [35].

It is interesting that technology is often presented as a solution to human biases. However, the successful introduction of technology is very much dependent on taking the human element into account, so that cognition is correctly and effectively distributed [36]. Once these human element issues are understood, relatively simple and practical solutions are available [2,24]. Such solutions entail, for example, breaking the base rate expectation. With AFIS technology, it can be done by randomizing the list of prints provided to the human examiner. In the verification process (where base-rate expectation is to verify a match—see §2(e)), it will require introducing non-matching, but similar prints into the verification stream, so the verifier does not expect all IDs to be actual matches [2].

(g) Crime scene investigators

The first stage in forensic evidence processing does not take place in the laboratory but actually starts at the crime scene. The growing body of studies that examine the human element in forensic work (see §2(f); [24–36]) focuses on work conducted in the forensic laboratory. But, there are basically no studies or research on the effect of contextual information and bias at the earlier stages of forensic work: the collection, documentation and preservation of evidence at a crime scene.

A huge number of decisions are actually made by the crime scene investigator (CSI) in the field. Only a small amount of evidence is provided to the laboratory for further analysis. Initially, the CSI must determine what kind of evidence to look for, and where. This initial identification, collection and documentation is of paramount importance to the forensic investigation, and can undermine it when critical pieces of evidence are overlooked.

The entire investigation can be compromised if overlooked evidence constitutes the sole link between the suspect(s), victim(s) and crime scene, providing case resolution. If such evidence is not identified and collected at the crime scene, it may be forever lost, and the case may go unsolved or 'cold', or perhaps end up with a wrongful conviction.

CSI decisions are very different than those made in the forensic laboratory. First, the analysis in the laboratory can be easily controlled, for example, by managing and isolating the contextual information that the examiners require to do their job. In contrast, the CSI's work in the field, at the crime scene, is full of potentially biasing influences. This creates complex challenges about how best to address cognitive bias and other human element issues. Second, in the laboratory, a piece of evidence can most often be re-examined and re-analysed, because the evidence is usually not consumed in testing. In contrast, the CSI's decision not to collect or document a certain piece of evidence almost always cannot be revisited. Dissipating evidence [37] is quick to disappear, and once the CSI's work is finished, the crime scene is no longer preserved, and any uncollected evidence is usually lost.

One must also remember that CSI decisions depend on and require contextual information and hypothesis formulation, which guide them in their search for evidence. It is critical that these are well determined, as they can lead to identification and collection of important evidence or mislead the investigator and direct them down the wrong path.

CSIs are well aware of (and take effective steps to minimize) physical contamination. However, the problem of cognitive contamination and bias has not really been addressed (or even researched) in this realm. CSIs are especially vulnerable to contextual bias, because the complexity of contextual exposure at the crime scene is very different than that experienced while working within a forensic science laboratory.

(h) Training

All the aspects discussed so far have related to the actual work of the forensic examiner, be it at the crime scene, in the laboratory or in court. However, some human elements in forensic science take place before the forensic work. These include training, and also the selection of people during recruitment.

Training is a critical part of forensic science. There is much discussion about training requirements and standardization. However, this area also suffers from a lack of input from cognitive neuroscience insights into the factors involved in people's ability to learn. A few examples to illustrate issues pertaining to training are provided below.

Forensic training should be effective and efficient on three different and distinct aspects of human cognition: first, the learners must be able to acquire the information. This is usually the main (and sometimes only) aspect of learning that is emphasized in training. People take a training course, and then get tested. Acquiring the information and associated skills is indeed important, and the human element is critical here because it is not what you teach, but what they learn, that counts (you can teach the best and most important things, but if the listeners do not learn anything, then you have failed; it is about what they actually learned). So, the first set of questions relate to the learners ability to acquire information and skills, and here one must consider a variety of cognitive issues, such as cognitive load, chunking and mental representations.

The second aspect is the ability to remember what has been learned. Often people acquire information (and do very well on the tests afterwards), but forget almost all of the acquired information within a few weeks. In forensic, as in other settings, training is not fulfilling its role if the acquired information and skills are forgotten and lost. Cognitive neuroscience has good insights into human memory systems, ways to encode and retrieve information and a whole set of ways to make learning memorable.

The third and final aspect is the ability to apply and use the information and skills which were learned and remembered (one can acquire and remember them, but they may not impact and change how they do their job). So, it is important that the training is applied and used in actual forensic work, that it has a practical impact. Here, too cognitive neuroscience has much to offer. Issues here relate, for example, to when and how information is transferred from the training to practice, and not only the transfer of information and skills, but also their generalizability (which enables a flexible application to a wide range of circumstances).

These three aspects of training are cognitively different and distinct. However, they are highly interrelated. If you acquire information in a certain way, then appropriate mental representations are formed. That allows the information to be easily acquired, remembered and used. Small, seemingly unimportant, differences during training can make a great impact on all the three aspects of training. Cognitive neuroscience can be a great ally in directing training, so it is effective and efficient, by helping to answer questions such as what examples to use during training, the order in which to present them, how to make training memorable, etc. The proper answers to such questions have far reaching implications for the effectiveness of training. The important point is that one must take into account the human element here, the learners.

Another training consideration relates to the cognitive profile of the learners, that is, if and how much they are suited to carrying out the forensic work for which they are being trained. But, cognitive profiles for the work can be used in advance of training, which brings me to the next issue.

(i) Selection during recruitment

Having the right people for the job is very important. Some people just have the right aptitude and raw cognitive abilities that enable them to excel in being various types of forensic examiners. These people are easy to train, they deliver high-quality work, perform their job quickly and are able to tackle the most complex and challenging cases with relative ease.

Because a forensic examiner is currently a very popular and positive figure in popular culture, many would like to enter this profession. Therefore, there are many candidates to choose from. Here, again is a critical human element in forensic science, and the forensic community again needs to take input and contribution from cognitive neuroscience.

Having scientifically appropriate and validated tools for selection and recruitment is very important. These must be specific for each forensic discipline, because each requires a different set of skills and cognitive abilities. Developing such tools entails two main steps: first, understanding the cognitive underpinning of the forensic discipline, and second, developing tests that measure and quantify those skills.

Understanding the cognitive underpinning of the forensic discipline requires developing a *cognitive profile* of the domain. A cognitive profile explicates the underlying abilities, the building blocks that are needed for performing the job required by the forensic examiner in that specific discipline. For example, in fingerprinting such a cognitive profile may include specific elements in ability to allocate visual attention, use of visual imagery (inspection, rotation and transformation of mental images), dealing with and filtering noise, perceiving and comparing visual features, and visual search.

Once a cognitive profile has been established, one needs to develop tests that measure and quantify the aptitudes that are specified in the cognitive profile. It is important to:

(1) Test the underlying abilities. Not to use actual case evidence for this purpose, but to use testing materials that capture the cognitive ability that underpins the evaluation of the case evidence in a particular discipline.
(2) Make sure that tests are developed scientifically, in accordance with cognitive and psychometric methods. This will entail developing test items with clear criteria and selectively manipulating difficulty and insuring proper administration of the test items (e.g. using the staircase method).
(3) Make sure that the tests are relevant, that is, that they test the actual abilities needed (as specified by the cognitive profile). An example of a mismatch between what is tested and the abilities needed is the widely used form blindness test for fingerprint examiners.

(j) Proactive forensic science

This new view of a cognitively informed forensic science suggests a proactive approach. Rather than being reactive once crimes are committed, being proactive would take forensic steps before a crime is ever committed. Such an approach would anticipate a crime and take forensic steps pro-actively. 'A proactive forensic science is a conceptual change, a fundamental shift in viewing the scope and endeavour of forensic science. Proactive forensic science does not wait for a crime to be committed for it to be called into action' [38, p. 325].

An example of a proactive forensic science is the steps taken to find ways to develop fingerprints off new polymer banknotes before these come into circulation [39]. Other examples would be the tagging of inks for accurate identification and dating [40], or anticipating new 'designer drugs' [41] and the misuse of weapons (and therefore test firing them so as to enable future firearm comparison and identification [38]).

A proactive forensic science goal is to 'try to foresee trends in future crime and develop preventative measures ahead of time. In other words, they are trying to be one step ahead of the criminals, so that when the trend changes they will be ready' [38]. Therefore, a critical part in a proactive forensic science is to have an understanding and insights into the human element.

3. Conclusion

The past few years have seen a major change in forensic science. After decades of ignoring the significance of the human element in forensic work, a new area of *cognitive forensics* has emerged. The realization that the human element plays a critical role has profound implications across the forensic sciences.

The implications of these insights have begun to shape the work of forensic scientists. Steps are starting to take form (e.g. by the UK Forensic Regulator, the US Forensic Science Standard Board and National Commission on Forensic Science), which will ultimately transform the face of forensic science. Indeed, the FSSB and NCFS have established expert groups specifically on human factor issues.

These advances will enhance forensic science, but like any change, they will require some rethinking and re-evaluating of current practices and beliefs. Cognitive neuroscience provides many insights into the human element, and therefore can contribute much to the changes and improvement of forensic science.

Data accessibility. More information is available at www.cci-hq.com.

Acknowledgements. I thank Joseph Almog, Stevan Harnad, Michael Risinger and two anonymous reviewers for comments on an earlier version of this paper.

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