LAW AND THE REVOLUTION IN NEUROSCIENCE: AN EARLY LOOK AT THE FIELD

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This piece is a lightly cleaned-up version of the keynote address I delivered at the University of Akron School of Law's Neuroscience, Law & Government Symposium. It was intended, at the symposium, as one attempt at an overview of the field and remains such in this publication. It is only lightly footnoted, mainly with references to specific studies or cases discussed in the text or to other pieces I have written, where more complete discussions, and citations, can be found.[1]

Look at my sweater. How many colors does it have? Listen to my voice. Am I a tenor, or a baritone or a bass? Feel the chair. Think about the feeling of the chair on your back and your bottom and now twitch the big toe on your right foot. Now ask yourself, what is the speaker doing here?[2]

The short answer is that I am trying to demonstrate the most fundamental and unsettling reality pushing the field of law and neuroscience. Everything that you just perceived, saw, heard, felt, or

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1. Several years ago I published two other pieces that provide some overview of these issues, although, for various reasons, I prefer the organization in this piece to that of the earlier discussions. *See* Henry T. Greely, *The Social Consequences of Advances in Neuroscience: Legal Problems; Legal Perspectives, in* NEUROETHICS: DEFINING THE ISSUES IN THEORY, PRACTICE, AND POLICY 245-63 (Judy Illes ed., 2006); Henry T. Greely, *Prediction, Litigation, Privacy, and Property: Some Possible Legal and Social Implications of Advances in Neuroscience*, *in* NEUROSCIENCE AND THE LAW: BRAIN, MIND, AND THE SCALES OF JUSTICE 114-56 (Brent Garland ed., 2004).

2. This introduction made more sense during the live delivery of these comments. For some of this list of requests, you readers will just have to use your imaginations—which also exist only because of the firings of your neurons.

contemplated—as far as we can tell it is all neurons giving off and taking up neurotransmitters. And that's it. The entire universe that exists within each of our skulls seems to be the product of these electrochemical reactions. That's all. It is a daunting vision and one that has taken me a long time to accept. But I have ultimately become convinced of its truth, largely because there doesn't seem to be any place for anything else to be. Certainly modern neuroscience works on the premise that our minds, our thoughts, our perceptions, our emotions, our beliefs, our actions, are all generated by our brains, by the roughly 100 billion physical neurons and their several hundred connections (or synapses) per neuron.

This is important today because we are in the middle of a revolution in neuroscience. Compared to 30 years ago, we know almost infinitely more about how the human brain works. Compared to 30 years from now, most neuroscientists think we know basically nothing. We are on the steepest part of the learning curve about how the human brain works. This revolution in neuroscience, like all scientific revolutions, is really a revolution in tools. Sometimes the tools are physical, sometimes they are conceptual. Magnetic resonance imaging (MRI) machines are tools. Genetic analysis is a tool. Statistical methods are tools. Those and other tools are giving us the ability, for the first time, to look inside living, healthy human brains and to see what is happening. And they are giving us the chance to begin to correlate the physical states of the brain, revealed by these tools, with the states of the mind that are produced by those activities.

The most important word in that last sentence was "begin." We are not nearly there yet in terms of the depth of our understanding, but we are moving inevitably in the direction of a much greater understanding of how the brain works, of how the brain creates the mind, and of the correlation between particular physical states in the brain and mental states. This, I submit, will be enormously important to our society. We are social creatures. We live in packs, we live with each other, and a large part of what we do with our brains is try to figure out what others are thinking, feeling, and planning to do. Our society is built on our understandings of the human brain as reflected in our expectations for what people will do. Soon we will be better able to understand, in new ways and using new tools, what people are thinking, planning, or doing.

This will be particularly important for the law, because although the law may seem to be concerned about bodies, it is actually usually concerned about brains, or at least about minds. If my fist were to make forceful contact with Judge Rakoff's chin, I might or might not be in legal trouble. It could matter whether I had been thrown from a car after somebody had negligently run into our car, or if I were having an epileptic seizure at the time, or if we had gotten into an argument about the Yankees and tempers flared. All that can make a difference. The law is usually worried about individuals' motives, purposes, intentions, knowledge, and other mental states, in addition to their actions.

So knowing more about brains—and as a result being able to know more about minds and mental states—may fundamentally change, in important ways, the legal system of the United States and every other country in the world. I do not think that neuroscience will make the legal system dry up and blow away, although there are neuroscientists who (nearly) claim that. I do believe that it will change it in important ways. So what I would like to talk about in the next few minutes is the ways in which I think neuroscience is likely to affect the law. I can guarantee two things: first, that some of the things I tell you about won't happen, and second, that some things I don't tell you about (because I haven't imagined them) will happen. We are in a stage of such uncertainty in the face of rapidly increasing knowledge, that all we can really be certain about is the uncertainty of our ability to predict the future. Actually, it is very easy to predict the future; it is just hard to be right, so take my guesses with a grain, or a boulder, of salt. My humble prediction is that the following five areas will be the most important intersections of law and neuroscience: prediction, mind reading, responsibility, treatment, and enhancement.

PREDICTION

Let's start with prediction. I suspect that some people in this room are fifty-five or over. We are now able with various neuroimaging techniques, particularly MRI and positron emission tomography (PET) scans to look into the brains of healthy living people and see to what extent their neurons are coated with a little protein called beta amyloid 42, forming amyloid plaques. Alzheimer's disease, that terrible thief of memory and ultimately of conscious awareness, is defined pathologically as a dementia in which the dead and dying neurons of those affected are covered with amyloid plaque on their outsides and contain tangled masses of another protein, called "tau," in their interiors. We still are not sure whether amyloid plaque causes the disease or is just a side effect of the disease, but we do know that if you've got Alzheimer's disease, you have amyloid plaque. We can now take healthy 55 year-olds, look at their brains and say "Ah, this man has a lot of amyloid plaque, this woman has only a little amyloid plaque, and this person's amyloid plaque is in the frontal lobe or the temporal lobe or the parietal lobe."

We cannot yet say what the chances are that someone with a given amount of amyloid plaque at age 55 will have Alzheimer's disease at age 65. But in a few years we should be able to say that, because researchers are several years into studies predicting future Alzheimer's disease from earlier levels of amyloid plaque. (There is also neuroimaging research into trying to detect and quantify the presence of tau tangles.) Now assume we can make good predictions of future Alzheimer's disease from present plaque build-up. What should we do? Should we start testing people? Should we test, for example, nominees for the federal bench? What about presidential candidates? Long-term care insurers are likely to be interested in peoples' level of amyloid plaque build-up. Should we allow those insurers to require such testing, to require applicants to disclose if they have been tested, or to use such test results in deciding when to issue insurance? Long-term care insurance is not covered by the new federal Genetic Information Nondiscrimination Act,[3] but, of course, even if it were, this is not genetic information but neuroimaging information.

A whole set of ethical, legal, and social issues have arisen from genetic testing.[4] All or almost all of those issues will appear again if we are able to predict (with reasonable accuracy) serious neurological disorders like Alzheimer's disease or Parkinson's disease or any of a variety of other nasty diseases. We will have questions of when we do and do not want to use such predictive testing, questions of discrimination, questions of privacy, and a host of other concerns

Now consider the possibility that we could predict some other brain-based problems. Of the roughly 4 million 12-year-olds living in the United States today, about 30,000 of them will, sometime within the next 15 years, be diagnosed with schizophrenia, a terribly disabling and dehumanizing disease. Nearly one percent of the adult population ends up with schizophrenia, so almost one percent of those 12-year-olds will

3. Pub. L. No. 110-233, 122 Stat. 881 (2008).

4. *See* Henry T. Greely, *Genetic Testing for Cancer Susceptibility: Challenges for Creators of Practice Guidelines*, 11 ONCOLOGY 171 (1997); Barbara A. Koenig et al., *Genetic Testing for BRCA1 and BRCA2: Recommendations of the Stanford Program in Genomics, Ethics, and Society*, 7 J. OF WOMEN'S HEALTH 531 (1998); Laura McConnell et al., *Genetic Testing and Alzheimer's Disease: Has the Time Come?*, 4 NATURE MEDICINE 757 (1998); Laura M. McConnell et al., *Genetic Testing and Alzheimer's Disease: Recommendations of the Stanford Program in Genomics, Ethics, and Society*, 3 GENETIC TESTING 3 (May 1999) (special issue of eighteen articles stemming from PGES 1997 project).

be diagnosed with it—but we don't know which one percent. What if we did? Neuroscientists are looking for various differences in the structure and functioning of the brains of people who have schizophrenia from the brains of people without the disease. A next step could be to look at a broad swath of 12-year-olds and study them prospectively, to see if the researchers can distinguish early differences in the brains of those who will get schizophrenia from those who will not. The research would not necessarily be for the purpose of prediction, but would be in order to understand the course of the disease better, to develop preventive measures, and to identify affected people to begin intervention early. This approach might or might not work, but if it did provide accurate predictions, what will we do with those predictions?

My freshman dorm included one classmate I believe was schizophrenic—at least, he had auditory hallucinations. One Saturday night he ran screaming from his room complaining that his roommate was playing the stereo too loud—but no music was playing. He did not have a good university experience, nor did his roommate, nor did the people around him in the dorm. Should universities test people for their risk of schizophrenia, leaving aside for a moment issues of the Americans with Disabilities Act?[5] Should the military test recruits for schizophrenia? People with schizophrenia are not much more likely to commit violent crimes than anyone else, but one still might not want somebody to have an assault weapon in his hands when he has his first psychotic episode. Similarly, should the police be able to test recruits for schizophrenia?

We seem to operate with a presumption that knowledge is always good, a view to which academics may be particularly prone. But knowledge can harm people as well as help them. I don't know whether we will be able to predict Alzheimer's disease or schizophrenia, but I am confident that we will soon be able to predict, with a high degree of accuracy, some neurological and mental illnesses. Then we will have to answer the question, "What do we do now?" Laws on testing, discrimination, privacy, and other issues will necessarily feature in our answers.

But let's get back to the legal system itself. What if we could predict violent behavior? Well, we actually can predict violent behavior. There is at least one strong genetic predictor of violent behavior. People with Y chromosomes are much more likely to behave violently that those without Y chromosomes. But the fact that men are much more

5. 42 U.S.C. §§ 12101-12134 (West 1990).

violent than women in their criminal behavior is not all that helpful for the legal system. What if we could get better results by looking not at the genes, but by looking at mental patterns?

Professor Kent Kiehl, a colleague in the Law and Neuroscience Project, is very interested in psychopaths.[6] He estimates that psychopaths make up one to two percent of the general population, but fifteen to twenty-five percent of the prison population.[7] "Psychopath" does not necessarily mean Hannibal Lecter, eating human liver with Chianti and fava beans. Research into "psychopaths," as a subset of those with antisocial personality disorder, has been spearheaded by Dr. Robert Hare of the University of British Columbia. Hare developed a checklist of twenty questions that is widely used to detect psychopathy based on a person's traits and history.[8] He defines a psychopath based on a lack of empathy or concern for others.[9] Psychopaths are extraordinarily self-centered, very glib, charming, and, usually, good liars.[10] The two murderers in Truman Capote's "non-fiction novel" *In Cold Blood*[11] would probably have scored very high on the Hare psychopathy checklist.

Kiehl is doing functional magnetic resonance imaging (fMRI) scans of hundreds of prisoners, looking for brain features that distinguish psychopaths from other prisoners.[12] What if you could do a brain scan and determine to a high probability whether a criminal defendant was a psychopath, with, for example, a 60-70 percent chance of recidivism within five years instead of only 20-30 percent? Would that make a difference to a judge or a jury? What if you were a juror in a capital case in the sentencing phase? Would you want to know if someone is a psychopath or not if it affects his odds of committing another murder? How would we want to use that information? Go back to my 12-year-olds. What if you can say that these particular 12-year-olds will be psychopaths while the others won't be? What do you do with the children you are confident will be psychopaths?

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6. For an interesting profile of Kiehl and his work, see John Seabrook, *Suffering Souls: The Search for the Roots of Psychopathy*, THE NEW YORKER, Nov. 10, 2008, *available at* http://www.newyorker.com/reporting/2008/11/10/081110fa_fact_seabrook.

7. *See* Seabrook, *supra* note 6.

8. *See* ROBERT D. HARE, THE HARE PSYCHOPATHY CHECKLIST—REVISED 1-2 (1990).

9. *Id.*

10. *Id.*

11. TRUMAN CAPOTE, IN COLD BLOOD: A TRUE ACCOUNT OF A MULTIPLE MURDER AND ITS CONSEQUENCES (1966).

12. Seabrook, *supra* note 6.

Of course, this depends, in part, on how good the test is, both in terms of its specificity (avoiding false positives—people it identifies wrongly as psychopaths) and its sensitivity (how well it avoids false negatives—people it identifies wrongly as not psychopaths). The test looks better if it is 99.9 percent specific and sensitive than if it is 80 percent specific and sensitive. And, no matter how good the test is, part of us rebels at the idea of doing something to somebody who hasn't done anything wrong yet. On the other hand, who wants to be the person who has to tell grieving family members that "we knew this guy was going to do something bad to somebody, but we couldn't intervene until he acted. We're sorry the victim was someone you loved."

If we can identify with great confidence future violent criminals, either before or early into their criminal careers, our society will have hard questions to answer about what we do with that information. I would note that society's action would not necessarily be to lock someone up and throw away the key. There are intermediate positions—treatment of some sort, a GPS bracelet, warning the neighbors, increased surveillance, or other steps. These may or may not work, but it is important to remember that intervention need not be all or nothing.

It certainly is not clear whether neuroscience will ever be able to make such confident predictions, or that it will be able to add to and improve the predictive factors we already use—in juvenile justice, in the exercise of prosecutorial discretion, or in sentencing or parole decisions. It does provide a different kind of information for use in prediction, which may or may not prove valuable. The general point remains: if neuroscience can help us improve our predictions of people's future behavior and future mental characteristics, whether it is neurological disease, mental illness, criminal behavior, or some other socially aberrant behavior, we will have to decide when and how to use that increased ability to predict. And that will be a real challenge.

MIND-READING

We all read minds; we read minds all the time. Humans are social animals, and reading the minds of other humans is very important to us. We want to know whether this person is going to take a swing at us or hand us a glass of wine. And if he does hand us a glass of wine, we want to know if it is because he wants us to get drunk and make fools of ourselves or because he is just being friendly. People who cannot read minds are at a huge disadvantage. It is thought that one aspect of autism is the inability to put oneself in another person's place.

We know we read minds all the time, but we also know that we don't do it perfectly—otherwise, poker could not exist and dating would be quite different. Neuroscience can already help us read minds better. In March 2008 I organized a panel at Stanford for Brain Awareness Week and, somewhat provocatively, called it "Reading Minds." I thought the scientists on the panel would complain about the title, but, in fact, they said "yes, we do that all the time." Their reaction was partly a result of the brain areas they study: the visual system and the motor system. In these two areas our ability to use neuroimaging to "read minds" is unusually advanced, thanks in large part to functional magnetic resonance imaging.

Functional magnetic resonance imaging uses an MRI machine (or "scanner") to look for changes over time in the ratio of oxygenated to de-oxygenated hemoglobin in the brain.[13] The scanner will measure this ratio in thousands of cubic areas, called "voxels," each a few cubic millimeters in size. These measurements become potentially important because of the "BOLD" hypothesis. BOLD stands for Blood Oxygen Level Dependence; the BOLD hypothesis is that areas of the brain where the neurons have recently "fired" will see, a few seconds after the firing, an influx of fresh, more highly oxygenated blood. This signal can then be used to assess what brain regions are active during various mental activities, by having people in a scanner see, hear, do, move, or think about something and then, a few seconds later, see which of the voxels had an increase in the ratio of oxygenated to de-oxygenated hemoglobin. The signals are noisy, the statistical methods are controversial, and even the underpinnings of the BOLD hypothesis are questioned—but fMRI is nevertheless leading the revolution in neuroscience by showing us something, in a safe and non-invasive way, about the workings of living human brains.

Early this decade, Nancy Kanwisher from MIT did a fascinating mind-reading experiment involving the visual system.[14] She put people in the scanner and showed them pictures of either famous faces or familiar places, randomly assorted.[15] They would see an image on a

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13. There are many descriptions and discussions of how fMRI works. I often refer people to John C. Gore, *Principles and Practice of Functional MRI of the Human Brain*, 112 J. CLIN. INVEST. 4 (2003). This article is relatively short and, though occasionally taxing, should be accessible to lawyers. It has the advantage of discussing experiment design issues and not just the physical basis of fMRI.

14. *See* Kathleen M. O'Craven & Nancy Kanwisher, *Mental Imagery of Faces and Places Activates Corresponding Stimulus-Specific Brain Regions*, 12 J. COG. NEUROSCIENCE 1013 (2000).

15. *Id.* at 1014-17.

screen inside the scanner for a few seconds, then a few seconds of darkness, then another, randomly chosen, face or place—over and over for many minutes.[16]

Kanwisher had earlier helped identify an area in the brain called the "fusiform face area" that "is activated" or "lights up" (gets a slightly higher ratio of oxygenated to de-oxygenated blood) several seconds after the person sees a picture of a face. The fusiform face area is itself somewhat controversial, with some evidence that it is activated whenever a person sees something of a kind that he usually examines in detail (a car collector and a picture of a vintage car, for example). But we all pay close attention to faces. As social animals we spend a great deal of time and effort trying to read others, mainly by reading their faces.

In her experiment, Kanwisher was able, with nearly perfect accuracy, to tell when the people in the scanner were seeing pictures of faces and when they were seeing pictures of places by examining whether, a few seconds after the picture was flashed on the screen, the subjects' brains showed activation in the fusiform face area.[17] (She also identified what she calls the parahippocampal place area, which she argues is differentially activated when people see places.[18])

She took the experiment another step and, without showing the subjects images of anything, asked them to visualize, to themselves, either a face or a place.[19] Her accuracy went down, but she was still able to tell over 80 percent of the time whether a person was visualizing—was thinking about—a face or a place.[20] This surely is some form of mind-reading.

More recently, in January 2008, a group from Carnegie Mellon came out with a study where they showed people primitive line drawings of objects.[21] The objects were five different tools—a drill, a hammer, a screwdriver, pliers, and a saw—and five different buildings—an igloo, a hut, a house, a castle, and an apartment.[22] The group was able, with about 80 percent accuracy, to tell not just when each subject was seeing a tool or a building, but which tool and which building the subject was

16. *Id.* at 1020-21.
17. *Id.* at 1014-19.
18. *Id.* at 1013-14, 1017-19.
19. *Id.* at 1014, 1017.
20. *Id.* at 1017.
21. Svetlana V. Shinkareva et al., *Using fMRI Brain Activation to Identify Cognitive States Associated with Perception of Tools and Dwellings*, 3 PLoS ONE 1 (2008), *available at* http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0001394.
22. *Id.* at 1.

seeing.[23] On the visual side, then, we are making real progress in some forms of mind reading, although it is hard to see the legal application of these methods. It is difficult to imagine a situation where someone might use expert testimony as to whether a witness, while in a scanner, was seeing or thinking about a face or a place, a drill or an igloo. Nevertheless, it is a proof of principal, at least in one brain system.

As to motion, we also know what parts of the brain are activated when somebody is about to move some part of his or her body. A great deal of research is ongoing with people who are quadriplegic or otherwise unable to move in an effort to read their minds. One possible application would be to read the mind to determine, for example, that the subject wanted to move his right arm and then use that information to move a prosthetic right arm.

This is hard work to do, at least in humans. To get the necessary level of detail about neuron activation, most researchers are implanting microelectrode arrays in the subjects' brains. This kind of invasive research can make both the subjects and IRBs, the "institutional review boards" that oversee human subject research, nervous. Much of the work, therefore, is going on in monkeys. Monkeys become quite good at moving prosthetic arms by thinking about moving them—at least as long as they are adequately rewarded with apple juice or other monkey treats. The monkeys are not paralyzed, but they will have an arm immobilized during the experiment. When they think about moving their arm as necessary to get the reward, the pattern of their neuronal firings can be used to move a prosthetic arm. We are, at least in the motor system, reading human and monkey minds to determine when and where they want to move their arms.

This research has much greater practical application than being able to figure out whether someone is thinking of a face or a place. Hundreds of thousands of people with severe movement limitations may be able to will themselves to move using this sort of mind reading. Although this could have wonderful medical implications, again, it seems unlikely to be important in the legal system. So consider the three possible legal applications: pain, bias, and deception.

Pain is a ubiquitous subject of dispute in the American legal system.[24] It is not high profile, it is not sexy, and it does not appear

23. *Id.* at 3-7.

24. For a good discussion of some of the issues raised by neuroimaging for pain, see generally Adam J. Kolber, *Pain Detection and the Privacy of Subjective Experience*, 33 AM. J.L. & MED. 433 (2007). Stanford's Center for Law and the Biosciences held a conference on this subject on December 4, 2008, from which a publication should ultimately be forthcoming.

often in the United States Supreme Court or the Harvard Law Review, but the existence and extent of pain figures into hundreds of thousands of legal disputes every year in the United States, whether lawsuits for personal injury or administrative proceedings (and judicial appeals) over workers' compensation or Social Security disability. We are confident that some of those complaining of pain are exaggerating and that some are flat-out lying. Once in a while, defense counsel gets lucky and an investigator films claimants jumping up and down on a trampoline when they are supposed to be in intense pain. That kind of evidence is rare and in many cases there are not very good ways to tell whether someone truly is feeling pain.

But, of course, pain is in the brain. If I pinch the back of my left hand, my hand hurts but only because parts of my brain interpret signals from my hand as painful. Parts of the brain that keep track of sensory input from particular regions (the primary and secondary somatosensory cortices) will react, helping me localize the sensation to the back of my left hand, but the sensation of pain—the "ouch"—seems to be related to activation in other brain regions. Some researchers have identified what they call a pain matrix that includes at least three other brain regions: the anterior cingulate cortex, the insula, and part of the thalamus. What if we could use the pain matrix to detect when somebody is really in pain or not? It could help resolve hundreds of thousands of legal disputes through quick settlement, not only detecting those who are malingering but also accurately identifying those who really are feeling pain.

Bias is a second area where the law might be interested in mind-reading through neuroscience. The Sixth Amendment to the Constitution guarantees criminal defendants "an impartial jury."[25] But, at this point, that only guarantees the defendant a "not demonstrably partial" jury. It means that the lawyers and the judge can remove prospective jurors for expressed bias or for an open history of bias, but we all suspect that sometimes people are biased and will not admit it. What if we could look into somebody's brain and decide whether they were biased against a particular defendant? One could imagine a "neuro-voir dire," where potential jurors are put in a scanner and shown images relevant to a possible bias in the case—a bias against African-Americans, against men, against Catholics, against the police, or whatever other category might be relevant to the particular case. Their brains' reactions could then be examined for signs of bias.

25. U.S. CONST. amend. VI.

Researchers are already looking for correlations between brain activation and bias. The work is sometimes presented in very simplistic way. For example, one might say that seeing pictures of one group of people causes activation in a subject's amygdala, which is associated with fear, and so therefore that subject fears that group of people. But the amygdala is also associated with emotions other than fear, so these kinds of simple associations need to be examined critically. But some researchers are examining brain activation and bias in a rigorous way, including Elizabeth Phelps at New York University.[26] They may (or may not) be able eventually to say with a high degree of confidence that a particular person is biased against some other people. If so, what follows?

Could a lawyer introduce an fMRI analysis of the defendant in an employment discrimination case to show bias? Could criminal defense counsel compel an fMRI examination of the arresting police officer on the basis of the defendant's assertion of bias? Will we allow, or even require, neuro-voir dire? One can even imagine—barely—a brave or foolish lawyer who, expecting to lose at the trial level, demands a brain scan of the trial judge, in the hopes of proving bias against her client.

Deception is a third legally relevant category and one that is particularly timely now. Can neuroimaging determine whether or not someone is lying? In the fall of 2007, Dr. Judy Illes and I published a long article on neuroscience and lie detection.[27] We reviewed every published peer-reviewed article we could find about using fMRI for lie detection.[28] We found 12 through March 2007;[29] there are now about 16. Our conclusion was "not proven."[30] This kind of lie detection may turn out to be valid and reliable or it might not, but we argue strongly that it has not been proven to work yet. But at least two companies are already selling fMRI-based lie detection in the United States. Give them $4,000 or $5,000 and they will scan you and tell you whether they think you are lying—and, if you want them to, they will tell the world their results.

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26. *See*, *e.g.*, Elizabeth A. Phelps et al., *Performance on Indirect Measures of Race Evaluation Predicts Amygdala Activation*, 12 J. COG. NEUROSCIENCE 729 (2000).

27. Henry T. Greely & Judy Illes, *Neuroscience-Based Lie Detection: The Urgent Need for Regulation*, AM. J.L. & MED. 33, 377 (2007). *See also* Henry T. Greely, *Neuroscience-Based Lie Detection: The Need for Regulation*, American Academy of Arts and Sciences (forthcoming 2009); Henry T. Greely, *Premarket Approval Regulation for Lie Detection: An Idea Whose Time May Be Coming*, AM. J. BIOETHICS, Mar.-Apr. 2005, at 50.

28. *See* Greely & Illes, *supra* note 27, at 394-405.

29. *Id.* at 394.

30. *See id.* at 402-05.

Society will first have to decide whether this works and then, if it does work, how we want it used. Do we want its use regulated? Do we want employers to be able to use it? What about schools or parents? Do we want the police, FBI, or intelligence community to be able to use it? Does it matter if it is voluntary or involuntary? Should we allow its involuntary use with a court order—a search warrant for the brain? Could it be used in court, and, if so, when and how? Does courtroom use of fMRI-based lie detection raise questions about the privilege against self-incrimination? Are brain scans "testimonial" in nature or, like blood tests or x-rays, "physical" measures? If the technology is proven sufficiently effective (whatever that may mean), lawyers and judges will have to grapple with these kinds of questions; so will legislators and citizens. And, of course, we will first have to decide whether these methods are "sufficiently effective," and how we should assess that effectiveness. Inaccurate lie detection clearly cannot be a good thing.

In none of these three areas—pain, bias, or deception—is neuroimaging yet able to read minds reliably. That may soon change. In all of these and other areas that I have not mentioned or imagined, our society and legal system will have to decide whether, when, and how to use this kind of mind reading.

RESPONSIBILITY

I have neuroscientist friends who say neuroscience is going to prove that humans have no free will and that, as a result, our criminal justice system will dry up and blow away. I doubt it. Even if neuroscientists convince themselves that humans have no free will, I doubt they will be able to convince the rest of us. I am not sure we have the free will to truly believe, and act as if, we do not have free will. I predict we will continue to punish people as if they have free will. And, of course, we would still have a criminal justice system even if we did not believe in free will. We might not punish criminals for reasons of retribution, but we would still be interested in criminal punishment for purposes of specific deterrence, general deterrence, incapacitation, and (perhaps) rehabilitation.

Yet neuroscience may well affect our sense of criminal (and civil) responsibility in some cases. Robert Sapolsky, a Stanford neuroscientist, makes this argument forcefully using the example of Tourette's syndrome, a condition involving physical and verbal tics, including, most dramatically, coprolalia, the spontaneous utterance of socially objectionable words. He points out that two hundred years ago, people with those symptoms would have been arrested; five hundred years ago, they might have been burned at the stake. Now we know it is a disease and we do not punish, arrest, or convict Tourette's patients for this behavior.

Sapolsky's example is a good one, but I think it shows the likely limits of neuroscience for criminal responsibility. Neuroscience seems unlikely to lead to major changes in our view of criminal responsibility, but it will make a difference in some individual cases where it convinces us that the defendant truly and convincingly could not control his actions. Whether that means we treat him more leniently or more harshly is not clear, but we are likely, on occasion, to treat some defendants differently.

Consider one case, reported in both the Archives of Neurology and USA Today.[31] A middle-aged man in Virginia had led a normal life, without ever showing any deep interest in pornography.[32] In his early 40s he developed an interest in child pornography.[33] Shortly thereafter, he behaved inappropriately with his 12-year-old stepdaughter, inappropriately enough that he was arrested and convicted.[34] As a first-time offender, he was sent to a diversion program, but he failed the diversion program because he propositioned everyone he saw.[35] Having flunked out of the diversion program, he was scheduled to appear in court to be sentenced to prison.[36] The day before the scheduled court appearance, he went to an emergency room, complaining of a terrible headache.[37] He was admitted by the psychiatry service, which suspected a non-physical cause for his headache.[38] Eventually they sent him for an MRI scan—which revealed a benign tumor in his frontal lobe the size of a chicken egg.[39]

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31. Jeffrey M. Burns and Russell H. Swerdlow, *Right Orbitofrontal Tumor with Pedophilia Symptom and Constructional Aprxia Sign*, 60 ARCHIVES OF NEUROLOGY 437 (2003); *Doctors Say Pedophile Lost Urge After Tumor Removed*, USA TODAY, July 28, 2003, *available at* http://www.usatoday.com/news/health/2003-07-28-pedophile-tumor_x.htm.

32. Burns & Swerdlow, *supra* note 31, at 437.

33. *Id.*

34. *Id.*

35. *Id.*

36. *Id.*

37. *Id.*

38. *Id.* at 437-38.

39. *Id.* at 438.

Surgeons removed his tumor, and the man claimed to have lost all interest in pornography, child or adult.[40] He took the diversion program again and this time passed easily.[41] He was therefore not sent to prison, but attempted to rebuild his life.[42] About a year later, the man again developed a persistent headache and again began secretly collecting pornography.[43] Another CT scan showed that the tumor had grown back.[44] It was once again removed and he reported, again, that he had no more disturbing impulses.[45] And there the story ends, at least as far as we know.

If that's the defendant in front of you—as a prosecutor, a judge, or a parole board–what do you do with him? And why? This was not a neuroscience case; it was a case where the "external cause," if a tumor inside one's own skull can be called "external," is extraordinarily, though still not perfectly, clear. But I suspect neuroscience will give us more such cases, either in rare individuals or in unusual classes of people. If so, the law will have to decide how to handle such offenders.

TREATMENT

The explosion of knowledge about neuroscience has come about because of our interest in treatment. Money for neuroscience research, basic and applied, comes mostly from the National Institutes of *Health* (NIH). NIH is spending billions of dollars on neuroscience, through the National Institute of Mental Health, the National Institute for Neurological Disorders and Stroke, the National Institute on Aging, the National Institute of Child Health and Human Development, the National Institute on Drug Abuse, and, to a lesser extent, all of the other NIH institutes. Congress does not appropriate this money in order for neuroscientists to learn cool things, to get tenure, and to win prizes. It is being spent in the hope of improving human health. If it pays off, as I am confident it will to some significant extent, we will have better methods of prevention of and treatment for schizophrenia, bipolar disorder, depression, Parkinson's disease, Alzheimer's disease, and so on. And this will be a wonderful thing. But we may also develop

40. *Id.*
41. *Id.*
42. *Id.*
43. *Id.*
44. *Id.*
45. *Doctors Say Pedophile Lost Urge After Tumor Removed*, *supra* note 31.

treatments for other things, for criminal or other anti-social behavior, and those treatments could turn out not to be so wonderful.[46]

In 1949 a Portuguese neurologist named Egas Moniz won the Nobel Prize in medicine and physiology for his invention of a procedure that came to be known as the prefrontal lobotomy.[47] Within twenty years, his discovery was viewed as barbaric and its use nearly stopped, but, while it was popular, between about 1938 and 1962, about thirty-five to forty thousand Americans, and uncounted others, were lobotomized. I have found no evidence that anyone was given a lobotomy as part of a criminal sentence, though I would not be surprised if a lobotomy had been required on occasion as part of a plea bargain. There is plenty of evidence, though, that people have been and still are interested in physical interventions in the brain as treatments for criminal behavior.

In the 1960s, various researchers experimented with neurosurgery to stop criminal behavior. With the fall of the lobotomy, this kind of "psychosurgery" went out of fashion. Today, we are using a fascinating technology called deep brain stimulation.[48] In this procedure, an electrode is surgically inserted into a particular location in the patient's brain and turned on, prohibiting stimulatory (or inhibitory) electrical impulses to that region of the brain. Deep brain stimulation has been approved by the Food and Drug Administration (FDA) for a variety of uses, including the treatment of Parkinson's disease. One of my colleagues with Parkinson's disease has been helped enormously by this procedure.

Like other FDA treatments, deep brain stimulation (or, to be precise, the medical device used for deep brain stimulation) is approved as safe and effective for specific uses, but may be used by physicians for other, so-called "off label" uses. Deep brain stimulation is being tried (usually in the context of a research protocol) for a wide range of conditions, including control of violent behavior. Several studies from an Italian group have showed that deep brain stimulation in a particular region can stop, or at least limit, some kinds of violent behavior.[49] The

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46. *See generally* Henry T. Greely, *Neuroscience and Criminal Justice: Not Responsibility but Treatment*, 56 U. KAN. L. REV. 1103 (2008).

47. *See* Bengt Jansson, *Controversial Psychosurgery Resulted in a Nobel Prize*, Oct. 29, 1998, http://nobelprize.org/nobel_prizes/medicine/articles/moniz/index.html.

48. *See* Greely, *supra* note 46, at 1113-15.

49. *See*, *e.g.*, Angelo Franzini et al., *Stimulation of the Posterior Hypothalamus for Medically Intractable Impulsive and Violent Behavior*, 83 STEREOTACTIC & FUNCTIONAL NEUROSURGERY 63 (2005).

subjects in these studies were not "average" violent criminals; they were deeply developmentally disabled people who exhibited frequent, irrational violent behavior.[50] Someone, somewhere, however, may well make the jump from these subjects to violent criminals.

In fact, seven states in the United States currently require use of a technology that directly alters the brain as part of sentencing for some crimes. Of course, all of the states employ some less direct brain-altering technologies in sentencing—prison surely must change prisoners' brains.[51] But this technology makes chemical changes in the brains of some sex offenders that lead them to no longer think about sex.[52] The technology, commonly referred to as "chemical castration," involves the administration to male convicts of a drug called Depo-Provera.[53] This drug has been approved by the FDA for use as a female contraceptive, but it also blocks the release of testosterone in men.[54] Men who are treated with it (another "off label use") can sometimes have erections and even have orgasms and ejaculations, but they often report that they "just don't think about sex." Some convicts welcome this drug, because they feel tortured by their unwanted sexual urges, but the laws of those seven states make the administration of this brain-changing drug mandatory, not voluntary, in certain situations.[55]

There is a dark side to this drug. It is used in men at a much higher dosage than it is used in women for contraception. For women, though, it now has a "black box" warning, the highest kind of warning the FDA requires for drugs that it allows to remain in use. Use of Depo-Provera by women has been linked to decreased bone density, leading to the fear that its long-term use might lead to osteoporosis. What do the studies show about the long-term use of Depo-Provera, at much higher doses, in men? There seem to be no studies, so we don't know. Are we sentencing these men to a later life of terribly fragile bones? We don't know. And, as far as I can tell, we don't care. After all, these are sex offenders.

I worry about brain-based treatments for criminal behavior. Some such treatments may work well, and some may not, but they are aimed at

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50. *See id.*

51. Every experience changes your brain to some extent, in the short term or the longer term. Anyone who heard this talk, or who reads this article, and remembers anything about it does so because I have made some long-term physical and chemical changes in your brains.

52. *See*, *e.g.*, Larry Helm Spalding, *Florida's 1997 Chemical Castration Law: A Return to the Dark Ages*, 25 FLA. ST. U. L. REV. 117, 118, 122 (1998).

53. *Id.* at 120-22.

54. *Id.* at 122.

55. *See*, *e.g.*, FLA. STAT. § 794.0235 (1997).

people our society dislikes, if not loathes. Legislators, and the crime-worried public they represent, may well be willing to take risks with "criminals" that they would not allow for other people. We need to be careful to insist that any brain-based "treatments" for criminal behaviors are clearly demonstrated to be safe and effective.

ENHANCEMENT

I live near San Francisco, where the issue of performance enhancement has been closely associated with baseball star Barry Bonds. The use of performance enhancing drugs in sports has been extraordinarily controversial, sparking a backlash that might (or might not) be as strong as the players' drive to enhance. The ultimate outcome in sports remains, I think, unclear.

But we can do something similar to brains.[56] We already do. Do you, dear reader, use caffeine? It is a very useful temporary brain enhancer, at least for some people. Sometimes it has side effects, particularly at high doses, but most people find them tolerable. We have long used other "brain-affecting" drugs. Alcohol, for example, enhances some aspects of our brain's functioning and harms others. We have a variety of traditional foods, drinks, and drugs that we take in order to change how our brains are working in ways that we think, at least at the time, are improvements. What is changing is that we are getting better at it.

Adderall and Ritalin are drugs given to people, originally children or adolescents but increasingly adults, with Attention Deficit Disorder (ADD) or Attention Deficit Hyperactivity Disorder (ADHD). The drugs help these people concentrate better. It turns out that the same drugs also seem to help normal people—people who do not have ADD or ADHD—concentrate better. Every high school, college, medical school, or law school class I talk to about neuroscience includes students

56. I have written extensively about issues of human biological enhancement, in general as well as specifically about brain enhancement, genetic enhancement, and sports enhancement. My most immediately relevant article is Henry Greely et al., *Towards Responsible Use of Cognitive-Enhancing Drugs by the Healthy*, 456 NATURE 702 (2008). More generally, I suggest Henry T. Greely, *Regulating Human Biological Enhancements: Questionable Justifications and International Complications*, 7 U. OF TECH. SYDNEY L. REV. 87 (2005)/4 SANTA CLARA J. INT'L L. 87 (2006) (joint issue) (Stanford Pub. Law Working Paper No. 112, 2005), *available at* http://ssrn.com/abstract=846626 and Henry T. Greely, *Remarks on Human Biological Enhancement*, 56 U. KAN. L. REV. 1139 (2008). For some thoughts on enhancement in sports, see Henry T. Greely, *Disabilities, Enhancements, and the Meanings of Sports*, 15 STAN. L. & POL'Y REV. 99 (2004).

(usually quite a few students) who know people who have used Adderall or Ritalin for help in studying without having a prescription for the drugs.

This is brain enhancement. Adderall is a mixture of various amphetamines. It is not a benign drug and comes with some real dangers, as does Ritalin. But let's take the next step. There are a lot of drugs in development to try to improve memory, including some in phase 2 or 3 clinical trials. The drugs are aimed at people who are in the early stages of dementia or have other memory problems, including the baby boomers' increasingly common "age appropriate memory impairment." These drugs are in development and we do not yet know whether they will or will not work. Our rapidly increasing knowledge of human brains provides hope that some effective drugs will eventually be developed. If we make drugs that are effective in improving people with poorly working memory, will they also work for people with healthy memories? And, if so, what will we do?

For many years now, undergraduate organic chemistry has been a de facto gatekeeper for American medical schools. The course traditionally involves, among other things, memorization of many formulas, structures, equations, names, and so on. And a student's ability to memorize those things can determine whether he or she will have a chance to be a doctor, without any regard to how much organic chemistry doctors need or use. Would sophomore pre-medical students taking organic chemistry like a memory pill? Should we care whether they take memory pills? Should we care whether people cramming for the bar exam take memory pills? Should we care whether witnesses in court have taken a different kind of memory pill that helps them retrieve memories?

Or consider a different kind of brain enhancement, one that uses implants or connections between brains and computers as neuro-electronic interfaces (more commonly called brain-machine interfaces). Although this sounds like something out of Star Trek,[57] one such neuro-electronic interface has been clinically approved for almost 30 years now. The cochlear implant is used to treat forms of deafness where the auditory nerve is functioning normally but the mechanical part of the ear

57. It should sound like *Star Trek: The Next Generation*, to be specific. In its benign form, it is the vision-producing visor used by the character Geordi La Forge. In its scary form, it is the thorough integration used by the alien species, the Borg.

that stimulates the nerve is not working.[58] It turns a computer's analysis of sound into the appropriate stimulation of the auditory nerve so that deaf people hear. It is a neuro-electronic interface that works. Researchers are working on artificial retinas that would help the blind see by providing appropriate stimulation to their optic nerves.

The cochlear implant is used as a treatment for some people who do not have normal hearing. But it could also be used for enhancement. A cochlear implant should be able to allow its user to "hear" ultrasound or infrasound, including things like "silent" dog whistles. In Star Trek: The Next Generation, the chief engineer had a visor that stimulated his optic nerve and allowed him, blind from birth, to see. Although he normally used the visor for ordinary visible light, he could also set it for other types of electromagnetic radiation, such as infrared, ultraviolet, radio waves, or gamma waves, as well as various other forms of radiation that appear to exist only in the Star Trek universe. Depending on the nature of the artificial retinas we develop, we may well be able to do the same thing. As with enhancing drugs, various devices will be developed to treat human disease or disability but will provide the possibility of allowing people—the disabled or the "abled"—to go beyond the human norm. The possibility of human brain enhancement is real. It will, increasingly, happen. And we—"we" the legal system and "we" society as a whole—will have to decide what we want to do about it.

Personally, I think we should avoid applying to brain enhancement the kind of knee-jerk, negative reaction society has had to performance-enhancing drugs in sports. Perhaps this is because I am a teacher—my job is to enhance my students' brains, both by giving them more information and, as a law professor, by giving them a different way of using that information, a way we talk about as "thinking like a lawyer." That is my primary job.

Also, consider that, if two weightlifters are taking steroids, the world will neither long note, nor long remember, which one wins the gold and which one wins the silver. And the world will not be significantly improved if the record for a particular lift is 302 kilograms instead of 300. If one hundred scientists take cognitive enhancers, the world may well be better off because of discoveries that it would not have been made, or not made as quickly, without the enhancements.

58. For a fascinating discussion of cochlear implants from a patient's perspective, I recommend MICHAEL CHOROST, REBUILT: HOW BECOMING PART COMPUTER MADE ME MORE HUMAN (2005).

The question of brain enhancement raises a host of issues. I worry quite a bit about some of them, most notably safety, fairness, and coercion. Others worry about issues that do not trouble me in this context, primarily questions of naturalness and integrity. One way or another, though, because of the ongoing and accelerating revolution in neuroscience, we will have to grapple with all of these issues—and soon.

CONCLUSION

I have tried to group the main ethical, legal, and social issues raised by neuroscience into five categories: prediction, mind-reading, responsibility, treatment, and enhancement. There are other ways to categorize the issues, as well as a few other issues I could have raised. The key point, though, is that the revolution in neuroscience is giving us a much greater understanding of how our brains work, as well as the hope of better interventions to preserve, or improve, their functioning. Our brains make us the people we are; we care about them much more than we care about, say, our gallbladders. These changes in understanding the brain are therefore highly likely to affect society.

I have given you some examples of possible consequences. Some of them are likely to work, others will not, and others, as yet unmentioned or undreamt of, will come to pass. I would end with one note of caution. A few years ago, a British academic named Nikolas Rose tore into me in a hotel lobby for the way I was looking at the implications of neuroscience, particularly lie detection. He said (roughly) "you keep focusing on its implications for your constitution's First, Fourth, Fifth, Sixth, Seventh, and other amendments. But every time you talk about that, you make people think the technology will work, or, worse, does work." I started, reflexively, to defend myself and then realized that he was right.

People studying the ethical, legal, and social implications of neuroscience have to walk a tightrope. We have to worry about the implications if the technology does work, but we also always have to remember that there cannot be any good implications of using an ineffective technology. So we need to watch, and to talk about, both sides—the hypothetical future and the known present. We must always worry about how well this technology works now, under what circumstances, for what kinds of people, with what degrees of accuracy and confidence, and how we know those answers. But we must also ask, if it does work, what happens and what we could and should do about it. I believe—based more on faith than on empirical evidence—that if we pay attention to both sets of questions, we are likely to help our society maximize the benefits of these new technologies and minimize their harms. That, I submit, should be the main goal for all of us working in this field.

APPENDIX: QUESTION AND ANSWER SESSION

Q—Dean Martin Belsky: I want to take the Dean's privilege to ask a quick question. Are these issues the same as we hear about with gene mapping and genetic testing?

A: Some of them are and some of them aren't. Among the prediction issues, my Alzheimer's disease example maps perfectly onto genetic testing for Huntington's disease, except that it doesn't have family resonances that the shared family inheritance of genes provides. On the other hand, there really is no genetic equivalent to mind-reading. We can't look at your genes and say that you are thinking about a face or thinking about a place.

As for criminal behavior, Professor Nita Farahany, one of the speakers tomorrow, has written a lot about genetic prediction. There is a fair amount of interest in whether criminal behavior can be predicted or assessed genetically, and there are some interesting studies. Personally, I think the neuroscience route for predicting future violent behavior is likely to be less weak. I don't want to say "stronger" because both of them have big problems.

So in some areas there are genetic parallels, and in some areas they are completely different. I got into this field from law and genetics, originally because of the disease prediction issues. That looked very familiar, but then I realized that there were others issues, like lie detection, where there is no genetic equivalent. So some of the other things are different.

Q—Dean Belsky: Forty years ago when I studied this issue, the big thing was the XYY chromosome syndrome as a predictor of criminal behavior. And many years before that, people were looking at the shape and size of the cranium. Interest in these things as predictors of criminal behavior has died out as they have been disproven. Do you think some of these things will be disproved?

A: Yes.

Q—Dean Belsky: And do you think people will listen to their debunking?

A. Maybe. There are now literally thousands of peer-reviewed articles published every year about fMRI. Most of them will probably turn out to be either wrong or right but not very helpful. People have published articles on the brain site of romantic passion, the site of the nun's feelings of mystical union with God, the site of Tibetan monks' deepest level of meditation, the site of subtraction versus long division, and so on. Seriously, researchers have published on all of these things. Some of them will turn out to be right and some of them will turn out to be wrong. We don't know yet which will be which. I expect that some of it will work, although how accurately will be a key question.

The XYY chromosome syndrome is a nice example. Some of you may remember Richard Speck, killer of eight Filipino nurses in Chicago. He turned out to have two Y chromosomes and one X chromosome, where normal men have one Y and one X. It turns out that sex is more complicated than chromosomes. Some of us have odd sets, unusual pairings, or groupings of chromosomes. Some of us have one set of chromosomes, but some important genes are moved from one chromosome to another. So, in some circumstances, a person could actually be XY but a fully physiological female, or an XX and a fully physiological male.

In the 1960s, some researchers found that something like four percent of men in prison were XYY when it is only one in one-thousand males in the general population were XYY. Since the Y chromosome is "the male chromosome," people suspected that people with two copies of the Y would be "super males," very violent, very sexual, etc. After a great hullabaloo, it turned out that yes, more men in jail were XYY, but because XYY is also associated with lower intelligence. It costs a person about ten to twenty IQ points. People were there not for violent crimes but sorts of crimes that people who don't do very well in society often commit. The hypothesized link between XYY syndrome and violent crime was debunked, but it took a while. No one was sentenced or not sentenced on that basis but there was a lot discussion including in at least one Maryland Court of Appeals case about XYY.

That's why my main goal today is to say that, although this stuff is really interesting, we need make sure it works before we use it. Let's make sure we understand what it can and can't do. And, as a society, we don't do patience very well. The companies selling any new technology will have every incentive to make people think it is wonderful. The scientists who are doing the research, though bound by the norms of scientific honesty, will tend to believe in, and talk up, their own inventions—and will get more grants if their work is seen as exciting.

The media want stories that are headlined "Breakthrough!" They are not nearly as interested in a story laying out some interesting new finding of uncertain significance. That is what almost every honest science story really should say. Until a "discovery" has been replicated three or four times, don't believe anything about it other than that it may be provocative enough to justify further research. But, of course, since you are the dean, I will agree with you entirely, even though you are not *my* dean.

The key is to make sure the new technology works. We need to study it. Apart from new medicines, we don't have social gatekeepers for new technologies. Happily, in the courts, we have gatekeepers called judges, and they are often good, although perhaps not always, present company excluded. But we don't have those kinds of gatekeepers for the rest of society, and that worries me.

Q: The Dean asked my first question, but I have a couple of other questions. One is quick. As you mentioned that alcohol has enhancing and detrimental effects, I thought that it was only detrimental, and let me just give you the second question because it is more important . . .

A: Give me a glass of wine before I answer.

Q: There seems to be a lot of variation in how people's brains develop. Can you talk a little bit about how individualization in brain development will affect these technologies?

A: Great question. First, on alcohol, it depends on what traits you are thinking about enhancing. If you want to enhance your sociability, alcohol is arguably a potent enhancer. It may enhance other traits. After college I hung out at a bar with shuffleboard table. The first pitcher of beer made me play better, the second pitcher of beer made me *think* I was playing better, and the third pitcher of beer was definitely a problem. Alcohol enhances some things, to a point, and with some costs.

Your question about individual differences is actually crucial. Almost all of these studies are done with small *n*'s—a small number of subjects—because it is expensive to scan someone in an MRI—roughly a thousand dollars a head. So you get *n*'s of 8, 10, and 15. The biggest lie detection study I know of looked at 30 people. So the researchers don't have very many subjects, and they average the results for the ones they get. As of February 2007, twelve peer-reviewed articles had been published on fMRI-based lie detection. Nine of them only looked at group averages. These kinds of studies say, "On average, the brains of people experiencing something activate in this pattern." The fact that these are averages, however, means that there can be—and, in fact, always have been—some people with different patterns of activation. The move from group averages, which is what the science usually produces, to confident statements about individuals is going to be enormously difficult. We need a lot more research to be able to say what percentage of people activate in a particular pattern. Is it 98 percent, 80 percent, or 54 percent?

All brains are the same, just like all faces are the same. All brains are different, just like all faces are different. Every normal, healthy face has two eyes, two ears, a nose, and a mouth. Every normal, healthy brain has two hemispheres, each with a frontal, temporal, parietal, and occipital lobe. But, just as every face is a little different, every brain is shaped a little differently. Plus, every brain changes over time.

In fact, one of the trickier issues about neuroscience research concerns brain-scan databases. You can identify individuals from their brain scans. Everyone's scan—like everyone's brain—is slightly different. Researchers are putting together big databases of brain-scan results. If you've got the big research database with a lot of brain scans and other information in it and you have access to another MRI of someone who you know is in the database (a clinical MRI or another research MRI), you can find the person in the database by comparing the identified scan with the scans in the research database. You already had the brain scan, but now you have access to all the other information about that individual that is found in the research database. You can also reconstruct some of the facial structure from an MRI, as well, because the shape of the brain is correlated with the shape of the face and the shape of the skull, as well.

One of the most interesting MRI studies looked at the hippocampus, a brain structure associated with memory. The hippocampus is not apparently where memory is *stored* but it is crucial to the *making* of memories. If you lose your hippocampus, you can't make new memories. This study was of cabbies in London. How many of you have been in a cab in London? Their cab drivers always speak English, better than we do, and they always know where they are going. To become a cab driver in London you have to pass a complicated three-part test on what they call "The Knowledge." The final part is an oral exam where the examiners can ask you about the location of any alley in the 20-million-person metropolitan greater London area. Aspiring cab drivers study for years for this test. So researchers did MRI scans of London cabbies and of controls: people of the same age, sex, alcohol and tobacco consumption, and so forth, as the cabbies. The cab drivers had bigger hippocampuses. And the longer they had been cabbies, the bigger their hippocampus got. Your brain is not only different from everybody else's, but it changes all the time.

The hippocampus continues, throughout your life, to make new neurons. The old story that you don't make new neurons after age 5, 10, 15, or 20 is not true—although it may be true for many parts of the brain. At my age, I am mainly losing neurons, but I am adding new ones in some areas. All of our brains are constantly changing; they are dynamic entities, different from person to person and at different times in development.

Another good brain fact to know and tell is that while children's brains are developing, they are mainly killing neurons and abandoning synapses, not building them. My wife is a gardener. She has always said that pruning is much more important than planting. That appears to be largely true with brain development as well.

So all of that leads to differences between the brains of people. You have all, no doubt, heard the stories about the differences between the right brain and the left brain, differences that are largely but not entirely exaggerated. The left hemisphere of your cerebrum does control, and get inputs from, the right side of your body, and your right hemisphere controls the left side of your body. Some brain functions are found in the left hemisphere; some are found in the right. But there are people who as children have had one of the hemispheres of their cerebrums removed, usually because of incurable epilepsy where the surgery is the only way to keep the epilepsy from being deadly. Some of these people grow up to be very close to normal, even though they have only "half a brain." If the patient is young enough, areas that are normally found on one hemisphere will "move" to the other one. Broca's area, for example, is necessary to being able to speak. It is almost always found in the frontal lobe of the left hemisphere. Some people who had their left hemispheres removed when young are able to speak well. The area in the right hemisphere that corresponds to Broca's area has apparently filled the gap. Less dramatically, if you are a right-handed cellist, the part of your brain that controls the motions of your left fingers is bigger than in people who don't play stringed instruments. If you lose your left arm, the parts of the brain that control left arm motion (part of the motor cortex) and that receive information from the left arm (part of the somatosensory cortex) may be taken over by body parts.

As a result of all these facts, there is enormous individual variation in brains, but, as the law mainly cares about individuals, this is a real challenge. Anyone dealing with the application of neuroscience to law has to remember that most studies are about group averages, but there is no "group" in the witness box or the defendant's seat. Moving from the group average to the individual will be very hard—not necessarily impossible, but hard. That is a key problem to remember.

Q: When you did your meta-analysis of the peer-reviewed, published research on lie detection, was it easy to discern the qualifications of the person who interpreted the data? Could you tell whether it was a board-certified radiologist or some other person? Because I am finding that sometimes it is hard to tell.

A: We didn't specifically look at that. As far as I can recall, the people who interpreted the images were the principal investigators. I don't remember any of them being board-certified neuroradiologists. Instead, they had Ph.D.s in neurobiology or psychology or were neurologists. How important that is may depend on what you are looking for.

Right now most of the research is, in some ways, fairly primitive. In a prototypical fMRI experiment the researcher rounds up the usual subjects—undergraduate psychology majors—and sticks them in a scanner, usually between midnight and 6 a.m. because that is when the hospital is not using the scanner for paying patients, so the researcher can get a good rate. The researchers put the subjects in the scanner and have them think something, do something, see something, or listen to something. Then the researchers look at the results for the average of all the subjects' brains, broken down into 4,000 or more little cubes called "voxels" and do tricky statistical analyses to see if there is a statistically significant difference between one state while the subjects were in the scanner, say, listening to Mozart, and a second state, say, listening to the Rolling Stones. If the researchers see a statistically significant result, they publish in a peer-reviewed journal, claiming that they have found the brain site of, say, rock and roll. Most of the work just finds correlations, which may or may not also involve causes. Brain region X might always be more activated by the Stones than by Mozart because, for example, the Stones are played louder, not because they are rock and roll.

I've just described fMRI experiments. Functional MRI is the poster child for current neuroscience, the method that is getting the most attention. The people who work with other methods, like EEGs, hate that. They have been working with this method for forty years and they think that they have important things to say, too, that are being overlooked. They might well be right. There are many tools. Attention is focused on fMRI but keep your eyes open for some of the methods that are currently less in favor, though not necessarily scientifically inferior.