SCIENCE AND THE LAW

Science in the interests of justice

3 – 4 October 2023

Conference report

THE ROYAL SOCIETY

Introduction

On 3 – 4 October 2023, an international meeting organised jointly by the Royal Society and the US National Academy of Sciences brought together leading scientists and prominent members of the legal community. Delegates from the UK and US discussed the approaches used by courts in their consideration, evaluation and management of scientific evidence and expert witnesses.

"Science regularly appears in court cases worldwide… while legal frameworks differ across jurisdictions, the science is (we hope) universal."

Sir Adrian Smith, President of the Royal Society.

"Our approaches, our vocabulary and our decision-making timescales may differ, but ultimately both the scientific and legal communities have a duty to pursue the truth in service to society."

Dr Marcia McNutt, President of the National Academy of Sciences.

The conference opened with comments from Dr Marcia McNutt, President of the National Academy of Sciences, and Sir Adrian Smith, President of the Royal Society.

The mission of the US National Academies of Sciences, Engineering and Medicine is to "provide independent, trustworthy advice and facilitate solutions to complex challenges by mobilising expertise, practice and knowledge in science, engineering and medicine". The parallel purpose of the Royal Society is to harness our self-governing fellowship of many of the world's leading scientists, "to recognise, promote and support excellence in science, and to encourage the development and use of science for the benefit of humanity".

Science regularly appears in court cases worldwide, whether it be in litigation involving drugs and health care, DNA analysis in terrorism prosecutions or liability for damages resulting from climate change. While legal frameworks differ across jurisdictions, the science is universal. The National Academies of Sciences, Engineering and Medicine address this via the Committee on Science, Technology, and Law (CSTL). This initiative connects scientists with members of the legal and policy communities to discuss critical issues of mutual interest and concern. Similarly, the Royal Society's Science and the Law programme brings together scientists and members of the judiciary to discuss and debate key areas of common interest and to ensure that the best scientific guidance is available to the courts.

The purpose of this two-day conference was to explore the emerging science beginning to appear in court cases globally. Each session aimed to provide information relevant to the judiciary in its consideration, evaluation and management of scientific evidence and expert witnesses in the courts. This conference, however, was not intended to instruct the judiciary on how to resolve the disputes before it. Neither was it designed to transform judges into scientists, but rather equip them to recognise the significant questions, engage in informed conversations and isolate the scientific and technical complexities relevant to their cases. The conference organisers shaped the agenda specifically with judges in mind, but in the hope that discussions would be valuable to the wider scientific and legal communities.

The conference agenda was led by:

- Professor David Baltimore ForMemRS NAS / NAM, President Emeritus and Judge Shirley Hufstedler Professor of Biology, the California Institute of Technology;
- Lord Anthony Hughes of Ombersley PC FRS, former judge of the Supreme Court of the United Kingdom;
- Dame Julie Maxton DBE, Executive Director of the Royal Society;
- Dr Anne-Marie Mazza, Senior Director of the National Academies of Sciences, Engineering and Medicine;
- Judge David Tatel, US Court of Appeals for the DC Circuit; and
- Dame Anne Rafferty DBE, former Lady Justice of Appeal of England and Wales.

We would like to thank the conference organisers, speakers, planning committee and our generous funders: The Dana Foundation and Molly and David Lowell Borthwick for making the conference possible.

This report is not a verbatim record, but a summary of the discussions during the meeting and the key points raised. Comments and recommendations reflect the views and opinions of the speakers and not necessarily those of the Royal Society or National Academy of Sciences.

> "As two of the world's leading scientific bodies, we recognise our role in supporting the judiciary in its evaluation of cases underpinned by science and technology.'
>
> Dame Julie Maxton DBE, Executive Director of the Royal Society.

> "This meeting, which we hope will be the first of many, brought together leaders from the legal and scientific communities from the UK and USA to foster cross-jurisdictional dialogue and the exchange of best practice in the use of scientific evidence in the courts." -
>
> Dr Anne-Marie Mazza, Senior Director of the National Academies of Sciences, Engineering and Medicine.

Admissibility of scientific and expert evidence in England and Wales

Lord Anthony Hughes of Ombersley PC FRS, former judge of the Supreme Court of the United Kingdom, provided an overview of the UK judicial system, including the admissibility of expert evidence.

Image: Lord Anthony Hughes of Ombersley PC, former judge of the Supreme Court of the United Kingdom.

The judiciaries of the UK and US have much in common in their approach to scientific and technical evidence. Such evidence is introduced in court through expert witnesses who are permitted to offer opinions which go beyond the evidence permitted from lay witnesses.

Admissibility of expert witness testimony

Judges have an obligation to determine as a preliminary matter the admissibility of such expert witness evidence. In the UK, as established in *R v Bonython* (1984) 38 SASR 45, the judge must ask:

- Is the topic one on which the trier of fact needs expert assistance?
- If assistance is needed, is the evidence part of a body of knowledge or experience sufficiently organised to be accepted as a reliable corpus, so that special acquaintance with it by the expert will help?
- And if yes to both, then does the witness demonstrate sufficient special knowledge of that corpus of material for his opinion based upon it to be of assistance?

> "[In the UK judicial system], the expert witness must never assume the role of an advocate. She must stand sufficiently detached."
>
> Lord Hughes of Ombersley PC FRS.

However, there are notable differences of practice in the US and UK in the way admissibility review is undertaken. Such differences reflect the history and experience of each judicial system with expert evidence. In the 1970s and 1980s the UK experienced too much partisan expert evidence for comfort. Too often the expert saw himself as part of the litigation team from whom he received instruction. The result was a loss of expert independence and diminished value of expert evidence.

In England and Wales the courts responded by requiring much higher standards of independence and absence of partisanship amongst the experts. An early commercial court decision, *The Ikarian Reefer* [1993] 2 Lloyds Rep 68 at 81, required that:

- Expert evidence should be the independent product of the expertise, uninfluenced by the exigencies of litigation; and,
- It must be of independent assistance to the court. The expert witness must never assume the role of an advocate.
- Recognition that the expert's duty was to the court, and not to any party, was the key change. This change was enacted as an essential part of the Civil Procedure Rules, and shortly after that it was mirrored by the Criminal Procedure Rules.

Adducing expert evidence

Courts also follow rules about adducing expert evidence. The court grants permission to call an expert only if the expert is reasonably needed. The expert's report must identify any contrary line of research or science and explain why the expert disagrees with it. Each party may put written questions to the expert on the other side in advance of the trial. Also, the court can, and usually will, direct a meeting before trial of the experts on opposite sides, and require a joint report setting out the issues on which they agree and disagree, and the reasons for any disagreement. That meeting would normally be in the absence of the trial lawyers on either side.

As a result, in England and Wales pre-trial rulings on admissibility of evidence are rare. Pre-trial case management is designed to clarify the nature of the dispute, and queries about the expert evidence are regarded as a matter of weight rather than of admissibility. Such consideration of expert evidence is easier to achieve, of course, if the trial is by judge alone rather than by jury. Jury trials are now rare in civil actions in the UK. But in fact, even in criminal trials where there is a jury there is relatively little admissibility debate. This contrasts with practice in the US, which may involve much more extensive testing of the expert evidence during the voir dire, a preliminary hearing to determine the admissibility of evidence and/or the competency of a witness or juror.

Admissibility of scientific and expert evidence in the United States

Judge David Tatel, US Court of Appeals for the DC Circuit, described the American judicial system with a focus on admissibility of scientific evidence and expert witness testimony.

Image: Judge David Tatel, US Court of Appeals for the DC Circuit.

In many ways, the American judicial system is similar to that of England and Wales. Like their British counterparts, US judges act as gatekeepers to ensure the integrity of expert testimony. But there are differences in how this gatekeeping role is executed. Unlike in England and Wales, where experts have a duty to the court which overrides any obligation to the parties, in the US experts remain tightly bound to the parties for whom they are testifying. Judges then independently assess the validity of the scientific foundations of proffered expert testimony, excluding testimony inadequately grounded in appropriate scientific methodology or unsuitably connected to the issues in dispute.

> "[In the US judicial system], judges have to be the referees, independently assessing the scientific and methodological foundations of proffered expert testimony."
>
> Judge David Tatel, US Court of Appeals for the DC Circuit.

A key reason for this divergence between systems is that in the US, the right to trial by jury is embedded in the seventh amendment to the US Constitution. This amendment reads "In Suits at common law, where the value in controversy shall exceed twenty dollars, the right of trial by jury shall be preserved, and no fact tried by a jury, shall be otherwise re-examined in any Court of the United States than according to the rules of the common law." Thus, lay juries, not judges, resolve all factual disputes in civil cases involving money damages. This includes factual disputes over complex scientific and technical issues in tort, product liability, antitrust and climate change cases.

Admissibility of evidence

As noted above, in the US system judges work to ensure the acceptable quality of scientific evidence presented to the jury. To help judges fulfil this gatekeeping task, the courts have adopted Federal Rule of Evidence 702, which codifies and expands the admissibility standard the Supreme Court set out in 1993 in *Daubert v. Merrell Dow Pharmaceuticals*. Before *Daubert* judges admitted expert testimony which was "generally accepted" by experts in the particular field. *Daubert,* and now Rule 702, require judges to evaluate several additional factors before admitting expert testimony, such as:

- whether the expert's testimony is based on sufficient facts or data and is the product of reliable methods; and
- whether the expert has "reliably applied the principles and methods to the facts of the case."

The *Reference Manual on Scientific Evidence* (a guidebook for US federal and state judges) contains an entire chapter on the standards of admissibility of expert testimony[1].

The judge's gatekeeping task under Rule 702 can be difficult. Some US judges have sought to assess the validity of the expert's methods using the "weight of the evidence" standard to determine admissibility rather than the more burdensome "preponderance of the evidence" standard. This effectively passes the job of expert evaluation on to the jury. Amendments to Rule 702 intended to stop this practice and ensure that judges fulfil their gatekeeping responsibilities came into effect in December 2023. This amendment marks another difference between the American system and that in England and Wales, where judges typically view the question of expert evidence as a matter of weight rather than admissibility.

In the US, pretrial evaluation of proffered expert testimony consumes a great deal of time and expense. Such evaluation includes resource intensive expert discovery followed by pretrial motions to exclude expert testimony. Resolution of such motions may effectively decide a case. Given this, it's unsurprising that fewer than one percent of civil cases filed in federal court are resolved by trial.

Links between expert witnesses and the parties they represent.

Efforts in the US to sever ties between experts and the parties they represent have been largely unsuccessful. For example, in 1993, following a change in procedural rules governing discovery, US courts sought to enhance the independence of testifying experts by requiring attorneys to disclose a great deal of information about the experts they expect to call. This included disclosure of draft reports and communications between attorneys and their experts. Attorneys complained that this disclosure violated work-product privilege and responded by employing two sets of experts: one for purposes of attorney consultation and another to offer testimony at trial. The result was an increase in expense with no offsetting benefits, and many of those disclosure requirements have now been repealed.

1. National Academies of Sciences, Engineering and Medicine (2011). Reference Manual on Scientific Evidence, Third Edition. Available from https://nap.nationalacademies.org/catalog/13163/reference-manual-on-scientific-evidence-third-edition (accessed 30 July 2024).

Forensic science – our past, present and future

Professor Niamh Nic Daéid FRSE, Leverhulme Research Centre for Forensic Science, University of Dundee, provided a brief review of forensic science. She highlighted several challenges that continue to face the field and called for new ways of working to address these issues.

Image: Professor Niamh Nic Daéid FRSE, Leverhulme Research Centre for Forensic Science, University of Dundee.

Fundamental concepts of forensic science are mentioned in texts from as early as the 13th century. In the 19th century techniques such as the use of blood patterns, fingerprint identification, toxicology, ballistics and document examination began to emerge as tools in the forensic scientist's toolbox. In the mid-1980s, human identification using DNA (DNA fingerprinting) was developed, followed by the emergence of digital evidence in the 1990s. The world is rapidly changing, and the development of new technologies and widespread adoption of AI is revolutionising how systems operate and how society works, creating significant challenges to the justice community.

> "Forensic scientists are increasingly under more pressure to deliver evidence quickly and cheaply, whilst still being robust enough to stand up to court-level scrutiny."
>
> Professor Niamh Nic Daéid FRSE, Leverhulme Research Centre for Forensic Science, University of Dundee.

In England and Wales, the commercialisation of forensic scientific services has arguably become a double-edged sword, driving both the need for greater efficiency while also requiring the books to be balanced (this marketisation is not the case is Scotland or Northern Ireland). This has led, perhaps unintentionally, to a reduction in the range of (specialist) scientific services available to the justice sector in England and Wales.

Regulation of forensic science

Forensic scientists are often seen as the 'expert in the room' in court cases. However, since publication of the US National Academy of Sciences Report in 2009[2] there have been continued concerns (most recently articulated by the House of Lords in 2019[3]), relating to the scientific robustness and interpretation of forensic evidence, as well as the quality of the scientific work undertaken and the competence of forensic scientists to fulfil their role. These concerns have caught the attention of and have been picked up in the media and independent case review groups. In England and Wales, 'how' forensic scientists and crime scene investigators undertake their work is, since October 2023, on a statutory footing overseen by the Forensic Science Regulator. However, this only addresses one side of the challenge, and the scientific robustness of some forensic science fields remains under question.

What do forensic scientists do and what are the challenges they face?

Forensic scientists have a range of roles which, if they attend a crime scene, include using their scientific knowledge and experience to recognise, record, retrieve and recover traces which might be evidence of activities alleged to have occurred. In the laboratory, the forensic scientist conducts scientific examinations of the items and traces recovered from scenes and individuals associated with the case. Finally, forensic scientists deliver their findings and evaluative opinions within the context of the case as both written and oral evidence, to a court and the triers of fact, be they judges or jury.

Forensic scientists attempt to detect and identify items or 'traces' (such as drugs, fibres or body fluids) recovered from a crime scene, victim or suspect in order to identify or categorise their characteristics and properties. To do this, they use existing knowledge and reference data of known origin and provenance (ground truth data) to recognise what they are looking at. Once samples are identified they can be compared with other relevant samples.

In a forensic case, a 'questioned sample', recovered from a crime scene, victim or suspect is first evaluated to determine whether there are enough characteristics present to make a comparison. If so, the analysed 'questioned sample' is compared to a 'reference sample' taken from items known to have an association with the alleged event (such as fibres from a victim's jumper).

Samples are compared in one of two ways depending on the sample type. They can be measured objectively (eg using a machine to identify drugs or create DNA profiles) or subjectively (eg looking at physical features left on a surface, for example when a bullet is fired from a gun, or a finger or shoe leaves a mark on a surface). The measured data or features observed from the 'questioned' and 'reference' samples are then compared by the forensic scientist looking for similarities and differences.

If the questioned and reference samples could potentially be associated with each other, the meaning of this finding is then evaluated within the case context. This might require specialist knowledge, including understanding of the background abundance of materials, how materials transfer between people and between people and surfaces and how long materials persist once transferred. Interpretation and evaluation are at the heart of the role of the forensic scientist where increasingly the question is not what the trace is or from whom it might have come but how it got to where it was found.

These processes present a series of challenges for forensic science - the first is that there is very little understanding of transfer and persistence of many evidence types on different surfaces and in different contact scenarios. Similarly, there is a lack of knowledge of the background abundance (or prevalence) of materials in circulation in the physical or digital world (for example the frequency of denim or white cotton fibres). A second challenge is related to feature comparison and that, with the exception of DNA, fingerprints and ballistics, very few datasets enable the repeatability and commonality (or otherwise) of the features that are examined to be evaluated (for example the differences and similarities of marks made by two screwdrivers on a window frame). The implementation of new advancements in AI through machine learning, is therefore problematic in these areas as little data exists to underpin their safe and unbiased deployment.

2. National Academies of Sciences, Engineering and Medicine (2009). Strengthening Forensic Science in the United States. Available from https://nap.nationalacademies.org/catalog/12589/strengthening-forensic-science-in-the-united-states-a-path-forward (accessed 30 July 2024).
3. House of Lords Science and Technology Select Committee (2019). Forensic science and the criminal justice system: a blueprint for change. Available from https://publications.parliament.uk/pa/ld201719/ldselect/ldsctech/333/333.pdf (accessed 30 July 2024).

Another challenge is one of culture and communication. Silos remain between the different areas of expertise across law enforcement, science, and law leading to poor communication within and across the disciplines. Similarly, increasing the understanding of the public around the opportunities and limitations of scientific evidence and need for it to be presented within the case context in court is vital.

Looking ahead

Looking to the future, these challenges are beginning to be addressed in the UK and US and elsewhere as the research, forensic science and legal community begin to work together, recognise that the issues we face have a commonality and start to think differently about how we propose and deliver co-created solutions. Communication challenges in particular are now being openly discussed and progress beginning to be made. One such example is through the Royal Society / Royal Society of Edinburgh judicial primers[4], simple prose by scientists which explains the opportunities and limitations of specific evidence types.

Providing the public with a deeper understanding of forensic science and the legal community through citizen science and public engagement is beginning to yield opportunities to develop foundational data sets needed to evaluate the significance of trace evidence recovered and examined by the scientists.

Most importantly, open discussions across the justice community are happening and common areas of concern identified and presented to funders to try and persuade them that relevant, often highly applied research which will build the data sets required and make them openly available across the research and practitioner communities, should be funded. There is a long road ahead but at least we are now walking on that road together and in good company.

> "From the scientist's perspective, our job in court is to enable the trier of fact… to understand what it is that we're saying within the context of the case, such that the trier of fact can make a decision. The decision is not ours as scientists, we are simply there as a tool for the court to use."
>
> Professor Niamh Nic Daéid FRSE, University of Dundee.

4. The Royal Society (2024). Science and the Law. Available from https://royalsociety.org/about-us/what-we-do/science-and-law/ (accessed 29 August 2024).

DNA mixture evidence: an example of the process to determine reliability

Retired Regents Professor Bruce Budowle, University of North Texas Health Science Center and Director of the Center for Human Identification, explained how to interpret DNA evidence, including from mixed samples, reliably and accurately.

Image: Retired Regents Professor Bruce Budowle, University of North Texas Health Science Center and Director of the Center for Human Identification.

DNA is found in every tissue, including body fluids, bones, teeth, skin tissue and hair roots. This feature makes DNA analyses one of the most effective tools for identifying the source of biological evidence (Table 1). DNA analyses can also eliminate candidate sources, an important aspect of its value in the justice system. However, the quality and quantity of biological evidence can be limiting - especially with complex mixture evidence and /or highly degraded DNA.

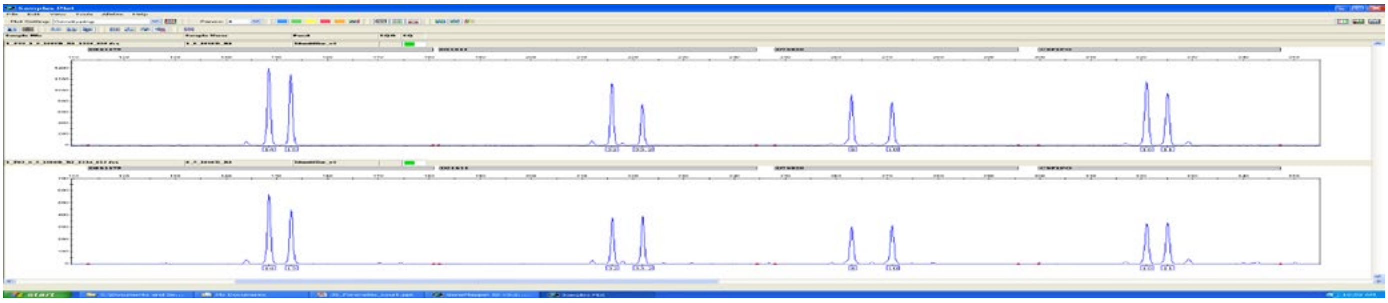
TABLE 1

The benefits and limitations of using DNA evidence.

What can DNA profiles tell us?	What can DNA profiles not tell us?	What can compromise the quality of DNA evidence?
The likelihood of a sample being from an individual(s). Whether an evidence sample might be probative. Whether an individual can be eliminated as the donor of an evidence sample.	When the sample was deposited. How the sample was deposited. A 100% certainty that the sample was from a particular individual.	Age and environmental conditions can cause the DNA to degrade but does not change its arrangement. Contamination. Complexity.

FIGURE 1

Example DNA profile with peaks for four different short tandem repeats (STR) markers shown.



DNA profiles

Identifying the likely source of a biological sample can be done by exploiting short tandem repeats (STRs), genetic markers commonly used for identity testing. These are short blocks of DNA which repeat ~5-50 times; the number of repeats varies among individuals. The human genome contains STRs at many different locations. Individuals have two copies of each autosomal STR because they inherit DNA from each parent. These two copies might or might not have the same number of repeats.

DNA profile analysis involves creating profiles which present as STR peaks, where peak position corresponds operationally to the number of DNA repeats at that location in the genome (Figure 1). The combination of the peak positions for different STRs creates an individual's DNA profile. If peaks from an evidence sample and a suspect's sample differ, the suspect is unlikely to be the source of the biological evidence.

With samples containing a mixture of DNA from different individuals, the profile may not be so easy to interpret. DNA mixtures may display more than two peaks for each STR marker. This presentation is due to the different individual's DNA comprising the mixture sample containing different numbers of repeats at a particular marker. In such cases, the number of peaks and their relative heights become important. Higher STR peaks indicate a larger quantity of DNA within the sample and concomitantly lower peaks indicate a lower quantity of DNA. The relative differences in heights of peaks can be used to identify likely major and minor contributors to the sample.

Suspect-driven bias

There are problems with bias (which should be avoided) in interpreting whether a person of interest is a potential donor of the evidence or should be excluded as a donor of the evidence. In several instances the DNA profile from a person of interest was used to assess inclusion or exclusion. Additionally, instances have occurred where an interpretation of a DNA sample was determined inconclusive, but should have been deemed an exclusion. Other examples of bias have been revealed after probabilistic genotyping analysis, in which the user did not apply the analysis properly leading to potential false inclusions.

Stochastic effects

The more DNA in a sample, the higher the STR peaks and the greater confidence that the DNA profile is accurately portrayed. Confidence is reduced regarding full representation of a DNA profile if an evidence sample is degraded and/or contains too little DNA. For these samples, DNA processing might fail to detect or amplify some DNA sequences, potentially resulting in a partially represented DNA profile. Setting a stochastic threshold or using probabilistic genotyping to address stochastic effects for the observed (and non-observed) STR peaks and their height allows scientists to consider the likelihood of missing or of partial data.

Software use

To help address bias and stochastic effects, probabilistic genotyping software is increasingly used to help interpret complex DNA mixtures. Computational techniques can produce likelihood ratios reflecting how likely it is to observe the DNA evidence if a given individual contributed the particular evidence sample as opposed to an unknown individual being the source of the evidence. However, such software should not be regarded as infallible. It is important the analysts assess the results so that at a minimum the results are intuitively supportable. In the context of courts, the expert reporting software results should understand how it operates and be able to explain the limitations of the technology to the courts.

> "In the past many scientists did not consider missing data. Human beings tend to consider only what they see, and not what might have dropped off the DNA profile." –
>
> Professor Bruce Budowle.

Voice recognition

Dr Anil Alexander, Chief Executive Officer and Co-Founder of Oxford Wave Research, provided an overview of the field of voice recognition. He described how automatic voice recognition is being used to provide evidence in court and highlighted associated risks and opportunities.

Image: Dr Anil Alexander, Chief Executive Officer and Co-Founder of Oxford Wave Research.

Voice recognition, also known as speaker recognition, is something people around the world do almost effortlessly on a daily basis. We all recognise voices we hear in a very intuitive sense and also think we are good at it. We rarely might also find ourselves earwitnesses to a crime. Recognising unfamiliar voices is, perhaps rather surprisingly, harder than one would think. The use of computers to help identify voices is increasingly popular, helping forensic practitioners estimate the strength of speech evidence and providing clear evidence to courts and juries.

Forensic voice comparison techniques

Spectrograms were used in the mid-twentieth century to compare speakers and identify voices. These were the so called voiceprints or 'voicegrams' widely used until about 1979 when a National Academy of Sciences report[5] effectively sounded the death knell to this term as the voice is not like fingerprints. They are largely unchanging for an individual, whereas the same word changes acoustically, at least slightly, every time it is spoken by a particular person. This can be partly attributed to human anatomy, with lungs, teeth, lips and vocal cords all affecting speech production. Further, age, accent and gender as well as background noise level are also sources of variability.

Taking this into consideration in forensic cases is important when determining whether the voice heard in an evidence recording is the voice in a known speaker recording. Modern methods of analysis largely fall into three categories:

- **Aural-perceptual approach**
  Using audible characteristics such as dialectal and sociolectal features, speech defects and voice quality to identify a voice.
- **Auditory-instrumental approach**
  Using acoustic measurements of parameters such as the average fundamental frequency, formants (acoustic energy) and articulation rate.
- **Automatic speaker recognition**
  Comparing statistical models based on acoustic parameters of compared voices, traditionally done on computers.

All three methods model the voice, either perceptually or using mathematical representations. They take a speech sample, remove extraneous non-speech sounds, extract features from the voice and finally model the speech. The final voice model can compare speakers and determine the likelihood of a speaker's identity.

5. National Research Council (1979). On the Theory and Practice of Voice Identification. Available from https://nap.nationalacademies.org/catalog/19814/on-the-theory-and-practice-of-voice-identification (accessed 30 July 2024).

Automatic speaker recognition

The last of the above three methods, automatic speaker recognition, is a rapidly developing field. In recent years, deep neural networks have produced highly performing voice models. Rooted in artificial neural networks, deep neural networks are, in their simplest form, a collection of nodes which mimic brain behaviour.

Millions of recordings can be passed into the neural network to train it to produce a voice model for an individual. Voice models are created for both the unknown evidence recording(s) and known (suspect) speaker(s). A likelihood ratio is the preferred way of providing evidence. In the adversarial system, there are two competing hypotheses:

- The speaker in the evidence recording is the known/suspected speaker (H0); and
- The speaker in the evidence recording is not the known/suspected speaker (H1).

Formal methodology and conclusion frameworks for forensic voice recognition vary across the world, but the percentage of practitioners using the automatic approach has increased considerably since 2011. Deep neural networks can handle large quantities of digital recordings in different languages and conditions, allowing for better accuracy.

Looking ahead

There are still many challenges facing forensic voice recognition. Fake voice creation is increasing, with naturalistic and similar-sounding speech created with minimal target voice samples. Open-source models have reduced entry barriers, allowing individuals freely to download models and easily create voices. The technology could be used to create fake news or propaganda, potentially undermining democracy. Legal frameworks need to be developed which deter the creation of fake voices.

Despite the risks, there are also positives to fake voice creation. Voices of vulnerable victims could be disguised in criminal investigations, and patients who have lost the ability to speak can benefit from fake voice creation in speech therapy.

> "Voice recognition can have a positive and meaningful impact in investigations and legal proceedings where there is balanced consideration of competing propositions, rigorous validation, and adaptation to emerging challenges"
>
> Dr Anil Alexander, Chief Executive Officer and Co-Founder of Oxford Wave Research.

Bayesian AI

Professor Stuart Russell, University of California at Berkeley, explained how probabilistic models have been used for legal reasoning and how open-universe probabilistic programs allow for the modelling of real-world situations.

Image: Professor Stuart Russell, University of California at Berkeley.

In a legal context, conclusions are reached based on evidence. An understanding of probability is important in assessing that evidence. A probability model is a set of possible worlds (that is, all the ways the world could be) and a probability associated with each of those worlds occurring. The classic example is a die roll: there are six possible worlds corresponding to the faces of the die, and the probability of each occurring on a given die roll is 1/6.

A probability model can be used to assess the probability that something is true given a specific collection of evidence. However, the usefulness of the model is dependent on the set of possible worlds it includes. To reason in the legal context, a rich set of possible worlds is required.

Probability of identity with partial observation

Probability models can be used to answer questions of identity where there is observation evidence. As an example, suppose there are N objects described by K binary features. A model can be used to determine the probability that two objects, X and Y, picked at random and with identical observed features, are the same object. Mathematically, the odds that $X = Y$ can be expressed as: $2K/(N-1)$.

The likelihood of a coincidence (that is, that X and Y are identical but not the same object) depends on the relative sizes of N (number of objects) and 2K (the number of possible descriptions in terms of K binary features). The analysis can be extended easily to the more realistic case where the measured value of each binary feature might be incorrect with probability p, and the descriptions of the two objects might differ by D bits. These types of calculations give a clear sense of how the accuracy of identification depends on factors such as the population size, the degree of matching evidence linking two objects, and the reliability of the evidence.

Probability of identity in the real world

In the real world, decisions about identity are sensitive to many factors. When examining the probability that car A and car B in two CCTV images of separate points on a freeway are in fact the same car, contextual factors such as time and place are important—for example, the cars might look identical, but if the upstream image were taken shortly after the downstream image, the cars must be different.

A major challenge in real-world situations is writing down the probability model and summing up all the probabilities of the possible worlds: we need to know in which worlds are they the same car, in which worlds are they different cars, and the relative probabilities of the two sets of worlds. However, this is dependent on various factors such as the effective number of possibly confusable vehicles, the level of detail and accuracy of the measured observations, and the likelihood that the vehicle will be at the downstream location given current traffic patterns and speeds.

Constructing the probability model

The probability model can be defined using three ideas allowing us to specify probability distributions over very large sets of possible worlds:

- **Idea 1**
  Bayesian networks decompose the process of generating a world into multiple local worlds, generating steps where probabilities can multiply. The probability of the whole world is the product of the probabilities of each of the steps occurring to build that world.

- **Idea 2**
  Events are relations among objects, forming a more complex structured representation of reality.

- **Idea 3**
  The numbers of objects which might exist can be modelled. For example, a Poisson distribution gives the probability of an event happening a certain number of times in a defined time or space interval.

These ideas make it possible to write down probability models covering infinitely many heterogeneous possible worlds in a natural way. With these rich sets of possible worlds, we can ask complex questions about identity and things have happened to explain a given observation.

Use case – detection of nuclear testing

These three ideas formed the model for the detection of nuclear testing used in global monitoring as part of the Comprehensive Nuclear Test Ban Treaty (CTBT). The system uses seismic waveform evidence from 150 stations to highlight possible nuclear tests and calculates the probability of seismic signal identity tens of thousands of times a day, monitoring the entire world as a probabilistic inference system. The model was implemented by the UN in 2018 and has decreased the error in detection by a factor of at least 2 when compared to the existing system which, however, is yet to be fully retired from use.

This is an open-universe probabilistic model that can be critiqued; that is, experts can read and understand the model, agree or disagree with its assumptions, and contribute their own research and data to quantify different parts of the model. This is important to avoid bias and improve the model's validity and accuracy.

> "With probabilistic tools, we can model very complex and very realistic problems [...] so there is really no reason for us to continue to suffer from fallacies or to shy away from reasoning properly about evidence."
>
> Professor Stuart Russell, University of California at Berkeley.

Forensic science in a virtual reality

Vincenzo Rinaldi, University of Dundee, explored how virtual reality can improve crime scene visualisation in the courtroom and described the current limitations of this evolving technology.

Image: Vincenzo Rinaldi, University of Dundee.

> "We have a responsibility to understand the limitations of the technology because we have already seen AI and other technology disrupting several fields."
>
> Vincenzo Rinaldi, University of Dundee.

Current state-of-the-art technology allows digitalisation of crime scenes within hours. This requires technologies to enable two steps: data acquisition and visualisation.

When replicating evidence from a crime scene, various methods and sensors can be employed. However, cost and difficulty of use preclude some technologies in some contexts. For example, although laser scanners are excellent sensors, use is expensive. Photogrammetry, which uses photographs to reconstruct the scene, is less expensive but could be less accurate.

Two-dimensional (2D) displays have traditionally been used for visualisation. Recent use of virtual reality (VR) enables the immersive 3D visualisation of a reconstructed environment through the use of headsets.

Trialling the technology

To create a VR visualisation of a crime scene, traditional cameras, already part of first responders' kits, can be used for data acquisition. The data is processed to create a 3D reconstruction which can be visualised on both 2D displays and immersive devices.

To test the technology, practitioners were invited to work in a VR environment to assess whether they could formulate a hypothesis by walking through the 3D reconstruction of a crime scene. Participants were at first hesitant to explore the space but over time became more comfortable using the technology. They could recognise the environment as a workplace and generate hypotheses coherently to the traditional exploration of the crime scene in real life.

Open dialogue between researchers, practitioners and those with roles in the legal field is important as the technology is still in development and has not yet been used in court.

Overcoming pitfalls and risks

Several risks are associated with use of VR technology in a legal context. It attracts a 'wow' factor, and the progress of research can be overestimated. Underestimation of its potential is also a possible issue, as it can be dismissed as no more than a gaming console. Excessive gamification is leading to companies creating software to commercialise VR as a novelty training tool without appropriate certification.

The largest risk is using the technology before its limitations have been fully understood. Users must be mindful that bias may be introduced in the reconstruction and that what is presented is what has been chosen to be captured. Education and contextualisation are key to combating misuse of the technology and understanding the value of the data. A development approach with a heavy focus on feedback via public engagement activities involving practitioners and those with roles in court aims to advise whether the technology is feasible and meets their requirements.

The validation of data underpinning the reconstructed environments is essential to understanding its limitations. Data from real scenes ('ground truth' measurements) are used to determine the uncertainties of measurements in the virtual space.

Looking ahead

VR technology has developed to a point where headsets are portable and might become the size of a contact lens. In future, robots and AI might be used to capture the spatial data and create the 3D reconstruction if it is too dangerous to enter the scene, or at risk of being contaminated.

Existing challenges in the evaluation of digital evidence

Dr Eoghan Casey, University of Lausanne and OwnBackup, focussed on the evaluation and interpretation of digital evidence as one of the biggest challenges facing the domain.

Image: Dr Eoghan Casey, University of Lausanne and OwnBackup.

Digital evidence has become progressively more important in court decision-making. However, the rapidly increasing volume, variety and complexity of digital data make thorough evaluation difficult, and uncertainty associated with this data challenging to express.

Challenges associated with the evaluation and interpretation of digital evidence

- **Quality of data**
  Personal health information collected using wearable technologies might not be reliable. In a 2018 trial in Germany, data from an iPhone health app was used as evidence that a suspect was exerting himself ('climbing stairs') at the time of the murder. However, changes in pressure can also register as exertion on these types of apps. Understanding how data is interpreted by such apps is an emerging area of study with implications for our justice system.
- **Quality of scientific analysis**
  Rigorous scientific analysis of data for the courts is often lacking. For example, in a recent case in the United States (Massachusetts v Arrington), iPhone Frequent Location History data was presented as evidence in a report submitted by police analysts. However, the analysts lacked the specialised knowledge to explain the data or justify its reliability. The issue was not that the evidence extracted from telecommunication systems was necessarily faulty. Rather, the scientific methods used to analyse it were lacking, and the evidence was presented as fact rather than with an attributed degree of uncertainty.

- **Quantifying uncertainty**
  There are two extreme schools of thought relating to the evaluation of digital evidence in the courts. One maintains it is not possible to quantify uncertainty in digital evidence, so this data should be treated as fact. The other claims justice necessitates a scientific interpretation of evidence, so if accurate quantification of uncertainty is not possible, the data has no place in court.

- **Admissibility in court**
  In a legal context, constraints on how electronic evidence can be used must be considered. For example, the European Court of Justice ruled in 2022 that the mass collection and retention of telecommunications and location data is a violation of human rights and cannot be justified within a democracy, even in the case of serious crime. However, retention and use of this data is permissible to address threats to national security.

- **Closed culture**
  It has been suggested that there is an underlying culture of reluctance to highlight past and current weaknesses in the electronic evidence presented in court. This is because newly identified weaknesses might undermine past cases which relied on the type of evidence in question.

> "The most successful way to combat the challenges in using digital evidence is to break down siloes and work together with other domains and disciplines, and to combine digital with physical evidence."
>
> Dr Eoghan Casey, University of Lausanne and OwnBackup.

Four initiatives to address the above challenges

- **Assign a quantified value to digital data**
  Dr Casey and colleagues have developed the C-Scale methodology. It enables practitioners with limited statistical training to assign a value to digital evidence which represents its strength given alternative hypotheses. The scale is a continuum running from C0 (evidence contradicts known facts; high uncertainty) to C6 (evidence is tamper proof; low uncertainty). However, there is debate about whether presenting the reliability and value of electronic evidence in this less definitive way is practical in the courts.

- **Define standards**
  The digital forensic research community recently came together to develop an approach to define all possible weaknesses in a digital investigation. This resulted in the creation of the Digital Evidence Weakness Taxonomy, which categorises possible errors and describes mitigation strategies and methods for error detection. In future, expert witnesses could be required to use a standard taxonomy to demonstrate how they have considered and mitigated possible weaknesses in the electronic evidence they submit. The taxonomy approach also applies to and is being considered by other forensic disciplines, such as fingerprint analysis, as a method of increasing transparency about how evidence could be flawed.

- **Create a standard reference dataset**
  The National Institute of Standards and Technology's Artifact Catalog's crowdsourcing approach to interpretation of digital traces can act as a standard reference point for digital data interpretation. This might allow experts to base significant decisions on digital data with greater confidence. It would also help to increase transparency in how data is analysed, highlighting areas where there is disagreement on how digital data should be interpreted, and where progress is necessary.

- **Increase scientific literacy**
  Increasing scientific literacy of digital evidence in the broader population as well as amongst future practitioners will help ensure it is used correctly and its limitations are better understood.

Likelihood ratios

Professor Gillian Tully CBE, King's College London, spoke to Lord Justice Colin Birss, Deputy Head of Civil Justice, about likelihood ratios and their use in evaluating the strength of evidence in court.

Image: Professor Gillian Tully CBE, King's College London, with Lord Justice Colin Birss, Deputy Head of Civil Justice.

"Numbers are a way of expressing uncertainty, rather than certainty."

Lord Justice Colin Birss.

"In court, we are often asked about possibilities, and it is very difficult to rule out with 100% certainty that something could not have happened. Possibilities are unhelpful; probabilities offer a useful alternative."

Professor Gillian Tully CBE.

Forensic scientists work with traces left from a past event, but, in many instances, the trace available is very limited. There is uncertainty associated with every scientific measurement of evaluation, and some uncertainties can be quantified more precisely than others. This uncertainty means scientific analysis does not give binary answers. Evidence should always be evaluated within a framework of circumstances and the positions of the parties.

Where there is uncertainty is it very difficult to exclude many possibilities, and in fact unhelpful to do so when attempting to evaluate the strength of evidence. Possibilities are binary: something is possible or it is not, and it can be difficult to rule out with 100% certainty that something is not possible. Probabilities, on the other hand, are not binary and enable logical reasoning.

Introducing likelihood ratios

A likelihood ratio (*LR*) is a ratio of two probabilities: the probability of scientific observations of the evidence under two different propositions (or hypotheses, *H*). Propositions are always evaluated in pairs. For example, in a criminal case, one proposition would represent the prosecution position (*H*p), and the other the defence position (*H*d).

$$LR = \frac{\textit{Probability of the observations if } H\text{p} \textit{ is true}}{\textit{Probability of the observations if } H\text{d} \textit{ is true}}$$

An example might be DNA match evidence. The likelihood ratio is the probability that the observed DNA profile is what one would expect if the sample were from the suspect, divided by the probability of seeing the observed DNA profile if the sample were from an unrelated person.

There is a danger of conferring too much certainty on data when it is put into a mathematical formula like the one above. Thus, expert witnesses need to be able to switch between describing likelihood ratios numerically and linguistically to suit the level of uncertainty within the evidence.

Transparency is critical. Assumptions need to be declared. It should be clear what propositions the expert witness is evaluating and what changes they would make if the propositions were to change. There must be transparency about the extent and quality of the data upon which the expert is basing evaluation.

The prosecutor's fallacy

Standard statistical interpretations of evidence can easily be misunderstood. Analysis should focus on the probability of the observed evidence rather than the probability of guilt. The prosecutor's fallacy occurs when the probability of observations if the proposition is true is assumed to equal the probability of guilt if those are the observations. For example, forensic analysis can indicate that the perpetrator has a blood type found among only 10% of the population, which means the probability of observing a matching blood type in any random person is 10%. However, this does not mean a 90% probability of guilt if a suspect has a matching blood type.

The defence fallacy

On the other hand, the defence fallacy is to focus exclusively on the probability of a match and disregard all additional evidence. For example, if the probability of a DNA match were 1 in 1 million, the defence might interpret this to mean that in the UK, population approximately 60 million, 60 people would be the equally likely source of that evidence. This assumes no other evidence in the case can be used to identify potential suspects.

Likelihood ratios take all evidence together to evaluate the respective propositions of the defence and the prosecution.

Scientists and legal practitioners often use 'probability' but tend to mean different things. In addition, courts tend to shy away from using numbers, which juries assume are definite. Likelihood ratios offer the courts both a numerical and a linguistic way of expressing probability which is understandable across fields.

PANEL DISCUSSION

Considering expert evidence

Two separate discussions on expert evidence were chaired by Dame Anne Rafferty DBE, former Lady Justice of Appeal of England and Wales and Chairman of the Royal Society Primers Steering Group.

Image: (left to right): Mr Justice Richard Meade, High Court Judge of England and Wales; Professor Gillian Tully CBE, King's College London; Dame Victoria Sharp DBE, President of the King's Bench Division; Dame Anne Rafferty DBE, former Lady Justice of Appeal of England and Wales; Professor Thomas D Albright, Vision Center Laboratory, Salk Institute for Biological Studies; Hon Barbara J Rothstein, United States District Court, Western District of Washington; and Professor Lucina Hackman, University of Dundee.

Panellists included Lord Anthony Hughes of Ombersley PC FRS, former judge of the Supreme Court of the UK; Judge David Tatel, US Court of Appeals for the DC Circuit; Professor Niamh Nic Daéid FRSE, University of Dundee; Professor Thomas Albright, Vision Center Laboratory, Salk Institute for Biological Sciences; Dr Joe Shelby Cecil, Civil Justice Research Initiative; Professor Gill Tully CBE, King's College London; the Honorable Barbara J Rothstein, United States District Court, Western District of Washington; Mr Justice Richard Meade, High Court Judge of England and Wales; Professor Lucina Hackman, University of Dundee; and Dame Victoria Sharp DBE, President of the King's Bench Division.

Panel discussions on the receipt, control and consideration of expert evidence covered a range of themes. Conversations expanded upon earlier talks by Lord Hughes and Judge Tatel which described jurisdictional differences between the US and UK.

Key points covered included:

Use of science in the courtroom

- Judges typically care about assessing the state of the science in a snapshot in time in the context of a single case. The result is a short timeline for judges focused on resolving the case and allowing parties to move on.
- After the conclusion of the case, judges do not continue to collect information, conduct experiments, or revisit the initial decision. The law might continue to develop at an incremental rate and judges might revisit the framing of the law, however the resolution of disputed facts by the jury is limited to a particular point in time.
- By contrast, scientists can postpone a decision, continue to collect information through additional experiments and might revisit and refine an earlier decision.

- The focus of the judicial inquiry should be on the validity of the science itself, and any inquiry into validity must assess the means of overcoming uncertainty and bias. Valid science will be repeatable and can be corroborated by others as a means of obtaining a consensus.
- Scientists also employ the adversarial system in determining the quality of scientific findings, challenging opinions, presenting alternative interpretations and gathering more information.

"When confronted with complicated, competing expert evidence, what can a judge in the UK do to measure which expert carries the day?"

Dame Anne Rafferty DBE, former Lady Justice of Appeal of England and Wales.

Assessing expert witness testimony

- Determining which expert is better qualified (particularly in the US justice system) is of limited use. Some aspects of experts' qualifications might indicate outstanding achievements unrelated to the issues in the case. Perhaps the expert with a shorter list of qualifications will be more familiar with the issues founding the dispute. Similarly, charisma and eloquence can be seductive but unrelated to proficiency. Faced with complex testimony from two or more expert witnesses, a judge in the UK might direct that the experts meet and identify those issues on which they agree and disagree, narrowing the dispute.
- In US courtrooms, duelling experts each representing a different party, can confuse juries. An independent review of the proffered testimony, as in the UK, would potentially limit many such problems (see *Strengthening the independence of expert witness testimony in the US* below).
- Training materials prepared by Inns of Court for barristers in England and Wales offer excellent guidance on the approach to expert testimony.
- Science primers developed for judges in both the US and UK have made scientific concepts clearer and more accessible to the trier of fact.

Expert report requirements

- Experts' reports should explicitly address the quality of each bit of evidence considered and the confidence of the expert in his or her conclusion. Often the court is faced with a binary decision, such as ruling evidence as admitted or excluded. The expert's report should recognise and address the specific ruling the judge must make.
- Experts' reports should indicate the evidence presenting the greatest challenge to their position and explain why it does not drive the expert's decision. Whilst both law and science are adversarial, the adversarial exchange has different ends. In law it is intended to terminate the inquiry, in science it is intended to generate further inquiry.

Expert witness involvement may differ depending on jurisdiction

- When giving evidence in England and Wales the expert witness has limited communication with the legal team and consequently rarely understands exactly how the expert evidence fits within the case and what to expect in court. Often, the expert is asked to explain complex scientific topics, and those explanations are always better after advance notice and a chance to prepare.
- By contrast, in Scotland forensic science experts participate in preliminary meetings which inform the expert about the nature of the case, how the expert evidence fits within the nature of the case, and likely issues.

"Those of us working in forensic science have a responsibility to know how the law works, not just what we are required to do within the law."

Professor Lucina Hackman, University of Dundee.

Strengthening the independence of expert witness testimony in the US

- Efforts to strengthen the independence of experts have fallen short in the US. Experts' ties to their sponsoring parties and attorneys are too engrained and have generated circumvention of requirements directed at expert testimony of greater independence.
- Nevertheless, US judges have developed innovative procedures to allow the courts some access to independent experts in extraordinary cases with especially demanding expert testimony.

Procedures include:

- The use of court appointed independent experts. This is rare due to judges' reluctance to interfere with the adversarial system. Judges are also concerned that satellite litigation might arise around appointment and payment of the expert. However, simply the announcement of an intention to appoint an expert might have a constructive effect, as the parties' experts might begin to moderate their planned testimony.
- The use of special masters with relevant skills to help judges with difficult scientific testimony. Special masters, often attorneys, have long been used to help the courts on accounting or a difficult computation of damages. More recently courts have appointed special masters with scientific and technical training to advise on resolution of conflicts over scientific evidence. The opportunity to appoint a special master is somewhat limited by Rule 53 of the Federal Rules of Civil Procedure, which authorises such an appointment to address "some exceptional condition."
- The use of 'technical advisors' to advise judges on complex scientific evidence. Technical advisors' function much like court law clerks, working closely with the judge outside the presence of the party. They are common in patent cases to educate the judge on scientific and technical issues necessary to understand the patent. Technical advisors are the most controversial form of extraordinary assistance since they may speak to the judge outside the presence of the parties.

"The US made a very serious effort to emulate some of the reforms that England and Wales have undertaken in attempting to make experts more independent of the parties. Those efforts largely did not work."

Dr Joe Shelby Cecil, Civil Justice Research Initiative.

"If [every expert] must state what data and assumptions have been used, it becomes clear where the differences lie between experts. It becomes much easier to examine where those differences lie and why those differences are there."

Professor Gill Tully CBE, King's College London.

"Trial judges only care about a snapshot in time… Science is trying to come up with something that will be a significant contribution to humanity, something that takes time. [Trial judges] are settling just one case."

The Honorable Barbara J Rothstein, United States District Court, Western District of Washington.

"In court, you have to reach a conclusion… in science, experts are much more willing to say, 'I don't know the answer'."

Mr Justice Richard Meade, High Court Judge of England and Wales.

"A step I would wish to see for the future is a more robust approach to admissibility. This is a job for both the advocates and the judge."

Dame Victoria Sharp DBE, President of the King's Bench Division.

Human genome editing and enhancement

Professor Robin Lovell-Badge CBE FMedSci FRS, Francis Crick Institute, discussed current, potential and speculative applications of human genome editing.

Image: Professor Robin Lovell-Badge CBE FMedSci FRS.

"When it comes to genetic enhancements, opinions can be very strong – especially when it involves changes to heritable DNA, where someone's children might carry the same alteration."

Professor Robin Lovell-Badge CBE FMedSci FRS.

The ethical implications of genome editing, particularly of heritable (germline) editing, are widely debated, as are their potential future applications for human enhancement. This enhancement could be temporary or long-lasting, and reversible or irreversible. The potential and speculative uses of genetic enhancement pose important questions for our judicial systems.

Genome vs epigenome editing

Genome editing is a method of altering one or more DNA sequences. It most often requires an enzyme to make cuts in DNA and a mechanism for recognising the specific DNA sequence to be cut. If the aim is to make more than a small alteration, a 'DNA template' is required to insert or replace a longer DNA sequence.

Conversely, epigenome editing can be used to alter the activity of genes in substantial ways, but it does not alter the DNA sequence. The epigenome consists of chemical compounds that affect how genes are expressed. A simple change in the expression of a gene can have long lasting impacts. Epigenetic editing cannot be detected in a forensic DNA analysis.

Potential and speculative uses of human genome editing

a. Somatic genome editing

Advances have recently been made in the use of somatic human genome editing (that is, making changes in non-reproductive cells) to treat conditions like sickle cell disease. Genomic changes made in this way are not heritable.

Many clinical trials using somatic genome editing techniques have taken place, with many more in progress or about to be initiated. However, long-term studies are needed to fully explore lasting consequences and any unintended side-effects of these treatments.

Somatic genome editing therapies can cost upwards of $1 million USD. Extremely high treatment costs are a substantial barrier to their widespread use and raise concerns around how to promote equitable access based on need.

b. Heritable genome editing

In theory, heritable genome editing could be used to prevent the inheritance of genetic disorders. For the genomic changes to be passed along to future generations, editing must be done in germline cells. This could involve editing the fertilised egg or editing the sperm or egg cell before fertilisation.

In practice, heritable modifications to the human genome are largely seen as unacceptable. Many countries have legal frameworks to strictly limit or prohibit the use of heritable human genome editing approaches. Basic research using genome editing techniques in human embryos for non-reproductive purposes is permitted in the US and the UK, although it is highly regulated. It is illegal to edit embryos that lead to pregnancy.

Speculative potential future uses for heritable genome editing could include treating infertility, promoting disease resistance, improving human robustness or quality of life, or altering traits such as height or eye colour.

Extreme examples of possible future uses could include the introduction of non-human traits, perhaps to improve sensory systems (eg to detect UV or infrared light) or to obtain nutritional benefit from substances humans cannot currently metabolise.

Cognitive enhancement: Do drugs work, why are people using them and what are the ethical and societal implications?

Professor Barbara Sahakian FMedSci, University of Cambridge, highlighted both the risks and benefits associated with the use of cognitive enhancing drugs.

Image: Professor Barbara Sahakian FMedSci, University of Cambridge.

Use of cognitive enhancing drugs for non-medical related reasons is increasing. Methylphenidate, a treatment for attention deficit hyperactivity disorder (ADHD) and modafinil, a wake promoting agent used in the treatment of narcolepsy, are commonly used as cognitive enhancing drugs, their use rising in both the UK and the US over recent years. Whilst many think it easy to distinguish between the use of drugs to treat a diagnosed illness as opposed to for enhancement purposes, this might not be so clear.

Use of cognitive enhancing drugs

Reasons for using drugs as cognitive enhancers are varied. Methylphenidate can be prescribed to reduce symptoms of ADHD, so an increase in prescriptions could be caused by an increase in ADHD diagnoses in children and adults. In a healthy individual, the drugs can be used to improve concentration and attention, which would facilitate the ability to study for extended periods. Cognitive enhancers can also be used to reduce fatigue, such as symptoms of jetlag, and increase the ability to stay awake, allowing longer hours of work.

A high percentage of modafinil used in the UK is supplied off label to healthy individuals, posing a range of ethical issues and the potential for misuse. The long-term side effects of using these drugs in healthy individuals are still unknown, and considerable dangers are associated with buying prescription-only drugs via the internet.

Parents might feel pressure to allow their children to use drugs when studying if they are aware of other children doing so and worry about others having an advantage. Similarly, university students might be tempted to use drugs to perform well in exams. The human brain is in development until approximately twenty-five and the risks of using drugs in a healthy developing brain are not fully understood.

Individuals in jobs with heightened responsibility, where mistakes have significant consequences, might see the advantage in using cognitive enhancers. A 2012 study[6], by Professor Sahakian, Professor Lord Darzi and co-authors, showed use of modafinil in sleep-deprived doctors prevented impulsive decisions and improved their cognitive flexibility. In this instance temporary cognitive enhancement might be beneficial to patient safety. This is especially important as doctors typically use caffeinated coffee to stay awake, and one side effect of excessive amounts is hand tremor, which could be dangerous for surgical and other procedures.

Research on the impacts of cognitive enhancing drugs on working memory

The Cambridge Neuropsychological Test Automated Battery (CANTAB), co-invented by Professor Sahakian, is a computerised cognitive assessment methodology. It can, for example, provide a good indication of an individual's working memory. Working memory is a subcomponent of executive functioning in humans, which contributes to effective planning and problem solving. Studies have shown that methylphenidate improves performance in CANTAB tests in both healthy volunteers and patients with ADHD[7,8,9].

Modafinil has also been shown to improve working memory in patients with first episode psychosis[10] and can improve performance in patients who are recovering from depression[11]. Individuals struggling to return to work after suffering depression might therefore benefit from prescribed modafinil, which might reduce fatigue and improve cognition.

Looking forward

Despite associated risks and ethical implications of off label use, cognitive enhancing drugs have the potential to help patients suffering conditions such as psychosis and depression. They can also benefit individuals working in high pressure jobs or antisocial hours, such as in the military, surgeons or shift workers. The debate lies in whether the government should work with the pharmaceutical industry to determine whether these drugs are safe and effective for healthy adults to use, and how, if at all, use should be restricted.

> "In individuals with neurological and psychiatric disorders these cognitive enhancing drugs may be of great benefit as treatments for the cognitive problems that they experience in daily life. In healthy individuals these drugs can also improve cognition, but safety and efficacy with long-term use still needs to be determined."
>
> Professor Barbara Sahakian FMedSci.

6. Sugden, C, Housden, C R, Aggarwal, R, Sahakian, B J, & Darzi, A. (2012). Effect of pharmacological enhancement on the cognitive and clinical psychomotor performance of sleep-deprived doctors: a randomized controlled trial.
7. Turner, D C, Blackwell, A D, Dowson, J H, McLean, A, & Sahakian, B J. (2005). Neurocognitive effects of methylphenidate in adult attention-deficit/hyperactivity disorder. Psychopharmacology, 178, 286 – 295.
8. Mehta, M A, Owen, A M, Sahakian, B J, Mavaddat, N, Pickard, J D, & Robbins, T W. (2000). Methylphenidate enhances working memory by modulating discrete frontal and parietal lobe regions in the human brain. The Journal of Neuroscience, 20(6), RC65.
9. Elliott, R, Sahakian, B J, Matthews, K, Bannerjea, A, Rimmer, J, & Robbins, T W. (1997). Effects of methylphenidate on spatial working memory and planning in healthy young adults. Psychopharmacology, 131, 196 – 206.
10. Lees, J, Michalopoulou, P G, Lewis, S W, Preston, S, Bamford, C, Collier, T, ... & Drake, R J. (2017). Modafinil and cognitive enhancement in schizophrenia and healthy volunteers: the effects of test battery in a randomised controlled trial. *Psychological Medicine*, 47(13), 2358 – 2368.
11. Kaser, M, Deakin, J B, Michael, A, Zapata, C, Bansal, R, Ryan, D, ... & Sahakian, B J. (2017). Modafinil improves episodic memory and working memory cognition in patients with remitted depression: a double-blind, randomized, placebo-controlled study. *Biological Psychiatry: Cognitive Neuroscience and Neuroimaging*, 2(2), 115 – 122.

Coma, vegetative state, and brain death: the contribution of functional neuroimaging

Professor Adrian M Owen FRS, University of Western Ontario, explained how functional neuroimaging is improving the accuracy of diagnoses and prognoses of patients in the vegetative state, the minimally conscious state and coma.

Image: Professor Adrian M. Owen FRS, University of Western Ontario.

Brain damage can be caused by head injury, infections, tumours, or oxygen starvation (eg due to cardiac arrest or stroke), and results in a variety of medical conditions. Clinicians typically group patients into five categories: locked-in syndrome; minimally conscious state; vegetative state; coma; brain death (Table 1). One of the main factors influencing categorisation is the patient's ability to follow commands. Squeezing a doctor's hand, for instance, might indicate some awareness. However, some patients might be physically unable to squeeze a hand.

It is important to diagnose patients accurately because the chance of recovery varies highly between each of the five groups, so decisions about patient welfare are made, in part, based on this categorisation. Recent incidents such as the recoveries of Michele De Leeuw and T Scott Marr after being taken off life support highlight the ethical implications of incorrect prognoses. It is therefore vital the methods used to determine brain states are of the highest quality. Functional neuroimaging provides a new way of diagnosing patients, whilst also improving accuracy of prognosis.

Functional neuroimaging

Functional magnetic resonance imaging (fMRI) measures oxygenated blood in the brain, providing an indicator of the areas requiring more oxygen due to use. The Owen lab uses fMRI and its optical equivalent functional near infra-red spectroscopy (fNIRS) to investigate the brain activity of patients in a vegetative state and to communicate with them. In 2010, the group asked questions of a patient in a vegetative state and told him to imagine playing tennis if the answer were yes, and to imagine walking round his house if the answer were no[12]. Upon this command, activity could be seen in different areas of the brain, known to plan sequences of movements on the one hand, and navigate mental space on the other. The same result was found in healthy individuals. This demonstrated that not only was the patient able to follow commands and communicate, but he had also been misclassified and was not in fact in a vegetative state at all. This avenue of binary communication might, in the future, allow clinicians to ask patients questions such as 'are you in any pain?' and 'do you want to continue living?'

12. Monti, M M, Vanhaudenhuyse, A, Coleman, M R, Boly, M, Pickard, J D, Tshibanda, L, Owen, A M, & Laureys, S. (2010). Willful modulation of brain activity in disorders of consciousness. New England Journal of Medicine, 362(7), 579 – 589.

In fact, a review of studies which scanned over 1,000 patients in the vegetative or minimally conscious state shows 20 – 25% of patients are aware and can perform tasks whilst in the scanner[13]. Similar studies of patients in coma show a number can respond to requests in the scanner. This implies they have been misclassified, potentially leading to grave consequences.

Improving prognosis

Decisions on the future of a patient are often made on the basis of prognosis. Functional neuroimaging has revealed that some patients with high levels of consciousness have been taken off life support. The Owen group has recently used resting state fMRI to predict neurologic recovery after brain injury[14]. Resting state fMRI measures networks of activity in the brain and is easy to acquire. Strong positive correlations between fMRI activity and recovery led the team to use a machine learning algorithm to predict the outcome of patients. The algorithm predicted poor outcomes with 80% accuracy and good outcomes with 77% accuracy, whilst clinical signs predicted with 64% accuracy for poor outcomes and 10% for good outcomes.

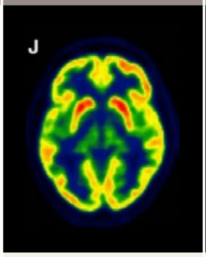
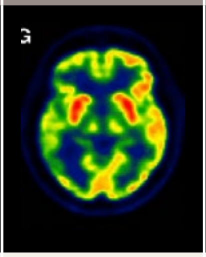
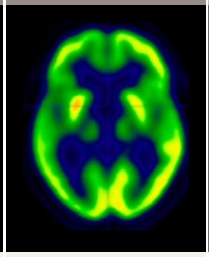
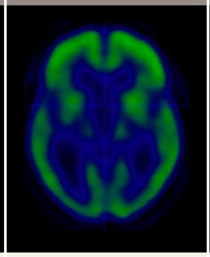
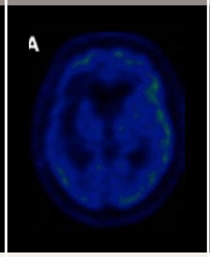
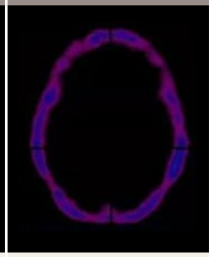
Functional imaging methods like fMRI and fNIRS can improve the accuracy of diagnosis and prognosis in vegetative state, in minimally conscious state, and in coma. Their use may lead to better informed clinical and legal decision making.

> "We can calculate the likelihood of a person recovering from vegetative state or coma much better with an algorithm than with clinical decision making."
>
> Professor Adrian Owen FRS, University of Western Ontario.

13. Kondziella, D, Friberg, C K, Frokjaer, V G, Fabricius, M, & Møller, K. (2016). Preserved consciousness in vegetative and minimal conscious states: systematic review and meta-analysis. Journal of Neurology, Neurosurgery, and Psychiatry, 87(05), 485–492.
14. Kolisnyk, M, Kazazian, K, Rego, K, Novi, S L, Wild, C J, Gofton, T E, Debicki, D B, Owen, A M & Norton, L. (2023). Predicting neurological recovery after severe acute brain injury using resting-state networks. Journal of Neurology, 270(12), 6071 – 6080.

TABLE 2

Categories of brain damage.

	Healthy brain	Locked-in syndrome	Minimally conscious state	Vegetative state	Coma	Brain death
PET scan of brain						
Description	Fully conscious and able to follow commands.	Entirely conscious and aware, but patients have lost the ability to physically move.	Some patients have some awareness.	Wakefulness without awareness. Eyes open.	Eyes closed. PET scan shows very little activity.	Irreversible cessation of brain function. PET scan shows 'hollow skull' phenomenon due to cell death.
Responds to instruction?	Yes	Some patients can blink eyes in response to questions.	Some able to squeeze hand occasionally but unable to respond to questions.	No	No	No
On life support?	No	No	No	Not always	Yes	Yes
Notes		Higher chance of recovery than other categories.	Some chance of recovery. 40% of patients are misdiagnosed as being in a vegetative state.	Slight chance of recovery as the brain's core functions may be unaffected.	PET scans of patients under general anaesthetic sometimes look like this, so recovery is possible.	According to both UK and US law, a person with brain death is dead and a death certificate can be issued.

The future of brain interfacing

Professor Philip Sabes, University of California, San Francisco, discussed the current state of brain interfaces, their potential applications and the ethical implications of their use.

Image: Professor Philip Sabes, University of California, San Fransisco.

"[In the US] we are lacking a regulatory framework, such as a Food and Drug Administration for medical devices. This would help to solve some new problems but also some old ones as well."

Professor Philip Sabes, University of California, San Francisco.

Brain interfacing involves the interaction of external devices with the human brain. Brain-machine interfaces are a set of such devices, and function in one of three ways. They can either 'write into' the brain, 'read out' what is occurring in the brain or both read and write in the brain (eg assistive limbs that have motor and sensory capabilities).

Brain-computer interfaces

Brain-computer interfaces (BCIs) read or write information in the brain. Two BCI devices are commercially available for research purposes: the Utah array and electrogorticography (Ecog). The Utah array is a 4x4mm silicone chip with 100 tines, inserted into the brain to record and stimulate neurons near its surface. Ecog involves silicone sheets laid on top of the brain with electrodes which record from a population of neurons beneath the surface. Ecog electrodes are considerably larger than the Utah array.

The Utah array and Ecog are considered viable medical devices. Whilst important for research, they are not yet integrated into everyday use, in part because they are not fully implanted and do not have the resolution appropriate for decoding movement or speech. Companies such as Neuralink, Paradromics and Neuroscience are developing smaller, fully implanted devices with additional capabilities with the potential to reduce infection and increase wireless communication. These new devices might be commercially available soon, and courts should be aware of their existence.

BCI devices have been used by people with tetraplegia to communicate. They are asked to imagine handwriting or speaking, and the machine can pick up on brain signals, initiating text to come up on a screen. This technology could be transformative for those with decreased capacity to communicate.

Future devices being developed now may be able to further transform lives. It has been proposed that in the future, BCIs may potentially help patients with cognitive problems (such as locked-in syndrome, minimal consciousness) communicate, or allow those with visual impairments to correct their eyesight. BCIs might also stimulate and record the brain to help post stroke, either to recover function or to induce plasticity.

The application of BCIs in non-medical scenarios is still likely to be more than a decade from coming onto the market.

Neuromodulation

Neuromodulation involves modifying patterns of neural activity to regulate one's own mental or physiological state, and devices doing this are already commercially and clinically viable. Many are used to treat movement disorders, such as deep brain simulation for Parkinson's disease, or to disrupt seizures. Future applications could possibly involve monitoring and controlling arousal, attention, pain, sleep, hunger, or addiction.

One of the complications with neuromodulative technologies is that is it difficult to determine what area of the brain to stimulate, and therefore increase reliability, without testing. However, testing is not allowed if the device is unreliable.

To develop neuromodulation, access to deep brain circuits is needed. This contrasts with BCI, which typically interfaces with the thalamus. In addition, neuromodulation will require precision in which individualised, or personalised, understanding of complicated neural circuits is available. There is currently less momentum for neuromodulating devices than for BCIs, but this could change in the next decade.

Ethical implications of brain interfacing

Privacy and security concerns are paramount in navigating the intricate landscape of brain interfacing. The potential for multidimensional control over mental states prompts ethical considerations akin to those posed by cognitive-enhancing drugs, especially if there are unintended or off-target effects. In addition, use of artificial intelligence (AI) to drive such devices implies some sort of hybrid control with the AI on activities of daily living, which raises questions of culpability, intent and error.

Human augmentation, neuroscience and medicine

Professor Alta Charo, University of Wisconsin-Madison, and Sir Robert Francis KC, Honourable Society of the Inner Temple, discussed the future of augmentation and enhancement with: Professor Robin Lovell-Badge FMedSci FRS, The Francis Crick Institute; Professor Adrian Owen OBE, University of Western Ontario; Professor Philip Sabes, University of California, San Francisco; and Professor Barbara Sahakian FMedSci, University of Cambridge.

"We've been augmenting, enhancing and altering ourselves since the beginning of our species' ability to do so. It's important not to treat innovative approaches to this as completely novel, but rather use existing frameworks of what we think is acceptable."

Professor Alta Charo, University of Wisconsin-Madison.

"Genetic and cognitive enhancement involves changes in our very being. In a consumer-driven society, could the bespoke enhancement of individuals be the future?"

Sir Robert Francis KC, Honourable Society of the Inner Temple.

The concept of brain interfaces considers the brain a computer to be decoded and therefore read, or as a program capable of instructing a machine. Where would liability lie were a harm done to a third party as a result? What about liability in an unauthorised invasion of a subject's privacy or body? The diagnosis of brain death and vegetative state remains a current challenge in court cases in which judges are asked to authorise or prevent life-sustaining medical treatment. How confident can we be of the accuracy of what we are told of the condition of the patient?

Overlying all these questions is the issue of how judges and lawyers are kept properly and objectively informed about relevant developments in scientific learning. How can we ensure that those subjected to new scientific processes purporting to be for their benefit are equipped to give properly informed consent or even opinion about the subject?

The panel discussed a number of themes related to human augmentation, neuroscience and medicine and their relevance to institutions of justice. Key points are summarised:

Regulation

- It is important not to treat emerging methods for augmentation and enhancement as completely novel. Humans have been augmenting and enhancing themselves for thousands of years, for instance with alcohol and drugs. New technologies should be viewed in frameworks which currently exist, such as legislation addressing a person's mental capacity and regulation prohibiting or allowing certain types of treatment. It might be necessary to understand that current frameworks could now be applicable to completely new groups of people.
- A regulatory framework for devices should be put in place. The Food and Drug Administration in the USA regulates safety and efficacy of devices intended for medical use, but there is no equivalent for consumer devices. Many items on the market are either regulated very little or not at all and this could be dangerous.

Education

- Consumer choice will drive a lot of the developments in new technologies. In addition, with human augmentation coming in many forms, it can be difficult to understand who or what is in control. Consequently, it is vital for the public to access appropriate, neutral information about the drugs, therapies or devices in which it might be interested. This will help those offered, or subjected to, these new treatment methods make informed decisions.
- Open dialogue and education are important for teaching not only the public but also the judiciary and lawyers, ensuring they understand not only the technology, but also what the users understand and think about it.

Ethical dilemmas

- Quality of life and wellbeing should be central to discussions about the manipulations and modification involved in human enhancement. Many of these manipulations are invasive or might result in addictive behaviour.
- The law might play a role in modulating wishes of employers, insurance companies and workers with regard to enhancing modifications. For example, the cognitive-enhancing drug modafinil has been approved for sleep disturbance due to shift work, as disrupted circadian rhythms have been found to result in accidents in shift workers. If insurance companies begin to demand that employers offer it or employers require employees to use it, it could have interesting repercussions in courts.
- People are now encouraged to declare their wishes regarding treatment in advance, eg whether they wish to be resuscitated or not. However, given that new medical treatments and augmentative modifications are more complicated than they were, the validity of prior decisions made in ignorance of this new science, raises new concerns.

Memory in the dock

Professor Ray Dolan FRS, University College London, discussed how memory and its contamination, consistence and accuracy might affect witness accounts in court.

Image: Professor Ray Dolan FRS, University College London.

> "Although current technologies for studying memory are very sophisticated, their accuracy is not at a level that any court should accept."
>
> Professor Ray Dolan FRS, University College London.

The functional role of memory is not merely to remember the past but to make sense of the present and to better anticipate the future. The latter renders memory particularly subject to a range of motivational influences. In the context of the judicial system, long-term (as opposed to short-term) memory is the component most relevant in relation to evidence, and most specifically episodic (as opposed to semantic) long term memory. However, it can be difficult for juries and judges to interpret this evidence appropriately. Contamination effects, consistency in recall and the age of the memory can have variable impacts on its reliability.

How memory works

Memories can be divided into short-term (working) and long-term memory. Long-term memory can be parsed into implicit (unconscious) and explicit (conscious]. The latter refers to memories that can be brought to mind, either as a fact (semantic) or a recollection (episodic). Long-term memory derives from our sensory experiences of the world which must first be 'encoded' to allow them to be stored in the brain. This encoded information is then 'consolidated' (made stable) over 24 - 48 hours. Beyond this, enduring memories can be 'retrieved' through recall (the act of remembering) or recognition (knowing). In relation to the courts this retrieval process is most exercised and the assumption that it provides a veridical record of events needs to be considered in light of well-known confounding influences.

Contamination of memory

Among the most robust forms of memory contamination is what is termed the misinformation effect. Put simply, this relates to possibility of a person's recall of an event can becoming less accurate based upon provision of post-event information. This can arise in the context of the court by provision of misleading information in preparation for trial, or through leading questions during it. For example, studies show that a subject asked to read a witness statement or a police report of an event before giving their own account is susceptible to information from these sources seeping into their own recollection.

Even more subtle contamination effects are well described. For instance, simply asking 'how fast were the cars going when they *smashed* into each other?' leads to a higher estimate of speed than the same question posed as '... when they *hit* each other?'. Humans also have a strong disposition to remember pragmatic implications of events, rather than what actually happened. For example, 'the baby stayed awake all night' is likely to be recalled as 'the baby cried all night'.

Whilst retrieving a memory boosts its future retention this comes with the risk that memory retrieval renders it more susceptible to contamination. This is more likely after the passage of time when the original memory has weakened, whilst young children and older adults are more susceptible to contamination effects than younger adults.

Confidence and memory accuracy

Jurors and judges give greater weight to memories asserted with greater confidence, and a common assumption is that witnesses with high confidence are more likely to be accurate (eg US Supreme Court in Neil v Biggers 1972). For some types of evidence, such as eyewitness data, confidence can be a good indicator of accuracy even up to nine months post-event. However, convicting a defendant solely on high confidence memory-based eyewitness evidence can still lead to miscarriages of justice. Factors affecting confidence include: individual baseline confidence whereby some people are naturally more confident than others; translation of confidence level (which is subjective) into a quantitative estimate is inherently noisy; simply being asked about confidence increases later estimates of confidence. Thus, whilst confidence and accuracy are coupled there needs to be an awareness of factors influencing the assertion of confidence in a memory.

Consistency and accuracy in memory

It is often assumed that an inconsistent witness (one whose memories differ between earlier and later accounts of an event) is unreliable. Indeed, in such instances not only is the ‘unreliable’ evidence called into question, but so too is the entirety of the witness’s evidence. The evidence indicates that people more inconsistent in their recall are less accurate overall than those who show consistent recall, whilst information remembered inconsistently is also less accurate than is the case for consistently produced items. In addition, if a witness is inconsistent in some of their information over time, the evidence indicates that information they produce consistently is also less likely to be accurate[15].

Age and memory

The age of a memory and the age of a witness both have an important impact on memory. There is a well described decrease in memory accuracy as a function of age, most marked from about the age of sixty-five. It is important to note that our recognition memory tends to decline at a slower rate than recollective memory.

In relation to the age of the memory itself, what is remembered sooner after an event is more likely to be accurate than if remembered later. For example, a witness might at trial report recall of items which were not recalled at an earlier time, but these are less accurate than those recalled consistently over multiple opportunities.

Conclusion

The fallibility of memory is increasingly commented on both in the courtroom and in our wider culture. This fallibility is important but should not detract from the unique value of memory as evidence. Whilst memory is not a perfect record of the past, allowing the public and the courts to infer that memory is ‘the unreliable uncle’ would ultimately have detrimental effects on administering justice. A buttress against miscarriages of justice due to failures of memory is knowing the situations and contexts liable to compromise the veracity of memory and appropriately factoring these into the weighting of this unique form of evidence.

15. Stanley, S E & Benjamin, A S (2016). That’s not what you said the first time: A theoretical account of the relationship between consistency and accuracy of recall. Cognitive Research: Principles and Implications, 1(14).

A human information processing approach to forensics

Professor Thomas D Albright, Vision Center Laboratory, Salk Institute for Biological Sciences, presented the limitations of eyewitness testimony, and discussed how the courts could benefit from adopting the use of scientific advances in human information processing techniques.

Image: Professor Thomas D Albright, Vision Center Laboratory, Salk Institute for Biological Sciences.

"Very important questions for the courts and for law enforcement are 'How accurate is eyewitness testimony?', and 'How do we find the answer to that question?' "

Professor Thomas D Albright, Vision Center Laboratory, Salk Institute for Biological Sciences.

Eyewitness identification is a memory-based, sensory pattern-spotting process performed daily by the brain[16]. Examples include recognising a face in a crowd or finding a car in a car park. During the eyewitness identification process, a sensory stimulus is presented to the witness; it is then stored in their memory and later compared against another sensory stimulus in a line-up.

During the identification process, the observer performs two operations:

1. Measuring the degree of similarity between the memory and incoming stimulus. Each similarity measurement has a degree of certainty associated with it.
2. Deciding whether the measured similarity between the observer's memory and what they are currently viewing exceeds their internal similarity threshold. If it does, the observer classifies the observation as a match.

The quality of the observer's identification depends on the influence of:

- **Uncertainty**
  This is influenced by the quality of both the initial and line-up viewing conditions. For example, poor illumination, long distance and short duration of viewing.
- **Bias**
  In the absence of certainty, observers might rely on their expectations based on prior experience.
- **Overconfidence**
  Self-confidence isn't necessarily proportional to the quality of the identification.

Assessing predictive value: The traditional approach

Determining the quality of the observer's final identification depends on understanding the weight of uncertainty, bias and overconfidence. However, objectively quantifying their presence is a significant challenge. In 1977, the US Supreme Court issued a ruling designed to provide some context for inferring the value of the eyewitness decision. It relied on intuitions about the nature of visual perception and memory to determine the accuracy of the witness's report, namely:

- The witness's opportunity to view the criminal at the time of the crime;
- The witness's degree of attention;
- The accuracy of his/her prior description of the criminal;

16. National Academies of Sciences, Engineering, and Medicine (2014). *Identifying the Culprit: Assessing Eyewitness Identification*. Available from https://nap.nationalacademies.org/catalog/18891/identifying-the-culprit-assessing-eyewitness-identification (accessed 30 July 2024).

- The level of certainty demonstrated at the confrontation; and
- The gap between crime and confrontation.

Assessing predictive value: Adopting a more scientific approach

In the US, some people recently exonerated based on new DNA evidence had been originally misidentified by eyewitnesses. Advances in the science of human information processing, in particular sensation and memory, could increase our ability to determine eyewitness accuracy. Approaches include:

1. **Predictive modelling**
   Empirical validation can be used to infer the statistical relationship between the state of viewing and the likelihood that the identification decision was correct. Lab experiments could simulate a range of witnessed crimes under varying conditions and record the accuracy of the eyewitness identification in each case. Multi-variate regression could then be applied to quantify the predictive relationship between the input conditions and the accuracy of the decision output. Other professions already utilise predictive prognostic tools. For instance, the medical sector routinely uses the conditions associated with a patient to predict their mortality likelihood.
2. **Isolating the observer's assessment of similarity from classification of a match**
   During identification, the witness first evaluates the similarity between their memory and what is before them. If the level of similarity exceeds the observer's internal threshold, they announce a match. Perceptual scaling refers to the concept that different observers can have different internal similarity thresholds. A classification from an observer with a low similarity threshold is less valuable than from one with a high threshold. One approach to overcome perceptual scaling between observers is to remove classification from the identification process. This can be done by showing the observer a series of paired comparisons, asking them to say which is 'more similar' each time. A ranking of recognition strength can then be created based on the observer's similarity measurements alone. This process has the potential to enable greater identification accuracy, as it is less susceptible to internal biases imposed by the witness.

Memory and eyewitness identification

Judge Jed S Rakoff, Senior District Judge for New York Southern District, Professor Thomas Albright, Salk Institute for Biological Studies, and Professor Ray Dolan FMedSci FRS, University College London, were joined by Mrs Justice Bobbie Cheema-Grubb, King's Bench Division, High Court of England and Wales, to discuss memory and eyewitness identification in the court.

"Limitations built into the human person [with respect to memory and perception] are not easily dealt with by the legal system."

Judge Jed S Rakoff, Senior District Judge for New York Southern District.

"In science, you are constantly evaluating, challenging and testing ideas. In court, we must come to a particular decision that is definitive at a moment in time – and it may be wrong."

Mrs Justice Bobbie Cheema-Grubb , King's Bench Division, High Court of England and Wales.

Mistakes in eyewitness identification have resulted in false convictions in both the UK and the US. A recent example of a miscarriage of justice was the Malkinson case in the UK, in which the only evidence was three eyewitnesses who identified the appellant. He was convicted of rape and murder and served 17 years in prison. Failures to disclose evidence including stored DNA samples of another person led to the convictions being overturned. As a matter of course UK judges warn juries against acting on eyewitness evidence where it is the sole identification evidence. It is subject to careful analysis by the judge as part of the legal directions to the jury.

The US's perceptual assessment of witnesses – a bespoke analysis - is not available to UK courts. There is therefore no understanding of whether the witness is unreliably confident or likely to become more and more confident.

Fewer cases rely on eyewitness evidence alone than in the past, due to improved surveillance (CCTV), DNA analysis and phone data. However, some cases rely only on evidence such as allegations of sexual misconduct, where there is no corroboration.

It would be a great opportunity for courts were it possible to make distinctions between memories (ie whether revisited, perhaps enhanced, or are 'raw' and deep-seated). Judges and scientists would need to decide what value to give to different 'types' of memory.

Key points discussed:

Emotion and memory

- Memories are affected by the emotions experienced during the encoding of a memory (when an event unfolds). During times of stress or high emotion (such as having a gun to the head), the memory of the event may be limited to the threat itself, the witness unable to recollect much of the wider context, *de facto* a spotlight effect. This is partially because our sensory systems, including the visual, are heavily affected by emotional state, such as exclusive allocation of a witness's attention to the actual source of a threat.
- The retrieval of the memory sometimes depends on the witness being in the same emotional state as that experienced when a memory was encoded, technically known as state-dependent recall. This type of recapitulation is very difficult to repeat. Despite cross-examination being stressful, it does not recapitulate the precise emotions or state previously experienced.
- In future virtual reality might provide relevant cues which could help witnesses remember prior events, including boosting recognition and potentially facilitating recall events. For example, being able to see a room in which an attack took place might give a witness a richer set of cues. Equally, such technologies might inadvertently contribute to false memories.

The cross-race effect

- The cross-race effect refers to the human tendency of better recognising faces in one's own racial group compared to others. Studies suggest it is related to perceptual learning including early childhood learning of facial features (hence in children from mixed race families or multicultural cities the cross-race effect is less pronounced).
- Some US states have adopted jury instructions which refer to the cross-race effect as a potential source of bias.

Avoiding bias and memory contamination

- Many miscarriages of justice arise from contamination of evidence as a result of inappropriate, biased lines of questioning. It would therefore be useful to create guidelines, training and education for those in law enforcement and prosecutors on how memory can become contaminated and how to interact with suspects or witnesses to avoid it.
- In addition, although not current practice, it would be helpful for police to record the status of as many variables in a suspect's life as possible. This information could later guide investigations of the subject.
- Some mock jury trials have shown that when judges give detailed information about bias in eyewitness identification, acquittal is significantly more likely than when they do not. This is because jurors believe the judge is sending a subliminal message that s/he does not believe the witness is credible. Similarly, in mock trials in which two experts give opposing evidence on the credibility of a witness, the jury discounts the opinions of *both*.
- In the US, most criminal prosecutions end with plea deals rather than trials. In cases including an eyewitness, the prosecutor usually suggests accepting the plea deal, and the testimony of the witness is never tested. It would be helpful to educate prosecutors to ensure that when they use eyewitness testimonies in a plea negotiation, they have some understanding of the limitations of eyewitness identifications and factors that can affect their reliability.
- The presentation and collection of evidence in a particular order can influence the actions of the police. For example, in a case involving two suspects, if there is eyewitness evidence on suspect A, the investigation into suspect B will often be dropped. Better training within the police and prosecutors would help mitigate such problems.

The science behind climate change and its mitigation

Professor Eric Wolff FRS, University of Cambridge, gave an overview of the relationship between greenhouse gas emissions, climate change and the concept of net zero.

Image: Professor Eric Wolff FRS, University of Cambridge.

"I would hate anyone to think at 2° warming we're all doomed but 1.9° we're fine."

Professor Eric Wolff, Cambridge University.

Greenhouse gases (GHG) in the Earth's atmosphere absorb outgoing radiation and re-emit it in all directions so that comparatively more energy is retained when GHG concentrations are higher, resulting in a global temperature rise. As GHG emissions increase due to human activities, global warming is evident in ocean heat, global sea level and global surface temperature maps. Stopping global warming means stabilising the Earth's temperature and this requires reaching net zero GHG emissions. As long as GHGs continue to be added to the atmosphere faster than they are withdrawn, the Earth will continue to increase in temperature.

Carbon dioxide (CO_2) is a key GHG emitted through human activity. In the last 200 years, CO_2 levels have increased by 50%, far exceeding the natural range. To combat the effects of climate change, the United Nations Framework Convention on Climate Change was established in 1994. It pledges to 'stabilise GHG concentrations…at a level that would prevent dangerous anthropogenic interference with the climate system' and has now been signed by 198 countries globally. The Paris Agreement of 2015 defined dangerous levels as warming above 2°C, setting a global target of "preferably" 1.5°C warming compared to pre-industrial levels. Although a tangible 2°C target makes logistical sense, it is scientifically arbitrary. In reality, any temperature increase is dangerous, as the negative impacts of climate change increases with every tenth of a degree of warming.

Paths to reaching net zero

As part of the global mission not to exceed the 2°C warming limit, the UK pledged to achieve net zero GHG emissions by 2050 and instituted the Climate Change Act. This legally commits the nation to reduce its carbon emissions by 100% compared to 1990 levels. The Climate Change Commission was established to set 5-year carbon budgets for the government and suggest scenarios for how each budget could be met. Although the UK has met each budget so far, this will become increasingly difficult as budgets must become more ambitious. Approaches to reduce emissions include:

- **Reducing emissions to zero**
  This predominantly refers to reducing fossil fuel consumption, which release GHGs when burnt. In future, fossil fuel-dependent industries like transport and construction will need to be electrified, with electricity produced from renewable energy sources such as solar, wind or nuclear. In addition, sustainable energy storage technologies will need to be developed and scaled up. At present, hydrogen is the favoured green energy-storage technology, although methods of creating it without burning fossil fuels will first need to be adopted at scale, and large-scale storage will have to be allocated and tested.

- **Counteracting emissions**
  'Negative emissions' refers to the process of actively removing carbon from the atmosphere. For industries such as aviation, where reaching zero emissions is unlikely, the nation might have to rely on negative emissions to reach overall net zero. However, whilst technologies such as carbon capture and storage exist, they are not yet feasible at the scale required. Some are concerned that the government is placing too much confidence on negative emission technologies, which have not yet proved feasible, to reach net zero by 2050.

- **Cumulative emissions and attributing responsibility**
  It has been shown that any rise in the global temperature depends on the total cumulative emissions in the atmosphere. This means that every tonne of CO_2 emitted in recent centuries has equal responsibility for the negative impacts of climate change occurring in the present. Cumulative emissions are currently used to calculate the total remaining carbon budget available to stay under the 2°C warming limit. However, cumulative emissions might also be used to attribute historic and geographic responsibility for climate damages and mitigation. For example, in 2021 the UK and US were responsible for 1% and 14% of global emissions, respectively. However, since 1750 they have been responsible for 4.6% and 29% of cumulative emissions. But does it make sense to attribute responsibility to nations, fossil fuel extractors, emitters or end users?

Legal cases, whether attributing causes to losses due to extreme events, or estimating future impact of new facilities or policies, are likely to be confronted with the output of models, with differing findings. The IPCC provides an assessment of these efforts and its conclusions may be important to the courts.

Attribution: from global climate change to individual damaging events

Professor Gabi Hegerl FRS, University of Edinburgh, outlined the science behind climate change attribution. She also described how Intergovernmental Panel on Climate Change reports could be used in the courts.

Image: Professor Gabi Hegerl FRS, University of Edinburgh.

Climate change attribution refers to the process of establishing the most likely causes for changing global temperature. Climate models derived from physical principles can simulate weather and climate conditions. Such models must consider all contributing factors to climate change. These include:

- **Natural climate variabilities**
  Climate anomalies such as abnormally cold winters are influenced by climate variabilities such as wind direction.

- **Natural influences**
  This includes volcanic eruptions and changes in the sun, which can affect climate temperature.

- **Human influences**
  These include activities such as land use change, pollution and greenhouse gas emissions.

The observed climate can only be reproduced when both natural and human influences are incorporated into climate models, emphasising the major impact human activity is having on the Earth's rapidly changing temperature.

Attributing extreme event trends to human activity

Types of extreme weather events include drought, heatwaves, flooding, and tropical cyclones. The state of attribution science for changing trends in extreme events directly linked to global warming (such as heatwaves) is more certain than for trends in extreme events linked to weather patterns (such as droughts). However, it is sometimes possible to work round this. For example, whilst an increase in rainfall deficit can be difficult directly to link to human activity, compounding factors such as water deficits in soil due to hotter temperatures can.

Attributing individual extreme events to human activity

It is significantly more difficult to measure human influence on individual extreme events. Currently there are two main approaches:

- **Probabilistic approach**
  This focuses on calculating the probability of the hazard occurring in today's climate versus a pre-industrial one rather than a detailed study of how events are caused. One limitation of this approach is that the likelihoods calculated are model-dependent and current modelling limitations mean they can vary significantly.

- **Storyline approach**
  This approach is deterministic rather than probabilistic and focuses on trying to determine the driving factors in a specific event. The impact of human activities in influencing those factors is then assessed.

At present, our ability to estimate the influence of anthropogenic climate change on specific events is limited by our physical understanding of how events change, and our ability to quantify this change, and this limitation is much stronger for some event types than others. This indicates the need for technical progress in areas including modelling and the recovery of additional historical data.

Intergovernmental Panel on Climate Change (IPCC) as an authority in the courts

The only evidence for the future state of the climate are model predictions based on past and present data, and our best scientific understanding of how the climate system works. However, current models are limited in their ability to simulate small-scale or complex climate systems. As present, predictions can differ between models, and therefore could be used to contradict each other in court. In these cases, the IPCC reports could be used as an authority. They draw on scientific understanding, supported by data and modelling tools to arrive at consensus assessments of the future state of the climate. The reports are also designed to be policy relevant yet policy neutral and are endorsed by UN governments. They are thus a good reflection of the state of current science, of confidence levels, and of areas of disagreement.

> "The ability to understand the causes of extreme events depends heavily on the event type."
>
> Professor Gabi Hegerl FRS, University of Edinburgh.

Interactions between climate change and air quality in policy and science

Professor David Fowler CBE FRS, UK Centre for Ecology and Hydrology (Edinburgh Research Station), explains how air pollutants have been controlled with policy and regulation as well as how statistics can be used in litigation.

Image: Professor David Fowler CBE FRS, UK Centre for Ecology and Hydrology (Edinburgh Research Station).

"The levels of significance that we use commonly in science for testing hypotheses and analysing data to deduce quantitative links between variables appear equally useful in law."

Professor David Fowler CBE FRS, UK Centre for Ecology and Hydrology (Edinburgh Research Station).

Most air pollutants are emitted as gases. Sulphur in fuel is oxidised to form sulphur dioxide (SO_2) and sulphates which, if not neutralised, become sulphuric acid. Volatile organic compounds (VOCs) such as methane, propane, and others are generated by human activity as well as vegetation. Nitrogen oxides (NOx) are produced by combustion processes in air. Ammonia comes from agriculture, largely from the livestock industry. It has a very short lifetime in the atmosphere, ranging from a few hours to a few days. Other greenhouse gases have far greater lifetimes: methane has a 10-year lifetime, NOx a 100-year lifetime and carbon dioxide (CO_2) a lifetime spanning centuries.

Air quality in policy and regulation

Major air quality issues and fatalities in the 20th century ultimately led to new legislation. In 1956, the Clean Air Act was passed in the UK and led to the banning of coal burning in most urban areas, moving industry, including power stations, to the countryside. Over a 30-year period, concentrations of black smoke and SO_2 in major cities decreased by three quarters. However, as power stations released pollutants higher into the air to disperse far above ground level, more pollutants were being exported overseas to mainland Europe. Observations in air chemistry began to show that the air in Europe was becoming acidic and widespread lake acidification was observed in southern Scandinavia, affecting fish populations, suggested to be a result of long-range transport of sulphur from the UK, Germany and France.

A UN conference in Stockholm in 1972 discussed the human environment. This led to the establishment of the UN Economic Commission for Europe (UNECE) convention on Long Range Transboundary Air Pollution (LRTAP) in 1979, with 49 parties in the convention. It aimed to address control of emissions of sulphur, NOx, ozone (O_3), heavy metals, persistent organic compounds (POPs) and VOCs.

The EU also introduced directives on the emissions of pollutants from large combustion plants for big power stations and heavy industry. The Air Quality Framework Directives were aimed at controlling particulate matter, SO_2, NOx, O_3, VOCs and carbon monoxide (CO). The science is assimilated into chemical transport models which allow identification of the pollutants exported from one country to another. The European Environment Agency coordinated the monitoring and modelling to support the directives implemented.

Comparing UK data on emissions of air pollutants from 1970 to 2016 shows much improvement. Emissions of sulphur have declined by two orders of magnitude and other pollutants have decreased by at least two thirds. Ammonia is the only pollutant not controlled effectively by most countries in Europe.

Air quality and climate change

Emissions of pollutants and greenhouse gases affecting climate change and air quality derive from the same sources. Net-zero initiatives to tackle climate change overall led to cleaner air although some routes have negative effects. For example, some trees emit high levels of VOCs, in particular isoprene, a precursor to O_3. This could lead to reforestation activities having an adverse effect on some emission levels. Hydrogen has the potential to be a useful fuel for a net-zero future but also produces NOx when burned.

Litigation case study

In a legal case brought against an oil burning power station using Orimulsion (an emulsion of sulphuric acid and water), the claimants (nearby landowners) alleged that pollution from the power station resulted over five-years in sustained crop damage in the surrounding farmland. Their statistical analysis demonstrated the probability of the damage being due to contamination from the power station's activities.

‘What did the law do in the climate crisis, Daddy?’ – Market perspectives on climate change

The Lord Mayor, Alderman Professor Michael Mainelli, discussed the current state of carbon markets. He also described economic mechanisms that could incentivise green investment.

Image: The Lord Mayor, Alderman Professor Michael Mainelli.

> “The climate debate ends with the question: ‘does society really want to pay the cost?’”
>
> The Lord Mayor, Alderman Professor Michael Mainelli.

Awareness of the societal need to reduce carbon emissions is not compelling enough on its own to effect large-scale change. Increasing market price is a known, effective driver of consumer behaviour. This was exemplified in 2011, when miles driven in America dropped a record 4% per capita alongside a 32% increase in oil prices.

The true cost of carbon should be calculated and incorporated into market valuations to drive a reduction in consumption and encourage investment into non-fossil fuels. However, some audit mechanisms designed to encourage divestment, such as Environmental Social Governance (ESG) standards, risk inciting confusion and establishing a separate carbon currency independent of monetary terms. In fact, one MIT review found that, depending on the ESG rating algorithm used, a company’s ESG ‘score’ could be in the 95th percentile of one algorithm while simultaneously in the 20th percentile of another. Internalising the cost of carbon into existing markets, and treating carbon like a regular commodity, might decrease confusion and advance progress towards net zero.

The carbon market

The cap-and-trade emissions trading scheme was established in 1992 to combat sulphur oxide (SOx) and nitrogen oxide (NOx) emissions. Within four years, SOx and NOx emissions halved, demonstrating that emissions markets can be effective mechanisms for change. Therefore, in 1997, COP3 agreed to create a similar cap-and-trade emissions trading scheme for carbon. A carbon market works by setting a gradually dwindling limit on the total carbon emissions permitted by all market participants. This incrementally lowers the competitiveness of fossil fuels and accelerates investments into alternative energy sources like solar and wind. But an effective carbon market requires correct pricing. It must also issue the correct number of carbon permits such that supply doesn’t exceed demand, causing the price of carbon to plummet. Governments must also be prepared to pay the price of change. The Stern Review calculated the cost of necessary climate action as 2% of global GDP annually. In the UK, this is equivalent to £800 per citizen. Equivalently, this is a saving of 10 tonnes of emissions per citizen per year where the cost per tonne is £80.

Currently, major expectations are on voluntary carbon markets to drive the necessary change. However, in 2022, the value of voluntary carbon offsets traded was roughly £2 billion, whilst the value of the traded global markets for carbon permits grew to £835 billion. This signifies the vital role of global compliance markets in reaching net zero.

Stabilising the carbon market

Traditional economic levers such as regulation, standards, bans, taxes and awareness all play a role in implementing a successful carbon market to reduce carbon emissions. However, mechanisms must also stabilise and de-risk the market. Vital to this is ensuring that government policies are long-term and consistent. Given the rise in climate litigation globally, legally binding carbon targets appear insufficient incentives for governments to abide by their climate commitments. Meanwhile, direct capital incentives have a proven ability to drive market change and could be better harnessed to achieve net zero emissions targets. Economic mechanisms that could help to incentivise green investment include:

- **Outcome-based green bonds**
  These are sustainability-linked bonds paying a higher interest rate if the corporate or sovereign does not meet its outcome targets. Unlike standard green bonds, the terms of issuance do not stipulate the bond's spending strategy, only its target, thereby allowing greater freedom and growth towards green outcomes.

- **Policy-linked sovereign bonds/ bond-cuffs**
  A significant deterrent to investing in green technologies is the short-termism exhibited by governments in net zero policies. Their constantly changing approaches result in an unstable market where investors feel that matching GDP growth and investing in fossil fuel alternatives are at odds. Investors currently deal with this by using fossil fuel as a hedge for renewables. To encourage investment away from fossil fuels, government could offer policy-linked performance bonds as an alternative hedge. By tying policy-performance to sovereign green bonds, governments economically 'cuff' themselves to abide by their net zero commitments. In the face of economic penalty, the participating government might be more incentivised to make net zero a policy priority, thereby stabilising the carbon market and encouraging investment. Policy-linked sovereign bonds have had demonstrable success in Chile and Uruguay already.

PANEL DISCUSSION

The science and economics of climate change

Mr Justice Ian Dove, Judge of the High Court of England and Wales, chaired a discussion on the legal implications of climate change. Panellists included: Professor David Fowler CBE FRS, Centre for Ecology and Hydrology; Professor Gabi Hegerl FRS, University of Edinburgh; Professor Michael Mainelli, Z/Yen Group and City of London Corporation; His Honour Judge Thomas Teague KC, Chief Coroner of England and Wales; and Professor Eric Wolff FRS, University of Cambridge.

Image: (left to right): Lord Mayor, Alderman Professor Michael Mainelli; His Honour Judge Thomas Teague KC, Chief Coroner of England and Wales; Professor David Fowler CBE FRS, UK Centre for Ecology and Hydrology; Professor Gabi Hegerl FRS, University of Edinburgh; Professor Eric Wolff FRS, University of Cambridge; and Mr Justice Ian Dove, Judge of the High Court of England and Wales.

The Chairman set the scene by noting that climate litigation can be brought against governments, planning authorities, companies or individuals. Common litigation challenges include:

1. Challenges relating to statutory infrastructure. In the context of the UK, there is a comprehensive statutory architecture provided by the Climate Change Act 2008 and reinforced by the work of the Climate Change Committee (CCC). The CCC is required to produce carbon budgets reported to the government and giving rise to further policy. It is in the context of those reports and that policy that public law courts become involved.
2. Challenges to individual decisions on the basis of public law principles: For example, in 2023, in a case against the UK government's decision to approve $1.15 billion of financing for a mega gas project in Mozambique claimants argued that the funding was incompatible with the Paris Climate Agreement. So far, there have been no challenges in public law citing public nuisance as a legal avenue for attribution litigation.

3. Challenges to individual decisions based on environmental regulations. Challenges have been brought relating to how far the responsibility of projects should extend when assessing the greenhouse gas emissions attributed to them. For example, a case in the Irish supreme court in 2022 argued that a cheese factory's environmental impact assessment should include the methane emissions from cows.
4. Challenges relating to human rights. The English and the Welsh jurisdictions, for example, faced challenges based on Human Rights Articles 2, 3 and 8, but dismissed them on the basis they are not engaged or infringed. Recent cases in the European Courts of Human Rights have the potential to be authoritative.
5. Challenges relating to air quality. Public health litigation relating to air quality raises similar questions about attribution to those relating to green house gas emissions. So far, these have been raised in the context of inquests in the UK.

Learnings from these litigation challenges show that demonstrating causation and quantifying attribution with confidence is a matter for science. Relatedly, developing smart policies and economic mechanisms designed to be effective to achieve net zero emissions targets is the responsibility of scientists, economists and politicians. The law is an enforcement mechanism rather than a means to make change.

The panel discussed several topics related to climate change litigation, including:

The relationship between policymakers and the judiciary

- The duty of the policymaker is to establish legal standards, whilst the role of the judge is to uphold the laws defined by policymakers.
- Issues arise when policies and regulations set by politicians and scrutinised by judges are inconsistent across jurisdictions. As judges are confined by jurisdiction, where possible standards should be consistent nationally and internationally.

The balance of probabilities: statistical vs legal probability

- It is important not to confuse statistical probability with the balance of probability.
- Whilst a judge might consider statistically based evidence, the ultimate decision depends on the totality of the evidence. The key question for a judge is whether the case for saying that a factual proposition is correct is, on balance, stronger than for saying it is not.

Tipping points in legal attribution

- Barring heat events impossible in a pre-industrial world, extreme weather events have always been influenced by weather conditions. Therefore, it is highly unlikely that extreme weather events will ever be entirely attributable to human activity.
- Where extreme weather events can be partially attributed to human activity, approaches to identifying who is at fault and therefore legally responsible for damages are inconsistent.

The role of the coroner

- A coroner in the UK is a judge who exercises an inquisitorial jurisdiction investigating deaths which are unnatural, violent, unexplained or occurred in state custody.
- Importantly, coroners are precluded from appearing to assign civil or criminal liability on the part of a named person.
- It can be expected that coroners will increasingly investigate deaths resulting from extreme weather events due to climate change.
- The scope of a coroner is tightly defined by stature, strictly limited to answering the questions: 'Who was the deceased? When, where and how did they die?'
- In most cases, 'how' is taken to mean the direct means (for example, heat stroke), without including the wider circumstances (such as ruling that the heat wave causing the heat stroke was itself attributable to climate change).
- In 2021, the UK saw an unusual inquest into the death of a young girl who died of asthma-related respiratory failure. The family obtained an independent expert report which presented robust evidence that exposure to atmospheric pollution contributed to the fatal asthma attack. This evidence was incorporated into the final decision on cause of death.
- However, in most cases it would not be consistent with a coroner's statutory role to seek further evidence of this nature. Had the family not obtained an independent report, 'air pollution' would not have been listed as a cause of death alongside 'asthma'.

Overpopulation

- Many environmental problems are linked to overpopulation.
- The carbon footprint of an average individual in the Global South is much smaller than in the Global North. This must be accounted for when ascribing responsibility for climate change.

Next steps

- Methane is one of ten primary greenhouse gases and contributes significantly to global warming. It also has a relatively short lifetime. After approximately 12 years, most emitted methane has reacted with ozone to form carbon dioxide and water.
- Controlling methane emissions in the short term could be an attractive and relatively effective means of achieving 2050 climate goals and getting a faster return on investment.
- There is a need to work across siloes (ie science and government) and geographies (ie local and global) to achieve meaningful change in mitigating and adapting to climate change.

> "Lawyers are the last resort; we are in the rearguard, not the vanguard"
>
> Mr Justice Ian Dove, Judge of the High Court of England and Wales.

Closing keynote

In his closing keynote, Dr Vinton Cerf FRS, Google, summarised his key learnings from the conference.

Image: Dr Vinton Cerf FRS, Google.

"Science teaches causality. It teaches us how the world works. We clearly want the available science to inform judicial decisions. Science, however, is not absolute."

Dr Vinton Cerf FRS, Google.

The role of science in the law

Jurisprudence seeks a considered decision based on a standard set of laws and informed by current science. Science identifies causality and explains how the world works, both essential to good judicial decisions.

Science is also needed in the courts reliably to attribute actions to parties. As emerging areas of science appear in court, accompanying attribution models must be developed. For example, in future it might be necessary to determine to what extent a brain implant can influence the actions and emotions of an individual.

Difference between science and law

Whilst both disciplines seek the truth, their differing approach to 'truth' can impose constraints on their functioning relationship. Whilst science regards truth as an evolving pursuit, the law considers it absolute. The practice of law is the delivery of justice in accordance with a set of adopted rules. The law does not generally seek to change itself or deviate from conventionally accepted guidelines, but rather adhere to the legislation imposed upon it. However, the principle of *stare decisis* often finds itself contending with evolving precedents of case law and reinterpretation of established law.

Progress in science is driven by change. Scientists seek to challenge the status quo by pushing the boundaries of current theories and modifying them accordingly. Therefore, if the accepted science which informed a legal decision does change, then an effective framework must enable the law to re-assess its previous decisions based on the new 'best science'. Associated with this, maximum transparency relating to how data is handled, how scientific analysis is done, and whose opinions are incorporated into a legal decision is crucial not only for delivering justice, but also for re-examining a challenged legal decision.

The approach to scientific evidence in the court

One distinction between the UK and US approach to scientific evidence is that in the UK experts are responsible to the courts rather than the litigants. Arguably, this mitigates against ulterior motives, and supports the objective presentation of science.

Implementing universally accepted standards for how evidence should be collected, processed and evaluated could address existing uncertainties around the best use and treatment of scientific evidence in courts. It might also help to clarify uncertainty around the science required to indicate the value of evidence, what incentives drive scientific testimony and what qualifies scientific evidence as admissible.

Common misunderstandings about scientific evidence include:

- **Plausibility does not imply certainty**
  The value of an argument is not determined by its plausibility, as there may be multiple plausible explanations for a set of facts.

- **Precision does not necessarily indicate accuracy**
  Precision refers to the reproducibility of a given set of measurements, whilst accuracy refers to how close those measurements are to the true value. Over-precision can attach undue weight to testimony.

- **Correlation is not causation**
  Large language models can recognize patterns in input and output data to generate a statistical view of correlation. However, the law should be careful not to extract erroneous conclusions from implied correlations.

- **Confidence does not guarantee reliability**
  Jurors should not accept evidence on the basis of how it is presented rather than on why it makes sense. Promising credentials, or a confident delivery of an expert testimony, does not guarantee that the content is reliable. Tangentially, this also applies to large language models, which can appear confident even when wrong.

Future considerations

- There is some uncertainty around the potential impact of emerging technologies, such as large language models, on the judicial system and wider society. However, it is worth remembering that technology can improve agency and justice and is not just a potential threat to be mitigated.

- The preservation of evidence is vital to justice. However, increasing use of digital evidence raises concerns about its long-term preservation, integrity and provenance. It is not clear for how long a piece of digital evidence will be accessible. Therefore, measures must ensure that digital evidence is preserved in such a way that it can be re-examined if necessary.

Conclusion

This meeting brought together leading scientists and prominent members of the legal community from the UK and USA to explore approaches by courts in their consideration, evaluation, and management of scientific evidence and expert witnesses.

Image: Professor Dame Sue Black DBE FRSE, The Baroness Black of Strome, Lancaster, UK.

The conference considered scientific evidence which appears in court today as well as emerging areas of science, including neuroscience, human enhancement, and climate change attribution, which might appear in the courts in the coming years.

The conference formed part of the respective Science and the Law programmes at the National Academy of Sciences and the Royal Society.

Key themes from the *Science in the Interests of Justice* meeting include:

Receipt, control and consideration of expert evidence

- The focus of the judicial inquiry should be on the validity of the science itself, and any inquiry into validity must assess the means of overcoming uncertainty and bias. Valid science will be replicable and can be corroborated by others as a means of obtaining a consensus.
- Determining which expert is better qualified (particularly in the US justice system) is challenging as some aspects of experts' qualifications might indicate outstanding achievements unrelated to the issues in the case. Perhaps the expert with a shorter list of qualifications will be more familiar with the issues which are the source of the dispute. Similarly, charisma and eloquence can be seductive qualities but unrelated to the proficiency of the expert.
- Judges typically care about assessing the state of the science in a snapshot in time in the context of a single case. The result is a short timeline for judges focused on resolving the case and allowing the parties to move on. By contrast, scientists can postpone a decision, continue to collect information through additional experiments and might choose to revisit and refine an earlier decision.

Medicine, human augmentation and neuroscience

- It is important not to treat new methods for augmentation and enhancement as completely novel. Humans have been augmenting and enhancing themselves for thousands of years, for instance with coffee, eye wear, alcohol and drugs. New technologies should be viewed within the context of frameworks which already exist.
- Quality of life and wellbeing should be central to discussions about the manipulations and modifications involved in human enhancement.
- There are many cases of miscarriages of justice arising from flawed evidence as a result of inappropriate, biased lines of questioning. It would therefore be useful to create guidelines, training and education for those involved in law enforcement and for prosecutors on how memory can become contaminated and how to interact with suspects or witnesses in order to avoid it.

Image: Mr Justice Mark Wall, High Court Judge of England and Wales.

The science of climate change

- The duty of the policymaker is to establish legal standards, while the role of the judge is to uphold the laws defined by policymakers. Issues arise when the policies and regulations set by policymakers and scrutinised by judges are inconsistent across jurisdictions.
- Extreme weather events have always been influenced by weather conditions. Therefore, it is highly unlikely that extreme weather events will ever be entirely legally attributable to human activity alone.
- There is a need to work across siloes (ie science, government, and culture) and geographies (ie local and global) to achieve meaningful change in mitigating and adapting to climate change.

The Royal Society is a self-governing Fellowship of many of the world's most distinguished scientists drawn from all areas of science, engineering, and medicine. The Society's fundamental purpose, as it has been since its foundation in 1660, is to recognise, promote, and support excellence in science and to encourage the development and use of science for the benefit of humanity.

The Society's strategic priorities emphasise its commitment to the highest quality science, to curiosity-driven research, and to the development and use of science for the benefit of society. These priorities are:

- The Fellowship, Foreign Membership and beyond
- Influencing
- Research system and culture
- Science and society
- Corporate and governance

For further information
The Royal Society
6 – 9 Carlton House Terrace
London SW1Y 5AG

T +44 20 7451 2500
W royalsociety.org

Registered Charity No 207043

Cover Image: ©iStock.com / atlantis1986.

Issued: September 2024 DES8367_5