Brain Mapping of Deception and Truth Telling about an Ecologically Valid Situation: Functional MR Imaging and Polygraph Investigation—Initial Experience[1]

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Purpose: To examine the neural correlates during deception and truth telling by using a functional magnetic resonance (MR) imaging technique and an ecologically valid task and to compare the results with those of a standard polygraph examination.

Materials and Methods: All subjects gave written informed consent for this HIPAA-approved study, which was approved by the institutional review board of Drexel University. Eleven healthy subjects (five female and six male subjects; mean age, 28.9 years) were randomly assigned to the group of guilty subjects or the group of nonguilty subjects. Each group consisted of two separate functional MR imaging conditions: "lie-only condition" and "truth-only condition." The lie-only condition was used to compare brain activity during a known lie to control questions and a subjective lie to relevant questions. The truth-only condition was used to compare brain activity during a known truthful response to control questions and a subjective truthful response to relevant questions. Functional MR images were acquired with an echo-planar sequence, and statistical analysis was performed. Physiologic responses were measured with a standard four-channel polygraph instrument.

Results: During the deception process, specific areas of the frontal lobe (left medial and left inferior frontal lobes), temporal lobe (right hippocampus and right middle temporal gyrus), occipital lobe (left lingual gyrus), anterior cingulate, right fusiform gyrus, and right sublobar insula were significantly active. During the truth telling process, specific areas of the frontal (left subcallosal gyrus or lentiform nucleus) and temporal (left inferior temporal gyrus) lobes were significantly active. The polygraph examination revealed 92% accuracy in deceptive subjects and 70% accuracy in truthful subjects.

Conclusion: Specific areas of the brain involved in deception or truth telling can be depicted with functional MR imaging.

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Determining whether an individual is telling the truth or telling a lie has been a goal of humankind for centuries (1). Early methods of lie detection—as well as some modern techniques—rely on observations of proposed nonverbal indicators of deception, such as increased perspiration, changing body positions, or subtle facial expressions (1–3). However, there has been an effort to develop and use technology (ie, the standard polygraph and infrared thermal imaging [4]) to aid in the identification of deception by measuring changes in sympathetic nervous system responses.

Of several techniques that are currently used and several others that are being developed to aid in the detection of deception, the standard polygraph examination is the most reliable (reliability, 80%–90%) and widely used (5). Although the polygraph test has become the most common method used to detect deception, it has several drawbacks (6–8). These include failure of the examiner to properly prepare the examinee, misinterpretation of physiologic data on the polygraph charts, and subjectivity involved in polygraph testing. One of the major problems with the polygraph test is that it is entirely based on measurement of the sympathetic nervous system response; however, sympathetic nervous system response is not unique to deception and it can occur in other normal emotional states (ie, guilt, excitement, anger).

Functional magnetic resonance (MR) imaging based on blood oxygen level–dependent (BOLD) imaging is a method that is used to measure indirect responses that are tightly coupled with neuronal activity, and it is used to map human brain functions (9,10). This technique may enable accurate mapping of the regions of the brain that are involved in higher cortical functions, including cognitive processes such as deception and truth telling. Results of several functional MR imaging studies have shown the prefrontal cortices, parietal lobes, and anterior cingulate are activated during judgment, manipulation of information, and planning of response, including inhibition (10–17). These studies did not use standard polygraph techniques or innovations from that field of expertise or a real-life task that would elicit cognitive and emotional responses. The techniques used in these studies varied and included guilty knowledge testing (13), digit memory testing (12), card sorting testing (13), and neuropsychologic evaluations (11, 14,15). Thus, the purpose of our study was to examine the neural correlates during deception and truth telling by using functional MR imaging and an ecologically valid task and to compare these results with the results of a standard polygraph examination.

Advances in Knowledge

- With 1.5-T functional MR imaging, we were able to detect unique and overlapping areas in the brain associated with deception and truth telling.
- More areas of the brain were activated during deception than during truth telling.

Materials and Methods

Working Model of Deception

On the basis of published imaging data, we devised a working neurological model of deception to guide our investigation and to better show the cognitive complexities involved in formulating a lie (Fig 1). This model is described in detail in the Appendix.

Subjects

We recruited 12 subjects for this study; however, the data of one subject were eliminated because this subject accepted guilt prior to the start of the study, even though this subject was instructed to lie and try to beat the test. Thus, the experiments were performed in 11 healthy volunteers (five female and six male subjects; mean age, 28.9 years) who were screened for drug use, neurological and neuropsychiatric illness, and contraindications to MR imaging performed with a standard 1.5-T imager (Vision; Siemens, Erlangen, Germany). Ten subjects were right handed, and one was left handed. All subjects gave written informed consent, and the institutional review board of Drexel University approved the study. The study was compliant with the Health Insurance Portability and Accountability Act. All subjects underwent an initial preparation phase, an interview phase, a polygraph test, and a functional MR imaging examination. The order of the functional MR imaging examination and the polygraph test was randomized. In the preparation phase, subjects were given the following instructions by one of the investigators (S.H.F.):

> Scenario 1, guilty subjects: You have been chosen to fire a gun inside the hospital. The only person that will know that you fired the gun is the researcher who gave it to you. After firing the gun, your role in this project is to fool everyone else into believing you did not fire it. The researchers who will interview you and test you via the polygraph and functional MR imaging have been told that you are a suspect in the shooting because someone who looks like you appeared on a video surveillance system in the area around the time of the shooting. Your role is not to be identified as the shooter.

> Scenario 2, nonguilty subjects: Someone fired a gun today inside the hos-

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Abbreviations:
BA = Brodmann area
BOLD = blood oxygen level dependent

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> pital. The researchers that will interview you and test you via the polygraph and functional MR imaging have been told that you are a suspect in the shooting because someone who looks like you appeared on a video surveillance system in the area around the time of the shooting. Your role is to be cooperative and truthful, since you did not fire the gun. You want to do well in the interview and testing and demonstrate to them you are innocent.

The relevant situation used in this study was a mock shooting, in which a starter pistol with blank bullets was fired in a testing room in the functional neuroimaging center at Drexel University. Prior to the study, subjects were informed about gun safety and instructed to fire a pistol with blank bullets. None of the subjects reported having any distress or upset feelings. They were asked to wear goggles for eye protection. The functional MR imaging laboratory is a safe environment, and care was taken to not affect other medical projects. This was followed by an interview phase that used the forensic assessment interview technique (22), in which the subjects were asked about their involvement in the study and basic demographic information was gathered. Functional MR imaging and polygraph testing were performed after the interview.

Of the 11 subjects, five were asked to tell the truth (scenario 2; ie, they were not involved in the relevant situation), and six were asked to deliberately lie (scenario 1; ie, deny their involvement in the relevant situation). We pooled the subjects who were asked to lie; hereafter, they are referred to as guilty subjects. We also pooled the subjects who were asked to tell the truth; hereafter, they are referred to as nonguilty subjects. The subjects were informed that they would be rewarded $25 for correctly following the instructions given by one of the investigators (S.H.F.). For guilty subjects in the lie-only condition (ie, subjects were asked to lie to all questions), the relevant question was a subjective lie, since the shooter declared his or her lie with a “yes” response, which was actually the truth. In nonguilty subjects, subjects who told the truth lied to relevant questions, which they declared with a “yes” response and admitted to a crime they did not commit. Similarly, for guilty subjects in the truth-only condition (ie, subjects were asked to respond truthfully to all questions), the relevant question was a subjective truth, since the shooter declared the truth with a “no” response, which was actually a lie. In nonguilty subjects, the subjective truthful response to relevant questions was “no,” since the subjects truthfully denied the act they did not commit.

Polygraph Measurements and Analysis

A certified polygraph examiner (N.J.G., with 26 years of investigative, administrative, and polygraph experience) performed the interviews and polygraph

Figure 1

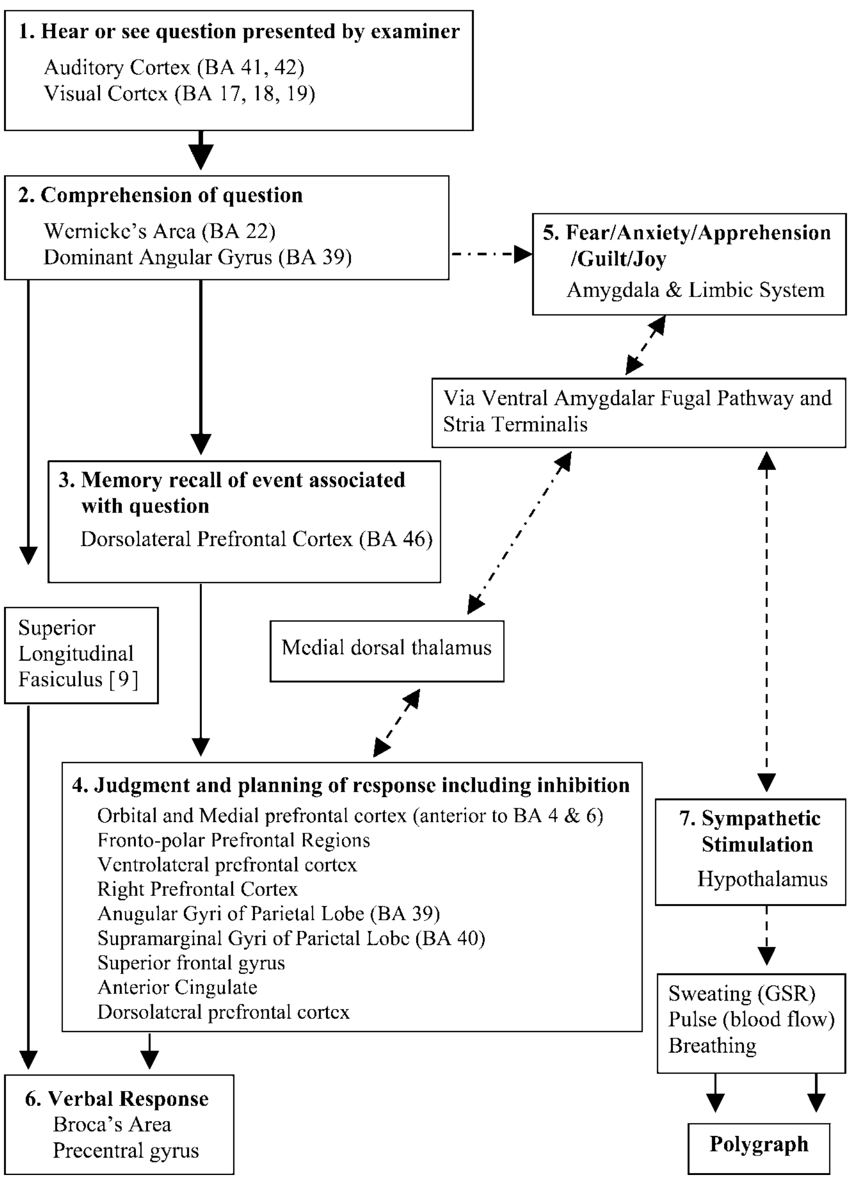

Figure 1: Diagram shows hypothetical model of deception. *GSR* = guilty subject response.

measurements in all subjects. The physiologic responses from the healthy subjects were measured by using a four-channel computerized LX-4000 (Lafayette Instrument, Lafayette, Ind) polygraph instrument. Three different types of physiologic responses were measured. The rate and depth of respiration were measured with two different pneumographs secured around the chest and abdomen. A blood pressure cuff placed around the subject's bicep was used to measure cardiovascular activity. The galvanic skin conductance, which is a measure of electrical conductivity related to perspiration, was measured with electrodes attached to the index finger of volunteers. All polygraph signals were digitally recorded, and responses were displayed in a moving chart on a laptop computer by using LX software (Lafayette Instrument). The polygraph results were analyzed with the following three methods of polygraph scoring: *(a)* Polyscore software (23), which was developed at the Johns Hopkins University applied science laboratory (Baltimore, Md); *(b)* the objective scoring system (24), which was developed by Donald Krapohl (U.S. Department of Defense, Polygraph Institute, Ft Jackson, SC); and *(c)* Poly Suite software (25,26), which was developed at the Academy for Scientific Investigative Training (Philadelphia, Pa).

Functional MR Imaging

In the functional MR imaging experiment, a boxcar block design was used for image collection. The order of the functional MR imaging and polygraph procedures was randomized across subjects. Subjects were instructed to remain still during the examination. The auditory stimulus was controlled from outside the imager by using Presentation software (Neurobehavioral Systems, Albany, Calif) and delivered through headphones that were compatible for use in the MR imaging environment. Subjects listened to digitally recorded questions read by the same investigator who performed the interviews and polygraph tests. The same voice was used across all subjects and recordings of questions, which were matched as closely as possible in length, volume, and clarity. All questions were designed to be answered with "yes" or "no" responses, and subjects were instructed to respond by using designated keys on an MR-compatible response box (Resonance Technology, Northridge, Calif). The question format that was used in this study was based on a modified positive control polygraph questioning technique. The questions used in the polygraph examinations and the functional MR imaging studies were the same.

Initially, a high-spatial-resolution (matrix size, 256 × 256) T1-weighted spin-echo sequence (repetition time msec/echo time msec, 500/14) was used to acquire anatomic images. Twenty-five contiguous transverse MR images were positioned and aligned parallel to the anterior commissure–posterior commissure line covering the entire brain (27). Later, functional MR images were acquired with the echo-planar sequence in the same plane as the structural images. The imaging parameters were as follows: 4000/54; matrix, 128 × 128; field of view, 22 cm; section thickness, 5 mm; number of signals acquired, one. In-plane image resolution was 1.72 × 1.72 × 5.00 mm.

The subjects were presented with five blocks of control questions, five blocks of rest, five blocks of relevant questions, and five blocks of rest, for a total of 20 blocks and 120 volumes. During each 24-second block, six volumes of echo-planar images were acquired, yielding a total of 120 echo-planar imaging volumes. It was expected that subjects denying their involvement in the relevant situation would produce a greater autonomic response to the relevant questions than to the control questions (Figs 2, 3). Continuous imaging was performed until all 20 blocks were completed.

Two separate functional MR imaging sessions were conducted. The first imaging session, termed *lie-only condition*, was conducted to compare brain activity during the known lie to control questions with brain activity during the subjective lie to relevant questions. This was followed by another imaging session, termed *truth-only condition*, in which brain activity during a known truthful response to control questions was compared with brain activity during a subjective truthful response to relevant questions. The questions were randomized and repeated between different blocks. The instructions pertaining

Figure 2

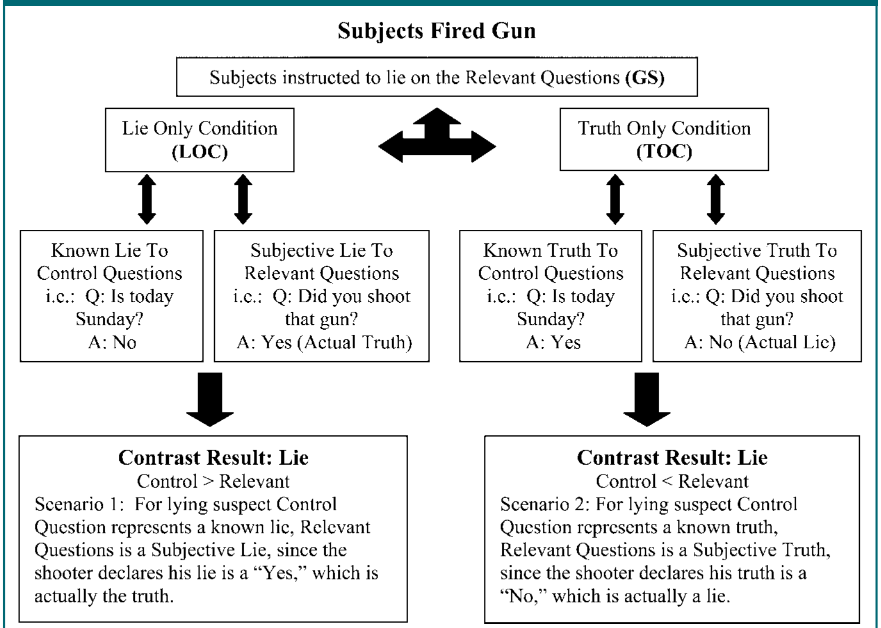

Figure 2: Diagram shows functional MR imaging analysis strategy for guilty subjects *(GS)*.

to the lie-only condition and the instructions pertaining to the truth-only condition were given while the subjects were inside the imager and prior to the specific experimental condition. At the end of the examination, all subjects were debriefed about the study and their participation by two investigators (F.B.M. and S.M.P.). This debriefing covered the role of the subjects in the study, expected outcomes, and who to contact if the subjects had additional questions.

Image Processing and Statistical Analysis

Postacquisition preprocessing and statistical analysis were performed with statistical parametric mapping software (SPM2; Wellcome Department of Cognitive Neurology, University College of London, London, England) (28) in the Matlab environment (Mathworks, Natick, Mass) by two investigators (F.B.M. and S.M.P.). Images were converted from the Vision (Siemens) format to the Analyze (Analyze Direct, Lenexa, Ky) format adopted in the statistical parametric mapping software package. A three-dimensional automated image registration routine (six-parameter rigid body sinc interpolation; second-order adjustment for movement) was applied to the volumes to realign them with the first volume of the first series used as a spatial reference. All functional and anatomic volumes were then transformed into the standard anatomic space by using the T2-weighted echo-planar imaging template and the statistical parametric mapping software normalization procedure (29). This procedure involved the use of a sinc interpolation algorithm to account for brain size and position with a 12-parameter affine transformation, followed by a series of nonlinear basic function transformations (ie, seven, eight, and seven nonlinear basis functions for the x, y, and z directions, respectively) with 12 nonlinear iterations to correct for morphologic differences between the template and the given brain volume. Next, all volumes underwent spatial smoothing by convolution with a Gaussian kernel of 8-mm^3 full width at half maximum to increase the signal-to-noise ratio and account for residual intersession differences.

Figure 3

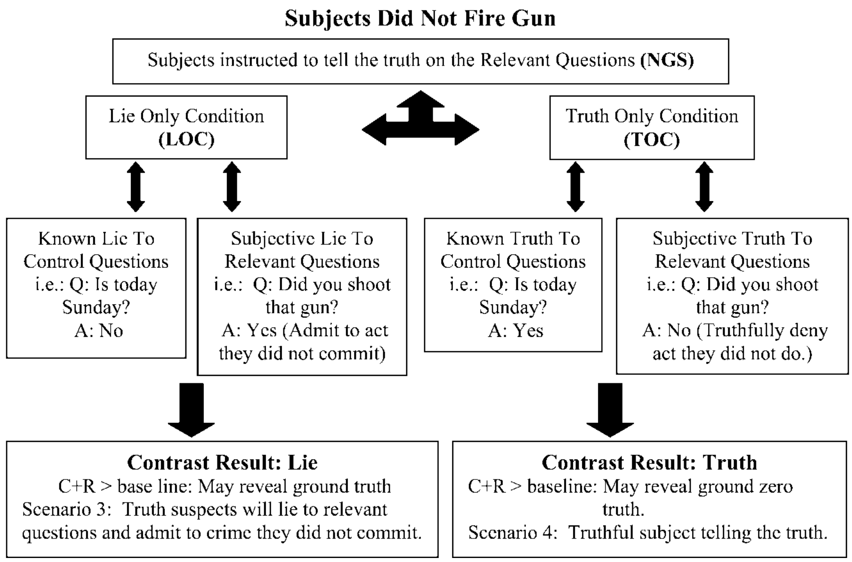

Figure 3: Diagram shows functional MR imaging analysis strategy for nonguilty subjects *(NGS)*. *C* + *R* = control and relevant.

Subject-level statistical analysis was performed with the general linear model of SPM2 software (Wellcome Department of Cognitive Neurology). The functional MR images corresponding to the relevant and control conditions in the two trials (ie, lie-only condition and truth-only condition) in the two groups of subjects (ie, guilty subjects and nonguilty subjects) were modeled by using a canonical hemodynamic response function. Contrast maps were obtained with the following linear contrasts of events: *(a)* relevant versus control questions (lie effect: guilty subjects, lie-only condition), *(b)* control versus relevant questions (lie effect: guilty subjects, truth-only condition), *(c)* relevant and control questions versus baseline questions (lie effect: nonguilty subjects, lie-only condition), and *(d)* relevant and control questions versus baseline questions (truth effect: nonguilty subjects, truth-only condition).

Next, group-level random-effects analyses for main effects were performed by entering whole-brain contrast parameters into one-sample *t* tests. A significance threshold based on spatial extent with a height of 3.00 or more and an uncorrected cluster probability of .001 or less were applied to the effects of interest, and surviving voxels were retained for further analyses (spatial extent threshold > 10 voxels). Statistical parametric maps were generated to show visual representation of the areas of the brain where statistically significant differences between BOLD contrast during truth telling and that during deception are present. The analysis scheme that was performed in this study and sample questions are shown in Figures 2 and 3.

Results

To evaluate the demographic characteristics between the group of guilty subjects and the group of nonguilty subjects, we performed a *t* test for age times number of nonguilty subjects divided by number of guilty subjects and a χ^2 test for sex times number of nonguilty subjects divided by number of guilty subjects. The results showed no significant differences between the groups.

Polygraph Data Results

A total of 11 subjects completed this study; six were guilty and five were not guilty (Table 1). In the group of guilty subjects, Polyscore and the objective scoring system had one inconclusive result each; however, analysis with the Polyscore technique showed 100% correlation (Table 2). In the nonguilty subjects, accuracy varied across the three scoring methods. With data from the three polygraph charts, Polyscore and the objective scoring system were used to properly identify three of five nonguilty subjects, while polygraph results in two subjects were inconclusive. Poly Suite enabled proper identification of four of the five nonguilty subjects as truthful, with inconclusive polygraph results in one subject. Accuracy for examination of nonguilty subjects ranged from 60% to 80% (Table 2).

Table 1

Polygraph Results for Individual Subjects

Subject No.	Guilt	Method of Polygraph Scoring: Polyscore	Objective Scoring System	Poly Suite
1	Guilty	Deception indicated	Deception indicated	Deception indicated, −39
2	Guilty	Deception indicated	Deception indicated	Deception indicated, −40
3	Not guilty	No deception indicated	No deception indicated	No deception indicated, +26
4	Not guilty	Inconclusive*	Inconclusive	Inconclusive, +5
5	Not guilty	No deception indicated	No deception indicated	No deception indicated, +36
6	Not guilty	Inconclusive†	Inconclusive	No deception indicated, +16
7	Guilty	Deception indicated	Inconclusive	Deception indicated, −24
8	Guilty	Deception indicated	Deception indicated	Deception indicated, −58
9	Guilty	Inconclusive	Deception indicated	Deception indicated, −23
10	Guilty	Deception indicated	Deception indicated	Deception indicated, −32
11	Not guilty	No deception indicated	No deception indicated	No deception indicated, +54

Source.—References 28, 29, and 30.

* Probability of deception indicated = .78.

† Probability of deception indicated = .94.

Table 2

Accuracy of Algorithms used to Interpret Polygraph Studies

Accuracy	Polyscore (%)	Objective Scoring System (%)	Poly Suite (%)
Guilty subjects	100	100	100
Not guilty subjects	60	60	80
Mean accuracy	80	80	90

Table 3

Local Maxima of BOLD Changes in Guilty Subjects during Lie Experiment

Region	Hemisphere	Coordinates: x	y	z	*z* Score
Lingual gyrus (BA 18)	Left	−17	−83	−6	4.56
Middle occipital gyrus (BA 19)	Left	−35	−85	8	4.40
Sublobar, insula (BA 13)	Right	39	−9	19	4.05
Fusiform gyrus (BA 37)	Right	28	−47	−10	4.04
Sublobar, insula (BA 13)	Left	−38	15	17	4.00
Precentral (BA 4)	Left	−52	−1	15	3.86
Precentral (BA 43)	Left	−52	−9	12	3.15
Anterior cingulate (BA 32)	Right	6	39	−5	3.62
Caudate body	Left	−20	−18	23	3.99

Note.—Lie condition 1.

Functional MR Imaging Results

Significant areas of activation were seen in all lie conditions ($P < .001$, spatial extent threshold > 10 for lie condition 1 [ie, lie-only condition in guilty subjects]; $P < .005$, spatial extent threshold > 10 for lie condition 2 [ie, truth-only condition in guilty subjects] and lie condition 3 [ie, lie-only condition in nonguilty subjects]) (Tables 3–5, Fig 4). In lie condition 1, activations were seen in the left lingual gyrus, left middle occipital gyrus, bilateral sublobar insula, right fusiform gyrus, left precentral gyrus, right anterior cingulate, and left caudate body. In lie condition 2, activations were seen in the right inferior parietal lobule, left inferior frontal gyrus, left medial frontal gyrus, right anterior nucleus of the thalamus, left lingual gyrus, and left caudate body and tail. In lie condition 3, activations were seen in the right hippocampus, left precuneus, right middle temporal lobe, right paracentral lobule, right precentral gyrus, bilateral precuneus, and left posterior cingulate areas. Significant areas of activation (Table 6, Fig 5) during the truth experiment in nonguilty subjects ($P < .005$, spatial extent threshold > 10) were seen in the left subcallosal gyrus, left lentiform nucleus, right precuneus, left interior temporal lobe, left parietal lobule, left posterior cingulate gyrus, and right precentral gyrus.

Summary of Results

During the deception process, 14 regions were found to be significantly active. Our results show areas of the *(a)* frontal lobe (left medial, left inferior, and bilateral precentral gyri) (Brodmann areas [BAs] 9, 10, and 6), *(b)* temporal lobe (right hippocampus and right middle temporal gyrus) (BA 19), *(c)* parietal lobe (bilateral precuneus and right inferior parietal lobule) (BA 40), *(d)* occipital lobe (left lingual gyrus) (BA 18), and *(e)* anterior and posterior cingulate, right fusiform gyrus, and right sublobar insula and thalamus regions to be significantly active during deception. During truth telling, seven regions were significantly active. These active regions were seen in the frontal lobe (right precentral, left subcallosal lentiform nucleus) (BAs 46 and 10), temporal lobe (left inferior temporal gyrus) (BA 20), parietal lobe (right precuneus, left inferior parietal lobule), and posterior cingulate gyrus.

Table 4

Local Maxima of BOLD Changes in Guilty Subjects during Truth Experiment

Region	Hemisphere	Coordinates x	y	z	*z* Score
Inferior parietal lobule (BA 40)	Right	36	−48	45	4.25
Inferior frontal gyrus (BA 9)	Left	−56	15	25	4.06
Medial frontal gyrus (BA 9)	Left	−4	54	38	3.92
Sublobar, thalamus, anterior nucleus	Right	6	−5	13	2.83
Lingual gyrus (BA 18)	Left	0	−88	−4	3.41
Caudate body	Left	−6	4	9	3.34
Caudate tail	Left	−14	−20	20	3.14

Note.—Lie condition 2.

Table 5

Local Maxima of BOLD Changes in Not Guilty Subjects during Lie Experiment

Region	Hemisphere	Coordinates x	y	z	*z* Score
Hippocampus	Right	30	−27	−2	4.38
Precuneus	Left	−20	−56	56	4.16
Middle temporal lobe (BA 19)	Right	46	−79	21	3.62
Paracentral lobule (BA 5)	Right	2	−44	56	3.62
Precentral gyrus (BA 6)	Right	50	−4	41	3.54
Precuneus (BA 31)	Left	−14	−45	35	3.52
Precuneus (BA 7)	Right	12	−59	62	3.47
Posterior cingulate (BA 30)	Left	0	−62	9	3.47

Note.—Lie condition 3.

Discussion

In our study, we used stimulus paradigms and conditions that simulate the processes of lying and truth telling to map the areas of brain activation with BOLD functional MR imaging. The stimulus we used (ie, a starter pistol with blank bullets) elicits sensory activation (ie, visual, tactile, auditory, olfactory) and has emotional content (ie, fear, anxiety, apprehension) so as to simulate the natural reaction to committing a crime, thus activating essential emotional components involved in the process of deception and truth telling. We used knowledge and techniques that have been used in polygraph studies to collect functional MR imaging data. The polygraph test helped us determine whether subjects were lying or telling the truth. Polygraph test results showed good matching to the actual event when subjects were asked to lie; however, the results were not as conclusive when subjects were asked to tell the truth.

It is likely that a subject cannot mask functional MR imaging brain activation patterns. We believe the brain areas that are active during deception will always be active when the subject tells a lie. Likewise, we believe the same areas will always be inactive when the subject tells the truth. A subject can attempt to create a false-negative outcome (ie, deceptive person erroneously determined to be truthful) by attempting countermeasure techniques to irrelevant or comparison questions during the polygraph examination. The cognitive aspects of telling a lie are not measured by a polygraph, since this test is only used to measure the anxiety expressed by the limbic system. The polygraph does not measure the result of activity in the frontal lobe that is presumably working to inhibit the truth and construct a lie.

Fourteen areas of the brain were active during the deceptive process across the three lie conditions. The lingual gyrus of the left hemisphere, which is associated with differentiating language, was active. The lingual gyrus, middle occipital gyrus of the left hemisphere, and fusiform gyri of the right hemisphere have been associated with silent reading of sentences and are probably associated with linguistic processing of sentences, as well as mental sequencing associated with sentence structure and meaning (18). Sublobar insula areas have been shown to be associated with feelings of disgust and nausea. The anterior cingulate is involved in a number of processes, but attention and response inhibition are the probable causes of activation in this study. The inferior parietal lobe in the right hemisphere and the inferior frontal gyri in the left hemisphere may be part of the so-called mirror neuron system involved in mentally representing one's own behaviors, as well as similar behaviors in others. The inferior parietal lobe in the right hemisphere is also involved in representation of the self-concept in the mind; therefore, patients who have lesions in this area—especially in the right hemisphere—experience misidentification syndromes when they no longer believe the left half of their body belongs to them (hemibody neglect syndrome). The medial frontal gyrus has been associated with social cognition or thinking about other people's thoughts, social interactions, and the consequences of such interactions. The caudate is the part of the basal ganglia involved in motor control. The hippocampus, which is primarily associated with memory and emotions (18), was active during the deception process in the current study. The precuneus is involved in autobiographical memory, expert memory for past behaviors in which the person has been involved, and determination of mental imagery (ie, whether one's mental imagery is correct). The posterior cingulate is associated with some emotional processing and functions similar to those of the precuneus. The posterior cingulate may also be associated with internal feelings of discomfort.

During truth telling, of the seven regions activated, the only new activated area that was seen in addition to the previously mentioned activated areas was the inferior temporal lobe in the left hemisphere, which has been associated with memory of faces and may be involved in spatial and temporal encoding of events (ie, when, where, and how events occurred).

Figure 4

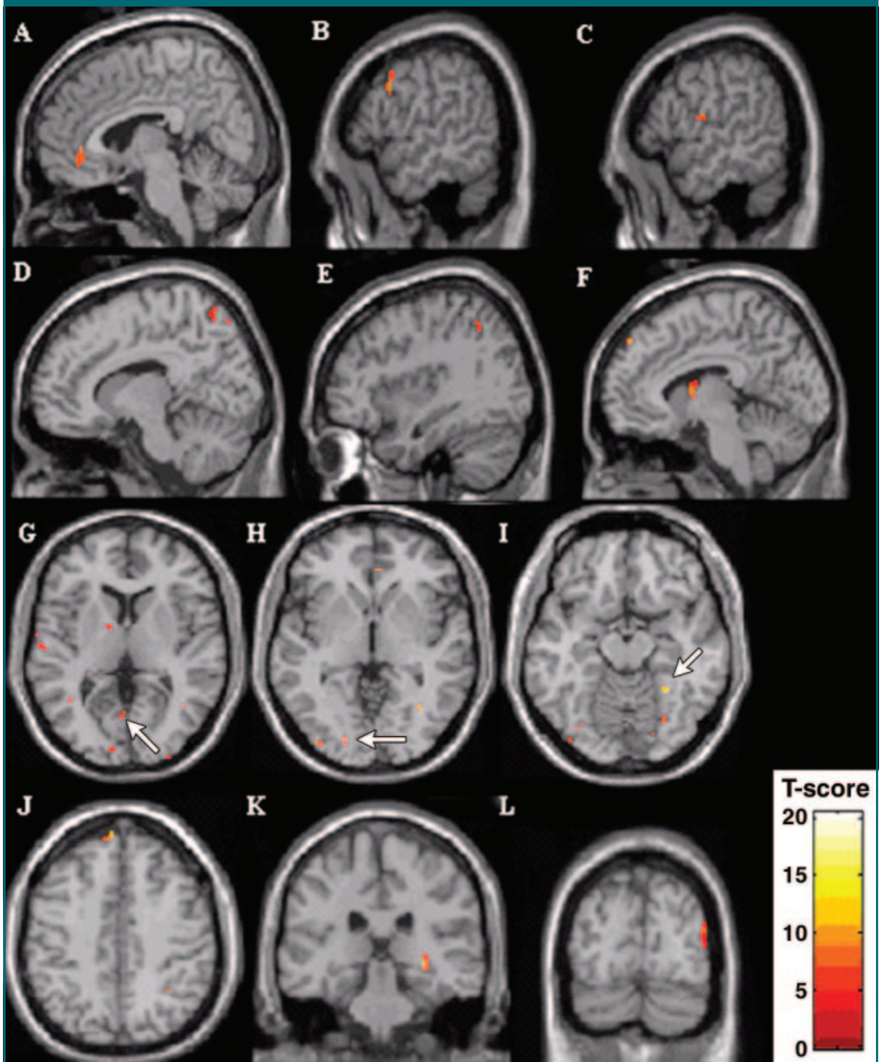

Figure 4: Functional MR images show significant areas ($P < .001$, spatial extent threshold > 10 for lie condition 1; $P < .005$, spatial extent threshold > 10 for lie conditions 2 and 3) of activation that are seen across the three lie conditions. Functional MR images were obtained with an echo-planar pulse sequence (4000/54) and show, *A*, anterior cingulate (sagittal section); *B*, left inferior frontal gyrus (sagittal section); *C*, left precentral gyrus (sagittal section); *D*, precuneus (sagittal section); *E*, inferior parietal lobule (sagittal section); *F*, sublobar insula or thalamus (sagittal section); *G*, posterior cingulate (transverse section [arrow]); *H*, left lingual gyrus (transverse section [arrow]); *I*, right fusiform gyrus (transverse section [arrow]); *J*, left medial frontal gyrus (transverse section); *K*, right hippocampus (coronal section); and *L*, right middle temporal (transverse section).

A major limitation of this study was that one of the investigators (F.B.M.) had knowledge about all phases in the study, which was necessary to coordinate the group role assigned to each subject (guilty subjects or nonguilty subjects) and thus established "ground zero" truth to measure the accuracy of the polygraph test and functional MR imaging procedures that were to follow. The other researchers were blinded to subject condition. In future studies, all investigators should be completely blinded to eliminate any bias. Furthermore, future studies should use a larger sample size and age- and sex-matched controls.

In summary, our results show there are specific areas of brain function that may be used to dissociate the processes of deception and truth telling. There were overlapping and specific areas of involvement underlying these processes. When comparing our results with the hypothetical model of deception, we found that many areas of the brain that are associated with planning, inhibition, and emotion may also be involved in deception. Our results show that deception is associated with activation of the limbic system, parts of the frontal lobe that are probably involved in suppressing or inhibiting the truth, and parts of the temporal lobe that might be involved in memory encoding and retrieval. Furthermore, anxiety is presumably associated with deception, which is reflected in the activation of the limbic system. When a subject tells the truth, however, there is far less anxiety, and an alternative cognitive thought process does not need to be inhibited. Thus, fewer brain areas are active in the frontal and limbic system during the truth telling process.

These results are preliminary, and it is too early to predict whether functional MR imaging will replace other

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methods of examining deception, either in conjunction with other techniques or as a stand-alone procedure. Future functional MR imaging studies involving a large sample size and conventional reliability and validity methods are required to establish the utility of this method as a test for deception.

Table 6

Local Maxima of BOLD Changes in Not Guilty Subjects during Truth Experiment

Region	Hemisphere	Coordinates x	y	z	z Score
Subcallosal gyrus (BA 47)	Left	−16	17	−9	4.11
Sublobar, lentiform nucleus	Left	−22	19	−3	3.88
Precuneus (BA 7)	Right	20	−50	54	3.74
Inferior temporal (BA 20)	Left	−65	−22	−16	3.52
Parietal lobule (BA 40)	Left	−48	−40	48	3.50
Cingulate gyrus	Left	−4	−26	33	3.45
Precentral gyrus (BA 6)	Right	42	−1	37	3.00

Note.—Truth condition.

Figure 5

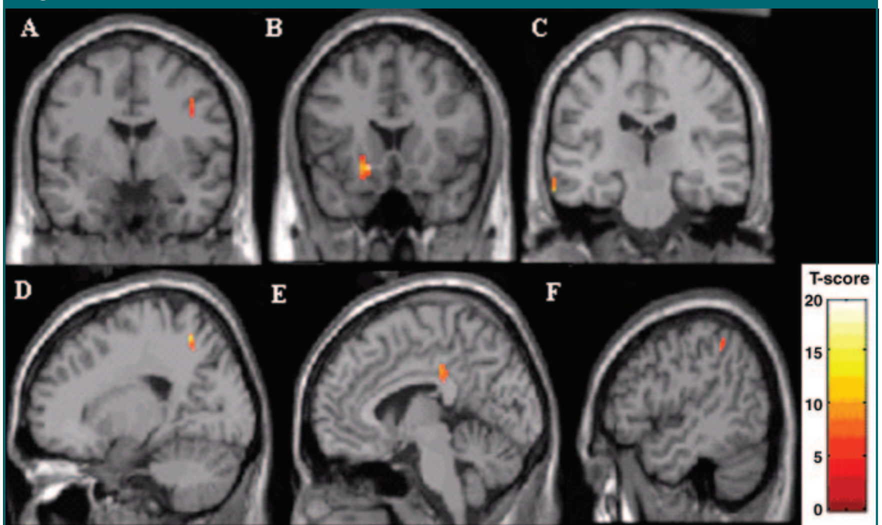

Figure 5: Functional MR images show significant areas ($P < .005$, spatial extent threshold > 10) of activation that are seen during the truth condition. Functional MR images were obtained by using an echo-planar pulse sequence (4000/54) and show, *A*, precentral gyrus (transverse section); *B*, subcallosal gyrus or lentiform nucleus (transverse section); *C*, inferior temporal (transverse section); *D*, precuneus (sagittal section); *E*, posterior cingulate (sagittal section); and *F*, parietal lobule (sagittal section).

Appendix

On the basis of published imaging data, we devised a working neurologic model of deception to guide our investigation and better show the cognitive complexities involved in formulating a lie (Fig 1). This model takes into account data that are focused on the neural components of deception and data that pertain to neural substrates associated with processes such as inhibition and reward circuitry. It also shows the chain of events involved in conventional polygraph testing.

The process of producing a lie or truthful response begins with hearing or seeing the question, understanding it, and then recalling the event or fact that relates to the question. The perception of the question by means of hearing or vision activates the corresponding auditory cortex (BAs 41 and 42) or visual cortex (BAs 17, 18, and 19). This is followed by receptive language comprehension, which has been linked to activation in the Wernicke area (BA 22), which comprises the posterior portion of the superior temporal gyrus, and the dominant angular cortex (BA 39) (12). Once the question posed to the person is understood, he or she may attempt to recall the event associated with the question. Although the role of the frontal lobes in recall of memory is unclear, areas in the prefrontal cortex are likely to be involved in moderating memory (18–20). The amygdala is an area of the brain associated with emotions such as fear and anxiety. Functional MR imaging studies have shown that recall of an event that is associated with anxiety stimulates the amygdala (18). It should not be misunderstood that activation of the amygdala is representative of inhibition or deception, as one can recall and speak truthfully of an event that involves anxiety. This misunderstanding may form the basis for the false-positive results in polygraph measuring. The polygraph is used to measure the output of the limbic system, including the amygdala, which regulates functions of the sympathetic nervous system, such as heart rate, respiratory rate, and electrodermal response. The limbic system may be activated in situations of anxiety or fear, regardless of the nature of the responses of a subject (18).

After recall of the event of importance, the subject must plan a response consistent with truth or deception. If a person wishes to answer a question truthfully, the person will plan and construct a truthful response. If a person wishes to produce a deceptive response, it is hypothesized that either an additional area of the brain is marshaled to produce such a response or, perhaps, a different activation of the same area is needed to construct the deceptive response. In producing a deceptive response, inhibition or concealment of the truth is obviously a key aspect of the construction. It is this step in the process of deception that has been the focus of intense study with functional MR imaging, since this is the unique cognitive function in the process of lying. There is some consensus among investigators that the prefrontal cortex is an area involved in planning a deceptive response and inhibiting the truth (11,13,18–22). Some functional MR imaging studies of deception demonstrated activation of the anterior cingulate cortex (12–14) and areas of the right hemisphere (13,14). The final component of producing a deceptive or truthful statement involves motor response. These responses may include a truthful or deceptive utterance, or simply pushing a "yes" or "no" response key in the imager. Such a response involves the use of the motor system in the frontal lobe (18).

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