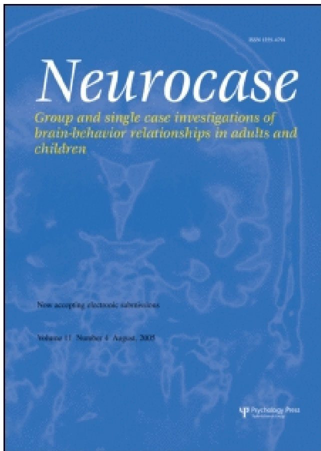

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fMRI investigation of the cognitive structure of the Concealed Information Test

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fMRI investigation of the cognitive structure of the Concealed Information Test

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We studied the cognitive basis of the functional magnetic resonance imaging (fMRI) pattern of deception in three participants performing the Concealed Information Test (CIT). In all participants, the prefrontoparietal lie activation was similar to the pattern derived from the meta-analysis (N = 40) of our previously reported fMRI CIT studies and was unchanged when the lie response was replaced with passive viewing of the target items. When lies were replaced with irrelevant responses, only the left inferior gyrus activation was common to all subjects. This study presents a systematic strategy for testing the cognitive basis of deception models, and a qualitative approach to single-subject truth-verification fMRI tests.

Keywords: fMRI; Deception; Lie-detection; Guilty knowledge test; Concealed information test; Control question test; GKT; CIT; CQT; Left inferior frontal gyrus; Ventro-medial Prefrontal Cortex; Meta-analysis.

INTRODUCTION

There are two ways to determine the truth: detect the truth itself or detect the lie and infer the opposite. Physiological measurements during a formal forced-choice or free-response query are the basis of most methods used to determine the subjective truth. The query protocols are relatively independent from the method used to collect physiological data, making the body of knowledge about these protocols acquired with polygraph measures, relevant for the newer measures such as fMRI. Most formal query paradigms used for truth determination with physiological markers, belong to one of two formats: the Control Question Test (CQT), directed at identifying the lie by comparing possible lie with known truth, and the Concealed Information Test (CIT), also known as the Guilty Knowledge Test (GKT), focused at identifying the physiological markers of 'concealed' knowledge directly. In its classic form, the CIT involves negative answers to a series of questions, some of which are related to the topic of the interrogation. The CIT does not discriminate between physiological response due to lying and orienting or other reasons, such as simple recognition of a stimulus (Lykken, 1991) and is thereby not considered a 'lie-detection test' in the strict sense of the word (Verschuere, Crombez, De Clercq, & Koster, 2004). The extent to which nonspecific physiological responses are controlled in the CQT depends on the closeness of match between the presumed lie and control items. Thus, the CQT and CIT are extremes on a continuum, as evidenced by the introduction of hybrid deception-generating paradigms (Furedy, Gigliotti, & Ben-Shakhar, 1994). One paradigm that our group has recently used to successfully discriminate between lie and truth with fMRI in a laboratory setting,

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has been referred to as a 'modified GKT (CIT)' (Langleben et al., 2005). This model incorporated control (i.e., known truth) items that were used to compare fMRI signal during lie and truth. The early fMRI studies of deception used the overlapping prefronto-parietal (PFP) lie pattern of the CIT and CQT type paradigms to postulate that response inhibition and behavioral control were the key cognitive components of deception (Langleben et al., 2002; Spence et al., 2001, 2004). Though assuming that the PFP pattern is specific to at least some forms of deception is tempting, the very structure of these tasks suggests that they may engage systems that are also involved in other types of cognition and behavior such as working memory, exogenous and endogenous attention, and behavioral and cognitive control. Dissociating the cognitive processes specific to lying from these parallel cognitive processes could enhance the accuracy of fMRI-based lie detection. The goal of this pilot study was to manipulate some of the key parameters of the CIT in order to provide an experimental framework for formally investigating basic cognitive operations such as attention, orienting, and working memory, all of which may contribute to the pattern of fMRI signal elicited by forced-choice deception paradigms.

Our working hypotheses were:

1. Brain response during deception elicited by the standard binary forced-choice CIT ('Stim Test') will be similar to the average deceptive response pattern observed in our prior fMRI CIT studies (Langleben et al., 2002, 2005).
2. The observed Stim Test pattern will remain unchanged after the following manipulations of the CIT:
    a. passive viewing of the CIT task stimuli, in the absence of a query or deceptive response;
    b. replacing deceptive and truthful responses with irrelevant (non-deceptive, evaluative) responses.

METHODS

Subjects

Subjects were three healthy, right-handed, English-speaking, college-educated females (16 years of education), 24, 24 and 25 years of age. To produce a regions-of-interest (ROI) template for qualitative analysis of the single-subject data, data from two previously reported fMRI CIT studies (Langleben et al., 2002, 2005) were subjected to meta-analysis. These data were acquired from 40 (12 female, 28 male) right-handed, English-speaking participants, 19–50 years of age. Each subjects' medical and psychiatric status was ascertained through a detailed assessment by a board-certified physician (D.D.L.). Substance abuse was excluded by a urine drug test. Candidates receiving prescription medications, those with a history of DSM IV Axis I psychiatric disorder, as well as those with any chronic medical illness or significant past trauma, were excluded. The study protocol was approved by the University of Pennsylvania Institutional Review Board.

Experimental procedure

Subjects participated in three consecutive tasks: a CIT in a format referred to by polygraph examiners as the 'Stim Test' (ST); (Matte, 1996; Elaad & Kleiner, 1986) and two manipulations of this task: Irrelevant Query CIT (IRQ); and Orienting CIT (OR). The ST was administered twice: before the scan session as a training session and during the scan session. The IRQ and OR were administered during the scan session only. After screening and informed consent, a designated team member met subjects, gave them the ST instructions, and conducted the ST. The subjects were then escorted to the scanner, where they were greeted by a different team member and performed the three tasks in the scanner, in a single fMRI session. During the scan session, the ST was performed first, and the order of the IRQ and OR was counterbalanced. Additional instructions specific to the IRQ and the OR were delivered via headphones prior to each task. The order of the fMRI tasks for Subject 1 and Subject 3 was ST, IRQ, and OR; and for Subject 2 the order was: ST, OR, IRQ.

Task instructions

The examiner asked each participant to pick a number from 3 through 8 (inclusive), write it down in secret on a separate sheet of paper, and place the paper in their pocket for the remainder of the study. Then the examiner presented each participant with the numbers 1 through 9 (inclusive) written on a sheet of paper. Subjects were instructed to deny having written the number they had in their pocket when asked about it and to tell the truth in response to questions about all other numbers.

After the questioning, the examiner instructed the subjects to adhere to the same instructions when questioned in the scanner.

Task design

Stim Test (ST)

The fMRI paradigm design of the ST was sparse event-related (Aguirre & D'Esposito, 1999; Dale, 1999). Stimuli were white numbers 1 through 9 (inclusive) presented on a black background, accompanied by a question: 'Do you have the number (X)?' Emulation of the green and blue response buttons of the fiber-optic response pad (fORP; Current Design, Philadelphia, PA) appeared on the bottom of the screen, with the words 'YES' and 'NO' above them, respectively. Stimuli classes were: Truth (numbers 3 through 8, inclusive, less the chosen number); Lie (the chosen number); and Control-Truth (numbers 1, 2, and 9).

Each stimulus, 1 through 9, was repeated 5 times throughout the experiment. Stimuli were presented for 3 s and separated by variable ISIs (10–16 s, mn = 13 s). The first presentation of each stimulus was in ascending numerical order, the second, third and fourth presentations of each number were in pseudorandom order, and the last presentation of each stimulus was in descending numerical order. This order approximated the polygraph ST format (Matte, 1996). The question appeared at the top of the screen, and stimuli were presented center-screen below the question (target area). During query trials, stimuli were presented in the target area; between each query trial (ISI) a fixation cross ('+') appeared in the target area. Subjects were asked to make a response to query trials using the fiber-optic response pad (fORP). Stimuli were presented and responses logged by Presentation® software (Version 0.70, www.neurolabs.com). The ST was 11 min 15 s long.

Irrelevant Query task (IRQ)

Stimuli, presentation order, stimuli classes, ISI, task duration, and display for the IRQ were identical to ST. The question 'Do you have the number (X)' was replaced with 'Is this number greater than 10?' Subjects were instructed to judge whether the number presented in the target area was greater than 10 or not (magnitude judgment) and press the corresponding 'YES' or 'NO' buttons on the fORP to respond. Prior to initiating the IRQ subjects were given two practice trials administered verbally over the scanner intercom to ensure the subject understood the instructions.

Orienting task (OR)

Stimuli, presentation order, stimuli class, ISI, task duration, and display for the OR were also identical to the ST. However, the question 'Do you have the number (X)?' was removed without replacement. Subjects were instructed to attend to each stimulus presented in the target area during the OR task.

After the modification of the ST query in the IRQ task and the outright removal of the ST query in the OR task, there was no longer an act of deception taking place in these two tasks. Thus, the 'Lie' and 'Truth' conditions of the ST were renamed to 'Target' and 'Distracter' conditions in the IRQ and OR tasks.

Image acquisition

MRI scanning was performed on a 3-Tesla Siemens Trio scanner (Iselin, NJ). Functional data were collected with a Blood Oxygenation Level Dependent (BOLD) sequence (TR/TE = 3000/30 ms, FOV = 240 mm, matrix = 64×64, slice-thickness/gap = 3/0 mm). For anatomical reference, registration of functional data, and for normalization of functional data to a standard T1 template (Montreal Neurological Institute, MNI) a T1 magnetization prepared, rapid-acquisition gradient echo (MPRAGE, TR/TE = 1630/3.87 ms, FO = 250 mm, matrix = 192×256, slice-thickness/gap = 1/0 mm) sequence was used to collect a high-resolution image of each subject's brain. Task stimuli were presented via a video projector (Powerlite 7300; Epson America, Long Beach, CA) and refracted to the subject's visual field with a head-coil mounted mirror.

fMRI data preprocessing

Preprocessing: FMRI and MRI data were preprocessed and analyzed using FMRIB's Software Library (FSL) fMRI Expert Analysis Tool (FEAT) (Smith et al., 2004). Functional data were brain-extracted (Smith, 2002), motion-corrected to the median functional image using b-spline interpolation (4 df), high-pass filtered (60 s), and spatially smoothed (9 mm full width at half maximum (FWHM), isotropic). The anatomical volume was brain-extracted and registered to the standard space T1 MNI template using tri-linear interpolation with FMRIB's Linear Image Registration Tool (FLIRT, 12 df; Jenkinson & Smith, 2001). The median functional image was registered to the anatomical volume, and then transformed to the MNI template.

Statistical analysis of imaging data

Statistical images 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 canonical Hemodynamic Response Function (HRF, double gamma). The nine regressors along with their temporal derivatives, and an intercept form were entered into single-subject GLMs for analysis of each task. A contrast of beta-coefficients for the Lie regressor versus the average of the Truth regressors (and Target versus the average of Distracter [IRQ and OR]) were made for each task and resulting images were converted to percent signal change as well as *z*-statistic maps. The Control-Truth condition, a standard element of a conventional Stim Test, was not included in the analysis. It was not considered comparable to the Truth condition because subjects were instructed that the numbers 1, 2, and 9 could not be used as Lie items.

CIT meta-analysis

Raw data volumes for Lie and Truth conditions from the previously reported GKT1 (Langleben et al., 2002) and the Lie and Repeat-distracter in GKT2 (Langleben et al., 2005) experiments were subjected to the preprocessing steps described in the 'fMRT data preprocessing' section. Contrasts of parameter estimates for Lie and Truth (in GKT1 and GKT2) conditions were entered into a group GLM where a one-way *t*-test was performed to identify significant activation differences between conditions. The resultant t-map was thresholded at a voxel-height probability of $p < .001$ and cluster-probability of $p < .05$. The thresholded and cluster-corrected volume was then converted to a binary image (0 = non-significant, 1 = significant voxels) for use as a masking volume.

ROI analysis of the ST, IRQ, OR data

ST, IRQ, and OR contrasts were masked by the binary functional result of the CIT Meta-analysis (both described above). Difference in mean percent signal change was calculated from the Lie > Truth and Target > Distracter contrasts within each of the masked ROIs. Scaling factors for percent signal change were comparable between tasks and subjects as the task-design was sparse event-related, allowing all events to be isolated, all events were of the same duration, and the design matrix was identical between each task and each subject.

RESULTS

Behavioral data

The error rate for all three subjects in all tasks was 0%.

CIT meta-analysis (Figure 1)

The Lie > Truth ($N = 40$) comparison revealed significant activations in bilateral inferior frontal gyrus (IFG), bilateral inferior parietal lobe (IPL, primarily supramarginal gyrus [SMG]), a cluster extending between the superior frontal gyrus (SFG) and the anterior cingulate (ACC), the dorsal region of the ACC, bilateral middle temporal gyrus (MTG), and the precuneus (BA 7) (Table 1). All reported coordinates are in the MNI standard space. The resultant meta-analysis volume was thresholded at a voxel-height of $p < .001$, and a cluster-probability of $p < .05$ was used to control for Type I and II errors.

Subject 1 (Figure 2A)

During the ST, Subject 1 exhibited increased activation in the Lie > Truth comparison in the bilateral IFG, IPL/SMG, SFG, dorsal ACC, and the right MTG. During the IRQ, increased Target-activation was present in left IFG. Lastly, during the OR increased Target-activation was present in the bilateral IFG, IPL/SMG, SFG, dorsal ACC, and the left MTG. There was an overlap between ST (Lie) and OR (Target) related activation in six regions. The overlap between ST (Lie) and IRQ (Target) was present only in the left IFG.

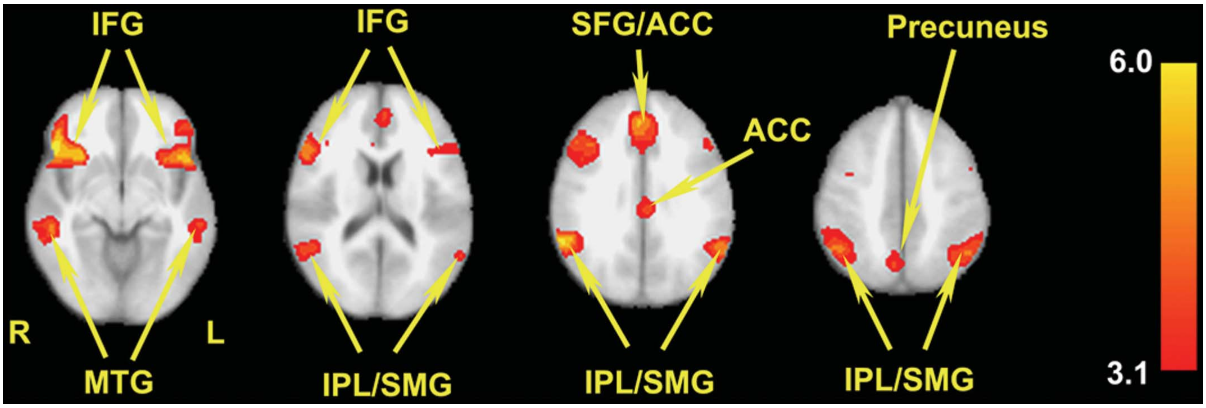

Figure 1. fMRI results of CIT Meta-Analysis (N = 40) Lie > Truth Contrast. Results are z-statistic maps thresholded at voxel-height probability of $p < .001$, and cluster-probability of $p < .05$, displayed over the MNI T1 anatomical template in radiological convention (the right side of the brain is on the viewer's left). Significant clusters of activation are located in bilateral IFG, IPL, SFG, Dorsal ACC, MTG, and precuneus.

TABLE 1
fMRI results of the CIT Meta-analysis (N = 40) Lie > Truth contrast

Region	*Brodmann area*	*X*	*Y*	*Z*	Z_{max}
IFG L	44, 45, 47	–44	20	–4	5.38
IFG R	44, 45, 47	50	26	–4	5.95
IPL/SMG L	40	–58	–52	32	5.17
IPL/SMG R	40	60	–48	30	5.46
ACC	8, 32	2	32	36	5.2
ACC (dorsal)	24, 31	–4	–26	28	4.11
MTG L	20, 21, 39	–58	–32	–12	3.92
MTG R	20, 21, 39	52	–34	–8	4.48
Precuneus	7	8	–68	42	4.05

Coordinates (X, Y, Z) are in MNI standard space. Results are thresholded at voxel-height probability of $p < .001$ and a cluster-probability of $p < .05$.

Subject 2 (Figure 2B)

During the ST, Subject 2 exhibited increased activation in the Lie > Truth comparison in the bilateral IFG, IPL/SMG, SFG, dorsal ACC, and MTG. During the IRQ, increased Target-activation was primarily in the left IFG, left MTG, and precuneus. Lastly, during the OR, increased Target-activation was present in every ROI: bilateral IFG, bilateral IPL/SMG, SFG, dorsal ACC, bilateral MTG, and precuneus. The overlap between ST (Lie) and OR (Target) related activation was in all ROIs except the precuneus. Increased Lie/Target activation was shared between ST and OR only in the left IFG and left MTG.

Subject 3 (Figure 2C)

In this subject, increased activation in the Lie > Truth (or Target > Distracter) comparison was present in all ROIs in all three tasks: bilateral IFG, IPL/SMG, SFG, dorsal ACC, MTG, and precuneus.

DISCUSSION

Meta-analysis of the Lie vs. Truth contrast in the two CIT paradigms produced a prefronto-parietal pattern that included the bilateral IFG and IPL, bilateral MTG, as well as the SFG and ACC. A recognized flaw of the CIT is the stimulus familiarity confound i.e., the concealed Lie stimulus was more familiar to the participants than the Truth stimuli (Langleben et al., 2002). Nevertheless, the fact that similar prefronto-parietal activation pattern has also been reported in fMRI studies that have used non-CIT deception paradigms (Abe, Suzuki, Mori, Itoh, & Fujii, 2007; Kozel et al., 2005; Nunez, Casey, Egner, Hare, & Hirsch, 2005; Spence et al., 2001) supports our use of these regions in subsequent *a priori* ROI analyses. The ST reported here is a CIT that has been controlled for familiarity, yet it shows an activation pattern similar to the CIT meta-analysis across all three subjects, downplaying the importance of the familiarity confound.

The OR task is essentially a passive viewing of the ST; there is no query and no behavioral

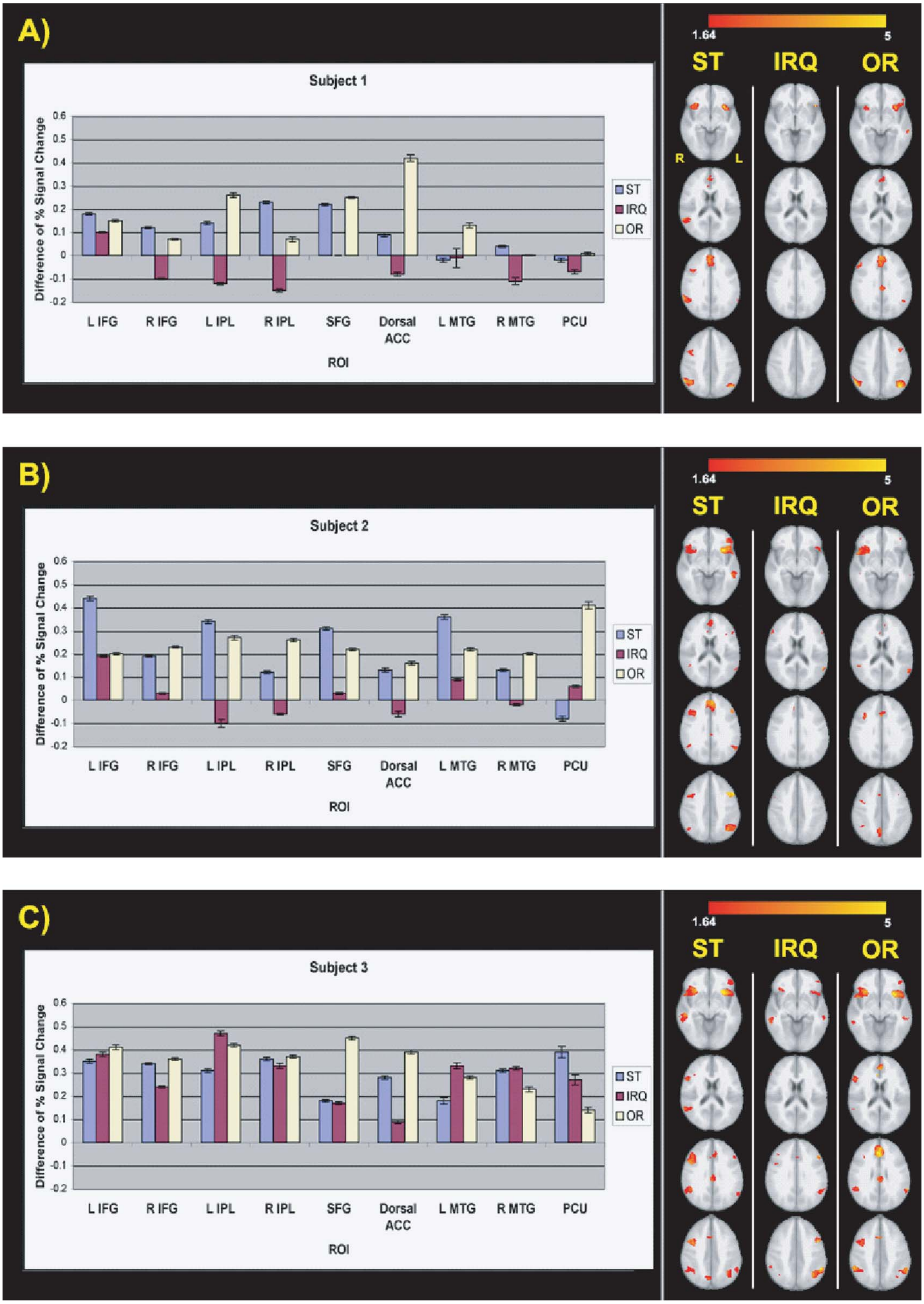

Figure 2. ST, IRQ, and OR. Subject 1 (A), Subject 2 (B), and Subject 3 (C): (LEFT) Difference in mean percent signal change between Lie > Truth conditions (ST) and Target > Distracter conditions (IRQ and OR). (RIGHT) fMRI whole-brain results of Lie > Truth (ST) and Target > Distracter (IRQ and OR) contrasts thresholded at a voxel-height probability of $p < 0.05$, uncorrected for multiple comparisons and masked by thresholded CIT meta-analysis Lie > Truth contrast (Figure 1). Results are z-statistic maps displayed over the MNI T1 anatomical template in radiological convention (Subjects' right is on viewer's left).

response is required. These manipulations convert the ST Lie and Truth items into the Target and Distracter stimuli of the OR. The Target vs. Distracter contrast in the OR task shows prefronto-parietal, ACC and MTG activation, all virtually identical to the ST Lie vs. Truth pattern. These findings may call for a departure from the prevailing hypothesis that postulates that prefrontal activation is specific to deception. One caveat is that this similarity could have been caused by an order effect: since ST always preceded the OR, the cognitive set of lying established by the ST may have been maintained despite the change in instructions from deception to passive observation. However, the fact that for two out of three subjects the ST and OR pattern similarities did not persist in the IRQ, which also followed the ST, argues against this interpretation. In addition, even this more conservative interpretation demonstrates that pairing of a motor response to item recognition is unnecessary in eliciting the pattern observed in the ST. Confirmation of the similarities between the fMRI response pattern during a lie and a generally salient item in a counterbalanced experiment would suggest that the CIT is indeed a test of some of the cognitive operations involved in deception, such as orienting, endogenous attention, and matching to target. Such confirmation would also suggest that a CIT is unable to specifically indicate a deceptive response.

Unlike the results of the ST and the OR, the IRQ results varied across subjects. The expected prefronto-parietal activation was observed in Subject 3 only. In Subjects 1 and 2, shared activation during irrelevant responding to the target item was only found in the left IFG. The order effects between the ST and the IRQ are the same as between the ST and the OR. Since the OR and IRQ were counterbalanced, the difference in fMRI response to the target item between OR and IRQ could not be attributed to order effects. We hypothesize that the cognitive interference of the irrelevant response (magnitude judgment) to the formerly concealed item could effectively disrupt the cognitive set/order effect imposed by the ST. The applied significance of this interpretation is that cognitive interference may be an effective countermeasure to CIT-based fMRI interrogation. The direct comparison made between target and distracter in analysis of IRQ should, in theory, yield no difference between conditions, as all trials involve presumably the same cognitive and behavioral response pattern. We hypothesize that the remarkable persistence of the left IFG during the IRQ for both subjects represents maintenance of target stimulus-saliency throughout the testing session. The left IFG has been shown to be involved with retrieval of semantic knowledge in a variety of domains and is sensitive to increased working memory load (Badre, Poldrack, Pare-Blagoev, Insler, & Wagner, 2005; Brass & von Cramon, 2004; Feredoes, Tononi, & Postle, 2006; Jonides & Nee, 2006; Lauro, Tettamanti, Cappa, & Papagno, 2007; Thompson-Schill, D'Esposito, Aguirre, & Farah, 1997). Despite the distractive effect of the IRQ in inhibiting the full deceptive cognitive response, activation of the left IFG due to stimulus-saliency, and consequential working memory competition to break behavioral set, may be predictive of a concealed target. Persistence of the left IFG in the IRQ task is in agreement with our previous report of increased left IFG response during Lie conditions (Langleben et al., 2005).

The data presented here are derived from only three subjects and is therefore preliminary. Their main value is in reporting a possible method for formal study of a traditional deception model through the use of a systems neuroscience approach. Replication of these findings in a larger sample would provide imaging data amenable to a random effects analysis as well as sufficient reaction-time data. The manipulations of the CIT we reported have several limitations which could be addressed by future larger studies: first, simultaneous removal of the query and response requirement in the OR precludes it from dissociating the contributions of the response and of the query to the CIT fMRI pattern. The potential of order effects and habituation could be avoided by counterbalancing across all three tasks rather than only the IRQ and OR. Between-tasks comparisons could not be made due to confounds of novelty and repetition of stimuli, a limitation that could also be overcome with a larger sample size. Finally, the experiments proposed here might not answer the fundamental question of whether there is a brain response pattern characteristic of deception that is independent of the structure of the task used to elicit it.

In conclusion, the meta-analysis data presented here confirm the relevance of prefronto-parietal brain activation to deception. Together with the results of the ST, these preliminary data support the internal validity of the fMRI-adapted CIT model of deception. Deceptive behavior is not essential for the CIT-type response pattern, while cognitive distraction can significantly attenuate it. The manipulations presented here are a blueprint for the use of cognitive neuroscience methodology to decode the contributions of basic cognitive operations to the brain pattern of deception, and to help the search for the existence of an activation pattern specific or even unique to deception. In the cases reported here, the left IFG activation has been resistant to cognitive distraction, suggesting that it may be a marker of deception and/or concealed information that is independent of the structure of the query used to elicit deceptive behavior. No model to-date has convincingly dissociated a brain fMRI signal of deception from the brain activity associated with basic processing of the cognitive task used to elicit deceptive behavior. Such a model may require consideration of social interaction, exercise of agency, and moral judgment during deceptive behavior (Frith, 2007; Greene, Nystrom, Engell, Darley, & Cohen, 2004; Watson, 2001).

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