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Functional Magnetic Resonance Detection of Deception: Great as Fundamental Research, Inadequate as Substantive Evidence

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by Charles Adelsheim*

I. INTRODUCTION

Essential to the law's pursuit of truth, justice, and the efficient resolution of conflict is assessing the veracity of statements made by individuals both in and out of court. In this judicial context, untruthful statements can be, and no doubt are, made regularly by plaintiffs, defendants, and other witnesses. Humans are generally very skilled at deceiving others, yet they are poor at detecting deception. Because of this disparity, there is a strong demand for reliable scientific techniques to detect deception. The most popular technique is currently the polygraph examination. However, polygraph-based evidence is inadmissible as substantive evidence in nearly all jurisdictions. There are a number of techniques being developed with the hope of filling this unmet demand, one of which is the use of functional magnetic resonance imaging (fMRI) to detect deception.

While fMRI detection of deception shows promise, and while excellent fundamental research is being conducted, fMRI is not yet ready for deployment in the courtroom. To explain this conclusion, this Article consists of four sections: (1) a discussion of the phenomena of deception and the difficulties attendant to detecting deception; (2) an accessible

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primer on MRI, fMRI, and BOLD fMRI technology; (3) a review and analysis of the existent research studies of fMRI detection of deception; and (4) an analysis of why, given the research to date, fMRI detection of deception should not be admitted as substantive evidence in a court of law.

II. THE PHENOMENA OF DECEPTION

The ability to deceive one's peers seems to have developed as mankind evolved. There are advantages to being capable of deception, such as the ability to hide and monopolize scarce resources, or in the modern context, the ability to steal and get away with it.[1] Supporting this evolutionary perspective, there appears to be a correlation between the ability to deceive and brain size,[2] and "[d]eception has been observed in all primate groups."[3] Humans certainly excel at deceiving each other. However, there is a marked disparity between our ability to deceive and our ability to detect deceit.[4] There are abundant examples of this disparity, such as the ability of undercover officers to successfully infiltrate criminal organizations or the ability of adults to lie successfully in paternity cases (especially before the advent of DNA testing).[5]

Because of this disparity between our ability to deceive and our relative inability to detect deceit, mankind has tried to devise "scientific" means to detect deception for at least the last 100 years.[6] These attempts started with such primitive means as torture and trial by water (for example, witch hunting) and developed towards more scientific techniques. One early example of lie detection technology consisted of a balance table on which a suspect was carefully balanced and then interrogated. The underlying theory was that because lying is more difficult than telling the truth, when a person was lying, more

1. *See generally* Sean A. Spence & Catherine J. Kaylor-Hughes, *Looking For Truth and Finding Lies: The Prospects for a Nascent Neuroimaging of Deception*, 14 NEUROCASE 68, 69 (2008).

2. *See* Richard W. Byrne & Nadia Corp, *Neocortex Size Predicts Deception Rate in Primates*, 271 PROC. ROYAL SOC'Y LONDON B. 1693, 1695 (2004).

3. Jonathan T. Rowell et al., *Why Animals Lie: How Dishonesty and Belief Can Coexist in a Signaling System*, 168 AM. NATURALIST 180, 181 (2006).

4. *See* Paul Ekman & Maureen O'Sullivan, *Who Can Catch a Liar?*, 46 AM. PSYCHOL. 913, 913 (1991); *see also* Nancy L. Etcoff et al., *Lie Detection and Language Comprehension*, 405 NATURE 139, 139 (2000); Sean A. Spence, *The Deceptive Brain*, 97 J. ROYAL SOC'Y MED. 6, 6 (2004).

5. *See* Mark A. Bellis et al., *Measuring Paternal Discrepancy and Its Public Health Consequences*, 59 J. EPIDEMIAL CMTY. HEALTH 749, 751 (2005).

6. *See generally* KEN ALDER, THE LIE DETECTORS: THE HISTORY OF AN AMERICAN OBSESSION (2007).

blood would flow to his head, and the table would consequently tip towards his head. Another early "scientific" means of detecting deception was the rice test employed in China. According to this technique, a suspect would hold grains of rice in his mouth while being interrogated. The underlying theory here was that telling lies would impede saliva production; thus, if the questioned person was unable to wet the rice grains he was lying. Even the best of modern-day lie detection techniques–for example, the polygraph machine–are far from perfect, and the judicial system is aware of this fact.[7] This is why polygraph examinations are not admissible as substantive evidence in most courtrooms.[8]

The primary method used to determine the veracity of statements in court is to have the fact finder observe the demeanor of the witness. However, studies have shown that even the most highly trained individuals exhibit only slightly better than chance rates of detecting deception based solely on observing demeanor. Even if one were to accept demeanor as a reliable indicator of truthfulness, the courtroom is a highly formalized atmosphere to which most laypersons are unaccustomed. The courtroom can feel both strange and intimidating; thus, demeanor may be an especially weak indicator of truthfulness in the courtroom. In this light, it is understandable that there is a strong demand for a reliable way to differentiate between truthful and deceptive statements.

The proponents of fMRI detection of deception claim that it offers a reliable way to discriminate between truthful and deceptive statements. There are even two companies currently offering fMRI detection on a commercial basis, No Lie MRI, Inc. and the CEPHOS Corporation.[9] Certainly this and other neuroscience techniques hold great potential, and support for the proposition that neuroscience will play a role in the courtroom of the future that the upcoming Federal Judicial Center's *Reference Manual on Scientific Evidence* which will include a chapter on neuroscience.[10] However, thus far no courts have admitted fMRI deception detection as substantive evidence. Courts are justified in taking this position, as will become clear by the close of this Article.

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7. *See, e.g.*, United States v. Scheffer, 523 U.S. 303, 309-10 (1998).

8. *Id.* at 311.

9. For more information on No Lie MRI, Inc., see http://www.noliemri.com, and CEPHOS Corporation, see http://www.cephoscorp.com.

10. For more information regarding the third edition of the *Reference Manual on Scientific Evidence*, see http://sites.nationalacademies.org/pga/stl/development_manual/index.htm.

III. PHYSICS AND SCIENCE OF MRI AND FMRI

To effectively evaluate the strengths and weaknesses of fMRI lie detection, it is essential to have at least a rudimentary understanding of the science utilized in this technique. Since most lawyers, judges, and other legal practitioners do not have a strong science background, the discussion presented here will not dwell on minutiae and will instead strive to provide a comprehensible overview tailored to actual use of science in a courtroom.[11]

To understand fMRI, one must first understand "magnetic resonance imaging" (MRI). An explanation of MRI starts with a discussion of the fundamental building blocks of our physical universe. Everything that exists is made of atoms like carbon, hydrogen, and oxygen. These atoms, in turn, are made of electrons, which orbit a nucleus comprised of protons and neutrons. Essentially, an MRI scanner detects small differences in the density and behavior of certain protons.

This detection is possible because protons possess both angular momentum and a magnetic moment (also known as a dipole moment).[12] A simple yet behaviorally accurate analogy is that a proton can be thought of as a bar magnet spinning about its long axis or as a gyroscope with a bar magnet running along its axis of rotation. When there are an even number of protons in a nucleus, they will align in an anti-parallel manner, effectively negating their magnetic moments. When there are an odd number of protons in a nucleus, however, the nucleus will have a net magnetic moment and angular momentum. These nuclei with an odd number of protons are what an MRI machine can detect. Conveniently, hydrogen has only a single proton and also happens to be the most abundant atom in a human body. This abundance is due to the fact that there are two hydrogen atoms in every molecule of water, and a human body is composed of roughly 70% water.

Generally, the dipole moments of a water-containing body–such as a human brain or knee–are aligned randomly, which is to say that there is no net magnetic moment. It is impossible to extract useful information from randomly orientated magnetic dipoles; this is why an MRI machine creates and manipulates a strong primary magnetic field. In modern MRI machines, this primary field is 1.5 to 4 Tesla, or 30,000 to 80,000 times stronger than the Earth's magnetic field. When a subject

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11. For a more complete discussion of the science and technology of fMRI, see RICHARD B. BUXTON, INTRODUCTION TO FUNCTIONAL MAGNETIC RESONANCE IMAGING: PRINCIPLES & TECHNIQUES (2002), and SCOTT A. HUETTEL ET AL., FUNCTIONAL MAGNETIC RESONANCE IMAGING (2004).

12. HUETTEL ET AL., *supra* note 11, at 49.

or sample is placed into this strong primary magnetic field, the individual dipole moments of the hydrogen protons tend to align with the primary magnetic field, creating a net magnetic moment within the sample.

It is important to understand why the dipole moments align with the magnetic field. In the absence of an external magnetic field, the potential energy of an individual dipole moment is independent of orientation.[13] This is like saying that in the absence of gravity, a book on the floor and a book being held five feet off the floor have the same potential energy. When we introduce gravity to this situation, suddenly the book held five feet off the floor has more potential energy. If it is released, it will fall to a lower energy state, that of lying on the floor.

When we introduce a strong magnetic field, such as the primary field in an MRI machine, the magnetic dipoles align with that field because being aligned with the field is the lowest energy state. Another way to visualize what is happening is to picture a windmill. A windmill aligns with the wind because that is the lowest energy direction for the windmill to point. It is possible to push the windmill out of alignment with the wind, but the moment it is released the windmill will swing around to align with the wind, again in its lowest energy configuration. The windmill's behavior is analogous to the behavior of individual magnetic dipoles when placed in the MRI's strong primary magnetic field.

Once a sample is placed in the MRI machine and allowed time to align with the primary magnetic field–or "relax" as this process is called–the sample will have a net magnetic moment that is parallel with the MRI's primary magnetic field.[14] This is the lowest energy state for the individual protons. Other higher energy states also exist, to which an MRI machine can excite the protons. These states correspond to flipping the individual proton's magnetic dipoles, such that they are aligned antiparallel with the primary magnetic field. The energy difference between these two states is proportional to the strength of the primary magnetic field.

During scanning, the MRI machine generates a radio frequency pulse to excite some of the individual protons' magnetic dipoles into this higher-energy, antiparallel state.[15] The exact frequency of the excitation pulse depends on the energy difference between the high and low energy states of the proton dipole moments and thus is proportional to

13. *Id.* at 50.
14. *Id.* at 70, 72.
15. *See id.* at 54.

the primary magnetic field strength.[16] By varying the primary magnetic field strength along the axis parallel to the primary magnetic field and tailoring the frequency of the radio pulse, the MRI machine can selectively excite a "slice" of the subject or sample. This is to say, if you are in the bore of an MRI machine, and the primary magnetic field is weaker at your feet and stronger at your head, the excitation pulse can be tuned to excite any roughly one millimeter (mm) thick horizontal slice of your body.

After the protons in this slice are excited, they slowly relax back to their lowest energy state of being aligned with the primary magnetic field.[17] As they relax, the protons emit radio energy, which is detected by a receiver coil in the MRI machine.[18] The strength and timing of this received signal are a function of the density of the hydrogen protons in the body's tissue and of the molecular structure surrounding those protons. By varying the magnetic field along two additional axes and applying a good deal of math, the MRI machine can generate the stunning, detailed structural images that are commonplace today.[19]

Structural MRI images are composed of what are called voxels. Voxels can be thought of as the three-dimensional equivalent of a pixel, and in structural MRI, voxels are typically 1x1x1mm in size. Using structural scanning methodology, it takes fifteen to thirty seconds to scan and generate images of a human brain. Structural MRI is a mature, well-accepted technology that is widely used in medicine as well as other professions.

While structural MRI is a wonderful tool that produces extremely detailed images of soft tissue, these images are static–they do not reflect change over time unless the time scale is large on the order of days or years. Thus, the technology of fMRI was developed in the early 1990s to allow researchers to scan rapidly and repeatedly in order to see change over a period of seconds.[20] The trade-off is that generally the voxels employed are larger than those employed in structural MRI, typically on the scale of 3x3x3mm. Using an fMRI technique, researchers can scan a human brain every several seconds, resulting in a time series of images of the brain. While fMRI is a newer technique than

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16. *Id.* at 54.
17. *Id.* at 71.
18. *Id.* at 54.
19. *Id.* at 55.
20. fMRI was first discovered by Dr. Seiji Ogawa in 1990. Nikos K. Logothetis, *The Underpinnings of the BOLD Functional Magnetic Resonance Imaging Signal*, 23 J. NEUROSCI. 3963, 3963 (2003); *see also* S. Ogawa et al., *Brain Magnetic Resonance Imaging with Contrast Dependent on Blood Oxygenation*, 87 PROC. NAT'L ACAD. SCI. U.S. 9868 (1990).

MRI, it is nonetheless widely accepted. A brief search of scientific literature shows more than 2000 peer reviewed articles in which fMRI was employed.

IV. BOLD (BLOOD OXYGENATION LEVEL DEPENDENT) FMRI

Given this overview of MRI and fMRI technology, one might ask how this technology can possibly be used to detect deception. The answer lies in a technique known as BOLD (Blood Oxygen Level Dependent) fMRI.[21] To understand BOLD fMRI, it is necessary to understand a little bit about the human brain. One thing that makes the human brain different from the rest of the human body is that the brain is not capable of storing energy locally. Thus, unlike the rest of the human body, the brain is entirely dependent upon a constant flow of blood, which brings fresh oxygen and glucose to be metabolized by cells in the brain.[22] This dependence upon a constant supply of oxygen and glucose allows BOLD fMRI to indirectly detect neural activity.

Since the 1890s, scientists have understood that changes in blood flow and oxygenation in the brain–commonly called hemodynamics–are linked to neural activity.[23] Over time, this knowledge led to the development of the BOLD hypothesis. The BOLD hypothesis states that areas of the brain where neurons have recently fired will experience an influx of more highly oxygenated blood a few seconds after firing.[24] This phenomenon allows researchers to use fMRI to measure brain activity.

Of course, to an MRI machine moving blood is indistinguishable from stationary blood. It is the difference in blood oxygenation that fMRI can detect.[25] This detection is possible because deoxygenated hemoglobin (the molecule that transports oxygen from the lungs to the rest of the body) and oxygenated hemoglobin have different magnetic properties. Deoxygenated hemoglobin is paramagnetic and will reduce the MRI signal observed, while oxygenated hemoglobin is diamagnetic and will not affect the MRI signal at all.[26] When the local ratio of oxygenated hemoglobin to deoxygenated hemoglobin increases, more MRI signal will be observed. Several seconds after an area of the brain is activated, the

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21. *See* Henry T. Greely & Judy Illes, *Neuroscience-Based Lie Detection: The Urgent Need for Regulation*, 33 AM. J.L. & MED. 377, 380-81 (2007).

22. *Id.* at 380.

23. *See* C.S. Roy & C.S. Sherrington, *On the Regulation of the Blood-Supply of the Brain*, 11 J. PHYSIOLOGY 85, 90-92 (1890).

24. *See* Henry T. Greely, *Law and the Revolution in Neuroscience: An Early Look at the Field*, 42 AKRON L. REV. 687, 694 (2009).

25. HUETTEL ET AL., *supra* note 11, at 159-60.

26. *See id.* at 159.

local concentration of oxygenated hemoglobin will increase by about 1%, and that 1% increase will be visible on the fMRI image as a stronger signal. It will "light up," so to speak.

It is important to understand what exactly BOLD fMRI is capable of measuring. The spatial resolution corresponds to the size of the voxels being scanned, which in the case of fMRI is approximately 3x3x3mm. The temporal resolution corresponds to the time per scan, which, in the case of BOLD fMRI, is a full scan once every several seconds. Significantly, there is a time delay of two to ten seconds between the activation of an area of the brain and a detectable change in MRI signal.

There are two additional details that one must keep in mind. First, BOLD fMRI can measure only the change in blood oxygenation over time–in effect, the difference between a baseline of oxygenated blood in an inactive mental state and that of highly oxygenated blood resulting from the metabolic demands of neurons activated during the targeted mental activity.[27] Second, by using BOLD fMRI, it is possible to roughly measure the metabolic demands of active neurons, but it is not possible to directly measure neuronal activity per se.[28]

BOLD fMRI has greatly aided the field of neuroscience by allowing unprecedented, noninvasive access to the nearly real time workings of the human brain. More than 2000 published fundamental research studies have employed BOLD fMRI to accomplish such tasks as identifying the fusiform face area, a specialized structure in the human brain involved in identifying faces.[29] BOLD fMRI has also been used in nonresearch settings by neurosurgeons to identify the verbal center of a patient's brain to avoid damaging it during brain surgery.[30] No other technology allows researchers to noninvasively monitor and spatially distinguish activity in a human brain.

V. INHERENT WEAKNESSES OF BOLD FMRI

Unfortunately, BOLD fMRI also has several inherent weaknesses that affect the precision and accuracy of its images and results. Among these are low spatial resolution, partial volume effects, large vessel effects, noise, and the consequent study designs that involve block designs and

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27. *See* G.K. Aguirre & M. D'Esposito, *Experimental Design for Brain fMRI, in* FUNCTIONAL MRI 370-71 (C.T.W. Moonen & P.A. Bandettini eds., 2000).

28. *See id.* at 370.

29. *See* K.M. O'Craven & N. Kanwisher, *Mental Imagery of Faces and Places Activates Corresponding Stimulus-Specific Brain Regions,* 12 J. COGNITIVE NEUROSCI. 1013 (2000).

30. *See* Gerry Everding, *Better Brain Imaging Helps Surgeons Avoid Damage to Language Functions,* WASHINGTON UNIVERSITY IN ST. LOUIS (Nov. 4, 2003), http://news.wustl.edu/news/Pages/494.aspx.

image averaging, differences between scanners, inter-subject variability in hemodynamic response, and the issue of selecting and maintaining a baseline. We shall now review these weaknesses.

Unlike structural MRI, which employs voxels of 1x1x1mm, BOLD fMRI employs voxels of approximately 3x3x3mm. Essentially, there is a trade-off between speed and resolution. To scan the entire brain every several seconds, larger voxels must be used. The measured signal from a voxel is proportional to its size–the larger the voxel, the larger the total signal. Because in BOLD fMRI the change in signal due to neural activity is only 1%, these large voxels must be used to acquire meaningful data from several different parts of the brain at once.

As the voxel size is increased, the probability increases that each voxel will image several types of brain tissue. This is known as the partial volume effect.[31] Instead of a voxel containing only neuronal cells, it might also contain white matter, blood vessels, or cerebrospinal fluid. These additional constituents can reduce the MRI signal observed. Furthermore, the use of large voxels means that there are simply lots of neurons in each voxel. This is a potential problem because many different mental processes could result in increased signal within each voxel.

Large vessel effects occur when there is a signal change caused by blood flowing from an active region through a vein that extends some distance from that active region.[32] This effect is problematic because it can cause increased MRI signal (which correlates with neural activity) to appear in areas spatially distant from the actual areas of neuronal activity.

Another issue with BOLD fMRI is noise. In every MRI scan, there is some random noise due to thermal fluctuations, motion, cardiac rhythm, scanner artifacts, and other factors; the measured MRI signal from a voxel that has not actually changed at all may increase or decrease randomly.[33] This is an acute issue in BOLD fMRI because the change in MRI signal due to neural activation is only approximately 1%. In a given series of images of a human brain, one can easily find random noise in excess of 1%. Disastrous levels of noise can be introduced by small movements of the subject. The sensitivity of an fMRI scanner is such that merely blinking one's eyes or moving one's tongue is sufficient to render the scan useless.[34]

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31. *See* HUETTEL ET AL., *supra* note 11, at 189.
32. *Id.* at 191.
33. *See id.* at 219. *See generally* BUXTON, *supra* note 11.
34. *See* Greely & Illes, *supra* note 21, at 404.

Two techniques that are widely used to compensate for scanning noise are block design studies and image averaging. Block design studies are studies in which a subject is repeatedly asked the same or similar questions so that their brains experience the same cognitive functions repeatedly. This allows the researcher to gather multiple images of the same mental state. The researcher then averages together the scans from all such similar mental states, which allows for the random variation in MRI signal to be averaged out. The resulting averaged image should more precisely reflect the areas of the brain that were activated during the targeted cognitive process.

Another noisy aspect of BOLD fMRI stems from the fact that MRI scanning machines, though high tech and massively expensive, are heterogeneous in nature.[35] No two machines are precisely identical, and these differences actually result in slightly different scans.[36] If one were to scan the same inert object in two separate MRI machines, two slightly different images would result. These small differences between MRI machines make replication of results by independent labs more difficult. In addition to the differences between machines, there are differences between individuals in their hemodynamic response. These differences can arise from age, gender, race, health, drug use, and other factors. This means (in practical terms) that exactly how a person's brain and blood flow respond to neural activation varies qualitatively and quantitatively among subjects.

One additional issue of BOLD fMRI is choosing a baseline. Because BOLD fMRI is capable of measuring only change in blood oxygenation, the baseline state from which one observes excitation is very important. If an inaccurate baseline is chosen, it may be impossible to discern the activated areas of the brain when the mental process of interest occurs. For example, to isolate the areas of the brain concerned with reading words aloud, one might select a baseline task of passively viewing words. Having accounted for areas of the brain involved with visual word perception, the change in blood oxygenation resulting from reading words aloud instead of simply viewing them would contain only those areas activated while reading aloud.[37]

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35. *See* Lee Friedman et al., *Reducing Inter-Scanner Variability of Activation in a MultiCenter fMRI Study: Role of Smoothness Equalization,* 32 NEUROIMAGE 1656, 1656 (2006).

36. *Id.* at 1657.

37. Marcus E. Raichle, *An Introduction to Functional Brain Imaging in the Context of Lie Detection, in* USING IMAGING TO IDENTIFY DECEIT: SCIENTIFIC AND ETHICAL QUESTIONS 3, 5 (2009).

Despite the weaknesses of BOLD fMRI, it has been embraced as a paradigm-shifting technology. BOLD fMRI has given many insights regarding neuroscience and the mechanics of the human brain.

VI. THE STUDIES OF BOLD FMRI DETECTION OF DECEPTION

As noted above, there are currently more than 2000 peer-reviewed articles that either discuss BOLD fMRI or report on studies that employ BOLD fMRI. In the specific area of research relevant to BOLD fMRI detection of deception, there are (at the time of this Article) just over twenty published studies[38] and a number of articles that attempt to draw conclusions based on those twenty studies.

Though twenty is not a large number, there are considerably more studies of BOLD fMRI deception detection than in many other areas of forensic science that are routinely admitted in court–for example, ballistic analysis. Additionally, BOLD fMRI studies appear to be more rigorous than the published studies of polygraph-based lie detection, the low quality of which has been noted in recent National Academy of Science (NAS) reports.[39]

In addition to the technical weaknesses of BOLD fMRI, the stress experienced by the study participants can also create inaccuracies. Therefore, it is important to understand the actual experience of participating in a BOLD fMRI detection of deception study. Typically a study participant first fills out paperwork and background surveys, undergoes both physical and mental health screenings, and is given a general orientation of the study design. Next, the study participant is taken to a locker room where he removes his clothes and any metal jewelry and dresses in a hospital gown. Following this, the subject is placed in an MRI machine. This experience differs from what most people experience in an MRI machine during a medical scan. A study participant's head is enclosed by a cage of radio receivers and is immobilized as much as possible through the use of various restraints, such as straps and inflatable pads. Once the subject is secured in the

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38. *See, e.g.*, Nobuhito Abe et al., *Deceiving Others: Distinct Neural Responses of the Prefrontal Cortex and Amygdala in Simple Fabrication and Deception with Social Interactions*, 19 J. COGNITIVE NEUROSCI. 287 (2007); Nobuhito Abe et al., *Neural Correlates of True Memory, False Memory, and Deception*, 18 CEREBRAL CORTEX 2811 (2008); C. Davatzikos et el., *Classifying Spatial Patterns of Brain Activity with Machine Learning Methods: Application to Lie Detection*, 28 NEUROIMAGE 663 (2005); G. Ganis et al., *Neural Correlates of Different Types of Deception: An fMRI Investigation*, 13 CEREBRAL CORTEX 830 (2003).

39. *See generally* NATIONAL RESEARCH COUNCIL, THE POLYGRAPH AND LIE DETECTION (2003) (reviewing the validity and reliability of polygraph examinations).

MRI machine, a structural scan is taken of his brain. After this structural scan, the scanner will switch to fMRI procedures and continuously scan the subject's brain every several seconds. During the study, images (usually consisting of questions and prompts) will be projected onto a screen located outside the MRI machine. The subject will view these images through a small mirror located just above his eyes. Typically the questions or prompts will be displayed for two to five seconds, after which the subject will press one of two buttons next to one of his hands. Since any motion of the subject's head will destroy the fMRI images, the two buttons located near the participant's hand are the least disruptive avenue of communication available. During the entire question and answer session, the subject is surrounded by very loud noise and may experience nervousness or claustrophobia. After the question and answer session is complete, the subject is removed from the machine, allowed to dress, and possibly debriefed by study personnel.

A detailed explanation of each study involving BOLD fMRI detection of deception to date is beyond the scope of this Article. Instead, a summary of each type of study thus far conducted will suffice.[40] One group of studies could be classified as playing-card studies. Various study designs have been based on playing cards, presumably because playing cards are familiar to most people and yet hold no particular emotional relevance. One study of eighteen subjects involved giving participants a sealed envelope containing twenty dollars and a playing card. When placed in the MRI scanner, subjects were asked to lie about the kind of the card that they received in the envelope.[41]

A similar study using playing cards employed a slightly different structure in an attempt to make the lying more realistic. In this study, participants were given a sealed envelope containing twenty dollars and two playing cards. Participants were told to lie about having one of the cards and to be truthful about having the other. Questions similar to the one-playing-card study were displayed and responded to while the subject was in the MRI scanner.[42]

A second group of studies could be classified as hidden money studies. In the first such study, participants were brought to two separate rooms–a truth room and a lying room. In each room there was a fifty-

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40. *See infra* notes 41-47. Those interested in this topic may find it worth reading the papers originally published on each study of BOLD fMRI detection of deception, which will furnish greater detail than is necessary for purposes of this Article.

41. Daniel D. Langleben et al., *Brain Activity During Simulated Deception: An Event-Related Functional Magnetic Resonance Study*, 15 NEUROIMAGE 727, 729-30 (2002).

42. Daniel D. Langleben et al., *Telling Truth From Lie in Individual Subjects with Fast Event-Related fMRI*, 26 HUM. BRAIN MAPPING 262, 263 (2005).

dollar bill hidden under one of several objects (a lamp, a paperweight, and so forth). The participants were asked to find the money and then lie about the location of the money in the lying room while telling the truth about the location of the money in the truth room.[43]

In a variation on this study design, participants were brought to one room in which two fifty-dollar bills were hidden under two different objects. Participants were asked to find the money, tell the truth about one of the objects that concealed a fifty-dollar bill, and lie about the other object that concealed a fifty-dollar bill.[44]

A third group of studies employed a mock theft design, again in an attempt to make the lying employed by the participants more realistic. In these studies, the participants were brought to a room containing a ring and a watch and told to steal one of these two objects. After the participants "stole" either the ring or the watch, they were brought to the changing room and asked to change into a hospital gown and to place the ring or watch in their locker. During scanning, they were asked to deny having taken either the ring or the watch.[45]

In a fourth group of studies, the participants were asked about their background or their day. In this study design, the questions were displayed on the screen in one of two colors. The participants were instructed to lie if the question was presented in one color and to be truthful if the question was presented in the other color.

A fifth group of studies involved the subjects participating in a mock crime, again in an attempt to make the lies told more like real-world lies. In one such study, participants conducted a mock crime that involved firing a starter pistol; they were then instructed to deny committing the crime.[46] In a variant of this study, participants completed a mock sabotage scenario over the course of several days. The scenario involved "sneaking" into a campus security center, stealing a CD containing incriminating video files, destroying the CD, and returning a fragment of the CD to the study coordinators to prove the participants had accomplished their "mission." Participants were

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43. Frank Andrew Kozel et al., *A Pilot Study of Functional Magnetic Resonance Imaging Brain Correlates of Deception in Healthy Young Men*, 16 J. NEUROPSYCHIATRY & CLINICAL NEUROSCI. 295, 297-99 (2004).

44. Frank Andrew Kozel et al., *Brief Communications: A Replication Study of the Neural Correlates of Deception*, 118 BEHAV. NEUROSCI. 852 (2004).

45. Frank Andrew Kozel et al., *Detecting Deception Using Functional Magnetic Resonance Imagining*, 58 BIOLOGICAL PSYCHIATRY 605, 606 (2005).

46. Feroze B. Mohamed et al., *Brain Mapping of Deception and Truth Telling About an Ecologically Valid Situation: Functional MR Imaging and Polygraph Investigation-Initial Experience*, 238 RADIOLOGY 679, 681 (2006).

instructed to deny having committed the sabotage and then were questioned in the fMRI machine.[47]

Many of the studies described above employed a block design, and nearly all of the studies averaged the scans for truthful and deceptive responses, both intra-subject and inter-subject. A block design study employs groups of several consecutive questions that are designed to evoke the same response (lie or truth) from the participant. These alternate with blocks of other questions designed to evoke the opposite response (truth or lie) from the participant. This approach helps more clearly differentiate between the two conditions, lying or telling the truth. Intra-subject averaging refers to taking all the scans of an individual participant's truthful responses and averaging them together in order to smooth out random noise, then doing the same with the participant's deceptive responses. Inter-subject averaging refers to taking all of the individual participants' averaged deceptive response scans and averaging them together in order to gain an understanding about which areas of the brain are activated throughout the group when the participant is lying.

The practices of employing block design studies and intra-subject and inter-subject averaging are scientifically valid and have allowed for groundbreaking fundamental research to be conducted. These group-level results have shown that in general some areas of the brain activate more during deception than when an individual is telling the truth.[48] However, the law is concerned with individuals; thus, studies of individual responses to questions are necessary.

These studies are needed because, if introduced in court, evidence based on fMRI detection of deception will be used to establish the veracity of specific statements made by a specific witness. To be useful, the fMRI technique must be able to definitively determine the truthful or deceptive nature of these discrete statements by a single declarant; group-level studies are simply insufficient to prove whether fMRI lie detection can accomplish this task.

At this time, only four studies have been conducted that examined individual responses and attempted to categorize them as truthful or deceptive based on models of deceptive brain activation patterns derived from group studies.[49] The studies included tasks similar to those

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47. Frank Andrew Kozel et al., *Functional MRI Detection of Deception After Committing a Mock Sabotage Crime*, 54 J. FORENSIC SCI. 220, 221-22 (2009).

48. Ganis et al., *supra* note 38, at 833.

49. *See* Davatzikos et al., *supra* note 38, at 663; Kozel et al., *Detecting Deception, supra* note 45, at 611; Kozel et al., *Functional MRI, supra* note 47, at 228; Langleben et al., *Telling Truth From Lie, supra* note 42, at 263.

previously discussed, such as asking subjects to deny a previously committed mock crime or to lie about playing cards previously viewed while undergoing BOLD fMRI. The four studies reported accuracies from 76%-90%, specificities of 42%-85%, and sensitivities of 69%-85%.[50] Specificity measures the proportion of truths that are correctly identified, and sensitivity measures the proportion of actual lies that are correctly identified. Thus, the four studies falsely registered that participants were lying when they were being truthful 25%-58% of the time and falsely registered that participants were being truthful when they were in fact lying 15%-31% of the time.

VII. WEAKNESSES OF THE STUDIES TO DATE

Though these studies represent first-rate fundamental research, they are vulnerable to numerous attacks when one proposes their use as a foundation upon which to introduce BOLD fMRI lie detection as evidence in a court of law. It is one thing for research to detect a phenomenon such as the activation of certain brain areas during deception; it is another matter entirely to identify criteria to determine whether the phenomenon occurred in a particular case.

One weakness of the existent studies is the limited number of participants and their lack of diversity. Thus far, nearly all the study participants have been recruited from undergraduate populations. Most participants have been healthy young adults, almost all right-handed, and almost all Caucasian males. Very few study participants have been elderly, and no studies have included children. Due in part to medical and psychological pre-screening, no studies have included participants with physical or mental illness or those taking drugs either as medication or illegally. No study has been larger than thirty-one participants, and most studies have included just ten to fifteen participants. Collectively these studies have examined neither a representative sample of the population nor a large sample of the population. Thus, little is known about whether or how exactly the results obtained may differ across a large and diverse population.[51] Moreover, individuals

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50. Davatzikos et al., *supra* note 38, at 665 (80% accuracy, 90% sensitivity, 86% specificity); Kozel et al., *Detecting Deception, supra* note 45, at 610 (90% accuracy); Kozel et al., *Functional MRI, supra* note 47, at 226 (91% sensitivity , 42% specificity); Langleben et al., *Telling Truth From Lie, supra* note 42, at 267 (76.5% accuracy, 69% sensitivity, 84% specificity).

51. *See* Greely & Illes, *supra* note 21, at 403. For example, it is known that cerebral blood flow, and thus BOLD fMRI study results, varies in response to various factors, including age, pathologic conditions, hormone replacement therapy, and various medications. *See id.* at 380; *see also* G.K. Aguirre et al., *The Variability of Human, BOLD*

who suffer from mental illness or who use illicit drugs are generally at higher risk of being prosecuted for crimes,[52] and it is unknown how these factors may affect the results of fMRI detection of deception.

Another major weakness of these studies is that, as mentioned above, only four studies have attempted to identify deception on an individual level. As fundamental research, the existent group-averaged studies make valuable contributions to the field of neuroscience. However, the law concerns itself with the conduct of individuals, and these group-averaged studies have only general relevance to individuals. The group-averaged studies have shown that on average certain areas of the brain are more active during lying than during truth-telling.[53] But these averages are not informative on the question of how many individual subjects showed activation in each brain area. Nor do group-average studies even attempt to discern truth from deception on an individual basis. Thus, the group-averaged studies do not directly address whether a particular subject is lying at a particular time. The four studies to date that have attempted to apply models built from group-averaged studies to individual responses have met with some, but not overwhelming, success.[54] The studies reported accuracies from 76%-90%, specificities of 42%-85%, and sensitivities of 69%-85%.[55] While these studies show promise, it would be dangerous to allow such techniques to serve as evidence in court since the studies have shown less than reassuring levels of accuracy and dangerous levels of specificity.

A further weakness of the studies is their current lack of replication.[56] One of the foundations of scientific progress is the independent verification of results. To illustrate, consider the scandals that have surrounded cold fusion. One group published the results of an experiment in which they claimed to have successfully demonstrated cold fusion. Immediately after publication, other groups attempted to replicate the results with no success.[57] Thus, these subsequent studies

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Hemodynamic Responses, 8 NEUROIMAGE 360, 360-61 (1998); Mart Bles & John-Dylan Haynes, *Detecting Concealed Information Using Brain-Imaging Technology*, 14 NEUROCASE 82, 86-87 (2008).

52. There are estimates that psychopaths make up 1% of the general population but 15-25% of the prison population. *See* John Seabrook, *Suffering Souls: The Search for the Roots of Psychopathy*, NEW YORKER, Nov. 10, 2008, http://www.newyorker.com/reporting/2008/11/10/081110fa_fact_seabrook.

53. *See, e.g.*, Kozel et al., *Detecting Deception*, *supra* note 45, at 608.

54. *See* sources cited *supra* note 49.

55. *See* sources cited *supra* note 50.

56. Greely & Illes, *supra* note 21, at 402.

57. Malcolm W. Browne, *Physicists Debunk Claim of a New Kind of Fusion*, N.Y. TIMES, May 3, 1989, http://partners.nytimes.com/library/national/science/050399sci-cold fusion

served to debunk the claims of the first group. Currently, in the field of fMRI detection of deception experimental design and techniques vary wildly from lab to lab.[58] This is to be expected, as this is a new area of research, and individual labs are simply creating new study designs and trying them out. While this diversity in study design and technique is a good thing for the advancement of the field, the lack of replication is troublesome for establishing the admissibility of fMRI lie detection as evidence in court.

Not only are different labs employing different study designs and techniques, but the reported results from these studies are inconsistent and show activation in various different areas of the brain.[59] It is possible to find consistency among the various reported areas of activation, but one can only do so by defining regions of activation very broadly. These broader regions of the brain are "known to be correlated with a wide range of cognitive behaviors, including memory, self-monitoring, conscious self-awareness, planning and executive function, and emotion."[60] Thus, it may well be misleading to conclude that activation of such a relatively broad region of the brain indicates deception by a participant or, in a group study, by a larger number of participants.

Even more alarming is the fact that individual labs have had difficulty replicating their own results.[61] Similar but separate studies conducted by the same lab have reported significant variation in the precise areas of the brain activated.[62] In the Langleben lab, two different analyses of the raw data from one study identified two different sets of activated brain regions.[63] This lack of replication is alarming and certainly is a stumbling block to introducing fMRI lie detection in court.

The researchers' difficulty in identifying precise areas of the brain involved in deception is to be expected. Broadly defined regions of the brain are known to be involved in a variety of mental processes, which highlights the difference between correlation and causation as well as the fact that the former does not necessarily imply the latter. This is simply an application of the first principle of logic: although A may imply B, it does not necessarily follow that B implies A. While lying

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58. *See* Greely & Illes, *supra* note 21, at 402.

59. *See* Sean A. Spence, *Playing Devil's Advocate: The Case* Against *fMRI Lie Detection*, 13 LEGAL & CRIMINOLOGICAL PSYCHOL. 11, 13, 22 (2008).

60. Greely & Illes, *supra* note 21, at 403.

61. *See* Spence, *Playing Devil's Advocate, supra* note 59, at 24; *see also* Spence & Kaylor-Hughes, *supra* note 1, at 78.

62. Greely & Illes, *supra* note 21, at 382-83.

63. Spence & Kaylor-Hughes, *supra* note 1, at 77.

may activate broad regions of the brain, this is a correlative finding. It is entirely possible, if not likely, that activation in these regions may also be caused by a whole suite of other mental processes.[64] This is an issue that proponents of fMRI deception detection have not yet adequately addressed.

Another fundamental weakness of the existent studies is the artificiality of the deceptive tasks that participants perform. In every study the participants were instructed to lie.[65] A few studies allowed the participants to decide which of two lies to tell, but that is as close to deciding to tell a lie as the studies have come.[66] Being instructed to lie raises at least two issues. The first is that there may be qualitative and quantitative differences between lying on command and consciously deciding to lie. The second is the possibility that in the context of these studies in which participants have been instructed to lie about something, what the fMRI machine may be detecting is not (or is not solely) the mental process of lying but instead reflects the subject's recognition of the stimulus to which the subject has been instructed to respond by lying.

A further artificiality of the deceptive tasks performed is the low-consequence nature of the lies told. Some of the studies attempted to incentivize deception by attaching a monetary prize to fooling the system, but the gain or loss of twenty dollars is not really of great consequence. This level of consequence is qualitatively different than the possibility of going to prison, suffering financial penalties, or being the subject of social ostracization. It is entirely possible that the mental processes associated with high and low-consequence deception are qualitatively and quantitatively different.

In light of the nature of laboratory-based research, it is likely to be difficult, if not impossible, to create a good test of real-world lying. To echo *General Electric Co. v. Joiner*,[67] there may simply be "too great an analytical gap between the data and the opinion proffered."[68]

Another weakness of these studies lies in the simplicity of the analytical task. In these studies, researchers have been attempting to discern the difference between known lies and truthfulness.[69] This is

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64. *See* Allyson C. Rosen & Ruben C. Gur, *Ethical Considerations for Neuropsychologists As Functional Magnetic Imagers,* 50 BRAIN & COGNITION 469, 476 (2002).

65. Joseph R. Simpson, *Functional MRI Lie Detection: Too Good to be True?*, 36 J. AM. ACAD. PSYCHIATRY L. 491, 494 (2008).

66. *See* Kamila E. Sip et al., *Detecting Deception: The Scope and Limits,* 12 TRENDS COGNITIVE SCI. 48, 50 (2007).

67. 522 U.S. 136 (1997).

68. *Id.* at 146.

69. Ganis et al., *supra* note 38, at 830-31.

certainly a qualitatively different task from that of detecting unknown, spontaneous lies.

A further weakness of these studies is that most of them have not attempted to examine the potential differences between different types of lies.[70] Humans tell many types of lies, ranging from white lies told in social situations to the entirely deceptive existences lived by spies.[71] These different types and degrees of deception may activate different parts of the brain or activate various parts of the brain to different degrees.[72] No studies have examined the differences between being instructed to lie and voluntarily lying. As was previously mentioned, no studies have examined the difference between high- and low-consequence lies, such as the difference between a white lie and a lie upon which one's life depends. Only one study has examined the difference between rehearsed deception and spontaneous deception.[73] This last point deserves emphasizing because a defendant undergoing an fMRI-based lie test would probably have thoroughly rehearsed his lies, and the rehearsed nature of the lies could alter the activation pattern of his brain.[74] Perhaps telling a well-rehearsed lie would be more like telling a memorized story than lying and thus completely fool an fMRI deception test.

A further wrinkle relating to different types of lies is the issue of delusion. In some psychiatric conditions, subjective experience may be at odds with objective reality.[75] It seems likely that in the case of such a mental problem, an fMRI scan would not show any deception despite the falsity of what the subject believes to be the truth.[76] One study describes a medical malpractice case in which a patient accused her former psychotherapist of sexual abuse.[77] Both patient and doctor took and passed polygraph tests while other evidence suggested that the patient was suffering from a delusion.[78] In this situation, fMRI would likely be unable to resolve such inconsistent but subjectively honest testimony.[79]

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70. *But see id.* at 830.

71. *See* Bella M. DePaulo et al., *Lying in Everyday Life*, 70 J. PERSONALITY & SOC. PSYCHOL. 979, 993 (1996).

72. Ganis et al., *supra* note 38, at 833.

73. *Id.* at 830-31.

74. *Id.* at 831.

75. *See* Danel D. Langleben et al., *True Lies: Delusions and Lie-Detection Technology*, 34 J. PSYCHIATRY L. 351, 354-55 (2006).

76. *Id.* at 363.

77. *Id.* at 352.

78. *See id.* at 352-53.

79. *Id.* at 363.

Another major weakness of these studies is that none of them addresses the issue of countermeasures.[80] By analogy, the polygraph test appears to be vulnerable to countermeasures.[81] A NAS report entitled *The Polygraph and Lie Detection* cited this vulnerability to countermeasures as a reason to bar polygraph-based evidence.[82] At this time, there is no reason to believe that fMRI detection of deception is not vulnerable to countermeasures. If a subject wished to completely defeat the entire test, all he would need to do is blink his eyes or move his tongue, resulting in useless scanning data due to the excessive noise these simple actions would introduce.[83] It may also be possible to fool the test by altering the baseline from which excitation is measured. If a subject were to activate areas of his brain, perhaps by doing mental arithmetic while giving truthful responses, this might alter the baseline sufficiently to disguise deceptive responses.[84] The lack of data on the potential vulnerabilities to countermeasures will remain an issue until, and possibly after, such studies are conducted.

Yet another weakness of these studies is the issue of post-processing. The fMRI scanning process produces large amounts of data that must be processed into useful activation images of the brain. This process involves many steps, each of which must be evaluated and validated if one were to introduce the test as evidence in court. Some of the typical processing steps include realignment of each scan to the same spatial orientation to account for small head movements; normalization of each scan to a "standard" sized and shaped brain; and removal of noise and artifacts, which is similar to image enhancement.[85] There are some large assumptions inherent in these processes, such as assuming that there is a standard size and shape for a brain and that it does not distort the data to normalize each subject's scans to this standard model. As mentioned above, the final postprocessing step in the group-averaged studies is to average the truthful responses of all the participants together to create a composite average image, which represents the average activation when lying. At this point in the development and study of BOLD fMRI, it seems far-fetched to claim that the technique can detect deception in a single individual when both the foundational

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80. *Id.* at 360.

81. NATIONAL RESEARCH COUNCIL, *supra* note 39, at 151.

82. *Id.* at 22; *see also* Bles & Haynes, *supra* note 51, at 89.

83. *See, e.g.*, Greely & Illes, *supra* note 21, at 404.

84. *See id.* at 45. "It has been shown . . . that participants can learn to manipulate BOLD activity in specific regions." Bles & Haynes, *supra* note 51, at 89.

85. For discussion on the evidentiary use of image enhancement, see *People v. McWhorter*, 212 P.3d 692, 726 (Cal. 2009), and *State v. Swinton*, 847 A.2d 921, 935 (Conn. 2004).

studies and the specific testing of one individual depend for their final results on so much averaging and postprocessing of data.

A final weakness of the existent studies is the limited nature of subject responses. While in the MRI scanner, a subject cannot speak lest they disrupt the current scan. The only way a subject can respond is by pushing one of two buttons with his finger, indicating "yes" or "no." Due to this physical restriction, the exact form of the questions asked is very important and potentially determinative of the results of any attempted real-world test. It is entirely possible that a question could be phrased so that a subject could truthfully answer while being deceptive.

VIII. APPLICATION OF *FRYE* AND *DAUBERT* TO FMRI

If a party were to attempt to introduce the results of an fMRI lie test as evidence in court, that party would have to show the court that the evidence being proffered was relevant, and because this technique is hard science, the party would have to satisfy either the *Frye v. United States*[86] or *Daubert v. Merrell Dow Pharmaceuticals, Inc.*[87] standard of admissibility for scientific evidence.[88] Discussing how fMRI-based evidence may be used in court is not entirely an academic exercise, as the two private companies mentioned above are actively attempting to introduce fMRI detection of deception as evidence in the courtroom.[89] In a state such as California, which follows *Frye*,[90] the test of admissibility would be that "the thing from which the deduction is made must be sufficiently established to have gained general acceptance in the particular field in which it belongs."[91]

Establishing that fMRI lie detection has attained general acceptance, even within the relevant field, would be challenging at best and most likely impossible. The literature on this topic is replete with papers criticizing the research to date and urging caution in applying this technology to the high-stakes world of the courtroom. Even Dr. Langleben–who holds a patent on this technique, which No Lie MRI has

86. Frye v. United States, 293 F. 1013 (D.C. Cir. 1923), *superseded by* FED. R. EVID. 702, *as recognized in* Daubert v. Merrell Dow Pharm., Inc., 509 U.S. 579 (1993).

87. 509 U.S. 579 (1993).

88. United States v. Scheffer, 523 U.S. 303, 312 n.7 (1998).

89. *See* Simpson, *supra* note 65, at 491; *see also* Alexis Madrigal, *MRI Lie Detection to Get First Day in Court*, WIRED (Mar. 16, 2009), http://www.wired.com/wiredscience/2009/03/noliemri.

90. The *Frye* standard was adopted by California in *People v. Kelly*, 549 P.2d 1240, 1244 (Cal. 1976), *superseded by statute*, CAL. EVID. CODE § 351.1 (West 1995), *as recognized in* People v. Wilkinson, 94 P.3d 551, 564-65 (Cal. 2005).

91. *Frye*, 293 F. at 1014.

licensed and is attempting to commercialize–has recently publicly expressed his unease with commercial application of fMRI detection of deception.[92] Dr. Langleben "draws a clear distinction between 'deception researchers' like himself and 'the merchants of fMRI-based lie detection.'"[93] While fMRI deception detection has attained recognition as a research technique, it has not attained general acceptance as substantive evidence in a court of law.

In a state that has adopted the *Daubert* standard of admissibility for scientific evidence, the proponent would have to satisfy what are known as the "*Daubert* factors" to establish that the proffered evidence represents reliable scientific knowledge.[94] The *Daubert* factors ask the following questions: (1) whether the theory or technique is testable; (2) whether the theory or technique has in fact been tested; (3) whether the theory or technique has been subjected to peer review and publication; (4) what is the known or potential error rate; (5) whether there has been an "existence and maintenance of standards controlling the technique's operation"; and (6) whether the theory or technique has attained general acceptance.[95] It will also be difficult, if not impossible, to establish that fMRI detection of deception satisfies the test of admissibility required by *Daubert*.

In evaluating the first *Daubert* factor, it is arguably impossible to truly test fMRI detection of deception. The published study results are based on paradigms that share none of the properties of real-world lying.[96] The existent studies involve participants being told to lie about inconsequential things. It is not obvious how fMRI lie detection could ever be tested under anything resembling real-world conditions.[97] For a prospective study to test such real-world conditions, the study would have to somehow get participants to commit a crime and prosecute them for that crime, something that is clearly unethical to even consider. The other approach to testing fMRI lie detection under real-world conditions would be to retroactively test real defendants and then verify their results against the "objective" truth. The problem with this approach is that rarely, if ever, is the objective, absolute truth known in such real-world situations. Thus, reality is a far cry from the carefully controlled

92. *See* Madrigal, *supra* note 89 (reporting that No Lie MRI claims its test is over 90% accurate).

93. *Id.*

94. *Daubert*, 509 U.S. at 592-94.

95. *Id.* at 593-94.

96. Greely & Illes, *supra* note 21, at 404.

97. *Id.*

laboratory situation in which it is known with certainty which answers were truthful and which were deceptive.

In evaluating the second *Daubert* factor–whether the technique has been tested[98]–fMRI detection of deception fares better than some forensic evidence techniques, but overall this technique has not been tested to a sufficient extent.[99] As discussed above, there are currently about twenty published studies of fMRI deception detection, but these studies do not paint a clear picture that points to admissibility. The studies are replete with weaknesses, and their results are not consistent with each other.[100] Of critical importance here is the fact that only four studies have attempted to discriminate between truth and deception in individuals instead of simply examining group-averaged activation patterns. None of these studies has been independently replicated.

Regarding the third *Daubert* factor, fMRI detection of deception has been the subject of some peer review and publication.[101] Twenty primary studies have been published subject to peer review. However, the peer review consisted of evaluating only the study design and the analysis applied.[102] These published studies pass muster as valid fundamental science and nothing more. Though these studies reflect science that is perfectly valid under the regime of scientific study, the studies do not prove that this technique is ready to make definitive judgments of truth or falsity in the legal context.

The fourth *Daubert* factor concerns the known or potential error rate of the technique.[103] In evaluating this factor, only the four studies of individual responses have any validity. These studies reported accuracy rates between 70% and 90%, sensitivity between 69% and 91%, and specificity between 40% and 90%.[104] While not necessarily damning, these are not the error rates one would want to see if the consequences are high, as they are in many courtroom dramas. The reported specificity of 42%[105] is especially alarming since it appears that it would be relatively easy for an fMRI lie test to register a false positive, in effect determining that a subject was lying when he was in fact being truthful.

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98. 509 U.S. at 593.

99. As stated previously, only four studies have examined individual responses and attempted to categorize them as truthful or deceptive based on models of deceptive brain activation patterns derived from group studies. *See* sources cited *supra* note 49.

100. Spence, *supra* note 59.

101. *See, e.g.*, Spence, *supra* note 59, at 11.

102. *Id.* at 12.

103. 509 U.S. at 594.

104. *See supra* note 50.

105. Kozel et al., *Functional MRI, supra* note 47, at 226.

As to the fifth *Daubert* factor, the existence and maintenance of standards controlling the technique's operation, there simply are no standard techniques at this time.[106] As discussed above, this technique is still in its infancy, undergoing fundamental research. Each group studying fMRI lie detection is making up new study designs and trying them out.[107] Presumably, No Lie MRI and CEPHOS have in-house procedures that they follow, but any such procedures and standards have not been vetted by any outside, neutral authority.

The sixth *Daubert* factor is general acceptance.[108] As discussed above in the *Frye* analysis, there is no evidence of general acceptance even within the community of researchers who study fMRI detection of deception. As Dr. Langleben has stated, this technology is not ready for deployment in the real world.[109]

IX. CONCLUSION

There is a growing probability that neuroscience will play a role in court. In some contexts, this is entirely appropriate; for example, structural scans may be used to show that a defendant's brain is malformed as probative for proving his mental impairment. In the context of detecting deception, however, mankind's current understanding of neuroscience is not sufficient to support introduction of fMRI lie detection. This is a technique that is still the subject of very productive fundamental research, but this research is not mature enough to qualify as reliable scientific knowledge. Given the difficulties of testing fMRI deception detection in real-world conditions, it is debatable whether it will ever be admissible as substantive evidence. This is not to say that there are not other productive uses for this technique, such as its employment during investigation of crimes. The results of polygraph tests are similarly inadmissible in most courts, but that has not stopped the technique from being used extensively in non-judicial contexts. At least for now, the nonjudicial path is the appropriate one for the proponents of fMRI detection of deception to follow.

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106. *See* Greely & Illes, *supra* note 21, at 402.
107. *Id.*
108. 509 U.S. at 594.
109. Jane Campbell Moriarty, *Visions of Deception: Neuroimages and the Search for Truth*, 42 AKRON L. REV. 739, 748 (2009).