Detecting Deception Using Functional Magnetic Resonance Imaging

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Background: *The ability to accurately detect deception is presently very limited. Detecting deception might be more accurately achieved by measuring the brain correlates of lying in an individual. In addition, a method to investigate the neurocircuitry of deception might provide a unique opportunity to test the neurocircuitry of persons in whom deception is a prominent component (i.e., conduct disorder, antisocial personality disorder, etc.).*

Methods: *In this study, we used functional magnetic resonance imaging (fMRI) to show that specific regions were reproducibly activated when subjects deceived. Subjects participated in a mock crime stealing either a ring or a watch. While undergoing an fMRI, the subjects denied taking either object, thus telling the truth with some responses, and lying with others. A Model-Building Group (MBG,* n = *30) was used to develop the analysis methods, and the methods were subsequently applied to an independent Model-Testing Group (MTG,* n = *31).*

Results: *We were able to correctly differentiate truthful from deceptive responses, correctly identifying the object stolen, for 93% of the subjects in the MBG and 90% of the subjects in the MTG.*

Conclusions: *This is the first study to use fMRI to detect deception at the individual level. Further work is required to determine how well this technology will work in different settings and populations.*

Key Words: Deception, lie, detection, fMRI, BOLD, individual

Deception is ubiquitous in human societies and is essential for proper social interactions. In fact, the ability to lie develops naturally during maturation, and the lack of this ability is indicative of neuropathology (Spence et al 2004). Lying is a complex process requiring suppression of the truth, communication of a coherent falsehood, contextual knowledge of that falsehood, and modifications of behaviors to convince the receiver of ones actions. This complex and universal process would seem amenable to detection by brain imaging. The ability to measure noninvasively the correlates of lying in the brain within an individual could offer a significant improvement over currently available tools to detect deception.

In addition, this methodology could offer a unique opportunity to study the neural circuitry of patients for whom deception is a prominent component. Patients with conduct disorder, antisocial personality disorder, malingering, and substance dependence all have lying as a significant element in their disorder. Being able to noninvasively probe the neurocircuitry of deception in patients with these disorders might lead to a better understanding of the neuropathology, which could lead to improved diagnosis and treatment.

An accurate method to detect deception likely would have important implications for our society. Many legal, political, military, and industrial settings might benefit from an accurate method for detecting deception. Presently available technologies such as the polygraph and voice stress analysis lack rigorous scientific support (Brett et al 1986; Hollien et al 1987; Honts et al 1994; National Academies Press 2003). A fundamental limitation of voice stress analysis, thermal imaging, and polygraph testing is that they measure nonspecific peripheral emotional/autonomic arousal that might or might not be associated with lying. Another technology that does measure brain activity directly, event related potentials, has been used to attempt to determine if a person has prior knowledge of something significant (guilty knowledge test) (Farwell and Donchin 1991). Event related potentials for deception detection, however, does not detect deception, has limited scientific support (U.S. General Accounting Office 2001), and is susceptible to countermeasures (Rosenfeld et al 2004).

Blood oxygen level dependent (BOLD) functional magnetic resonance imaging (fMRI) is a relatively new technology that is used to study the function of the brain (Ogawa et al 1990). With this technology, investigators—including our study group—have found in group analyses that specific brain regions are significantly activated during deception (Ganis et al 2003; Kozel et al 2004a, 2004b; Langleben et al 2002; Lee et al 2002; Nunez et al 2005; Phan et al 2005; Spence et al 2001, 2004). Despite the diversity of paradigms and scanning parameters used to date, most studies have found activation in the anterior cingulate and the prefrontal cortex, areas involved in response inhibition and behavior modification (Bush et al 1998; Elliott et al 2000; MacDonald et al 2000; Pardo et al 1990, 1991). These regions have been activated when compared with the control condition of truth telling, a baseline state believed to require less conscious control than lying.

Because of the historically low signal to noise ratio, fMRI studies have not traditionally been able to make statements about individuals, but only groups of individuals. With improving technology and methodology, however, researchers have begun to be able to achieve reliable results at the individual level for cognitive tasks. As an example, Bush et al (2003) used the Multi-Source Interference Task to produce significant activation in the dorsal anterior cingulate cortex in all eight of their healthy subjects. All previous fMRI deception studies, including our own, however, have only looked for neural correlates of deception at the group level, not whether deception could be detected at the individual level.

In this study, subjects were asked to take a ring or watch and then lie about the object they took. With the first thirty subjects, we built an analysis model in which we could maximally detect

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deception for this Model-Building Group (MBG). After the model was designed, we then recruited and prospectively tested it with an independent sample (Model-Testing Group, MTG).

Methods and Materials

Subjects

The subjects were healthy unmedicated adults ages 18–50 years who were screened with a Structured Clinical Interview for DSM-IV Axis I Disorders (SCID-I) (First et al 1995), a pre-MRI screening form, a medical history, and a physical exam. They were evaluated with an Annett Handedness Scale (Annett 1970) and the State-Trait Anxiety Inventory (STAI) (Spielberger et al 1983). A urine sample was obtained for a drug urinalysis and a urine pregnancy test (if a female of child-bearing potential).

Detecting Deception Paradigm

Subjects were recruited from the University community at large to participate in a mock crime and then deny performing that crime while in a magnetic resonance scanner. At the initial screening visit, informed written consent (approved by the Medical University of South Carolina's Office of Research Integrity) was obtained. Subjects were screened and excluded for taking medications/drugs, being pregnant, or having a medical or psychiatric illness. Furthermore, subjects were given an opportunity to read the questions that they would be asked during the scanning day.

On the scanning day, subjects were taken to a specific room and instructed to "steal" a watch or a ring located in a drawer. The subjects placed the "stolen" object in a locker along with their other belongings while being observed by investigator ELG. Subjects practiced a simple Motor task and the Deception task outside of the scanner. Images were visually displayed to the subjects, and button-press responses and response times recorded with an Integrated Functional Imaging System (IFIS) (MRI Devices, Gainesville, Florida). During the Deception task, four types of questions (see appendix) were visually displayed to subjects: "ring"—regarding whether they took the ring; "watch"—regarding whether they took the watch; "neutral"—general questions with clear yes and no answers; and "control"—questions about doing minor wrongful acts. Subjects were instructed to answer the ring and watch questions as if they had stolen neither object and the control and neutral questions truthfully. Subjects were further informed that they would receive an additional $50 if investigator FAK could not tell when they were lying while being observed answering questions in the scanner. This provided an incentive for subjects to attempt countermeasures when lying. Because of the inability to detect deception immediately during the scanning session, all subjects received the additional $50. After scanning, subjects completed a questionnaire about the study, including what types of countermeasures they attempted, if any.

MRI Scanning

All images were acquired with a 3T MRI scanner (Intera, Philips Medical System, The Netherlands) with an eight-channel SENSE head coil. Subjects performed the Motor task (6 min), then the Deception task (16 min), and finally a T1-weighted structural scan. For the Deception task, 515 echoplanar imaging (EPI) transverse images (repetition time 1867 msec, echo time 30 msec, Flip Angle 90°, field of view 208 mm, matrix 64 × 64, SENSE factor 2, 36 slices, 3 mm with 0 mm gap, giving a voxel size of 3.25 × 3.25 × 3.00 mm^3) were acquired that covered the entire brain and were positioned with reference to the anterior commissure–posterior commissure line with a sagittal scout image.

The Motor task enabled the subjects to become familiar with the testing environment and to practice their responses of "Yes" and "No" with thumb and index finger respectively. For the Deception task, questions were presented visually for 3.5 sec. After a question, there was a visual prompt for the subject to answer "Yes or No" for 2 sec, followed by a "+" for .5 sec. Subjects were instructed to not answer until they saw the visual prompt of "Yes or No." The delayed response was to reduce the variability of response timing due to differences in reading speeds across questions and across subjects. Thus, each question took 6 sec. There were 20 questions for each category (80 unique questions total). The order of the type of question (i.e., ring, watch, neutral, control) was pseudo-randomized with a web-based randomization generator (www.randomization.com) but consistent across subjects. The IFIS system pseudo-randomly chose the actual question for the appropriate category. Thus, the order of the type of questions was consistent across subjects, but the order of the actual questions asked was varied. The 80 questions were presented once for the practice and in two separate sets that were administered consecutively for the scanning.

Data Analyses

For the behavioral data, responses (thumb pressed for "Yes," index finger pressed for "No") and reaction times were acquired via the IFIS. Data were inspected to verify subject behavioral participation in both the Motor and Deception tasks and to screen for irregularities. Responses that were not consistent, not answered, or not as specified in the protocol were identified and modeled as separate "nonprotocol" events.

The analysis of the fMRI data was performed with Statistical Parametric Mapping software (SPM2, Wellcome Department of Cognitive Neurology, London, United Kingdom—run on Matlab version 6.5 Release 13.0.1). Preprocessing of the fMRI data used the same SPM2 procedures and settings for both the MBG and the MTG. The images were reoriented to match the SPM2 EPI template and then realigned and unwarped to correct head movements and resulting susceptibility distortions. Slice timing was performed to correct for differences in slice acquisition time. Functional images were then spatially normalized to the SPM EPI template and resampled with a voxel size of 3 mm^3 (Ashburner and Friston 1999). After normalization, functional images were spatially smoothed with a Gaussian kernel with 8 mm full width at half maximum on the basis of the suggested standard of 2–3 times the output spatially normalized voxel size. By spatially smoothing the data, the errors will be rendered more normal in their distribution to help ensure the validity of inferences on the basis of parametric tests. Also, it will help adjust for inter-subject variations that persist after spatial normalization (Friston 2004). A general linear model within SPM2 was specified and estimated for the MBG and MTG to create individual *t* maps. The event-related design was convolved with a hemodynamic response function that approximated the expected activation patterns. Events were defined as occurring when the cue to answer "Yes "or "No" was presented to the subjects. Effects at each and every voxel were estimated with the general linear model at the first statistical level. The motion-recorded parameters generated during the "Realign" process were included as six user-specified regressors because of their potential to be confounds. The nonprotocol events were also included as a regressor. A high-pass filter (cut off frequency = 128 sec) was used to remove possible effects of low-frequency changes. Individual activated *t* maps were generated by defining the following contrasts and their inverse: Lie-Truth, Lie-Neutral, Lie-Control, Truth-Neutral,

Table 1. Subject Demographics and Behavioral Results

Demographics	Model-Building	Model-Testing	Significance
Screened/Scanned/Imaged	34/31/30	32/31/31	$\chi^2 = .07, p = .97$
Gender (M/F)	17/13	12/19	$\chi^2 = 2.0, p = .16$
Mean Age (SD, range)	30.4 yrs (± 8.3, 19–50)	33.4 yrs (± 9.7, 18–50)	$t = 1.3, p = .20$
Handedness (R/L/Mixed)	28/1/1	24/3/3	$\chi^2 = 2.3, p = .32$
Ethnicity (AA/A/C)	6/1/23	12/2/17	$\chi^2 = 3.2, p = .20$
Employment (FT/PT/U/S)	21/3/1/5	24/1/0/6	$\chi^2 = 1.9, p = .52$
Mean Education (SD, range)	16.2 yrs (± 2.5, 12–20)	16.3 yrs (± 2.5, 12–21)	$t = .16, p = .88$
Behavioral Results			
Object Taken (ring/watch)	16/14	15/16	$\chi^2 = .15, p = .70$
Mean % Questions Responded/Protocol (SD, range)	96.7% (± 2.5, 89.5–100)	96.1% (±3.4, 83.8–100)	$t = .7, p = .50$
Average Subject Reaction Time for Questions Responded Per Protocol			
Deceptive Mean (SD, range)	712 msec (± 135, 459–988)	750 (± 189, 457–1213)	$t = .9, p = .4$
Truthful Mean (SD, range)	747 msec (± 161, 452–1067)	773 (± 206, 474–1308)	$t = .6, p = .6$
Control Mean (SD, range)	722 msec (± 137, 461–1015)	744 (± 185, 490–1188)	$t = .5, p = .6$
Neutral Mean (SD, range)	673 msec (± 123, 425–938)	710 (± 169, 449–1011)	$t = 1.0, p = .3$
Statistical Significance of Average Subject Reaction Time for Deceptive Versus Truthful Responses	$t = .9, p = .4$	$t = .4, p = .6$	

Imaged, number of subjects from which imaging data acquired; Significance, testing the statistical difference between Model-Testing Group and Model-Building Group; Screened, number of subjects that underwent screening; Scanned, number of subjects eligible for screening; *t,* Student *t* test, two-tailed; AA, African-American; A, Asian; C, Caucasian; FT, full time; PT, part time; U, unemployed; S, student.

Truth-Control, and Neutral-Control. Individual contrast images generated at the first statistical level were then used to create group *t* maps at the second level in a random effects model (Friston and Frackowiak 1997). Cluster analyses were performed at identical corrected threshold of $p < .05$ (false discovery rate, FDR) for each group map with a spatial extent threshold of 25 voxels to correct for multiple comparisons (Friston et al 1994). We used FDR to reduce the chance of type II errors, especially because we were using an extent threshold to help correct for type I errors due to multiple comparisons. A "3dmerge" program from Analysis of Functional Neuroimaging (AFNI, 2.56b) (Cox 1996) was used to label each cluster on the basis of sizes of clusters from each cluster mask. Another AFNI program, 3dcalc, was also used to separate each labeled cluster. Seven Lie-minus-True clusters from the group analysis were, thus, individually separated in this way. The clusters defined by the group state-

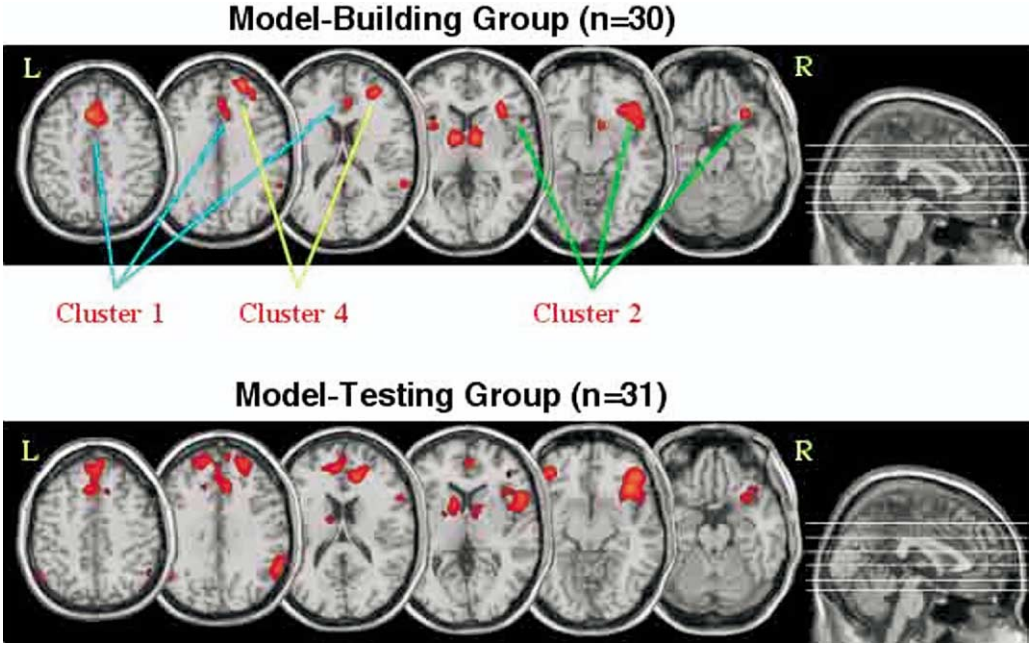

Figure 1. Neural correlates of deception. Group analyses of lie-minus-truth for the Model-Building Group and the Model-Testing Group, displaying the similar activation pattern for both groups. Areas of statistically significant (false discovery rate $p < .05$, $k > 25$) activation in **red to orange** are superimposed on the Montreal Neurologic Institute structural brain slices arranged from dorsal to ventral. The Clusters used for the individual analyses are indicated. The transverse slice locations (z = 46, 32, 18, 5, −10, −20 in mm) are the same for both groups and are indicated on the Sagittal Image.

Table 2. Group Analysis of Lie-minus-True Model-Building Group ($n = 30$)

Cluster	k	Complete Anatomic Area of Cluster	MNI Coordinates of Voxel With Largest *t* value	Anatomic Location of Voxel With Largest *t* value	Brodmann's Area of Voxel With Largest *t* value
1	327	R Anterior Cingulate[a]	−3, 21, 48	L supplementary motor area	8
		L Anterior Cingulate	9, 18, 42	R cingulate	32
		R Middle Cingulate	9, −3, 66	R supplementary motor area	6
		R Superior Medial Frontal			
		L Superior Medial Frontal			
		R Supplementary Motor Area			
2	271	R Orbitofrontal[a]	36, 27, 0	R insula	47
		R Inferior Frontal[a]	48, 15, −9	R insula	38
		R Insula	51, 24, −6	R orbitofrontal	38
		R Superior Temporal Pole			
3	231	R Olfactory	−9, −3, 6	L thalamus	N/A
		R Caudate	12, 0, 9	R internal capsule	N/A
		R Putamen	12, 3, −3	R pallidum	N/A
		R Pallidum			
		L Pallidum			
		L Caudate			
		R Thalamus			
		L Thalamus			
4	140	R Middle Frontal[a]	27, 51, 33	R middle frontal	46
		R Superior Frontal	36, 42, 21	R middle frontal	46
			33, 45, 33	R middle frontal	46
5	39	R Middle Temporal	60, −45, 21	R superior temporal	42
		R Superior Temporal	66, −48, 12	R middle temporal	22
		R Supramarginal			
		R Angular			
6	35	L Middle Temporal[a]	−57, −42, 30	L supramarginal	48
		L Superior Temporal	−57, −51, 39	L inferior parietal	40
		L Supramarginal			
		L Inferior Parietal			
7	27	L Putamen	−30, 12, 9	L insula	48
		L Insula	−30, 21, 6	L insula	48

Statistical Threshold is False Discovery Rate $p < .05$, k > 25. k, minimum number of voxels in cluster; R, right; L, left.
[a]Regions indicate brain areas of significant activations replicated from prior two studies.

ment were used as regions of interest (ROIs) on each of the subject's individual *t* maps. For the individual data analysis, with the clusters as ROIs, there was no correction for multiple comparisons, because the test of interest was not whether there were significant voxels in the anatomic region but whether the model produced an accurate detection of deception. The AFNI program "ROIstats" was used to determine the number of significantly activated voxels and average *t* value for each cluster in each individual; MRIcro was used to display the group fMRI maps, SPSS 11.0 was used to calculate *t* tests and χ^2, and Prism 4.0 to generate Figures 2 and 3.

Results

There were three changes from the MBG to the MTG (see appendix). One question was changed because of subjects' confusion about the question, and another question was changed for inappropriate grouping. For the MBG, the event time points corresponding to these questions were eliminated from the analysis. The third change was that physiological measurements were acquired on the MTG (data not reported).

Building the fMRI Detection of Deception Model

Defining the ROIs. For the MBG, we enrolled 31 of 34 subjects who signed a written informed consent (Table 1), and successfully scanned 30. For the Deception task, the group level analysis of Lie-minus-True revealed significant activation ($p < .05$, FDR, cluster minimum 25) in seven clusters. All five hypothesis-driven brain regions (right anterior cingulate; right inferior orbitofrontal; right inferior frontal; right middle frontal, and left middle temporal lobe) were significantly activated, consistent with our prior two studies (Kozel et al 2004a, 2004b) (Figure 1 and Table 2). For the seven clusters, the number of significantly activated voxels ($p < .001$) was determined for each individual subject with the contrast of Lie-minus-True. The purpose was to identify the least number of clusters that could be used as ROIs that most consistently differentiated when an individual was being deceptive. The results revealed that significant activations in cluster 1 (28 subjects), cluster 2 (30 subjects), and cluster 4 (27 subjects) accounted for the majority of subjects' activations. Twenty-six subjects had significant activation in at least one of these three clusters. If the significance threshold was lowered ($p < .05$), then all 30 subjects would have activation in one of these clusters. The determination of which clusters to use was not made on the basis of an anatomic location but rather on the group activation map of Lie-minus-True. An important point is that the three clusters chosen, however, corresponded to areas that were hypothesized to be correlated with deception (i.e., Cluster 1, right anterior cingulate; Cluster 2, right orbitofrontal and inferior frontal; and Cluster 4, right middle frontal) and overlap with our previous studies (Kozel et al 2004a, 2004b).

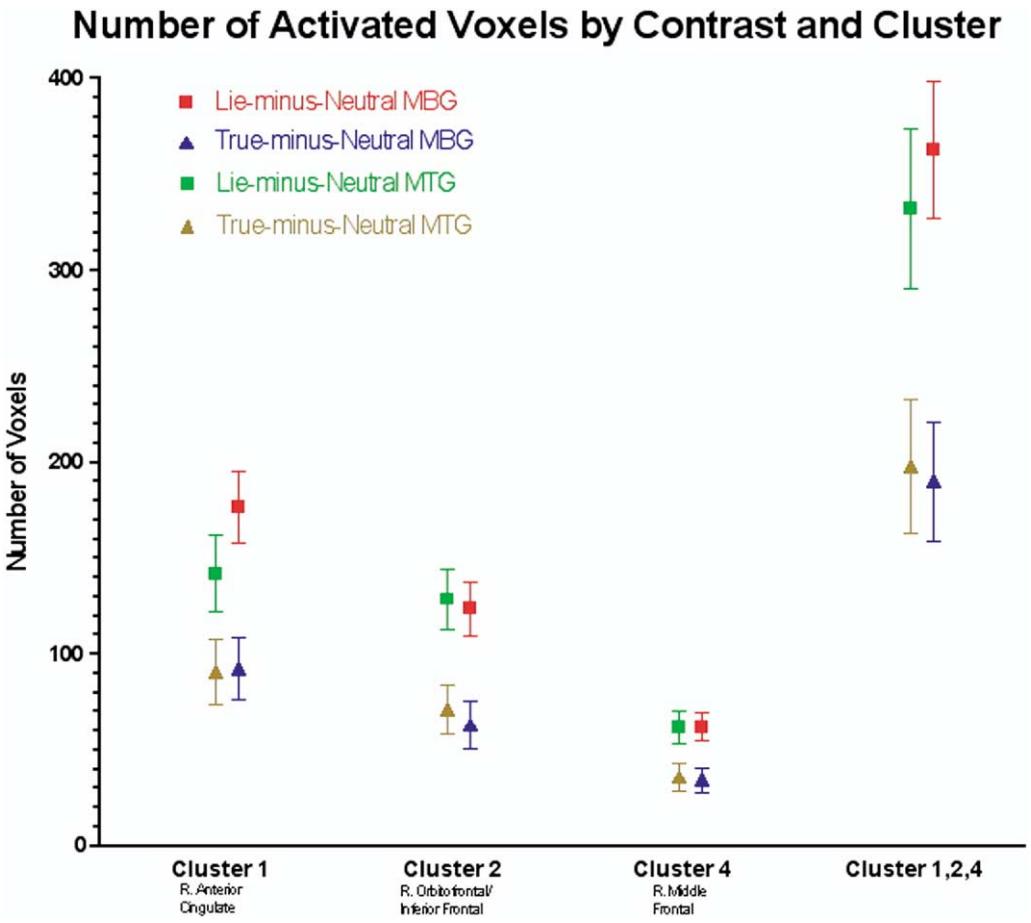

Figure 2. Number of activated voxels by contrast and cluster. Number of significantly ($p < .05$) activated voxels for Clusters 1, 2, 4 and combined 1, 2, and 4 for the Model-Building Group (MBG) and the Model-Testing Group (MTG). **Rectangles** and **triangles** represent the mean group voxel activation and the **lines** extending above and below represent one standard error. This figure displays the differential activation of these clusters by Lie contrasts versus True contrasts for each cluster. Also, the reproducibility between the two groups for each contrast and cluster is displayed.

Determining the Contrast and Statistical Threshold. Thus, Clusters 1, 2, and 4 were used as ROIs for the individual analysis. With the contrasts of Lie-minus-Control, True-minus-Control, Lie-minus-Neutral, and True-minus-Neutral, the number of activated voxels and average *t* values for each region (clusters 1, 2, and 4) were generated for each subject at various levels of significance ($p < .05$, $p < .01$, $p < .005$, $p < .001$, $p < .0005$, and $p < .0001$).

The Neutral and Control Comparisons were analyzed separately (i.e., Lie and Truth versus Control questions [Control Comparisons]; and Lie and Truth versus the Neutral questions [Neutral Comparisons]). A number of methods were investigated to maximize the accuracy of detecting deceptive versus truthful responses. The resulting two models with the best predictability were tested in the MTG.

Analysis Model to be Tested. Large differences were observed in the degree of activation for each individual and, therefore, a single reference threshold of the number of activated voxels could not be set to accurately predict deception for the Lie contrasts (Lie-minus-Neutral, Lie-minus-Control) versus the True contrasts (True-minus-Neutral, True-minus-Control). To account for the individual differences in activation, the number of significantly ($p < .05$) activated voxels for the Lie contrasts was subtracted from the True contrasts with both Cluster 1 and the combined Clusters 1, 2, and 4 (Figure 2). If the resulting value was positive, then it correctly identified a lie. If the resulting value was zero, then it was called indeterminate. If the resulting value was negative, then it was falsely identified as a truth.

The Neutral questions were used in the MTG because the mean differences in the number of activated voxels in the truth and lie conditions was greatest and they provided questions whose accuracy could more easily be determined, although the ability to predict deception was similar in the control and neutral questions.

Applying this method to the MBG, we could accurately predict the object taken in 27 of 29 subjects with one indeterminate [93% accurate, $\chi^2 = 19.20$, $p < .0001$] for Cluster 1, 26 of 30 subjects [87% accurate, $\chi^2 = 16.13$, $p < .0001$] for Cluster 2, 23 of 26 subjects and 4 indeterminate [88% accurate, $\chi^2 = 8.53$, $p < .005$] for Cluster 4, and 28 of 30 subjects [93% accurate, $\chi^2 = 22.53$, $p < .00001$] for Clusters 1, 2, and 4 (Figure 3). Cluster 1 and the combined Clusters 1, 2, and 4 were used to test this analysis method in the MTG. A critical point is that these data from the MBG were used to develop a method of analysis—not to test a method or determine its predictive power. Testing of the method was done with the MTG.

Reaction times, belief they were participating in a theft, countermeasures, and motivation by money were all analyzed to

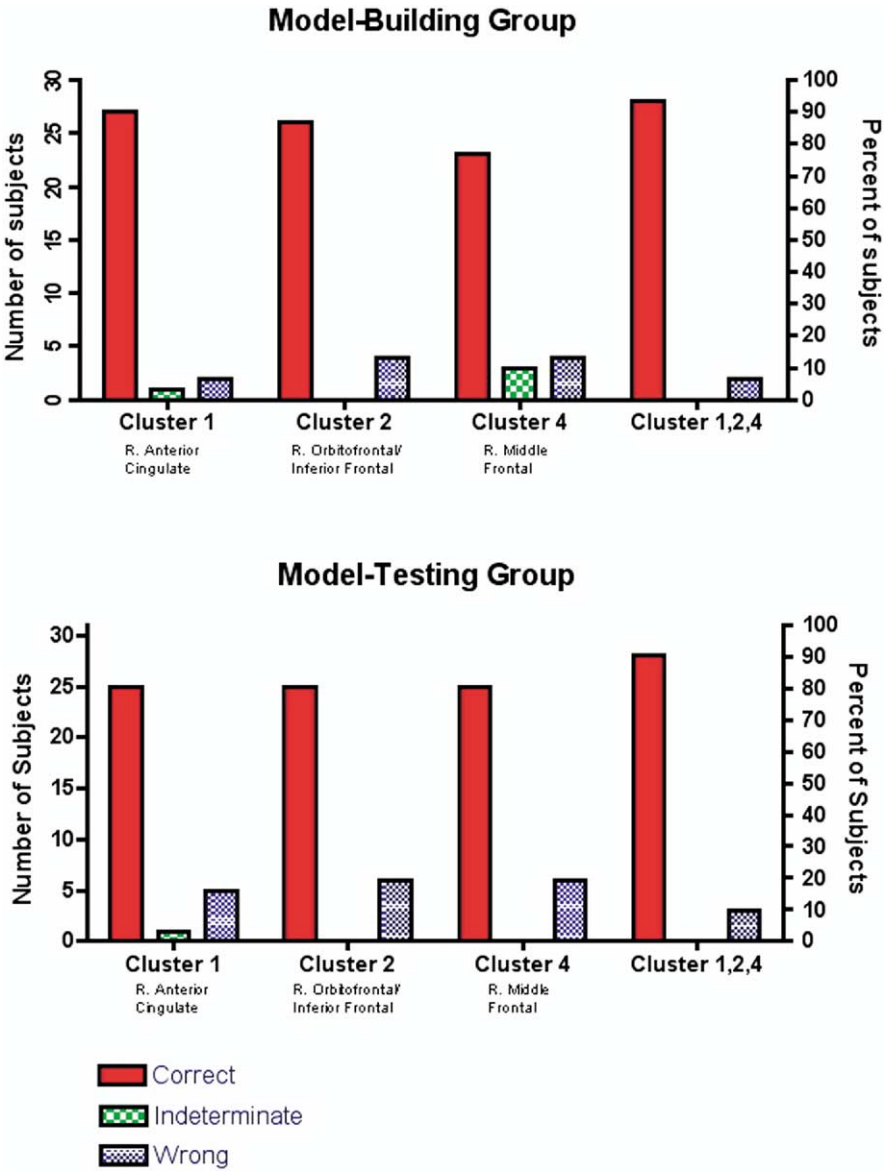

Figure 3. Accuracy of lie detection for individual subjects. The number of subjects in their respective category (model correctly identified lies versus truth [Correct]; model unable to determine when subjects lied [Indeterminate], and model incorrectly determined when subjects lied [Wrong]) is displayed on the **left** axis and percentage of total number of subjects is displayed on the **right**. The results are given for both the Model-Building Group and the Model-Testing Group with respect to which cluster or clusters were used as ROIs.

see if these could improve the model. None provided any better discriminatory power. Although reaction times have differentiated between truths and lies in previously published studies, it did not in ours. The likely explanation is that the delay between questions and responses in our paradigm normalizes any differences that might exist (Table 1).

Testing the fMRI Detection of Deception Model (MTG)

We enrolled and scanned 31 of 32 subjects who signed a written informed consent for the MTG (Table 1). There were no significant demographic differences identified between the MTG and the MBG. In this latter group, one subject was found to have a calcification of the falx cerebri, one subject did the reverse of the instructions, answering that he stole both the watch and the ring, and one subject started the paradigm but was not scanned owing to a concern about metal. All subjects were included in the analysis. The subject who did the reverse of instructions by answering that he took both objects was included (judgment made before analysis being performed) because he did lie and tell the truth. The subject for whom we were initially concerned about metal was started from the beginning of the protocol at a later date. The second time through the paradigm, she "stole" a different object from the first time. Interestingly, this subject was one of the subjects whose results were inaccurate using the model to be tested.

For the Deception task, the group level analysis of Lie-minus-True revealed significant activation ($p < .05$, FDR, cluster minimum 25) in seven clusters. Once again, the five brain regions consistent with our prior two studies and the MBG were significantly activated (Figure 1 and Table 3). Additionally, there was no significant difference between the MBG and MTG whole brain group maps of the Lie-minus-True analyses (two sample t test, FDR $p < .05$), although this study was not specifically designed to detect a difference if one existed.

The MBG method using Cluster 1 was able to successfully differentiate when the MTG subjects were being deceptive for 83% [25 of 30 with one indeterminate, $\chi^2 = 11.65$, $p < .001$] of the subjects, while the combination of Clusters 1, 2, and 4 achieved a higher accuracy of 90% [28 of 31, $\chi^2 = 20.16$, $p < .00001$] (Figure 3).

Table 3. Group Analysis of Lie-minus-True Model-Testing Group ($n = 31$)

Cluster	k	Complete Anatomic Area of Cluster	MNI Coordinates of Voxel with Largest *t* value	Anatomic Location of Voxel with Largest *t* value	Brodmann's Area of Voxel with Largest *t* value
1	1020	R Anterior Cingulate[a]	3, 18, 60	R supplementary motor area	6
		R Middle Frontal[a]	15, 36, 21	R anterior cingulate	32
		R Superior Frontal	15, 21, 66	R supplementary motor area	8
		L Middle Frontal			
		L Superior Frontal			
		R Superior Medial Frontal			
		L Superior Medial Frontal			
		L Anterior Cingulate			
		L Supplementary Motor Area			
		R Supplementary Motor Area			
2	598	R Orbitofrontal[a]	45, 39, −6	R orbitofrontal	47
		R Inferior Frontal[a]	42, 24, −9	R insula	47
		R Middle Frontal[a]	57, 15, 12	R inferior frontal	44
		R Superior Temporal Pole			
		R Insula			
3	187	L Orbitofrontal	−45, 36, −6	L orbitofrontal	47
		L Inferior Frontal	−36, 42, −12	L orbitofrontal	47
		L Middle Frontal	−51, 21, −3	L orbitofrontal	38
		L Superior Temporal Pole			
		L Insula			
4	186	L Middle Temporal[a]	−57, −51, 33	L angular	40
		L Supramarginal	−48, −54, 33	L angular	39
		L Superior Temporal			
		L Angular			
		L Inferior Parietal			
5	108	R Middle Temporal	60, −54, 33	R angular	40
		R Supramarginal			
		R Superior Temporal			
		R Angular			
		R Inferior Parietal			
6	99	L Pallidum	−12, 9, 6	L caudate	N/A
		L Caudate			
		L Putamen			
		L Thalamus			
7	49	R Pallidum	12, 6, 9	R caudate	N/A
		R Caudate			
		R Putamen			
		R Thalamus			

Statistical Threshold is False Discovery Rate $p < .05$, $k > 25$. k, minimum number of voxels in cluster; R, right; L, left.
[a]Regions indicate brain areas of significant activations replicated from prior two studies.

Discussion

We have shown that fMRI can be used to detect deception within a cooperative individual. In addition, we have replicated the five regions of significant activation for Lie-minus-True at the group level for the third and fourth time (MBG, MTG). Most fMRI studies to date, including all fMRI studies of deception, have only been able to make assessments on the basis of group data (all subjects averaged together). This study is important because it detects deception in an individual, an important first requirement in the development of this method as a potential lie detector.

The anterior cingulate, the orbitofrontal cortex, and the dorsolateral prefrontal cortex are involved in high-order decision making, response-inhibition, and go/no-go tasks (Bush et al 1998; Elliott et al 2000; MacDonald et al 2000; Pardo et al 1991). These results further imply that these regions are important for lying in humans. One possibility is that the anterior cingulate monitors the reading and incorrect (deceptive) response to a question. The anterior cingulate preferentially activates and then modifies the baseline behavior of the prefrontal cortex for deceptive responses. Further work should investigate this pathway in subjects with cingulotomies or other prefrontal brain damage as well as in subjects who did not activate this pathway. Failure to activate these regions by some of our subjects might highlight alternative regions (circuits) involved in lying, different types of lies (Ganis et al 2003), or different beliefs in the task at hand. Also, although this mock crime provides a scenario for which a good method of deception detection can be built, further studies will be needed to evaluate this paradigm in relation to real-world deception.

How realistic is our paradigm to detect deception? The vast majority of participants (20 MBG, 20 MTG) stated that the additional money was a strong motivator, and most subjects (20 in the MBG, 16 in the MTG) stated that they believed they were participating in a crime. In addition, to fool the examiner and potentially earn more money, some subjects (7 in the MBG, 6 in the MTG) performed countermeasures (pretending they did not

take the object, imagining a specific place, altering breathing, or delaying response), none of which reduced the chance of having the lies correctly determined in this study. These results would suggest that subjects were motivated, took the task seriously, and even tried to "beat" the test.

This study, however, did not evaluate real-world scenarios or lies with severe societal, emotional, or monetary damages. The level of risk for these subjects was relatively small compared with real-life situations in which lie detection would be needed (i.e., criminal or civil cases). Differences in the percentage of people trying to deceive in a group being tested (government employment screening versus specific incidence testing) make a profound impact on test performance characteristics. Although we studied a diverse sample with regard to age, occupation, and ethnicity, our sample was without significant medical illness, unmedicated, and without serious criminal histories. Further studies will be needed to determine how these factors impact on the ability of fMRI to detect deception and to determine day-to-day factors that might influence deception detection.

These results are an initial first step in developing this technology and will likely be improved with additional advances in imaging or statistical analysis. We are currently investigating new fMRI analysis techniques (e.g., multivariate analyses including demographic parameters of interest in the model) as well as integrating physiologic signals (e.g., pulse, respiration, and skin conductance [electrodermal activity]) to improve the accuracy of detecting deception.

A next step in developing this method would include a standardized protocol similar to the mock crime of taking the watch or ring in which there are verifiable lies and truths. The brain imaging results of this comparison would indicate whether the test adequately works for this particular subject. Then the subject would be questioned about the issue of interest, and interpretations made only if the verifiable lies indicated deception. Future studies using this methodology are presently being developed.

Importantly, this technique requires a cooperative subject. Any subject who refuses to answer questions, randomly answers questions, moves their head, or refuses to enter the scanner would not be able to be tested. Another important point is that this technology is not able to "read" a person's mind.

For the first time, we have shown that fMRI has the potential to reliably identify brain patterns associated with deception within an individual. Furthermore, we provide supporting data that unique, identifiable brain regions might be used to detect deception with a high degree of accuracy.

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The MUSC has filed patent applications for the development of fMRI testing for deception detection. Drs. Kozel and George are co-inventors in their role as MUSC faculty. They have no equity investment in this work other than their role as co-inventors. Dr. Laken is the President and CEO of Cephos Corporation and holds stock in the company. Cephos Corporation has exclusively licensed the MUSC patent applications and the Medical University of South Carolina Foundation for Research Development holds stock in Cephos Corporation.

Annett M (1970): A classification of hand preference by association analysis. *Br J Psychol* 61:303–321.

Ashburner J, Friston KJ (1999): Nonlinear spatial normalization using basis functions. *Hum Brain Mapp* 7:254–266.

Brett AS, Phillips M, Beary JF (1986): Predictive power of the polygraph: Can the "lie detector" really detect liars? *Lancet* 1:544–547.

Bush G, Shin LM, Holmes J, Rosen BR, Vogt BA (2003): The Multi-Source Interference Task: Validation study with fMRI in individual subjects. *Mol Psychiatry* 8:60–70.

Bush G, Whalen PJ, Rosen BR, Jenike MA, McInerney SC, Rauch SL (1998): The counting Stroop: An interference task specialized for functional neuroimaging - validation study with functional MRI. *Hum Brain Mapp* 6: 270–282.

Cox RW (1996): AFNI: Software for analysis and visualization of functional magnetic resonance neuroimages. *Comput Biomed Res* 29:162–173.

Elliott R, Dolan RJ, Frith CD (2000): Dissociable functions in the medial and lateral orbitofrontal cortex: Evidence from human neuroimaging studies. *Cereb Cortex* 10:308–317.

Farwell LA, Donchin E (1991): The truth will out: Interrogative polygraphy ("lie detection") with event-related brain potentials. *Psychophysiology* 28:531–547.

First M, Spitzer R, Williams J, Gibbon M (1995): *Structured Clinical Interview for DSM-IV (SCID)*. Washington, D.C.: American Psychiatric Press.

Friston K (2004): Experimental design and statistical parametric mapping. In: Frackowiak RSJ, Friston KJ, Frith CD, et al, editors. *Human Brain Function,* 2nd ed. Amsterdam: Elsevier Academic Press, 599–634.

Friston KJ, Frackowiak RSJ (1997): Images of the future. In: Mazziotta JC, editor. *Human Brain Function.* San Diego, CA: Academic Press, 487–517.

Friston KJ, Worsley KJ, Frackowiak RSJ, Mazziotta JC, Evans AC (1994): Assessing the significance of focal activations using their spatial extent. *Hum Brain Mapp* 1:210–220.

Ganis G, Kosslyn SM, Stose S, Thompson WL, Yurgelun-Todd DA (2003): Neural correlates of different types of deception: An fMRI investigation. *Cereb Cortex* 13:830–836.

Hollien H, Geison L, Hicks JW Jr (1987): Voice stress evaluators and lie detection. *J Forensic Sci* 32:405–418.

Honts CR, Raskin DC, Kircher JC (1994): Mental and physical countermeasures reduce the accuracy of polygraph tests. *J Appl Psychol* 79:252–259.

Kozel FA, Padgett TM, George MS (2004a): A replication study of the neural correlates of deception. *Behav Neurosci* 118:852–856.

Kozel FA, Revell LJ, Lorberbaum JP, Shastri A, Elhai JD, Horner MD, et al (2004b): A pilot study of functional magnetic resonance imaging brain correlates of deception in healthy young men. *J Neuropsychiatry Clin Neurosci* 16:295–305.

Langleben DD, Schroeder L, Maldjian JA, Gur RC, McDonald S, Ragland JD, et al (2002): Brain activity during simulated deception: An event-related functional magnetic resonance study. *Neuroimage* 15:727–732.

Lee TM, Liu HL, Tan LH, Chan CC, Mahankali S, Feng CM, et al (2002): Lie detection by functional magnetic resonance imaging. *Hum Brain Mapp* 15:157–164.

MacDonald A, Cohen J, Stenger V, Carter C (2000): Dissociating the role of the dorsolateral prefrontal and anterior cingulate cortex in cognitive control. *Science* 288:1853–1838.

National Academies Press (2003): *The Polygraph and Lie Detection. Committee to Review the Scientific Evidence of the Polygraph. Division of Behavioral and Social Sciences and Education.* Washington, D.C.: National Academies Press.

Nunez JM, Casey BJ, Egner T, Hare T, Hirsch J (2005): Intentional false responding shares neural substrates with response conflict and cognitive control. *Neuroimage* 25:267–277.
Ogawa S, Lee TM, Kay AR, Tank DW (1990): Brain magnetic resonance imaging with contrast dependent on blood oxygenation. *Proc Natl Acad Sci U S A* 87:9868–9872.
Pardo JV, Fox PT, Raichle ME (1991): Localization of a human system for sustained attention by positron emission tomography. *Nature* 349: 61–64.
Pardo JV, Pardo PJ, Janer KW, Raichle ME (1990): The anterior cingulate cortex mediates processing selection in the Stroop attentional conflict paradigm. *Proc Natl Acad Sci U S A* 87:256–259.
Phan KL, Magalhaes A, Ziemlewicz TJ, Fitzgerald DA, Green C, Smith W (2005): Neural correlates of telling lies: A functional magnetic resonance imaging study at 4 tesla. *Acad Radiol* 12:164–172.
Rosenfeld JP, Soskins M, Bosh G, Ryan A (2004): Simple, effective countermeasures to P300-based tests of detection of concealed information. *Psychophysiology* 41:205–219.
Spence SA, Farrow TF, Herford AE, Wilkinson ID, Zheng Y, Woodruff PW (2001): Behavioral and functional anatomical correlates of deception in humans. *NeuroReport* 12:2849–2853.
Spence SA, Hunter MD, Farrow TF, Green RD, Leung DH, Hughes CJ, et al (2004): A cognitive neurobiological account of deception: Evidence from functional neuroimaging. *Philos Trans R Soc Lond B Biol Sci* 359:1755–1762.
Spielberger CD, Gorsuch RL, Lushene R, Vagg PR, Jacobs GA (1983): *Manual for the State-Trait Anxiety Inventory*. Palo Alto, CA: Mind Garden.
U.S. General Accounting Office (2001): *Investigative Techniques: Federal Agency Views on the Potential Application of "Brain Fingerprinting."* Washington, DC: U.S. General Accounting Office.

Appendix

Neutral

1. Do you like to swim?
2. Do you like to read?
3. Are you awake?
4. Are you asleep?
5. Are you under age 50?
6. Are you over age 18?
7. Do you like the beach?
8. Do you live in the United States?
9. Do you live in South Carolina?
10. Do you like chocolate?
11. Do you like to watch TV?
12. Do you have a dog?
13. Do you have a cat?
14. Is it 2004?
15. Do you like movies?
16. Do you speak English?
17. Is it October?
18. Are you at MUSC?
19. Are you in a research study?
20. Are you a student?

Watch

1. Did you take the watch from the drawer?
2. Is the watch in your locker?
3. Did you take the watch?
4. Did you steal the watch?
5. Was the watch stolen?
6. Did you hide the watch?
7. Do you know who took the watch?
8. Is the watch with your possessions?
9. Is there a stolen watch in your locker?
10. Did you take a watch that is not yours?
11. Did you put the watch in your locker?
12. Did you hide the watch in your locker?
13. Did you remove a watch from the drawer?
14. Did you steal a watch from the drawer?
15. Did you place the watch in your locker?
16. Did you keep the watch in the drawer?
17. Did you leave the watch in the drawer?
18. Did the watch stay in the drawer?
#19. Was the watch moved from the drawer?
20. Is the watch in the drawer?

Control

1. Have you ever gossiped?
2. Have you ever done something illegal?
3. Have you ever done something immoral?
4. Have you used illegal drugs?
5. Have you ever deceived a loved one?
6. Have you ever made someone angry?
7. Have you ever committed a crime?
8. Have you ever cheated on a test?
9. Have you ever told a white lie?
10. Do you obey every traffic law?
11. Have you ever lied to your parents?
12. Have you ever cheated on your taxes?
13. Do you curse?
14. Have you ever faked an illness?
15. Are you a law-abiding citizen?
16. Have you ever forged a signature?
17. Have you ever kept the truth from someone?
18. Have you ever been arrested?
19. Do you speed?
20. Have you ever littered?

Ring

1. Did you take the ring from the drawer?
2. Is the ring in your locker?
3. Did you take the ring?
4. Did you steal the ring?
5. Was the ring stolen?
6. Did you hide the ring?
7. Do you know who took the ring?
8. Is the ring with your possessions?
9. Is there a stolen ring in your locker?
10. Did you take a ring that is not yours?
11. Did you put the ring in your locker?
12. Did you hide the ring in your locker?
13. Did you remove a ring from the drawer?
14. Did you steal a ring from the drawer?
*15. Did you place the ring in your locker?
16. Did you keep the ring in the drawer?
17. Did you leave the ring in the drawer?
18. Did the ring stay in the drawer?
#19. Was the ring moved from the drawer?
20. Is the ring in the drawer?

#Confusing question of "Did you put the watch/ring back in the drawer" replaced with this question for the Model-Testing Group.

*For the Model-Building Group, was mistakenly referenced as watch.