# Polygraphy and Functional Magnetic Resonance Imaging in Lie Detection:

## A Controlled Blind Comparison Using the Concealed Information Test

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**ABSTRACT**

***Objective:*** Intentional deception is a common act that often has detrimental social, legal, and clinical implications. In the last decade, brain activation patterns associated with deception have been mapped with functional magnetic resonance imaging (fMRI), significantly expanding our theoretical understanding of the phenomenon. However, despite substantial criticism, polygraphy remains the only biological method of lie detection in practical use today. We conducted a blind, prospective, and controlled within-subjects study to compare the accuracy of fMRI and polygraphy in the detection of concealed information. Data were collected between July 2008 and August 2009.

***Method:*** Participants (N = 28) secretly wrote down a number between 3 and 8 on a slip of paper and were questioned about what number they wrote during consecutive and counterbalanced fMRI and polygraphy sessions. The Concealed Information Test (CIT) paradigm was used to evoke deceptive responses about the concealed number. Each participant's preprocessed fMRI images and 5-channel polygraph data were independently evaluated by 3 fMRI and 3 polygraph experts, who made an independent determination of the number the participant wrote down and concealed.

***Results:*** Using a logistic regression, we found that fMRI experts were 24% more likely (relative risk = 1.24, $P < .001$) to detect the concealed number than the polygraphy experts. Incidentally, when 2 out of 3 raters in each modality agreed on a number (N = 17), the combined accuracy was 100%.

***Conclusions:*** These data justify further evaluation of fMRI as a potential alternative to polygraphy. The sequential or concurrent use of psychophysiology and neuroimaging in lie detection also deserves new consideration.

*J Clin Psychiatry 2016;77(10):1372–1380*
*dx.doi.org/10.4088/JCP.15m09785*


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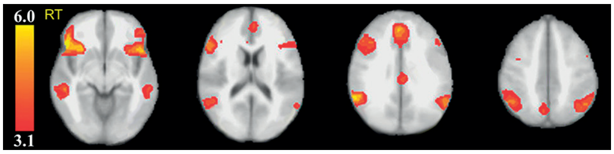
Deception is a common phenomenon with protean social manifestations. Deception motivated by internal conflict is important to psychotherapeutic practice[1] as well as all research that relies on self-reported symptoms.[2] Intentional deception of another individual or organization to gain a material advantage[3] is often morally proscribed, detrimental to the target, and can be illegal. In addition, dissimulation or malingering is a form of intentional deception that compromises psychiatric diagnosis and treatment especially in insurance, forensic, and substance abuse treatment settings.[4–14] Thus, objective and reliable means of detecting intentional deception are important for the theory and practice of psychiatry and are the focus of this report.

The polygraph test is a multichannel psychophysiological recording of a subject's electrodermal activity, heart rate, blood pressure, and chest excursion during a standardized questioning protocol.[15] Polygraphy remains the only physiological lie detector in worldwide use since its introduction in its present form more than 50 years ago.[16] One reason for polygraphy's longevity may be that, despite known flaws, it is more accurate[17] than either chance or human judgment unaided by technology.[18] Although polygraphy has not gained acceptance in general psychiatry practice, it is used in the management of sexual offenders[19–22] and in the thousands of background and security clearance investigations performed annually by the US Government.[16] The Concealed Information Test (CIT) is a variant of the polygraph test that uses a forced choice questionnaire format to elicit deceptive behavior.[23] The CIT is considered to be more reliable than the classic polygraph test by practitioners and researchers.[24,25]

Functional magnetic resonance imaging (fMRI) is the leading technology in cognitive neuroscience research, including studies of intentional deception.[26–30] These studies have been motivated by the hypothesis that brain activity is a more sensitive and specific marker of deception than the autonomic nervous system measures used in polygraphy.[31,32] The theoretical advantages of fMRI over polygraphy include the ability to localize the brain source of the signal with millimeter accuracy, time resolution on the order of seconds, and recording at the source of target behavior that bypasses the peripheral nervous system. The majority of fMRI studies of deception find activation in the brain regions associated with executive functions, such as the inferior frontal, inferior parietal, and superior frontal and anterior cingulate cortices (Figure 1).[33,34] Using this consistent activation pattern, several neuroimaging studies have shown that, under laboratory conditions, fMRI is fairly accurate at detecting deception in individual subjects; fMRI studies using machine-learning pattern classification algorithms reported accuracy greater than 90%.[35–37] These estimates compared favorably with the consensus accuracy estimate of polygraphy, prompting a public debate about the risks and benefits of further translational research on this topic.[2,17,31,34,38–46] However, the only published study[47] we are aware of that attempted to compare fMRI and polygraphy did not yield fMRI

**Figure 1. Pattern of Lie vs Truth Differences in Concealed Information Test Experiments (N = 60)[a]**




[a]Based on Hakun et al.[48] Image is a Z-statistic map thresholded at voxel-height probability of $P < .001$ and cluster probability of $P < .05$ displayed over axial MNI T1 anatomic template. Significant clusters are located in the anterior cingulate cortex, bilateral inferior frontal, inferior parietal and medial temporal gyri, and the precuneus.
Abbreviation: MNI = Montreal Neurological Institute.

**Clinical Points**

- Under laboratory conditions, fMRI was significantly more likely to detect deception than the polygraph test.
- Clinical trials are required to determine the true value of fMRI-based lie detection as a forensic tool.

data robust enough for a conclusive comparison. To fill this knowledge gap, we conducted a prospective, blind, within-subject comparison between psychophysiological and fMRI detection of concealed information.

## METHOD

Participants were 28 (16 female) healthy, right-handed English speakers with an average age of 24 (SD = 3.4) years and an average of 17 (SD = 1.6) years of education. The study protocol was approved by the University of Pennsylvania Institutional Review Board. The study was conducted between May 2007 and December 2009, with data collected between July 2008 and August 2009.

### Deception Task ("Stim Test")

The Control-Stimulation Test ("Stim Test") is a variant of the Concealed Information Test (CIT), a deception-generating paradigm that has been widely utilized in both laboratory and field research as well as with fMRI.[48] Stim Test is used by polygraph examiners[23] to demonstrate the presence of physiological response during instructed deception prior to the polygraph examination proper.[16]

### Experimental Procedure

Each participant had polygraphy and fMRI sessions in a counterbalanced order, with a 2-hour interval between them. Prior to the first session, the designated "unblinded" team member (E.L.B. [see Acknowledgments]) asked participants to secretly write down a number ("Lie Item") from 3 through 8 (inclusive) and conceal the note in their pocket for the duration of the study. Participants were instructed to deny having written or possessing this number during the study and to tell the truth in response to questions about all other numbers. While not explicitly stated, correct performance of the task required answering "no" to questions about all numbers. After completing both polygraph and fMRI sessions, the unblinded team member collected the notes with the numbers and debriefed the participants about any countermeasures they may have used to avoid detection. The results of debriefing and the notes were kept in sealed envelopes in a locked cabinet until data collection was completed.

### Polygraphy Data Acquisition and Expert Evaluation

A 5-channel computerized polygraph (Model LX-4000, Lafayette Instruments, Lafayette, Indiana) was used to record the electrodermal activity, respiration, heart rate, blood pressure, and body motion. Throughout the recording, the polygraph examiner (R.K.B. [see Acknowledgments]), who was blind to the concealed number, asked the question: "Did you write the number [X]?" where "X" was a whole number between 1–9, inclusive. The session comprised asking the subject about each of the numbers they might have (3–8) and the control numbers (1, 2, and 9) they could not have had, in ascending (1, 2, 3, 4, 5, 6, 7, 8, 9), random, and descending (9, 8, 7, 6, 5, 4, 3) order, generating a minimum of 3 runs for each subject. The examiner could add up to 2 additional runs at his discretion. Questions were separated by 10- to 30-second variable intertrial intervals (ITIs).

Polygraphy data were independently evaluated by 3 professional polygraph examiners, each with 20 or more years of experience and an advanced degree in a relevant field of study. One of the examiners (R.K.B.) also conducted the polygraph sessions. Experts were provided with binders containing printouts of the polygraph charts, with the polygraph examiner's (R.K.B.) and native program annotations, grouped by each subject's code. Experts used a standard form to record their opinion on the number most likely to be a lie for each participant. Experts were asked to employ whatever system they felt would yield the best results, based on their past professional experience with Stim Test and CIT. The rating form allowed for comments on each recording's quality and an option to reject it if quality was unacceptable. Experts did not communicate with each other before submitting their reports and were given up to 12 weeks to complete them.

### fMRI Data Acquisition and Analysis

The fMRI task used a sparse event-related design.[49,50] Stimuli were numbers 1 through 9 (inclusive) in white font against black background, accompanied by a question: "Do you have the number [X]?" Visual representations of the green and blue response buttons of the fiber-optic response pad (fORP; Current Designs, Philadelphia, Pennsylvania) appeared at the bottom of the screen, with the words "yes" and "no" above them, respectively. Stimuli classes were Probe (numbers 3–8, inclusive, one of which was the concealed number, ie, the Lie Item) and Known Truth (numbers 1, 2, and 9). Each stimulus, 1 through 9, was repeated 5 times throughout the experiment. Stimuli were presented for 3 seconds and separated by variable ITIs (10 ± 3 seconds).

During an ITI, a fixation cross ("+") appeared in the target area. The first presentation of each stimulus was in an ascending numerical order. The second, third, and fourth presentations of each number were in a random order, and the last presentation of each stimulus was in a descending numerical order. This order closely approximated the polygraph Stim Test format, including the number of item repetitions, which was the maximum number of repetitions used during the polygraph sessions. Stimuli were presented and responses logged by commercial stimuli presentation software (Presentation; Neurobehavioral Systems, Inc; San Pablo, California). Task duration was 11.25 minutes.

MRI data were collected on a 3 Tesla Siemens Trio scanner (Erlangen, Germany) with an 8-channel head coil. Functional data were collected with a blood oxygenation level–dependent (BOLD) sequence (repetition time/echo time [TR/TE] = 3000/21 ms, field of view [FOV] = 240 mm, matrix = 64 × 64, slice-thickness/gap = 4/0 mm). For anatomic reference, registration of functional data, and normalization of functional data to a standard T1 template (Montreal Neurologic Institute, MNI), a T1 magnetization-prepared, rapid-acquisition gradient echo (TR/TE = 1620/3 ms, FOV = 250 mm, matrix = 192 × 256, slice-thickness/gap = 1/0 mm) sequence was used for a high-resolution image of the subject's brain. A video projector (Powerlite 7300; Epson America, Long Beach, California) projected the stimuli onto a mirror mounted on the scanner head coil.

Imaging data were preprocessed and analyzed using the fMRI of the Brain (FMRIB) Software Library (FSL) fMRI Expert Analysis Tool (FEAT) (v.4.1, Oxford, United Kingdom).[51] Functional data were brain-extracted (ie, fMRI signal outside of the brain boundaries was removed),[52] motion-corrected to the median functional image using b-spline interpolation (4 degrees of freedom [df]), high-pass filtered (60 seconds), and spatially smoothed (9 mm full width at half maximum, isotropic). The anatomic volume was brain-extracted and registered to the standard space T1 MNI template using trilinear interpolation with the FMRIB Linear Image Registration Tool (FLIRT, 12 df[53]). The median functional image was registered to the anatomic volume and then transformed to the MNI template. Statistical maps were created using FEAT with an improved general linear model (GLM). Regressors were created by convolving concatenated stimuli time-courses for each number 1 through 9 with the standard hemodynamic response function (double gamma). The 9 regressors, along with their temporal derivatives, and an intercept form were entered into a single-subject GLM analysis.

### fMRI Expert Data Evaluation

***Thresholds and contrasts.*** The single-subject contrasts were displayed for rating at 2 statistical thresholds intended to reduce noise in the rendered image, $Z > 1.64$ and $Z > 2.33$. These thresholds were consistent with single-subject studies of deception[48,54] and other clinical fMRI applications.[55–58] They best approximated the data collected with polygraphy, which included nominal high- and low-pass filtering in the recovery of physiological signals. Three types of contrasts were generated for expert evaluation.

1. Probe (possible Lie Item) > All Items (ie, [Probe > All]) contrast. Since the analysis was blinded, each of the numbers 3 through 8 was a possible Lie Item. Numbers 1, 2, and 9 were "Known Truth" items. Thus, [Probe > All] contrast yielded 6 images, 1 for each possible Lie Item (3–8), contrasted with the average of all other numbers (1 through 9, except the item entered as a possible Lie Item).
2. Probe (possible Lie Item) > Known Truth (ie, [Probe > Known]) contrast. Each possible Lie Item (3–8) was contrasted with the average of the Known Truth items (1, 2, and 9), yielding 6 images.
3. Known Truth > All contrast. This contrast yielded 3 images.[59]

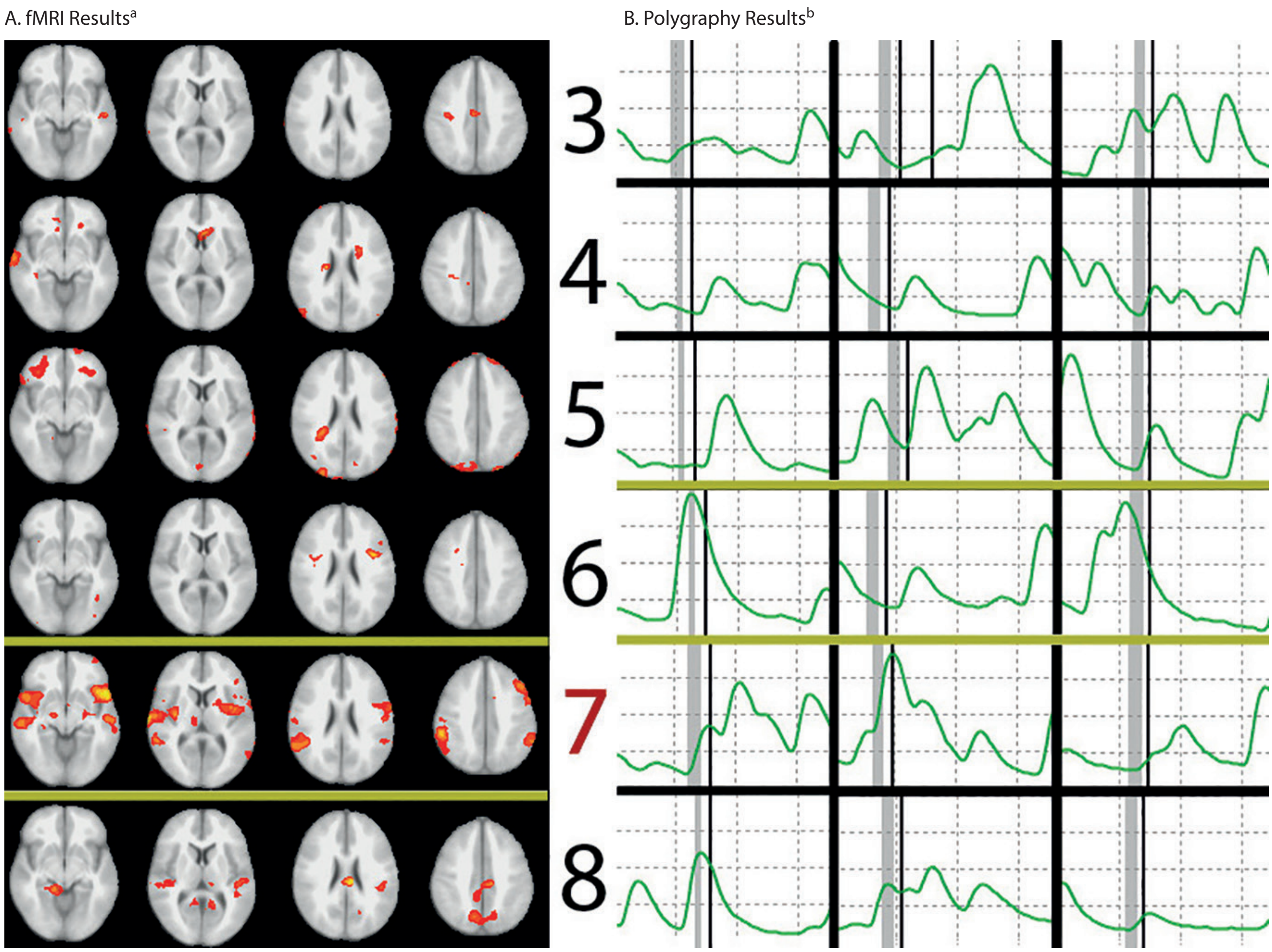
Each of the 15 contrasts for each participant was thresholded at $Z > 1.64$ and $Z > 2.33$ voxel heights, rendered on an average MNI T1 template in FSL Viewer[59] light-box display as axial slices through the brain at levels from the anterior cerebellum to the top of the brain, printed in color, and compiled into 2 binders, one containing the contrasts at the $Z > 1.64$ threshold (Figures 2 and 3, left panels) for each subject and the other, at the $Z > 2.33$ threshold.

***fMRI rating procedure.*** Three members of the University of Pennsylvania faculty with expertise in cognitive neuroscience and fMRI but no prior experience with deception research served as fMRI experts. In a 15-minute individual training session, each fMRI expert was familiarized with the deception paradigms utilized by our study team in previous studies.[27,35] This included a description of the Stim Test and an image of the pattern of the differences between lie and truth, based on a meta-analysis of 3 prior fMRI studies of deception (Figure 1)[48] pointing to the brain regions previously associated with deceptive responding.[35] Following the training session, fMRI experts were provided with binders containing subjects' fMRI contrasts as described above and the rating forms. They were then asked to identify the most likely Lie Item, using all the information available for each subject, that is, both types of contrasts and statistical thresholds, and any method of evaluation they chose. fMRI experts did not communicate with each other and were given up to 4 hours to complete their task.

### Comparison of fMRI and Polygraphy

Results of polygraphy and fMRI rater classification accuracy were examined for probability of identifying the Lie Item, since a Lie Item was present in all datasets. Binomial logistic regression with robust error estimation was applied to individual rater data for inferential comparison between methodologies; Fleiss κ and Cohen κ were used to evaluate the interrater (within-modality) and between-modalities agreement, respectively. Rater data were analyzed

**Figure 2. Participant #2: fMRI Correct and Polygraphy Incorrect**




[a]Each row is a selection of axial slices taken from the Probe > All contrast for each possible concealed number (probe), thresholded at the voxel-height $Z > 1.64$. All 3 fMRI raters correctly identified number 7 as the concealed number (gold bars).
[b]Representative fragments from the electrodermal activity polygraphy channel correspond to responses about the same concealed numbers. The gray bars mark the time of polygraph examiner's question ("Did you write the number [X]?"), and the thin black bars immediately following indicate the time of participant's "No" response. All 3 polygraph raters incorrectly identified number 6 as the Lie Item.
Abbreviation: fMRI = functional magnetic resonance imaging.

at both the individual (eg, logistic regression) and consensus (eg, methodology group-accuracy) levels. Each expert's accuracy in identifying the Lie Item was evaluated using signal detection parameters of sensitivity and specificity.[60] To evaluate accuracy of each modality, 2 decision rules were applied to the experts' ratings: "majority" (2 of 3 raters agreed on a particular item as being the Lie Item) or "unanimity" (all 3 raters agreed on a particular item as being the Lie Item). Additionally, when no agreement (majority or unanimity) was reached within a modality, the rating was scored as a "no determination" and classified as a miss. An across-modality decision rule measure was used to explore accuracy when (1) both modalities reached a majority (2 of 3) agreement regarding which particular item was the Lie Item and (2) the same Lie Item was selected by both modalities independently (see description of the PolyMR decision rule in Results).

All of the statistical analyses were conducted in Stata (Special Edition v.10.0, StataCorp, College Station, Texas).

## RESULTS

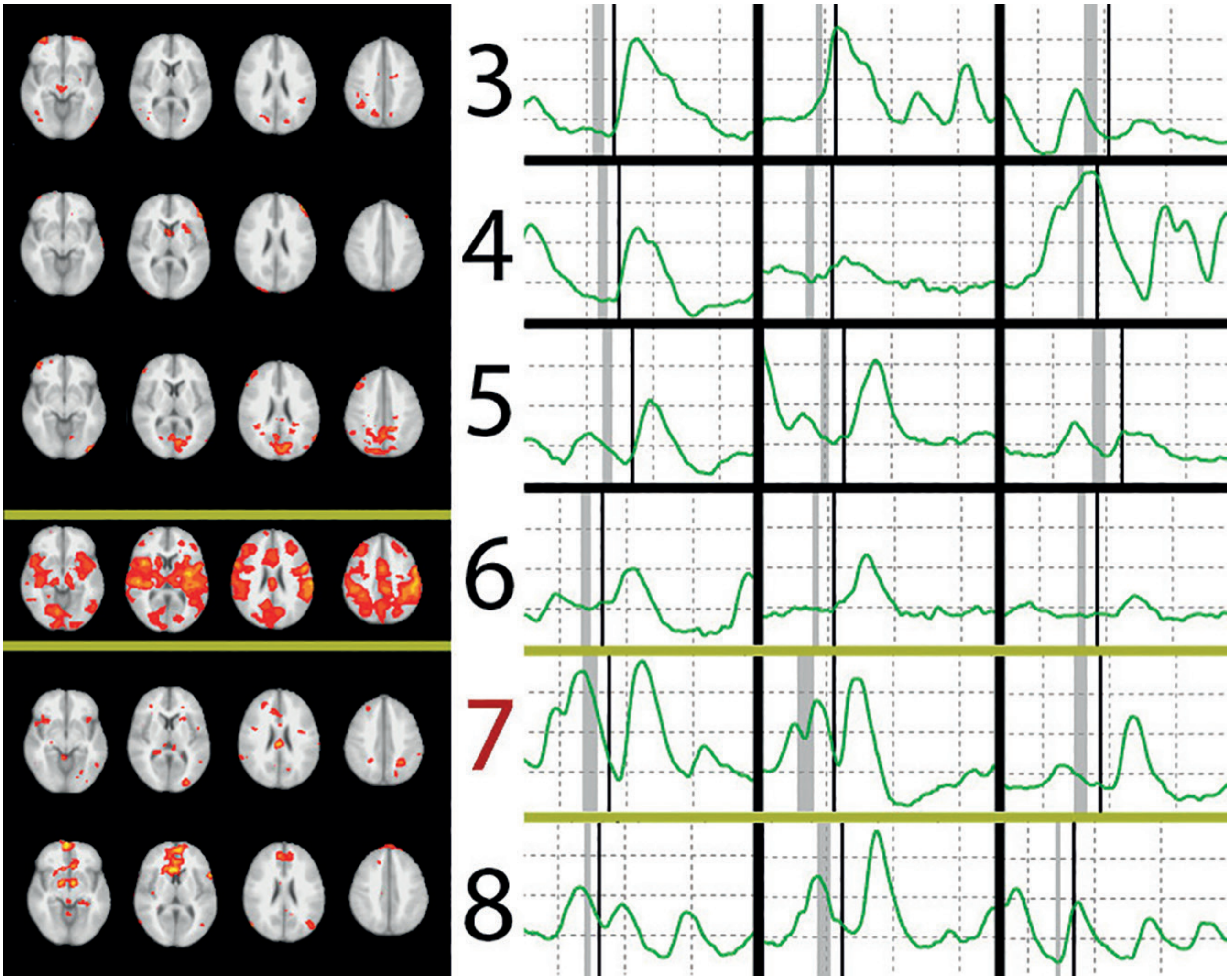
### Behavioral Data

No performance errors were observed during the polygraphy sessions. During fMRI sessions, the average error rate was 3.1%, and no participants made more than 3 errors during the 45-question task. To maintain an unbiased evaluation of the fMRI data, error trials were included in the fMRI analysis. Behavioral data were not available to the raters.

### Data Quality and Thresholds

Polygraphy raters reported the datasets of participants number 1, 3, and 6 to be of low quality. The flagged datasets did not overlap between the raters, and they did not exclude them from their ratings. fMRI raters did not judge any datasets to be of low quality. fMRI raters reported that the Probe > All contrast thresholded at $Z > 1.64$ was the most informative (see Figures 2 and 3 for examples).

**Figure 3. Participant #19: fMRI Incorrect and Polygraphy Correct**




[a]Each row is a selection of axial slices taken from the Probe > All contrast for each possible concealed number. Images are thresholded at the voxel-height $Z > 1.64$. All 3 fMRI experts incorrectly identified number 6 as the concealed number (gold bars).
[b]Representative segments from the polygraph electrodermal activity channel correspond to responses to questions about the same concealed number. The gray bars mark the time of polygraph examiner's question ("Did you write the number [X]?"), and the thin black bars immediately following mark the time of participant's "No" response. All 3 polygraphy experts correctly identified number 7 as the Lie Item.
Abbreviation: fMRI = functional magnetic resonance imaging.

## Detection Accuracy by Majority and Unanimity Rules

There were 6 possible Lie Items (#3, #4, #5, #6, #7, or #8). Therefore, the probability of a single expert correctly identifying a Lie Item by chance was 1 out of 6, or 16.7%. The probability of 2 of the 3 raters agreeing (Majority Rule) about a Lie Item by chance was 1/36 (2.8%) and of all 3 raters (Unanimity Rule) agreeing was 1/216 (0.38%). We found that using the Majority Rule, the polygraph experts detected 20 out of 28 (71.4%) Lie Items, while fMRI experts detected 24 out of 28 (85.7%) Lie Items, with both modalities performing significantly better than chance (both $Z > 5$, N = 28, $P < .001$). Applying the Unanimity Rule resulted in 17/28 (60.7%) Lie Item detection for polygraphy and 23/28 (82.1%) for fMRI, with both modalities yielding detection rates significantly greater than chance (both $Z > 4.5$, N = 28, $P < .001$). Detection rates for both decision rules are summarized in Table 1. To evaluate interrater agreement, Fleiss κ was independently calculated for each modality and showed strong within-modality agreement for both fMRI (κ = 0.883, SE = 0.05, $P < .001$) and polygraphy raters (κ = 0.783, SE = 0.05, $P < .001$).

## Comparison Between Modalities

Binomial logistic regression with robust error estimation was conducted on individual rater classification rates across all 28 participants (Table 1). Results of the logistic regression yielded a significant relative risk ratio (RR = 1.24; 95% CI, 2.3–3.5; $P < .001$), which suggests that, individually, fMRI experts were 24% more likely to detect a Lie Item than the polygraphy experts (a 14.3% overall increase in detection rates). The results of the logistic regression yielded an odds ratio of 2.81 (detection likelihood of fMRI raters vs polygraphy raters). Cohen κ was calculated based on the Majority decision rule

**Table 1. Polygraphy and fMRI Lie Determinations[a]**

| Participant Number | LIE Item | Polygraph Rater 1 | 2 | 3 | Decision Rule Majority | Unanimity | fMRI Rater 1 | 2 | 3 | Decision Rule Majority | Unanimity |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 6 | 6 | 6 | 6 | √ | √ | 6 | 6 | 6 | √ | √ |
| 2 | 7 | (6) | (6) | (6) | X | X | 7 | 7 | 7 | √ | √ |
| 3 | 7 | 7 | 7 | (4) | √ | ND | 7 | (5) | 7 | √ | ND |
| 4 | 8 | 8 | 8 | 8 | √ | √ | (5) | 8 | (6) | ND | ND |
| 5 | 6 | 6 | 6 | 6 | √ | √ | 6 | 6 | 6 | √ | √ |
| 6 | 5 | (3) | (3) | (8) | X | ND | (8) | (8) | (8) | X | X |
| 7 | 7 | 7 | 7 | 7 | √ | √ | 7 | 7 | 7 | √ | √ |
| 8 | 3 | 3 | 3 | 3 | √ | √ | 3 | 3 | 3 | √ | √ |
| 9 | 4 | 4 | 4 | 4 | √ | √ | 4 | 4 | 4 | √ | √ |
| 10 | 7 | 7 | (8) | 7 | √ | ND | 7 | 7 | 7 | √ | √ |
| 11 | 6 | (3) | (3) | 6 | X | ND | 6 | 6 | 6 | √ | √ |
| 12 | 4 | (5) | (5) | (5) | X | X | 4 | 4 | 4 | √ | √ |
| 13 | 6 | 6 | 6 | 6 | √ | √ | 6 | 6 | 6 | √ | √ |
| 14 | 4 | 4 | 4 | 4 | √ | √ | (3) | 4 | (5) | ND | ND |
| 15 | 5 | 5 | 5 | 5 | √ | √ | 5 | 5 | 5 | √ | √ |
| 16 | 4 | (6) | 4 | 4 | √ | ND | 4 | 4 | 4 | √ | √ |
| 17 | 3 | 3 | 3 | 3 | √ | √ | 3 | 3 | 3 | √ | √ |
| 18 | 5 | (6) | 5 | (4) | ND | ND | 5 | 5 | 5 | √ | √ |
| 19 | 7 | 7 | 7 | 7 | √ | √ | (6) | (6) | (6) | X | X |
| 20 | 4 | (6) | (3) | (6) | X | ND | 4 | 4 | 4 | √ | √ |
| 21 | 7 | 7 | 7 | 7 | √ | √ | 7 | 7 | 7 | √ | √ |
| 22 | 6 | 6 | 6 | 6 | √ | √ | 6 | 6 | 6 | √ | √ |
| 23 | 7 | 7 | 7 | 7 | √ | √ | 7 | 7 | 7 | √ | √ |
| 24 | 5 | 5 | 5 | 5 | √ | √ | 5 | 5 | 5 | √ | √ |
| 25 | 4 | 4 | 4 | 4 | √ | √ | 4 | 4 | 4 | √ | √ |
| 26 | 3 | (5) | (5) | (5) | X | X | 3 | 3 | 3 | √ | √ |
| 27 | 8 | 8 | 8 | 8 | √ | √ | 8 | 8 | 8 | √ | √ |
| 28 | 4 | (3) | (3) | (3) | X | X | 4 | 4 | 4 | √ | √ |
| **Total %** | | **67.8** | **71.4** | **71.4** | **71.4** | **60.7** | **85.7** | **89.3** | **85.7** | **85.7** | **82.1** |

[a]Lie Item determinations by experts in both modalities for each of the 28 participants. Incorrect LIE determinations are shown in red, and correct LIE determinations are shown in green. "X" indicates incorrect and "√" indicates correct consensus determinations. The "Lie Item" is the number each participant wrote down and kept in her pocket during both the polygraphy and fMRI sessions (ie, 3, 4, 5, 6, 7, 8). "Majority" refers to the Majority Rule (ie, at least 2 out of 3 experts agreed), and "Unanimity" refers to the Unanimity Rule (ie, all 3 expert raters reached consensus on the Lie Item). Cases in which no agreement was reached within modality were classified as "no determination" (ND) and treated as "incorrect" in analysis and excluded from the exploratory analysis of the cross-modality decision rule (PolyMR).
Abbreviation: fMRI = functional magnetic resonance imaging.

ratings, which is a more liberal threshold than the Unanimity Rule. Nevertheless, no significant cross-modality agreement was found, and it was in fact less than that expected by chance ($\kappa = -0.27$, SE = 0.08, $P = .149$). This result suggests that the sources of errors in the 2 modalities may be orthogonal (see Figures 2 and 3). A follow-up exploratory analysis of the rating data was conducted to test the combined fMRI-polygraphy decision rule, termed "PolyMR." The PolyMR rule required both a majority (2 out of 3) among experts in each modality and an agreement between modalities. If either of these 2 conditions was not met, the case was rated as "not determinate" and removed from further analysis. The PolyMR rule was conclusive in only 17 out of 28 subjects (60.7%); however, in these cases, it was 100% correct.

### Sensitivity and Specificity of Individual Experts

Experts' individual ability to distinguish the Lie Item from the foils was evaluated using signal detection parameters of sensitivity and specificity. Each rater had to detect 1 target (Lie Item) out of 6 numbers. The number of times a number was selected correctly (true positive [TP]) and the number of times a wrong number was selected as the lie (false positive [FP]) were used to calculate experts' individual sensitivity = TP/(TP + FN) and specificity = TN/(FP + TN). Table 2 shows a fair to moderate range of sensitivity values for polygraphy (0.68–0.71) and for fMRI (0.86–0.89), and high specificity range (0.94) for polygraphy and for fMRI (0.97–0.98).

## DISCUSSION

We found that under laboratory conditions, fMRI was significantly more likely to detect deception than polygraphy. This is, to the best of our knowledge, the first report of a controlled comparison between these modalities.[47,61] Despite the fact that the polygraphy raters were experts in the interpretation of CIT data, while fMRI raters were naive to it, the latter had greater interrater agreement. This confirms the robust nature of the neurophysiological correlates of deceptive responding at the single-subject level that has been suggested by prior studies evaluating the accuracy parameters of fMRI for lie detection in individual subjects.[35,37,48,54,62] The greater accuracy of the fMRI experts may be explained by the differences between the sources of fMRI and polygraphy signals.[47,61] While fMRI is able to parse the brain response to stimuli both in time and in space, polygraphy is a more integrative assessment of a subject's overall neurophysiological state.

Table 2. Sensitivity and Specificity Parameters of Raters' Accuracy

| Rater | True Positive | False Positive | True Negative | False Negative | Sensitivity | Specificity |
|---|---|---|---|---|---|---|
| Polygraph | | | | | | |
| Rater 1 | 19 | 9 | 131 | 9 | 0.68 | 0.94 |
| Rater 2 | 20 | 8 | 132 | 8 | 0.71 | 0.94 |
| Rater 3 | 20 | 8 | 132 | 8 | 0.71 | 0.94 |
| Average polygraph | | | | | 0.70 | 0.94 |
| fMRI | | | | | | |
| Rater 1 | 24 | 4 | 136 | 4 | 0.86 | 0.97 |
| Rater 2 | 25 | 3 | 137 | 3 | 0.89 | 0.98 |
| Rater 3 | 24 | 4 | 136 | 4 | 0.86 | 0.97 |
| Average fMRI | | | | | 0.87 | 0.97 |

Abbreviation: fMRI = functional magnetic resonance imaging.

Using a cross-modality decision rule (PolyMR), we observed a high (17 out of 17) correct detection rate in cases in which polygraphy and fMRI were in agreement, suggesting that the 2 modalities may complement each other. However, this suggestion contrasts with a prior study that did not find an improvement in the accuracy of lie detection using simultaneously acquired fMRI and electrodermal activity data.[62] Differences between simultaneous and sequential acquisition may be responsible. Electrodermal data collected simultaneously with tasks adapted for event-related fMRI may be suboptimal because the duration of the intertrial intervals in such paradigms may be insufficient for the skin conductance to return to baseline between questions.[63,64] In our study, acquiring polygraphy and fMRI data in sequence allowed us to adapt the experimental settings to each modality. For example, the polygraph test used a slower sampling rate than fMRI, which allowed the examiner to time the questions in a manner responsive to the subject's nonverbal cues.[65–68] Furthermore, the number of runs acquired from each participant was determined by the examiner's perceived quality of the data, as is customary in applied polygraphy but not with fMRI. Additional argument in support of the orthogonal nature of polygraphy and BOLD fMRI signal is the difference between the brain activation pattern of deception (Figure 1) and the brain activity pattern associated with electrodermal response that engages regions associated with interoception such as the insula.[66–68] This orthogonal relationship is further supported by the low ($\kappa = -0.27$) cross-modality agreement. Thus, our finding of very high precision of positive determinations of the sequentially acquired fMRI and polygraphy suggests a clinically useful approach that might be able to reach an overall accuracy acceptable for criminal proceedings, where avoiding convictions of the innocent takes precedence. For example, in the penalty stage of capital case hearings in the United States, the courts expect evidence with a very low risk of false-positive determinations but may be more lenient toward experimental methodology with relatively high false-negative rates.[34,40,69]

The aim of our study was to compare fMRI and polygraphy under uniform conditions rather than to determine the absolute accuracy of either one separately. Such a goal posed unique challenges stemming from the need to standardize data collection and analysis in 2 different biological modalities, while maintaining naturalistic conditions for the acquisition and data analysis for both. Unlike polygraphy, there is no consensus approach to qualitative evaluation of single-subject fMRI data.[70] While automated fMRI methods may be superior to the qualitative expert evaluation,[37] using them for only fMRI would put polygraphy at a disadvantage, as applying automated methods to polygraphy is not representative of the way most polygraphy data are evaluated in practice.[71]

A number of studies have proposed using visual inspection of thresholded statistical maps of fMRI contrasts between conditions of interest, such as eyes open and closed, similarly to the way radiologists interpret structural MRI images in a reading room.[48,54,57,58] Such contrasts are available on many state-of-the art clinical MRI scanners. Accordingly, our single-subject fMRI data were displayed at uncorrected statistical thresholds for fMRI expert rating. Though such thresholds are vulnerable to type I error in fMRI analyses, here they were utilized as a means of rendering fMRI statistical maps for display on standard anatomical templates, not for hypothesis testing.[57,72] Despite continuous improvement in algorithm-driven and automated analyses, human expert evaluation remains the standard of polygraph practice in the United States.[73] Although automated analysis of CIT polygraphy data has been shown in some studies to produce equal or higher accuracy than human raters,[74,75] none are considered a "field" standard.[23] For example, the automated analysis packages provided with commercial polygraph systems, such as PolyScore (v6.2, Lafayette Instruments LX Software Package) consistently underperform qualitative evaluation by human experts.[38,73,76,77] Thus, qualitative evaluations by human experts in both modalities preserved the ecological validity of the results.

We used a simple form of CIT rather than other questioning formats, such as the Comparison Question Test or Differentiation of Deception Paradigm.[78] CIT paradigms have been used extensively in polygraphy and fMRI lie-detection research, making it well suited for an across-modality comparison study.[79] CIT is based on the assumption that lying is associated with heightened neurophysiological response to stimuli of behavioral or autobiographical consequence.[35,80–83] The prefrontal-parietal fMRI activation[84] often observed with CIT (see Figure 1) overlaps with patterns observed in experiments investigating attention, response monitoring, long-term, and working memory processing (for discussion, see Gamer et al[84] and Hakun et al[48,85]), as well as deception paradigms other than CIT.[34,36,86,87] However, uncertainty about the extent to which the brain response generated by the CIT is specific to deception does not diminish the internal validity of our findings, since our goal was to perform a comparative efficacy trial rather than to determine the absolute accuracy of either modality, as has been done elsewhere.[17,36–38,88–91] The generalizability of our findings to real-world scenarios is limited by several factors. First, our design did not include nondeceptive participants, which limits generalizability of our results to the real-world accuracy of fMRI and polygraphy for credibility assessment.[31] Second, since polygraphy monitors the output of autonomic function, absence of perceived cost or threat of detection could have biased the relative accuracy of the 2 modalities in favor of fMRI.[89,92] However, a large body of fMRI literature on fear and anxiety[93,94] points to a well-defined pattern of fear-related activation that may actually give fMRI an advantage in dissociating fear-related and deception-related activation. Therefore, a definitive answer to the question of how a clinical setting might affect the relative accuracy of fMRI and polygraphy requires extending the present experiment to a real-life "clinical" trial.[72]

## CONCLUSIONS

In this prospective and blind comparison, fMRI was significantly more likely to detect deception than polygraphy. The fact that a decision rule that incorporated lie determinations from both modalities (fMRI and polygraphy) made no errors upon reaching consensus suggests that sequential polygraphy and fMRI examinations may have the potential to minimize false-positive lie determinations, a critical feature for any legal application. This study sets the stage for the more comprehensive trials that would include a control group of nondeceptive participants, manipulate the risk and benefit of deception in an ecologically valid fashion, and use algorithm-driven polygraph and fMRI testing and data analysis.[69] While the jury remains out on whether fMRI will become a forensic tool, these data certainly justify further investigation of its potential.

***Submitted:*** January 9, 2015; accepted July 8, 2015.

***Online first:*** January 19, 2016.

***Potential conflict of interest:*** All authors declared no conflict of interest.

***Funding/support:*** Provided by the US Army Research Office (ARO), No Lie MRI, Inc and the University of Pennsylvania Center for MRI and Spectroscopy.

***Role of the sponsor:*** Funders played no role in the conduct or publication of the study.

***Acknowledgments:*** Ronald K. Barndollar, MS, administered the polygraph tests. Elliott L. Busch coordinated the study. Eitan Elaad, PhD; Terence J. Thompson, PhD; and Ronald K. Barndollar, MS, rated the polygraph data. Dan H. Wolf, MD, PhD; Amy E. Pinkham, PhD; and Mark A. Elliott, PhD, rated the fMRI data. James W. Loughead, PhD, provided helpful comments on the study design. Gershon Ben Shakhar, PhD, commented on the early versions of the manuscript.

***Disclaimer:*** Dr Langleben, *JCP* Focus on Addiction Section Editor, was not involved in the editorial evaluation or decision to publish this article.

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