Neuroforensics

Exploring the Legal Implications of Emerging Neurotechnologies

PROCEEDINGS OF A WORKSHOP

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Forum on Neuroscience and Nervous System Disorders

Board on Health Sciences Policy

Health and Medicine Division

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Although the reviewers listed above provided many constructive comments and suggestions, they were not asked to endorse the content of the proceedings nor did they see the final draft before its release. The review of this proceedings was overseen by **ELI Y. ADASHI,** Brown University. He was responsible for making certain that an independent examination of this proceedings was carried out in accordance with standards of the National Academies and that all review comments were carefully considered. Responsibility for the final content rests entirely with the rapporteurs and the National Academies.

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Introduction and Background[1]

There is enormous potential for neuroscience to affect the law, according to Hank Greely, the Deane F. and Kate Edelman Johnson Professor of Law at Stanford University. The law is interested in both bodies and minds, he said—what people do, of course, but also why they did those things, what they were thinking about at the time, and what their intent was. Neuroscience provides possible new lines of evidence to illuminate these inner aspects of behaviors. Greely added that the law may also want to protect against the use of neuroscience techniques to invade privacy.

Although Greely called neuroscience "not ready for prime time" when it comes to the law, he noted that it has been invoked in many cases in the U.S. court system, for example, through neuroimaging of a criminal defendant's brain. Given that neuroscience has the potential to play an even greater role, he said the legal system will have to determine how best to bring this into play. With this in mind, the National Academies of Sciences, Engineering, and Medicine's Forum on Neuroscience and Nervous System Disorders, in collaboration with the Committee on Science, Technology, and Law (CSTL), hosted a public workshop on March 6, 2018. The workshop brought together stakeholders from neuroscience and legal communities in both the United States and the United Kingdom to explore the current uses of neuroscience, with a particular focus on neuroimaging technologies, in legal settings as well as the implications of potentially expanded use of these technologies in the future.

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[1]The planning committee's role was limited to planning the workshop, and the Proceedings of a Workshop was prepared by the workshop rapporteurs as a factual summary of what occurred at the workshop. Statements, recommendations, and opinions expressed are those of individual presenters and participants and have not been endorsed or verified by the National Academies of Sciences, Engineering, and Medicine. They should not be construed as reflecting any group consensus.

THE EMERGING USE OF NEUROTECHNOLOGIES IN THE LEGAL SYSTEM

Greely said that discussions about the intersection between neuroscience and the law began decades ago and intensified in 2002 with several meetings on neuroethics (Roskies, 2002). In 2007, the John D. and Catherine T. MacArthur Foundation launched the MacArthur Foundation Research Network on Law and Neuroscience, which supported interdisciplinary collaborative research, hosted many conferences, and published dozens of papers, books, and databases.[2]

Joshua Sanes, Jeff C. Tarr Professor of Molecular and Cellular Biology and Paul J. Finnegan Family Director of the Center for Brain Science at Harvard University, said neuroscience is permeating the legal system and that neuroscience evidence is being introduced at an increasingly rapid rate. Originally used mostly in death penalty cases, Sanes said it has extended to cases involving drugs, assault, burglary, child abuse, rape, fraud, theft, and kidnapping. Nita Farahany, professor of law and philosophy at the Duke University School of Law, has been tracking attempts to introduce neuroscience evidence into legal proceedings. Her study of cases adjudicated between 2005 and 2012 identified nearly 1,600 cases in which neurobiological evidence was used to bolster criminal defense arguments, and Farahany said these numbers are increasing each year. Neuroscientific evidence is introduced frequently in pretrial and sentencing proceedings to assess competency but has been less helpful in judging guilt, she said (Farahany, 2015).

Neuroscience has also begun to play an increasingly important role in making policy, particularly where the law is unclear or ambiguous, said Greely. Patti Saris, chief judge of the U.S. District Court for the District of Massachusetts, said that in several cases over the past decade, the U.S. Supreme Court prohibited the death penalty or mandatory life without parole for juvenile offenders under the age of 18, based in part on neuroscientific evidence that an immature brain renders these offenders less culpable than older individuals, and they may have better prospects in rehabilitation[3] (Drinan, 2016). Youthful offenders are now sometimes defined as those age 25 or younger, said Judge Saris, who recently completed a 6-year term chairing the federal Sentencing Commission. Yet, while a growing body of evidence suggests that people may not gain full reasoning

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[2]For more information, go to http://www.lawneuro.org (accessed April 26, 2018).

[3]*Roper v. Simmons*, 543 U.S. 551 (2005); *Graham v. Florida*, 560 U.S. 48 (2010); *Miller v. Alabama*, 567 U.S. 460 (2012).

skills until age 25, recidivism statistics suggest that younger offenders may recidivate at a much higher rate, most commonly for drug trafficking, said Judge Saris.

Judges frequently must rule on the admissibility of neuroscientific expert testimony in individual cases to determine whether a defendant is competent or had the requisite intent to commit the crime, said Judge Saris. Neuroscientific evidence is also being used more often by the courts and by probation officers to understand drug addiction, she said. Judge Saris added that in recent years, neuroforensics has also become important for the training of state and federal judges, although the early and strong message to judges from scientists was that it is too soon to use neuroimaging as a reliable method for assessing culpability or competency.

EXPLORING THE FUTURE OF NEUROFORENSICS

Greely said the neuroforensics field was pushed to the forefront by the emergence of functional magnetic resonance imaging (fMRI), which enabled seeing inside the brains of healthy people without harming them, and then correlating what was seen in the physical brain with the subjective mental state. The science is now maturing due to increased global investments in brain science and technology development, said Steven Hyman, director of the Stanley Center for Psychiatric Research at the Broad Institute of the Massachusetts Institute of Technology (MIT) and Harvard University. These initiatives are focused largely on tool building and increasingly on applications in animal as well as human models, said Hyman. For example, in the United States, the Brain Research through Advancing Innovative Technologies (BRAIN) Initiative includes participation by the Defense Advanced Research Projects Agency (DARPA) on projects using invasive technologies to repair the brains of soldiers injured in recent wars, as well as civilian populations with traumatic brain injuries. Research is also being performed on brain–computer interfaces that permit paralyzed individuals to control devices, including prosthetics, with their thoughts.

Khara Ramos, senior science policy analyst at the National Institute of Neurological Disorders and Stroke, said the BRAIN Initiative is focusing on brain circuits. By building better tools to record and modulate activity in brain circuits and detect abnormalities in brain function, novel ways to diagnose and treat brain diseases are likely to emerge, she added. In terms of understanding neural circuits and producing dynamic pictures of brain function, the BRAIN Initiative is funding efforts to improve large-scale monitoring of neural activity by recording from large ensembles of neurons in real time, said Ramos. They are also funding research in new imaging technologies and both invasive and non-invasive neuromodulation modalities. While many of these emerging technologies are currently confined to animal studies, a few participants noted that successful demonstration of their use may serve as an impetus for researchers in academia and industry to modify them in the future for use in humans.

Joshua Buckholtz, associate professor of psychology at Harvard University, added that neuroscience has developed at a pace that could scarcely be imagined in the early 1940s when Stephen Kuffler first described synaptic transmission (Kuffler, 1942). In recent years, the emergence of the new subdiscipline of cognitive neuroscience has harnessed an array of ingenious technologies and sophisticated tools such as fMRI, shedding light on the black box of the human mind. Yet, science moves much faster than policy making, and nowhere is this more evident than in the courts, said Buckholtz. The potential impact of these technologies on legal cases raises both hopes and fears, based on speculation that brain imaging holds the promise of detecting liars, determining criminal responsibility, quantifying pain and suffering, and predicting violence, he said. But Hyman cautioned that the use of these technologies raises important ethical questions about agency, responsibility, memory, and invasion of privacy, among others.

Throughout the workshop, participants raised an array of challenges that limit the translation of neuroscience research to the courtroom (see Box 1-1 for an overview of those limitations and subsequent chapters for additional detail).

BOX 1-1
Some Limitations to Translating Neuroscience Research to the Legal System

- The language used in the legal system is incompatible with measurements in neuroscience (Buckholtz and Faigman).
- Neuroscientific research mostly consists of statistical and probabilistic information and presenting this type of evidence in court will remain a challenge given the need for courts to make categorical decisions (Faigman).

- Science focuses on aggregating data across groups of individuals to make general references; however, in law, the specific individual is the focus. This group to individual problem (G2i) can bolster or weaken the case of an individual (Faigman and Sanes).
- Reverse inference—i.e., using neuroimaging data to determine what cognitive process or behavior is occurring—can lead to inaccurate conclusions given the complexity of neural networks involved in any given behavior (e.g., one specific network might not be the only one activated when a person is lying) (Buckholtz).
- Complex behaviors involve different patterns of brain activity, can differ due to individual characteristics and experiences (e.g., childhood trauma), and may involve brain regions that are difficult to measure (Buckholtz, Gallant, and Hoffman).
- Given that there are multiple contributing factors to behavior (genetics, environment, etc.), it is difficult to robustly replicate studies exploring the association of genetics and behavior (Neale).
- There is a lack of diversity in genome-wide association studies (GWASs), which have primarily been conducted in populations of European ancestry (Neale).
- Circumstantial and ecological validity—i.e., the extent to which the research findings are generalizable to settings outside the laboratory—limits the reliability of neuroscientific measures of deception (Buckholtz).
- Neuroscientific data might help better understand and test predictive systems (e.g., recidivism); however, these data are not commonly collected (e.g., Aharoni et al., 2013) (Buckholtz).
- Some non-invasive neuroimaging technologies lack precision, accuracy, and temporal and spatial resolution to be used reliably in a legal setting (Gallant).
- While modern machine learning methods have allowed researchers to make fairly complicated and detailed maps that illustrate what kinds of information are encoded where in the brain and to create decoding models, it is limited to the accuracy and quality of brain activity measurements (Gallant).
- Additional testing for sensitivity, specificity, and generalizability is needed for brain signatures in the development of biomarkers for pain (Wager).
- Some neurotechnologies (e.g., deep brain stimulation) may have side effects, such as the disruption of working memory, which might affect a person's ability to provide a truthful testimony (Gunduz).

NOTE: These points were made by the individual speakers identified above; they are not intended to reflect a consensus among workshop participants.

WORKSHOP OBJECTIVES

The workshop was intended to advance an understanding of neurotechnologies that could impact the legal system and the state of readiness to consider these technologies and, where appropriate, to integrate them into the legal system, said Hyman. By engaging an interdisciplinary group of scientists, clinicians, jurists, and legal scholars, the workshop aimed to assess, in a coordinated and proactive manner, how best to integrate neuroscientific evidence into legal practice, said Buckholtz. The use of neuroscientific evidence to make legal determinations about minds and brains always needs to be constrained by the limits of scientific inference, he said, and resolving inferential issues that lie at the intersection of law and neuroscience will be required to fulfill the promise of neuroscience with respect to the law. Sanes added that the workshop could provide an opportunity to get ahead of the curve with some of the more innovative technologies, preventing the inappropriate use of these technologies in legal settings. Judge Saris proposed that the workshop could serve as a first step toward the development of a consensus report that would outline best practices—as accepted by the scientific community—regarding the use of these technologies. Such a consensus report would help judges and policy makers understand the reliability of current neuroscientific methods. See Box 1-2 for the Statement of Task for the workshop.

BOX 1-2
Statement of Task

An ad hoc committee will plan and conduct a 1-day public workshop that will bring together key stakeholders from academia, the legal community, government and regulatory agencies, industry, and nonprofit organizations to explore and advance efforts to identify and evaluate the potential effects of emerging neurotechnologies on the legal system.

- Provide an overview of current state-of-the-art neurotechnologies, and the use and impact of neuroscience evidence in the legal system.

- Explore emerging neurotechnologies—including methods for observing or affecting the central nervous system and the genetics of cognition and behavior—and their potential implications and use by law enforcement, the courts, regulatory agencies, and others (e.g., pain and lie detection).
- Consider the potential use of large databases created from research and clinical initiatives (e.g., Human Connectome Project, BRAIN Initiative, and large genetics databases) by the legal system.
- Discuss the ethical and societal considerations associated with the use of neuroscience evidence in criminal, administrative, and other judicial proceedings.
- Highlight topics at the nexus of emerging neurotechnologies and the law for further study, such as potential opportunities for developing standards for using evidence from emerging neurotechnologies in the legal system and identifying potential stakeholders across sectors that may be impacted by this multidisciplinary area.

The committee will develop the agenda for the workshop, select and invite speakers and discussants, and moderate the discussions. A proceedings of the presentations and discussions at the workshop will be prepared by a designated rapporteur in accordance with institutional guidelines.

ORGANIZATION OF THE PROCEEDINGS

Chapter 2 summarizes how neurotechnologies and neuroscience currently may produce different levels of evidence for use in legal settings, despite questions about the validity of that evidence. Chapter 3 peeks into the future, exploring emerging technologies that may potentially reveal even more detailed and complex information about human behavior to be used in court. In Chapter 4, judges and legal scholars weigh in with a discussion of how to establish frameworks and standards for using neuroscience evidence, both now and in anticipation of new neurotechnologies on the horizon. Chapter 5 concludes with some thoughts about remaining areas needing exploration and potential next steps to move the field forward.

2

Use of Neurotechnologies and Neuroscience in Legal Settings: Case Studies

Highlights

- Existing and emerging neurotechnologies that assess brain structure, neural activity and connectivity, molecular composition, and genomic variation may provide evidence of mental status and other capabilities (Sanes).
- Currently there is no coherent mapping between the legal and neuroscientific constructs of mental states and behaviors (Buckholtz).
- Using scientific evidence to detect deception is complicated by the complex factors that contribute to lying, as well as by group-to-individual (G2i) problems; scientific studies aggregate data to make generalized inferences, but the law requires information on individual cases (Buckholtz).
- Electroencephalography (EEG), magnetoencephalography (MEG), functional magnetic resonance imaging (fMRI), and neurologic pain signatures that incorporate multiple measures provide potential objective biomarkers of pain that have been introduced in court despite unclear criteria for establishing their sensitivity, specificity, and generalizability (Wager).
- Using patterns of neural activation detected with fMRI or EEG, scientists have been able to decode or "read" conscious and unconscious information from the brain, which may be useful for detecting deception, emotional state, and other mental processes, or for recovering memory (Gallant and Nestor).
- Using data from extremely large genetic studies may enable the creation of genetic risk predictors for behaviors associated with criminal behavior or violence, although genes alone will likely never be enough to fully explain such complex behaviors (Neale).

NOTE: These points were made by the individual speakers identified above; they are not intended to reflect a consensus among workshop participants.

Neurotechnologies, both old and new, are making it possible to introduce neuroscientific evidence into the legal system, including in the courtroom and for administrative decisions, said Joshua Sanes. This chapter provides a snapshot of how neuroimaging technologies, among others, have been used to detect deception, identify pain, and decode neuronal activity in the brain, and discusses the contributing role of genetics to predict human behavior and decision making.

STATE OF THE ART OF TECHNOLOGIES RELEVANT TO THE LEGAL SYSTEM

Riding a wave of expanded interest in the development of neuroscience technology, the BRAIN Initiative and other international projects have generated technologies that enable peering into the living human brain to look for evidence of mental status and other capabilities, said Sanes. These technologies include measures of structure, neural activity and connectivity, molecular composition, and genomic variation. The explosion in their capabilities has been facilitated by increased computational ability, artificial intelligence, machine learning, and the development of large databases, he added.

These technologies may, in the future, have the potential to enable prediction of the dangerousness of individuals or their likelihood to recidivate, assess volition and intent, determine competence to stand trial, reveal biological mitigating factors that might explain criminal behavior, distinguish chronic pain from malingering, recover lost memories, or distinguish between real and false recovered memories, said Sanes. They also offer the potential to optimize treatment and reduce recidivism, he added. Sanes predicted that advances in technology will be rapid and shocking—not necessarily more reliable, but more compelling.

Yet, Joshua Buckholtz suggested that the overlap is relatively small in regard to what the law wants neuroscience to do or thinks neuroscience could do better than what is done now; what people, including some scientists, have claimed neuroscience can do; and what neuroscience can actually do, now or in the future. Moreover, he said, no one knows what falls into that intersection because no systematic evaluation of the overlap has been conducted; thus, there has been no consensus framework for aligning legal goals, social expectations, and neuroscientific methods.

To create such a framework, Buckholtz cited three domains of engagement among neuroscience and law: revealing mental states, determining the capacity for self-control, and predicting future behavior. In each of these domains, brain imaging offers some promise, although Buckholtz cautioned that expectations should be modest. Mental states that might be elucidated by brain imaging techniques such as fMRI could enable identifying levels of intent, demonstrating bias in a witness or juror, quantifying suffering, or detecting lies, said Buckholtz. The use of fMRI to detect deception is discussed in greater detail below.

At the intersection of law and neuroscience, the capacity for self-control involves three elements: (1) measuring maturity, (2) detecting impairments, and (3) validating the presence of legally relevant disease states, said Buckholtz. Neuroscientific evidence in this domain is typically aimed at reducing responsibility by introducing biology as a mitigating factor, he said, but there has been no coherent mapping between the legal and scientific constructs of self-control (see Figure 2-1). To explain the gap between the legal and scientific constructs, Buckholtz offered a hypothetical example of a man charged with a violent crime who performs poorly on tests that measure response inhibition, action cancellation, impulsive choice, and intentional control. But to conclude that performance on these tests reflects a mental defect that caused a substantial inability for a man to conform his behavior to requirements of the law is impossible at this time because the law's language is incompatible with measurements of neuroscience, said Buckholtz. To a cognitive neuroscientist, constructs like volitional capacity or irresistible impulse are meaningless, said Buckholtz; conversely, standard cognitive neuroscience terms such as "action cancellation" and "response inhibition" mean nothing to people making legal policy. If policy makers want to take advantage of neuroscientific knowledge, they need to engage in some hard thinking about whether any of the self-control domains that neuroscientists can access affect legal liability, he said.

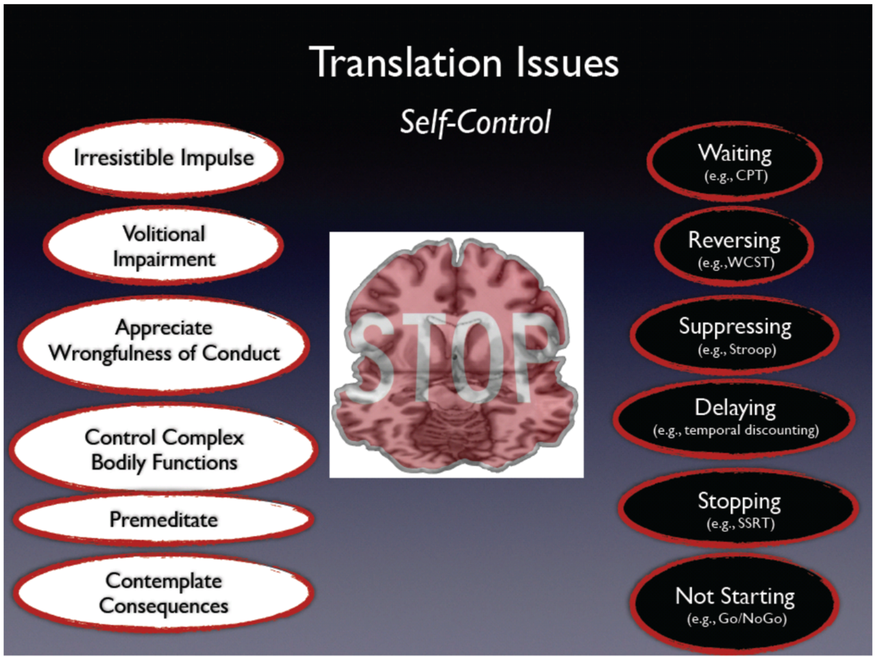

FIGURE 2-1 Mapping legal and scientific constructs of self-control. Legal concepts that pertain to self-control on the left have not been mapped in a coherent way onto a specific mental process that can be assessed by performance on neuropsychological tests on the right.
NOTE: CPT = continuous performance task; SSRT = stop-signal reaction time; WCST = Wisconsin Card Sorting Test.
SOURCE: Presented by Buckholtz, March 6, 2018.

Predicting future behavior such as violence risk—for example, genetic studies have shown links between certain genotypes and violent behavior (Tiihonen et al., 2015)—is particularly fraught, with a high potential for misuse of science to determine treatment response in parole and civil commitment hearings, said Buckholtz.

DETECTING DECEPTION WITH NEUROIMAGING

Lie detection using a polygraph, which is generally not admissible in court, is a neuroscience technology that looks at the autonomic nervous system to deduce whether a person is telling the truth or lying, said Sanes. Original lie detection technologies relied on assessment of the peripheral measures of autonomic (sympathetic and parasympathetic) activity such as skin conductance, pulse, and breathing rate. Newer technologies assess central nervous system activity and are therefore more powerful, he said, yet still have significant inferential issues.

For example, science focuses on aggregating data across groups of individuals to make generalized inferences; whereas, the law focuses on making a determination about one specific individual. This problem—known as group to individual or G2i—is discussed in more detail in Chapter 4. According to Buckholtz, group or population-level data are only relevant to the law to the extent that they bolster or weaken the evidence provided in an individual case. For example, he described a hypothetical study using fMRI to compare the brain activity of people lying versus telling the truth about a set of facts. If the differences are statistically significant, they can be used to make a generalizable universal inference about lying. One example might be that lying recruits a network involving specific brain regions. However, for some people, brain activity in that region stays the same or is even lower in the lying condition. Relying on this brain-based measure thus can lead to erroneous conclusions, said Buckholtz (Buckholtz and Faigman, 2014).

He added that reverse inference can lead to equally erroneous conclusions. Reverse inference relies on the following logic: If X brain network is activated during some psychological state or behavior Y, one might infer that whenever network X is active, that state or behavior must be occurring. However, even though it might be possible to identify a brain network that is reliably activated when a person is lying, one cannot assume that this network is activated *only* when the person is lying.

Another problem with detecting lies is that deception is not unitary. Complex behaviors such as lying have complex causes and, because motivation varies depending on circumstances, different instances of lying likely involve different patterns of brain activity, said Buckholtz. Ecological validity also limits the reliability of neuroscientific measures of deception, he said. For example, lying under stressful conditions such as a police interrogation is very different from lying in the sterile environment of the scanner.

Stuart Hoffman, senior scientific advisor for brain injury at the Department of Veterans Affairs, added that among incarcerated felons, there is also a high rate of traumatic brain injury associated with a decoupling of the regulation of blood flow in the brain. Because blood flow is what fMRI measures, the ability to detect deception in individuals with brain injury could be compromised. Profound childhood trauma and social deprivation can also imprint the brain, said Buckholtz. Indeed, criminal behavior is multifactorial and cannot be reduced to a single brain imaging measure, he said. Thus, in a study by Aharoni and colleagues, low activity within the anterior cingulate cortex (ACC) correlated with earlier rearrest (Aharoni et al., 2013). But Poldrack and colleagues showed that the predictive power of the ACC, while statistically significant, is small and impacted by a range of cognitive processes and behavioral dispositions (Poldrack et al., 2009). Although some of these factors, such as risk of anxiety and schizophrenia, may in aggregate affect risk of antisocial behavior, they are not isometric with crime risk, said Buckholtz.

Given the expense and potential prejudicial nature of neuroscientific evidence, Buckholtz emphasized the need for rigorous evaluation of the incremental validity of brain imaging data over behavior itself or actuarial measures.

IDENTIFYING PAIN THROUGH NEUROIMAGING

Pain intersects with legal issues in cases related to determining qualifications for disability, workers' compensation, or insurance benefits, as well as in determining the size of those awards and as evidence in tort claims, said Tor Wager, professor of psychology and neuroscience at the University of Colorado Boulder. Yet, determining the presence, severity, and causes of pain has proven difficult and is complicated by personal predispositions and emotional responses to the experience of pain as well as to gender and racial health disparities in the treatment of pain (IOM, 2011).[1]

Neuroscience can illuminate plausible mechanisms, said Wager, and while much is known about the neurophysiology and pharmacology of pain, much less is known about how pain is represented as a physiological response that could be assessed as a biomarker or mental experience. Although the gold standard for reporting pain remains a subjective numerical rating scale, neuroimaging and other neurologically based technologies such as electroencephalography (EEG) or magnetoencephalography (MEG) have been invoked in legal settings as potentially more objective measures of pain. More recently, fMRI and other measures are increasingly being used as biomarkers to assess patterns of brain activity as potential biomarkers linked to self-reports of pain. These technologies will

[1]For more information, go to https://painconsortium.nih.gov/sites/default/files/NINDS-Pain-Infographic_508C.pdf (accessed June 18, 2018).

augment rather than replace pain reports and provide insight into the mechanisms underlying pain, said Wager.

However, Wager noted that whether imaging scans are admissible as scientific evidence is determined in large part by adherence to the Frye and Daubert criteria and Rule 702 of the Federal Rules of Evidence[2] (see Box 2-1).

Wager cited a case in which a man was burned by a glob of molten asphalt, developed chronic pain, and sued his employer for damages. Joy Hirsch, then a professor of neuroscience, radiology, and psychology at Columbia University, presented expert testimony, including data that she said showed that patterns of fMRI activity in the man's somatosensory cortex were consistent with claims of pain. An expert representing the defendant countered that Hirsch's testimony did not meet the Frye standard. However, the judge ruled in favor of allowing Hirsch's testimony, saying it would be based on "generally accepted scientific principles and inductive reasoning from her own research" (Davis, 2016). The employer settled the case and it did not go to trial.

Wager referred to this case as a "cautionary tale." He cited "the problem of specificity," noting that even very small areas of the brain—a single

BOX 2-1
The Evolution of Rules Regarding Testimony by Expert Witnesses: The Frye and Daubert Standards and Rule 702 (The National Court Rules Committee, 2018) Presented by David Faigman, Chief Judge Patti Saris, and Tor Wager

The Frye criteria, delivered in *Frye v. United States*, 293 F.1013 in 1923, hold that expert scientific opinion is admissible when a technique is generally accepted by the scientific community. In 1994, in *Daubert v. Merrell Dow Pharmaceuticals*, 509 U.S. 579 (1994), the Supreme Court ruled that Federal Rules of Evidence regarding expert testimony supersede *Frye*. These guidelines task the judge with determining whether expert testimony truly represents scientific knowledge and is relevant and reliable with regard to the facts presented.

The Daubert standards are now embedded in the Federal Rule of Evidence 702, which defines the qualifications of an expert witness and the basis of the testimony and requires the expert to apply "the principles and methods to the facts of the case." See Chapter 4 for additional discussion.

[2]For more information, go to https://www.rulesofevidence.org/article-vii/rule-702 (accessed April 26, 2018).

voxel on a scan, for example—represent multiple neural populations with different functional properties that can be activated across many different tasks (Logothetis, 2008). For pain, the positive predictive value of these measures is quite low, he said, but can be improved. Working with a Presidential Task Force of the International Association for the Study of Pain, Wager, Hank Greely, and others recommended a consensus set of standard criteria for establishing biomarkers of chronic pain (Davis et al., 2017) (see Box 2-2).

Wager and colleagues have developed a framework for biomarker development that uses machine learning or multivariate pattern-recognition techniques to optimize patterns that are predictive of clinical outcomes such as the pain experience; generalize the pattern across multiple populations, scanners, and labs; and characterize the properties of the pattern when applied to conditions that might be confused with the targeted outcome (Woo et al., 2017). To apply this framework to pain, they developed an fMRI-based neurological pain signature (NPS) based on scans done in individuals exposed to different intensities of painful heat (Wager et al., 2013). These scans showed activity in several brain regions known to be related to pain: the cingulate cortex, insula, medial and ventrolateral thalamus, somatosensory cortex, and posterior insula (see Figure 2-2). By collaborating with other investigators worldwide, sharing data, and prospectively testing hundreds of individuals across many different conditions, Wager and colleagues have demonstrated that NPS is sensitive and generalizable across multiple types of evoked pain and multiple testing sites (Zunhammer et al., 2017).

In terms of specificity, NPS has been tested in different ways and shown to differentiate between physical and non-physical pain, such as that experienced as a result of social rejection (Woo et al., 2014), exposure

BOX 2-2
Consensus Criteria for Establishing Biomarkers of Chronic Pain, as Recommended by a Presidential Task Force of the International Association for the Study of Pain (Davis et al., 2017) Presented by Tor Wager

- Precisely defined measures
- Replicated and applied without adjustment across laboratories, pain variants, and populations
- Sensitive and specific to pain
- Generalizable to patient group and test setting

to aversive images (Chang et al., 2015), or vicarious experience of other people's pain (Krishnan et al., 2016), even though these experiences activate some, but not all, of the brain regions activated by physical pain. Wager said his team has also shown that NPS is sensitive to drug treatment, but insensitive to placebo effects (Zunhammer et al., 2018).

For use in legal settings, further validation of NPS and other brain signatures in development as biomarkers of pain will require additional testing for sensitivity, specificity, and generalizability as well as more extensive tests of the effects of countermeasures such as distraction, said Wager. Large data resources and biobanks will be essential in this regard, he said.

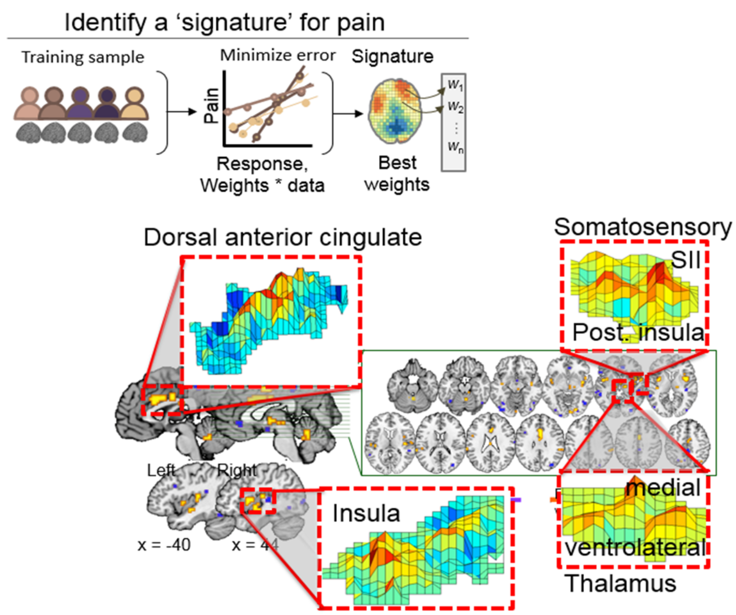

FIGURE 2-2 Measures of pain using functional magnetic resonance imaging (fMRI). To identify a neurologic pain signature, a training sample of people are exposed to four levels of painful heat while undergoing fMRI. An optimal pattern of brain activity from different brain regions is deduced using machine learning techniques.
SOURCES: Presented by Wager, March 6, 2018; Wager et al., 2013.

"BRAIN READING"

Neuroimaging techniques such as fMRI and EEG enable scientists to measure and quantify patterns of brain activation, and then use those patterns to decode or reconstruct stimuli perceived by an observer. Jack Gallant, Chancellor's Professor of Psychology at the University of California, Berkeley, has been exploring the use of fMRI to decode conscious and unconscious information from the brain. His research suggests that this could potentially be used as a form of lie detection that, by comparison to traditional lie detectors, makes more nuanced kinds of judgment beyond whether someone is lying or not. So-called brain reading might also make it possible to recover memories or other kinds of information such as emotional state or subconscious desires or goals, according to Gallant.

Brain reading involves assessing brain activity in response to various types of stimuli (visual, semantic, emotional, etc.) and then mapping the systematic relationship between those stimuli and brain activity, said Gallant. Creating these maps is extremely complicated, he said, given that the brain contains some 500 distinct brain areas and brain structures, organized into a giant, highly interconnected network. Moreover, brain activity is distributed not only spatially but also evolves over time (Breakspear, 2017), yet no current non-invasive technology can measure human brain activity in both space and time. EEG and MEG, for example, have good temporal but poor spatial resolution, while fMRI and functional near-infrared spectroscopy (fNIRS) have good spatial but poor temporal resolution. fMRI signals, for example, are captured on a time scale of about 2 seconds, so everything a person thinks, says, perceives, or feels during those 2 seconds is captured in a single measurement, discarding most of the information generated.

Gallant and colleagues have built a "brain viewer" that combines fMRI with machine learning methods to make complicated, detailed, 3D functional maps of information encoded in the brain during semantic or visual tasks.[3] Every brain location represents multiple related kinds of information, and every type of thought is represented in a network of regions across the brain, said Gallant. So, for example, if one thinks about a dog, more than a dozen different brain locations represent different aspects of the concept of dog: how dogs look and sound, memories of previous dogs one has encountered, emotional reactions to dogs such as fear, and so on.

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[3]The interactive 3D semantic map can be viewed at http://gallantlab.org/huth2016 (accessed April 26, 2018).

Once these encoding models of brain activity in association with specific kinds of conceptual information have been generated, they can be converted into decoding models that are beginning to allow investigators to recover what a person experienced by measuring brain activity, said Gallant. For example, his lab has been able to reconstruct the physical structure and decode contents of photographs and movies presented to subjects during fMRI scans (Huth et al., 2016; Nishimoto et al., 2011; Stansbury et al., 2013). Gallant noted that decoded fMRI signals are fairly representative of the image presented, although not sufficiently accurate or precise to be used as evidence in court.

Adrian Nestor, assistant professor of psychology at the University of Toronto, Scarborough, has also been working with fMRI and EEG to decode patterns of brain activation. Nestor and other investigators have, for example, demonstrated the ability to decode faces from brain activity (Cowen et al., 2014; Nestor et al., 2016). While Nestor agreed that EEG has poor spatial resolution, his research suggests that information from EEG data can be extracted to reconstruct meaningful visual stimuli. The appeal of EEG is that it is widely available, portable, and much cheaper than fMRI, he said. The approach used by Nestor and colleagues is to determine the neural correlates of facial identification by extracting and aggregating spatiotemporal information from components of EEG signals obtained from healthy volunteers in response to viewing face images, then using pattern analysis to reconstruct images. Because EEG signals are intrinsically noisy, a proof-of-concept study required collecting large amounts of data from 13 individuals, presented multiple times over multiple sessions, with 54 faces and developing a procedure to map specific components of the EEG signal onto specific facial features. The results of this study indicated that EEG indeed supports facial image reconstruction; although the perceptual quality of the reconstructions was poor, according to Nestor (Nemrodov et al., 2018).

Nestor noted that the appearance of an individual as captured by a photograph can vary dramatically due to lighting, facial hair, makeup, etc. One advantage of his approach is that it reconstructs images based on facial structure such as the distance between the corner of an eyebrow and the tip of the nose. These facial landmarks are more consistent for a given individual than other characteristics that affect appearance such as those mentioned above. His lab has also shown that optimal reconstruction is obtained using information extracted from EEG signals captured between 50 and 600 milliseconds after stimulus onset (Nemrodov et al., 2016).

He concluded that while facial image reconstruction from EEG signals is feasible, additional studies will need to be conducted with a more heterogeneous group of subjects, including older adults and individuals with various types of deficits. Nestor also suggested that it may be possible to apply the approach to memory-based rather than perception-based reconstruction, and to reconstruct signals other than faces, such as auditorily presented words, although he acknowledged that these techniques will require substantial advances in hardware optimization and statistical methodology. This research may have implications in the legal system in the future, said Nestor, when identifying a person of interest, or establishing a mode of neural-based communication with someone who is incapable of verbal communication.

Gallant also urged caution in terms of expectations about whether and when these approaches might be ready for use in the legal system. With current technologies, Gallant said it is only possible to decode visual imagery from the brain about one-third as well as decoding an actual visual experience (Naselaris et al., 2015). However, Gallant predicted that as neuroscience progresses, advances in the ability to measure brain activity will inevitably be translated into better methods for decoding the brain. His lab has been working on systems to decode speech and social information, while others have attempted to decode dreams, he said. While networks involved in processing visual information are fairly well understood—which greatly facilitates the decoding of visual information—decoding language is limited by the poor temporal resolution of fMRI. Decoding emotional information is even more difficult because emotions are stored in brain structures whose activity is more difficult to measure. Even information stored in long-term memory is potentially recoverable. However, the way that long-term memories are stored in the brain is not understood, so decoding long-term memories would require that they be accessed and moved into working memory, said Gallant.

The ability to decode the brain is primarily limited by the quality of brain measurements, although progress in this area is moving forward rapidly, thanks to research funding programs such as the BRAIN Initiative. Gallant predicted that the next generation of fMRI will markedly improve the spatial resolution and improve the quality of spatial maps, but still will not address the time issues. The accuracy of brain models has also advanced in recent years due to advances in computer power and machine learning technologies, he said. He was less sanguine about the potential for other technologies such as fNIRS, focused ultrasound, photoacoustic approaches, and microwave radar to substantially advance the field of human brain decoding in the near future, although they have worked well in rodents, whose thinner skulls allow deeper penetration into the brain.

Gallant stated that current methods of non-invasive brain measurement lack the precision and accuracy to provide evidence for use in legal settings. With the possible exception of detecting lies under very restricted circumstances, he said information decoded from the brain is no more reliable than taking testimony from a person. He noted, however, that improvements in another imaging technology, diffusion MRI, which detects anomalies in structural connectivity in the brain, may enable better associations between brain damage and criminal behavior (Waller et al., 2017).

GENETIC CONTRIBUTIONS TO BEHAVIOR PREDICTION

DNA has entered the realm of the law primarily based on the idea that genetic variation gives each individual a unique "genetic barcode." However, Benjamin Neale, assistant professor in the Analytic and Translational Genetics Unit at Massachusetts General Hospital, noted that genetic variation also influences mental illnesses such as schizophrenia and bipolar disease and may also contribute to behavioral characteristics such as the propensity for violence. Technological advances over the past two decades have vastly improved the ability of scientists to capture all the genetic variations in a population and then, through genome-wide association studies (GWASs), to ask whether individual variants are more common in a group of individuals with a certain trait. The key to the successful identification of risk variants is to collect very large samples, said Neale.

Neale described a 2011 study by the Psychiatric Genetics Consortium (PGC) as an example of how genetic data may be used to predict the risk of schizophrenia. This example is not intended to conflate propensity for violence with schizophrenia, but merely to illustrate the potential predictive power of genetic studies. In this study of more than 9,000 individuals with schizophrenia and more than 12,000 controls, variants at five new genetic loci were identified that are associated with schizophrenia (Schizophrenia Psychiatric Genome-Wide Association Study Consortium, 2011). Neale noted that carrying these variants does not guarantee someone will develop schizophrenia, but rather each influences the risk for schizophrenia in the population as a subtle nudge. By 2013, with more than 35,000 cases and nearly 47,000 controls, PGC had identified 97 genome-wide significant sites. Each of these sites individually increases the risk of developing schizophrenia by only a tiny percentage, but they can be aggregated into a polygenic risk score to create a predictor (International Schizophrenia Consortium et al., 2009; Schizophrenia Working Group of the Psychiatric Genomics Consortium, 2014). Neale said that with this approach, polygenic scores with an odds ratio of around 20 can be constructed contrasting the highest and lowest risk groups. However, he cautioned that the absolute risk is only about 3 percent, even in those people with the highest risk scores.

A similar approach has been used to build a polygenic risk score for heart attack. Importantly, said Neale, the cardiology community has incorporated traditional epidemiological risk factors such as age, sex, cholesterol levels, and smoking status into these risk scores to come up with a composite score that does a much better job of predicting heart attack risk. Similarly, in the context of adjudicating the degree to which someone has a tendency toward violence, Neale advocated examining not only genetics but behavior as well, rather than treating these two factors in isolation.

Neale also cited substantial pitfalls with using genetic risk predictors. Most GWASs have been conducted in populations of European ancestry, yet a recent study showed that these scores translate poorly to different ancestral populations (Martin et al., 2017). Even as these predictions improve with the aggregation of more data, they will always remain probabilistic, said Neale. In nearly all circumstances, genes are not fate, he said, and with complex behavioral phenomena such as violence or criminality, environment plays an essential role. A purely genetic explanation for an individual's phenotypic presentation is thus highly unlikely. Even if a risk score had a 90 percent chance of predicting a certain trait or behavior, Neale said that it should not have undue influence over the evaluation of the individual. Genes can help build a story, he said, but should not be considered de facto or declarative in terms of evidence.

Another problem with associations of genetics and behavior is the failure to robustly replicate studies, said Neale. He cited the case of the monoamine oxidase (MAOA-L), the "warrior gene" genotype, which has been linked to aggression and antisocial behavior (Dorfman et al., 2014) and has been cited in at least 11 legal cases, usually in the context of sentencing rather than determining guilt (McSwiggan et al., 2017). However, a meta-analysis of studies demonstrated that the contribution of this gene to aggression was weak and heterogeneous (Ficks and Waldman, 2014). Many studies have also cited a gene–environment interaction in which MAOA-L gene carriers who experienced childhood trauma showed more antisocial behavior, although these studies also have not been consistently replicated

(McSwiggan et al., 2017). Indeed, according to Buckholtz, the biggest predictor of antisocial behavior, swamping other predictors by far, is early life maltreatment. Neale noted that the field of genetics is rapidly evolving, and as a result, even many commonly accepted associations between genes and behavior have proven unreliable.

3

Looking into the Future: Novel Uses of Emerging Neurotechnologies with Potential Legal Applications

Highlights

- Deep brain stimulation has been widely used to treat neurological disorders such as Parkinson's disease, and could conceivably have applications for forensic evidence collection, to promote truth telling, and to recover memories, although there are both scientific and ethical barriers to doing so (Gunduz).
- Continuous recording of brain activity via implanted microelectrodes could enable people with devastating brain damage to regain volitional control over movement and communication (Cash).
- Capturing brain activity continuously may also elucidate the neurological basis of volition, intent, and memory, which could eventually be used in legal settings (Cash).
- Technologies with the potential for "mind control" raise substantial ethical, practical, and legal issues (Cash and Greely).

NOTE: These points were made by the individual speakers identified above; they are not intended to reflect a consensus among workshop participants.

The BRAIN Initiative and other national-level brain projects around the world, as well as ventures launched by companies in the private sector, have ushered in what Khara Ramos called "a transformative time for the development of novel neurotechnologies," which have enabled discovery of unexpected aspects of brain function. Although most of these new and emerging neurotechnologies are designed to better understand neurological deficits or provide benefits to patients—not to answer legal questions—they eventually may be applied in legal settings, said Sydney Cash, associate professor of neurology at Harvard Medical School, adding that discussing the potential legal implications early in development of these technologies may be beneficial. Ramos agreed, adding that this workshop provides an opportunity to proactively consider the implications.

CLOSED-LOOP DEEP BRAIN STIMULATION

Aysegul Gunduz, director of the Brain Mapping Laboratory at the University of Florida, admitted that she had not considered the legal implications of her work until receiving an invitation to the workshop. Nonetheless, as she proceeded to describe the research conducted in her lab, several concepts emerged with potential application to the law.

Gunduz's research focuses on the billions of neurons in the human brain that synchronize to create electrophysiological waves, or brain rhythms, which are modulated to control behavior. Both neurological and psychiatric disorders are characterized by distortions of normal modulations, she said. For example, clusters of neurons located deep in the brain, known as the subthalamic nucleus (STN), have been shown to play an important role in movement disorders such as Parkinson's disease (PD) (Rossi et al., 2015). Gunduz and colleagues use deep brain stimulation (DBS) to target the STN with an electric pulse that works like a pacemaker to modulate the pathological rhythms generated in these circuits and bring the brain to a healthier state. In PD or essential tremor, for example, DBS can lead to a suppression of symptoms. The technology has also been used for other disorders such as dystonia and obsessive-compulsive disorder, and is under investigation for Alzheimer's disease, Tourette's syndrome, and drug addiction.

Gunduz and colleagues, with support from the BRAIN Initiative, are trying to make these devices smarter, so that they can deliver electricity to the brain on an as-needed, individualized regimen, to make treatment more effective, reduce side effects, and preserve battery life. To achieve this, they are working with individuals who have kinetic tremors (a subset of individuals with essential tremor), which appear only when a movement is initiated. If the intention to move can be detected, it may be possible to deliver DBS before the tremor begins, and stop the stimulation when intent is gone. They place a sensing electrode on top of the premotor cortex, which has been shown to be activated before a movement starts, and then attach that electrode to the device that delivers the DBS. In one patient given the task of pouring water from one cup to another, the patient's system was able to detect the intent to move and deliver stimulation to the deep brain before the movement began, reducing the tremor and allowing the task to be completed successfully.

DBS may have uses in legal settings. An example is for forensic evidence collection, said Gunduz, although those uses are far in the future and would need to overcome substantial ethical barriers. For example, placing electrodes deep in the brain could conceivably be used to detect lies, although fMRI studies show that the networks activated during the complicated act of lying cover a broad area of the brain not yet accessible to implantable electrodes, she said (Langleben et al., 2005). Gunduz noted that neuromodulation may also be used to promote truth telling. Studies have shown that damage to the dorsolateral prefrontal cortex leads to less honest behavior in tasks that pit honest motives against self-interest, raising the interesting yet highly speculative possibility that an area of the brain could be stimulated to make people more truthful (Zhu et al., 2014).

Gunduz also mentioned a group of projects funded by DARPA with the overall goal of developing a fully implantable closed-loop brain stimulator to restore active memory (DARPA RAM)[1] in soldiers who have suffered traumatic brain injuries. A recent study demonstrated that targeted stimulation of the lateral temporal cortex rescued poor memory encoding and improved later recall (Ezzyat et al., 2018); another proof-of-concept study recently demonstrated that electrical stimulation of an area of the hippocampus known to be important in memory formation resulted in improved short- and long-term retention of visual information (Hampson et al., 2018). While these studies show promise in restoring memory, Gunduz cautioned that electrical stimulation may also disrupt working memory rather than improve it; thus, she does not see it as either an ethical or scientifically probable approach to obtain truthful testimony.

CONTINUOUS RECORDING OF BRAIN ACTIVITY

Cash expanded on the idea of recording brain activity as a means of understanding the neural basis of volition. Cash's lab has been trying to decode motor activity and language processing in persons with tetraplegia (partial or total paralysis in all four limbs and torso caused by illness or a spinal cord injury), such as those who have suffered devastating strokes that leave them paralyzed and often unable to communicate with voice.

[1]To learn more about DARPA RAM, see https://www.darpa.mil/program/restoring-active-memory (accessed April 28, 2018).

Working with the interdisciplinary research at BrainGate,[2] they have tested a microelectrode device that decodes motor activity from the brain via a set of electrodes implanted in the motor cortex, then uses that decoded information in real time to control a sophisticated multidimensional robotic arm (Hochberg et al., 2012). Essentially, said Cash, a patient can control the robotic arm simply by thinking about what he or she wants to do. This highly invasive approach facilitates the collection of very precise information from one location at extremely high temporal resolution, that is on the order of submilliseconds, enabling the investigators to decode the activities of individual neurons while the patient is performing a task.

The same technological approach can also be used to decode auditory information, said Cash. Using data captured from a microelectrode array implanted in the superior temporal gyrus brain, a multidisciplinary research team at Harvard–MIT and the University of California, San Diego, have shown that single neurons are tuned to specific phonemes, thus enabling spoken words to be decoded (Chan et al., 2014). Eventually, said Cash, this technology may move beyond decoding to facilitating the restoration of function, for example, by allowing non-verbal individuals to communicate by typing. Work is under way already, with help from BRAIN Initiative funding,[3] to make these arrays fully implanted and fully wireless. Another approach would integrate implantable arrays with electrodes implanted into muscles to direct muscle activation in patients with tetraplegia (Ajiboye et al., 2017).

Ultimately, the goal would be to move beyond enabling people to complete prescribed tasks in controlled test environments to the point where they would be able to have complete volitional control in natural settings, said Cash. To move in this direction, Cash and the BrainGate team have been working experimentally with a Watch, Imagine, Act paradigm. Using implanted multielectrode arrays, they record neural activity at a single neuron level in participants with epilepsy or tetraplegia as they look at a movement, imagine doing the movement, and then attempt to perform the movement. The researchers have found that single neurons in the motor cortex fire at different rates depending on whether they are watching, imagining, or acting. This system thus provides information

[2]To learn more about BrainGate, see http://www.braingate.org (accessed April 28, 2018).

[3]BRAIN UH2-NS095548, Hochberg and Nurmikko.

about volitional state with very high temporal resolution. Cash and colleagues are trying to look at continuous activity in patients doing whatever they wish to do.

A major challenge, he said, is analyzing the enormous amounts of multidimensional data collected in these experiments—not only the neural activity data but behavioral data as well. Video recording allows them to collect information on types of movement, joint position, contextual information, and audio information; to decode that information; and to integrate it with neural data using sophisticated analytical approaches.

Cash said these "embryonic" efforts to understand the neurological basis of volition, intent, recovery of memory, etc., are not yet far enough advanced to be mapped onto legal frameworks or to be used within the justice system. Their use in predicting outcomes or responsiveness following incarceration is especially fraught, he added. Moreover, coupling these systems to neuromodulation to prevent antisocial behaviors, while biologically feasible, raises major ethical, practical, and legal concerns, Cash said. Indeed, Hank Greely commented that these technologies, such as implanted chips that can make someone do things or stop someone from doing things, seem to be moving closer to the dystopian prospect of mind control, requiring careful thinking about appropriate limits.

4

Developing a Framework for Use of Evidence from Emerging Neurotechnologies

Highlights

- Efforts are needed to establish general and specific criteria regarding the reliability and admissibility of neuroscientific evidence in court, and its use to make valid fact findings about behaviors, actions, or intentions of individuals charged with crimes (Buckholtz and Saris).
- Neuroscientific evidence is nearly always presented as expert testimony, which is frequently challenged by an opposing expert (Shen).
- Federal judges' decisions about admitting neuroscientific evidence is governed by the Federal Rules of Evidence, and this requires judges to understand and evaluate the scientific data presented. States vary in the standard they employ for evaluating the admissibility of scientific evidence (Saris and Shen).
- Translating scientific concepts into constructs appropriate for legal decision making requires consideration of whether group data pertain to an individual case, operationally defining legal concepts as scientifically measurable terms, and understanding the limits of using probabilistic data to explain categorical terms (Faigman).
- Establishing a common language between neuroscientists and legal scholars may help bridge the gap between neuroscience and the law; however, there are many challenges due to the many differences between scientific and legal concepts (Buckholtz and Faigman).
- To make decisions about the admissibility of neuroscientific evidence, judges need to understand the reliability and validity of the data as well as the mainstream academic views of the science (Faigman).

- Neuroscientific evidence must be viewed in the context of the broad legal system, including the availability of resources (Gertner).
- Neuroscience has the potential to reduce the reliance on normative value judgments about many legal concepts, such as those related to addiction, alcoholism, intent, and provocation (Gertner).
- Better education of judges and/or technical advisors may be needed to assist judges in making decisions about neuroscientific evidence, but may be insufficient to address concerns such as cognitive bias (Faigman, Gertner, Hervey, and Wager).
- Judges may also benefit from the availability of peer-reviewed evaluations of scientific evidence (Buckholtz and Faigman).

NOTE: These points were made by the individual speakers identified above; they are not intended to reflect a consensus among workshop participants.

There are fundamental scientific inferential challenges to using neuroscientific data in the courts and to making policy, said Joshua Buckholtz. One does not have to look very far to find so-called experts willing to make extraordinary claims about the coming neurolegal revolution, he said. This is why proactive and thoughtful efforts are needed to define the general and specific criteria that neuroscientific evidence, primarily neuroimaging, needs to fulfill before using it to make valid inferences about the behaviors, actions, or intentions of an individual. Judge Patti Saris agreed, expressing her hope that the workshop would be a first step toward developing scientific standards for evaluating neuroimaging technologies as a means of helping judges and policy makers understand the reliability of current neuroscientific methods.

ADMISSIBILITY OF EXPERT TESTIMONY: BATTLE OF THE EXPERTS

Francis Shen, associate professor of law and McKnight Presidential Fellow at the University of Minnesota, noted that thousands of cases have included some type of neuroscientific evidence going back to the 1940s (Denno, 2015; Farahany, 2015). Importantly, he said, this evidence is nearly always introduced through testimony from a human expert who, given the adversarial system under which the law operates, is crossexamined and/or countered by an opposing expert. According to Judge Saris, one of the most difficult decisions a judge must make is in regard to the admissibility of scientific expert testimony. For example, should this type of testimony be admitted to determine whether a defendant had the mens rea (criminal intent) to be capable of a crime?

Daubert hearings, discussed in Chapter 2, typically involve a battle of experts presented by both the plaintiff or prosecution and defense, and culminate in the judge issuing elaborate fact findings that are reviewable on appeal, said Judge Saris. David Faigman, the John F. Digardi Distinguished Professor of Law at the University of California Hastings College of Law and professor of psychiatry at the University of California, San Francisco, School of Medicine, added that the adversarial process leads to what might be called "expert mining," where both sides find experts who agree with their litigation position. He argued that *Daubert* has actually made it more difficult to get expert testimony admitted, citing the *Daubert* case itself, as well as in her cases of the "*Daubert* trilogy"—*Joiner* and *Kumho Tire*—in which the expert testimony was ultimately excluded.[1]

Judge Saris added that the multiple requirements specified by the *Daubert* decision have also made the judge's job more difficult. Before *Daubert*, judges could admit expert testimony if it was generally accepted by the scientific community. Now in federal courts and many state courts, the judge must be a "gate keeper" to determine if the evidence is reliable and relevant. The court must consider the five *Daubert* reliability factors[2]:

1. Testability of scientific theory or technique
2. "Whether the technique has been subject to peer review and publication
3. Known or potential rate of error
4. The existence and maintenance of standards controlling the technique's operation
5. General acceptance within the relevant scientific community"

Judge Saris highlighted the challenges of assessing these criteria; for example, can research conducted in animal studies published in a peer-reviewed journal translate to humans? What if the methodology and results in one peer-reviewed article is counter to what other researchers have

[1]*General Electric Company v. Joiner*, 522 U.S. 136 (1997); *Kumho Tire Company v. Carmichael*, 526 U.S. 137 (1999).

[2]*Daubert v. Merrell Dow Pharmaceuticals*, 509 U.S. 579 (1994).

shown in other journals? According to Shen, however, most evidence is never presented to a jury because the vast majority of civil cases are settled and criminal cases nearly always end with a plea bargain, in which the Federal Rules of Evidence do not apply. As part of a plea bargain, attorneys may present neuroscientific evidence regardless of its significance with the hope of getting a better deal for their client. The Federal Rules of Evidence also do not apply to what types of technology the police or government can use in their investigations, added Shen.

When presented in the courtroom, however, judges do have to apply Federal Rule of Evidence 702, as well as Rule 403, which Shen called a kind of "failsafe" rule. Rule 403 says the judge can "exclude relevant evidence if its probative value is substantially outweighed by danger of one or more of the following: unfair prejudice, confusing the issues, misleading the jury, undue delay, wasting time, or needlessly presenting cumulative evidence" (The National Court Rules Committee, 2018). As an example of how this has played out in the courtroom, Shen described a federal case in Tennessee, where a doctor was charged with defrauding the government by improperly billing for Medicare and Medicaid services.[3] To prove their case, the government had to show that the doctor did this knowingly. The defense presented expert testimony from another doctor who claimed that fMRI scans indicated that the accused doctor was telling the truth about not cheating or defrauding the government. The judge excluded the evidence, based on Rule 702, ruling the technology was not ready for courtroom use, and also ruled that the "danger of unfair prejudice substantially outweighed the probative value of the evidence" (Rule 403).

When neuroscientific evidence is allowed to be introduced, it is often in the sentencing phase of a trial, where the Federal Rules of Evidence do not apply. Shen said little is known about how that evidence affects juror decision making. Shen mentioned one death penalty case in which quantitative EEG evidence was offered by the defense to show that the defendant had "a broken brain." Three jurors interviewed by a reporter after the man was sentenced to life in prison indicated that the brain scans swayed their decisions (Miller, 2010). Shen and colleagues recently summarized empirical evidence regarding the effect of EEG memory recognition evidence on assessments of defendant credibility, concluding that there is "a tangled mess of contradictory findings" (Shen et al., 2017). He suggested that de-

[3] *United States v. Semrau* (2010), U.S. District Court for the Western District of Tennessee, No. 07-10074.

cisions based on Rule 403 will continue to be very contextualized and individualized, yet the data suggest that presentation of neuroscientific evidence can change outcomes. Shen compared the admissibility challenge of informative but incomplete brain evidence to instant replay in sports: It is used when available (meaning when the plaintiff has sufficient resources), when the stakes are high, and when the referee's decision is not trusted (Shen, 2016).

TRANSLATING SCIENTIFIC CONCEPTS INTO LEGAL CONSTRUCTIONS (AND VICE VERSA)

Faigman discussed three issues that must be considered in translating scientific research into constructs appropriate for legal decision making: (1) moving from group data in science to individual decision making in law (known as G2i); (2) operationally defining legal/normative concepts into scientifically measurable terms; and (3) presenting scientific research in court using probabilities rather than qualitative or categorical substitutes.

According to Faigman, the inherent challenges of G2i arise from the different perspectives of science versus law. As he wrote in his 1999 book *Legal Alchemy: The Use and Misuse of Science in the Law*, "While science attempts to discover the universals hiding among the particulars, trial courts attempt to discover the particulars hiding among the universals" (Faigman, 1999, p. 69). Science, said Faigman, first gathers evidence at the "G" level, asking whether what is being presented in court represents a general phenomenon, and second whether scientific research supports it. In the courtroom, however, a different question must be answered, that is, whether this case represents an instance of that phenomenon. For example, if battered woman syndrome is offered as a defense, one must ask first whether this syndrome exists and examine the scientific evidence supporting that claim, if, and only if, research supports the existence of the general phenomenon, one must next ask whether *this case* is an instance of that phenomenon (Faigman, 2008). However, scientific evidence is inherently probabilistic, said Faigman, while the law requires categorical decisions, in other words, whether the plaintiff's action is or is not attributable to the phenomenon offered as evidence. Jack Gallant noted that science's focus on "G" may be changing as cognitive neuroscience research increasingly focuses on individual studies of individual subjects, leading to the acquisition of more information on individual differences.

Translating scientific evidence to support legal or normative concepts such as intelligence, competency, or volitional control also requires operational definitions that enable measurement, said Faigman. Competency is a particularly difficult concept to operationalize, he said, because it can mean many different things depending on whether one is asking if a person is competent to be executed, to receive a life sentence without parole, to waive Miranda rights, to consent to institutionalization in a psychiatric hospital, or to make a decision about abortion, for example. Faigman described a series of cases in which the Supreme Court addressed competency to be executed based on intellectual disability.[4] These cases have been argued based on an evolving operational definition of intellectual disability under the Eighth Amendment, which "prohibits the imposition of cruel and unusual punishment." In *Atkins v. Virginia*, the Court left the decision to the states to define intellectual disability. In *Hall v. Florida*, Florida defined intellectual disability as an IQ score of 70 or below. In *Moore v. Texas*, the Court ruled that intellectual disability must be informed by the *Diagnostic and Statistical Manual of Mental Disorders*, 5th ed. (DSM-5) (American Psychiatric Association, 2013). Faigman suggested that this may not be the last word on determining competency for execution because the DSM-5 requires the presence of three factors: significantly subaverage intellectual functioning (IQ), deficits in adaptive functioning, and onset of deficits during the developmental period. "In a death penalty case, intellectual functioning is important because of its correlation with the ability to understand the gravity of the crime and the purpose of the penalty, as well as the ability to resist a momentary impulse or the influence of others."[5] However, Faigman argued that adaptive functioning is more important in determining eligibility for social services, and onset during early development may have no bearing on the question of competency to be executed. Moreover, Faigman argued that the Supreme Court has yet to explain how these three factors associated with intellectual disability in the DSM-5 fit the two principles that help define the Eighth Amendment standard for whether a person is competent to be executed: retribution (i.e., that the plaintiff is worthy of blame) and deterrence (i.e., that the plaintiff is cognitively capable of being deterred or that others might be deterred by imposition of the death penalty).

[4] *Roper v. Simmons*, 543 U.S. 551 (2005); *Atkins v. Virginia*, 536 U.S. 304 (2002); *Hall v. Florida*, 572 U.S. (2014); *Moore v. Texas*, 581 U.S. (2017).

[5] *Hall v. Florida*, 572 U.S. (2014) (Alito, J., dissenting).

Buckholtz suggested that a lingua franca—a common language—between neuroscientists and legal scholars could allow them to work together to generate operational definitions by clarifying legal standards, articulating what the law requires, and then deciding if legally meaningful inferences are scientifically valid and if there is incremental value to neuroscientific evidence over the much less expensive behavioral data. Faigman, however, argued that it may not be possible to use common terms to describe what are very different concepts. For example, evidentiary reliability does not necessarily correspond with scientific validity, volitional control may not be accurately reflected in studies that use delayed-reward discounting, and insanity does not equate with mental illness. Moreover, presenting statistical and probabilistic information in court will remain a challenge given the need for courts to make categorical decisions. Shen added that with regard to the admissibility of patterns of brain activity or other measures discussed above as biomarkers, it may be more useful to think of these measures as "biosuggestors" because they are not conclusive. Moreover, handling biomarker evidence in a legal framework will be very challenging, he said.

Faigman added that decision thresholds are often very different for science than for law. For example, the cost of making a mistake in diagnosing mental illness for the purposes of drug treatment is far lower than for deciding whether that person would face civil commitment to an institution.

EVALUATING NEUROSCIENTIFIC EVIDENCE

A problem with meeting requirements of the *Daubert* rule, said Faigman, is that there is currently no way for the court to know what the mainstream academic opinion is. Moreover, Judge Nancy Gertner, who served as U.S. District Judge of the U.S. District Court for the District of Massachusetts until her retirement in 2011, suggested that the courts may not be the best gatekeepers regarding which neuroscientific evidence should be admitted. Scientifically unsound forensic evidence is frequently admitted, she said, noting that the National Research Council in 2009 published a report that concluded that the courts have been utterly ineffective in assessing the research basis for forensic science (NRC, 2009). More recently, the President's Council of Advisors on Science and Technology (PCAST) issued a report to the president on ensuring scientific validity of forensic evidence admitted in criminal courts, concluding that clearer standards are needed to establish the validity and reliability of forensic methods (PCAST, 2016).

Neuroscientific evidence raises different kinds of questions in comparison to other forensic evidence, said Judge Gertner, in part because forensic evidence was established outside of any scientific context, and many types of forensic evidence have little scientific information to support them. Indeed, she said that criminal law is based, in large part, on normative value judgments. Legal concepts related to addiction, alcoholism, the impact of toxic stress, self-defense, and mens rea have not been adequately mapped onto validated neuroscientific concepts, she said, leading to policies such as Florida's stand-your-ground doctrine that not only have nothing to do with science but may even run counter to what neuroscience would suggest. The law treats addiction and alcoholism as voluntary choices, although neuroscience has made clear that there is a continuum in terms of the consequences of that first drink or first use of a drug. After several years of substance abuse, the concept of choice may become an illusion, she said. Moreover, while there are rules for some legal concepts such as provocation, these rules are gendered and troubling, based on normative decisions and value judgments, said Judge Gertner.

Neuroscience as it relates to the law also must be viewed in the context of the broader legal system, where lack of resources, ineffective assistance of counsel, and the absence of discovery may affect the outcome of a trial, she added. Decisions about admitting evidence become especially problematic at sentencing, where there are profound resource problems and the Federal Rules of Evidence do not apply, said Judge Gertner, leading to evidence being accepted that is "good enough," but not necessarily good. She said there are virtually no limits on what a judge can consider at sentencing, including untested generalizations about public safety, deterrence, risk assessment and prediction, and other factors that have nothing to do with the individual.

As described earlier, neuroscience may help elucidate legal constructs such as mitigation and aggravation, although such evidence may be less relevant to the question of culpability than it is to sentencing or rehabilitation and thus may require different rules regarding admissibility, said Judge Gertner.

Neuroforensics Training for Judges, Attorneys, and Law Enforcement

Tor Wager commented that one of the challenges for judges, attorneys, and law enforcement is addressing the knowledge gap—knowing whom and what to trust and under what circumstances. Judges need to understand the reasons why brain models may be wrong, for example, relying on evidence collected using different populations and different scanners, he said. They also need to understand probability and the limitations of evidence as conclusive proof, said Faigman. For example, he noted that for decades, firearms experts have been allowed to testify (usually without challenge) that a cartridge case can be linked to a particular gun to the exclusion of all other guns in the world, although this is a clear overstatement of what the evidence actually supports.

Judge Barbara Parker Hervey of the Texas Court of Criminal Appeals suggested that training of judges, attorneys, and law enforcement can bridge the gap between science and law, but it requires new legislation and adequate funding. Judge Hervey oversees a grant from the Texas legislature to educate judges, defense attorneys, and prosecutors on issues such as actual innocence and the challenges relating to eyewitness identification, false confessions, mental illness, and the use of informants. In 2008, they established the Texas Criminal Integrity Unit to look at wrongful convictions with the aim of making changes at the front end of the system rather than simply catching mistakes at the back end. Judge Hervey emphasized the need to collaborate with scientists, lawyers, and other stakeholders to ensure that all are trained at the same level. Shen added that some of the problems might be mitigated by training not only judges but also law students.

However, Judge Gertner countered that judicial education and training are not remotely enough to ensure appropriate decision making with respect to admission of evidence. She cited multiple examples of cognitive bias in courts, which have led to asymmetric decision making. For example, given time pressures facing judges, they typically only write opinions in cases that have been dismissed, which results in the law evolving on the basis of losing cases. Courts of appeals only see cases in which forensic evidence was admitted and the defendant was convicted, thus skewing the law in favor of admitted evidence. Precedent also strongly influences acceptance of evidence, she said, leading to old science being favored over new science. An indicator of this, she noted, is the fact that the admissibility of DNA evidence was held up for years while trace evidence was routinely admitted without objection. Courts also tend to rely on information that readily comes to mind and have difficulty with self-correction, she said.

Faigman also suggested that many lawyers and judges lack an understanding of basic research methods and statistics and thus may not be educable on the intricacies and limitations of neuroscience. Judges have to recognize when they are at the edge of their understanding, said Judge Gertner. She said the PCAST report attempted to address this issue, suggesting that with regard to expert scientific testimony, there may be a range within which a judge may appropriately base a decision, but beyond which additional technical advice is needed (PCAST, 2016).

Providing Judges with Peer-Reviewed Advice

Given that judges need to evaluate scientific evidence in real time and make decisions, Faigman suggested providing them with technical advisors with whom they can discuss evidentiary matters. He and others have started companies that send out expert reports for peer review from mainstream academic scientists. He said the American Association for the Advancement of Science (AAAS) also has established a program to identify court-appointed experts or technical advisors. Buckholtz advocated for a peer-review system to evaluate scientific information under the special master template, which would allow scientific information to be evaluated by an independent review conducted by scientists with relevant knowledge. He acknowledged, however, that there is no standardized system for conducting peer review of evidence such as the system that exists for peer review of grants and journals. Faigman added that many judges believe in the adversarial process and have been resistant to the idea of technical advisors or court-appointed experts.

5

Moving Forward: Potential Next Steps

Highlights

- The challenges of bridging neuroscience and the law will grow as neuroscience enables more sophisticated ways to assess brain activity and make useful inferences relevant to the law (Greely).
- Models that enable interpretation of anatomical and circuit dysfunction to infer brain function will require a method for determining how the model is useful at an individual level (Gallant and Wager).
- These models will also have to account for topological reorganization and cognitive reserve in the brain (Wager).
- Models may be built to inform specific legal concepts such as competency but will require definition of what capacities are necessary for each concept (Farahany).
- Data from large databases such as the UK Biobank database may be useful in normative models (Hyman).
- Actively monitoring populations to create a database comprising data from multiple modalities could be beneficial in building normative models but presents ethical and political challenges (Neale).
- Using neuroscientific evidence to help inform decisions regarding competency or the revocation of legal rights or to demonstrate vulnerability to elder fraud, raises challenging ethical questions (Shen).

NOTE: These points were made by the individual speakers identified above; they are not intended to reflect a consensus among workshop participants.

Neuroscience research is an ethical and moral imperative, said Hank Greely. Moreover, he said, the field of neuroforensics will inevitably grow and become more challenging as neuroscience enables more sophisticated ways to look at the brain and make useful inferences about the mind that will be relevant to the law. He added that every scientific revolution is built on the development of new tools and requires consideration of the legal implications that will follow from the next generation of these tools.

BUILDING THE NEXT GENERATION OF TOOLS

Among this next generation of tools are models that enable interpretation of the anatomical or circuit dysfunction in individuals to infer brain function, such as those discussed by Jack Gallant and Tor Wager. Calling it a formidable task to build such models, Frances Jensen, chair and professor of neurology at the University of Pennsylvania, suggested that investigators might start by using patient populations with known diagnoses or specific lesions as a way to backtrack into these systems. Gallant said this could be done by treating brain disorders as individual differences in building the models. To use such models in a medical setting, he said, it would be necessary to estimate where within the group data an individual patient "lives." This would require a method for quickly determining which person in the original sample most closely represents the subject of interest. Wager added that it would also be important, albeit challenging, to separate out predispositions (risk factors), consequences (things that change afterward), and current mediators of how a person feels. For the last factor, one strategy is to build normative models based on populations experiencing an event such as chronic pain.

Large databases such as the UK Biobank database might enable building such models if they contain the right kinds of information, said Steven Hyman. Alternatively, Benjamin Neale suggested that it may be possible to actively monitor the population to create a system that would leverage multiple neuroscience techniques for better prediction about the probability of reoffending. However, whether an aggressive government invasion of this type is acceptable is more a question for politicians than neuroscientists.

Another challenge in building these models is the fact that the brain undergoes topological reorganization in response to damage. New technologies are on the horizon that will be helpful in mapping spatial variation topologically, said Wager, and these data will also need to be incorporated into the models. Cognitive reserve adds another layer of complication to these models, he said, because it leads to substantial disconnects between structure and function.

Other models might be built to inform specific legal concepts such as competency, provocation, mental capacity, and volition. For example, Nita Farahany suggested that with regard to determining competency, it would be useful to define what capacities are necessary for decision making in different contexts, and then to determine whether anything in neuroscience maps to those specific competency skills and thus whether neuroscience can inform decision making in this area.

CONSIDERING THE LEGAL AND ETHICAL IMPLICATIONS OF USING NEUROSCIENCE TOOLS IN COURT

To help judges and others in the legal system have a better sense of what should be demanded of evidence before it is admitted at trial, Joshua Sanes suggested a National Academies consensus study. He noted that CSTL previously published a consensus report on eyewitness identification, and that some recommendations of that report were subsequently adopted by the Department of Justice. The study he currently envisions could address, for example, how to distinguish between types of data that are useful statistically over a heterogeneous population and those that can inform with some assurance on individual behavior and motivations. Greely noted that the Federal Bureau of Investigation (FBI) established an accreditation process for crime labs, and that courts are much more likely to admit evidence from FBI-accredited labs. With regard to neuroscience evidence, developing recommendations that respect the limits of basic science, and a set of procedures that are replicable and that can lead to reliable results, would be useful to judges, he said. Similarly, he noted that in order for a technology to be approved for medical use, it must go through rigorous evaluation by the Food and Drug Administration (FDA). One participant suggested that FDA might also be the arbiter of whether claims based on neurodiagnostics evidence can be used in court.

Hyman commented that further thought should be given to mechanisms to fund the adaptation of this fundamentally health-based research to the judicial system. Recognizing that federal funding for the research to adapt neuroscience tools to answer legal questions is likely to be limited, Hyman suggested that foundations or groups of foundations which understand the problems faced by courts could help move this research forward.

Using neuroscientific evidence in legal settings also raises many important ethical questions mentioned by Francis Shen, but not addressed in this workshop. Can the neurobiology of decision making help determine competence to make decisions? What, if any, legal rights should be taken away based on brain circuit abnormalities? How should the law handle probabilistic biomarkers of a mental disorder or a neurological condition such as Alzheimer's disease? For example, should evidence of neurocircuit abnormalities be admitted in elder fraud cases to demonstrate vulnerability of the person who has allegedly been defrauded?

Another necessary step, said Joshua Buckholtz, may be to "demarcate specific legal standards for which there is consistent agreement that no viable scientific operationalization exists." In those cases, he said, "scientific evidence should not be used as an 'empirical fig leaf' to prop up intuitions and preferences that are driving judgments" (Buckholtz et al., 2016, p. 28).

A

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B

Workshop Agenda

NEUROFORENSICS: EXPLORING THE LEGAL IMPLICATIONS OF EMERGING NEUROTECHNOLOGIES—A WORKSHOP

March 6, 2018
Keck Center of the National Academies
500 Fifth Street, NW, Washington, DC

Background: Current developments in neuroscience, genomics, and computing are allowing unprecedented insight into human cognition and behavior in health and disease. Technological advances in non-invasive neuroimaging, neurophysiology, genome sequencing, and other methods, together with rapid progress in computational and statistical methods and data storage, have facilitated large-scale collection of human genomic, cognitive, behavioral, and brain-based data. As relevant technologies have become more widely disseminated and less costly, datasets have become progressively larger and more informative. For example, technologies for studying the central nervous system, approaches such as genome-wide association studies (GWASs), genome sequencing, and initiatives such as the Human Connectome Project have begun to yield large databases that are more widely used than ever. Such databases make it possible to characterize and make probabilistic predictions about individuals by imputation from studies of large populations. Several ongoing research efforts, such as the Brain Research through Advancing Innovative Neurotechnologies (BRAIN) Initiative and the European Human Brain Project, are strong catalysts for the development of the next generation of methods for observing the brain and for making experimental and therapeutic interventions. The next decade promises a burgeoning use of these neurotechnologies.

The rapid development of neurotechnologies and associated databases has been mirrored by an increase in attempts to introduce neuroscience and behavioral genetic evidence into legal proceedings. Historically, the closest parallel to this kind of evidence has been the polygraph, which monitors peripheral consequences of nervous system activity to assess the veracity of testimony—and which is largely, but not entirely, excluded. Emerging neurotechnologies promise increased access to evidence obtained from the central nervous system and thus to brain function associated with complex behaviors and cognitive characteristics. Indeed, neuroscience evidence obtained from emerging neurotechnologies conceivably might be used by law enforcement, the courts, regulatory agencies, and others as factors in predicting dangerousness, assessing competence to stand trial, assessing volitional control over actions, revealing mitigating factors relevant to sentencing, predicting recidivism, distinguishing pain from malingering, verifying intent, and manipulating memories.

To better understand the potential impact of emerging neurotechnologies on the legal system, the Forum on Neuroscience and Nervous System Disorders, in collaboration with the Committee on Science, Technology, and Law (CSTL), will plan and conduct a 1-day public workshop bringing together leaders from academia, judicial and law enforcement systems, industry, government and regulatory agencies, nonprofit foundations, and other stakeholders to explore and advance efforts to identify and evaluate the potential effects of emerging neurotechnologies on the legal system.

Workshop Objectives:

- Provide an overview of some state-of-the-art neurotechnologies relevant to the legal system, and the use and impact of neuroscience evidence in the legal system.
- Explore emerging neurotechnologies—including methods for observing or manipulating the central nervous system and the genetics of cognition and behavior—and their potential implications and use by law enforcement, the courts, administrative proceedings, regulatory agencies, and others.
- Consider the potential use of behavioral genetics based on large genetics databases and by the legal system.

- Discuss the ethical and societal considerations associated with the use of neuroscience evidence in criminal, administrative, and other judicial proceedings.
- Highlight topics at the nexus of emerging neurotechnologies and the law for further study, such as potential opportunities for developing standards and procedures for using evidence from emerging neurotechnologies in the legal system and identifying potential stakeholders across sectors that may be affected by this multidisciplinary area.

WELCOME AND INTRODUCTION

8:00 a.m. **Overview of the Workshop**

Scientific Advances
STEVEN E. HYMAN, Broad Institute of Massachusetts Institute of Technology and Harvard University (CO-CHAIR)

Legal Developments
HENRY T. GREELY, Stanford University (CO-CHAIR)

8:40 a.m. **Discussion**

SESSION 1: CUTTING-EDGE NEUROSCIENCE AND NEUROTECHNOLOGIES AND THE LEGAL SYSTEM—CASE STUDIES

Session Objectives:

- Explore case studies of innovative neurotechnologies and cutting-edge neuroscience that are of great interest for use in various legal settings, including, for example, police investigation, suppression hearings, administrative proceedings, and settlement negotiations.
- For each case, discuss current use and what would be needed to appropriately use these neurotechnologies in legal settings in the future.

8:50 a.m.	**Session Overview** JOSHUA SANES, Harvard University (MODERATOR)
9:00 a.m.	**Presentations**
	Detecting Deception JOSHUA BUCKHOLTZ, Harvard University
	Can Brain Identify Pain? TOR WAGER, University of Colorado Boulder
9:30 a.m.	**Discussion**
9:45 a.m.	***Break***
10:00 a.m.	**Presentations**
	Mind Reading JACK GALLANT, University of California, Berkeley
10:30 a.m.	**Discussion**
10:45 a.m.	***Break***
11:00 a.m.	**Presentations**
	Electrophysiology Measures in Perception and Recognition ADRIAN NESTOR, University of Toronto
	Contribution of Genetics to Behavioral Prediction BENJAMIN NEALE, Broad Institute of Massachusetts Institute of Technology and Harvard University
11:30 a.m.	**Discussion**
11:45 a.m.	***Lunch***

SESSION 2: THE LANDSCAPE OF EMERGING NEUROTECHNOLOGIES—ANTICIPATING THE NEXT 20 YEARS

Session Objectives:

- Describe specific neurotechnologies and methods in conceptual or early stages of development and assess their projected paths for growth and implementation over the next 20 years.
- Evaluate the potential utility of emerging neurotechnologies for collecting evidence and information for use in the legal system, including out-of-court settings.
- Identify the challenges for developing scientific standards for use of evidence obtained from these technologies.

12:50 p.m.	**Session Overview** KHARA RAMOS, National Institute of Neurological Disorders and Stroke (MODERATOR)
1:00 p.m.	**Presentations** **Closed-Loop Brain Stimulation** AYSEGUL GUNDUZ, University of Florida **Understanding the Neural Basis of Volitional State Through Continuous Recordings in Humans** SYDNEY CASH, Massachusetts General Hospital/Harvard University
1:40 p.m.	**Discussion**
2:00 p.m.	***Break***

SESSION 3: DEVELOPING A FRAMEWORK FOR USE OF EVIDENCE FROM EMERGING NEUROTECHNOLOGIES—A WAY FORWARD

Session Objective:

- Brainstorm potential approaches to establishing frameworks and standards for using neuroscience evidence, in anticipation of the burgeoning use of neurotechnologies in the coming decades.

2:15 p.m. **Session Overview**
CHIEF JUDGE PATTI SARIS, U.S. District Court for the District of Massachusetts (MODERATOR)

2:25 p.m. **Presentations and Reflections**
DAVID FAIGMAN, University of California, San Francisco
FRANCIS SHEN, University of Minnesota
JUDGE BARBARA HERVEY, Texas Court of Criminal Appeals
JUDGE NANCY GERTNER (Ret.), Harvard Law School

3:45 p.m. **Moderated Discussion**

4:20 p.m. **Q&A**

SUMMARY AND CLOSING REMARKS

4:30 p.m. HENRY T. GREELY, Stanford University (CO-CHAIR)
STEVEN E. HYMAN, Broad Institute of Massachusetts Institute of Technology and Harvard University (CO-CHAIR)

5:00 p.m. ***Adjourn Workshop***

C

Registered Attendees

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National Institute of Neurological Disorders and Stroke

James Adams
Azusa Pacific University

Susan Amara
National Institute of Mental Health

Amanda Ampey
University of Wisconsin–Madison

Bryan Ampey
National Institutes of Health

Rachel Anderson
American Association for the Advancement of Science

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CRD Associates

Tiana Arroyo
Dedicated Donor Call

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Lee Herring
Strategic Science Communications

Barbara Hervey
Texas Court of Criminal Appeals

Ramona Hicks
One Mind

Megan Hoffman
Charter School District in Philadelphia

Nina Hsu
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Lord Anthony Hughes
The Supreme Court, United Kingdom

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