

Brain Mapping of Deception and Truth telling about an ecologically valid situation: An fMRI and polygraph investigation.

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Abstract

Purpose: The purpose of this study was to examine the neural correlates during deception and truth-telling using functional magnetic resonance imaging (fMRI) technique and an ecologically valid task, and compare the results to a standard polygraph examination.

Materials & Methods: Eleven healthy subjects were randomly assigned to one of two conditions: “Lie Only Condition” (LOC) or “Truth Only Condition” (TOC). Each condition represented a separate fMRI session. The LOC was carried out to compare the brain activity during “known lie” to control questions and subjective lie to relevant questions. This was followed by TOC, where brain activity during “known truth” to control questions, and subjective truth to relevant questions were compared. Functional images were then acquired with an echo planar (EPI-FID) sequence. All subjects gave written informed consent approved by the IRB of Drexel University.

Results: During the deception process the results show unique areas of frontal lobe (left medial, left inferior), temporal lobe (right hippocampus, right middle temporal gyrus),

occipital lobe (left lingual gyrus), anterior cingulate, right fusiform gyrus, and right sub-lobar insula regions to be significantly active. During truth telling, unique activation regions were seen in the frontal (left subcallosal gyrus/lentiform nucleus), and temporal lobes (left inferior temporal gyrus). The polygraph examination was consistent in the deceptive subjects, however there was only a 67% accuracy rate in the truth-telling subjects.

Conclusion: The results demonstrate that there are unique areas of the brain that are involved in the process of deception and truth-telling, which can be measured using fMRI.

Introduction

Detecting whether an individual is telling the truth or lying has been a goal of mankind for centuries ⁽¹⁾. Early methods of lie detection, as well as some modern techniques, rely on observations of proposed non-verbal indicators of deception such as increased perspiration, changing bodily positions, or subtle facial expressions ⁽¹⁻³⁾. However, the last century saw the development and use of technology to identify deception by measuring changes in sympathetic nervous system responses (e.g., the standard polygraph and infrared thermal imaging ⁽⁴⁾).

Among several techniques that are currently used and under development for detecting deception the standard polygraph is the most reliable (80-90%) and widely used technique ⁽⁵⁾. Although the polygraph has become the most common method used to examine deception, it has several drawbacks ⁽⁶⁻⁸⁾. These include failure of the polygraph examiner to properly prepare the examinee, a misreading of the physiological data on the polygraph charts, as well as areas of subjectivity involved in polygraph testing. One of the major problems with the polygraph is that it is entirely based on measurements of the response of the sympathetic nervous system, which is not unique to deception, and can occur in numerous other normal human emotional states such as guilt, excitement and anger.

Functional MRI based on blood oxygenation level-dependant imaging (BOLD) is a method which measures indirect responses that are tightly coupled to neuronal activity and is very widely used to map human brain functions ^(9,10). This technique may help to accurately map the regions of the brain involved in higher cortical functions including such interesting cognitive processes as deception and truth telling. Several recent fMRI

imaging studies have shown the involvement of prefrontal cortices, parietal lobes and anterior cingulate to be activated during judgment, manipulation of information and planning of response including inhibition ⁽¹⁰⁻¹⁵⁾. These studies did not use standard polygraph techniques or innovations from that field of expertise or a real life task that would elicit cognitive and emotional responses. The techniques used in these previous studies varied from guilty knowledge testing ⁽¹³⁾, digit memory testing ⁽¹²⁾, card sorting testing ⁽¹³⁾, and neuropsychological evaluations ^(11,14&15).

In a previous fMRI investigation by our group, we used the control question technique (CQT) ^(16, 17), which is one of the most acceptable polygraph methods used ⁽¹⁸⁾. Our findings showed poor correlation between regional BOLD signal and polygraph test scores, presumably due to insufficient BOLD signal arising from the CQT task. In the current study, we implemented cognitively challenging modified positive control polygraph task in an fMRI experiment and compared the results with standard computerized polygraph measurements using the Integrated Zone Comparison Technique ⁽¹⁹⁾, one of the frequently used polygraph testing paradigms.

A working model of Deception:

Based on currently published imaging data, we devised a working neurological model of deception in order to guide our investigation, as well as to better illustrate the cognitive complexities involved in formulating a lie (See Figure 1). This model, not only takes into account data that has focused on the neural components of deception, but also data pertaining to neural substrates associated with processes such as inhibition and

reward circuitry. It also shows the chain of events involved in conventional polygraph test (dotted lines).

The process of producing a lie or truthful response begins with hearing or seeing the question, understand it, and then recall of the event or fact relating to the question. The perception of question by hearing or vision will activate the corresponding auditory cortex (BA 41, 42) or visual cortex (BA 17,18,19). This would be followed by receptive language comprehension, which has been linked to activation in Wernicke's area (BA 22), which comprises the posterior portion of the superior temporal gyrus, as well as the dominant angular cortex (BA 39) ⁽¹²⁾. Once the question posed to the person is understood, the person may attempt to recall the event associated with the question. Although the role of the frontal lobes in recall of memory is unclear, areas in the prefrontal cortex is likely to be involved in moderating memory ⁽²⁰⁻²²⁾. The amygdala is an area of the brain associated with emotions such as fear or anxiety. It has been shown through fMRI studies that recall of an event that is associated with anxiety has a stimulatory effect on the amygdala ⁽²⁰⁾. It should not be misunderstood that activation of the amygdala is representative of inhibition or a deceptive situation, as one can recall and speak truthfully of an event that involves a high level of anxiety. This misunderstanding may form the basis for the false positives that result in the polygraph measuring. The polygraph measures the output of the limbic system, including the amygdala, which regulates the body's sympathetic functions such as heart rate, respiratory rate, as well as electro-dermal (sweat) responses. The limbic system may be activated in situations of anxiety or fear regardless of the nature of the subjects' response ⁽²⁰⁾.

After recall of the event of significance the subject must plan a response consistent with truth or deception. If the person wishes to be truthful in answering a question, then the person will plan and construct a response that is truthful. In contrast, if a person wishes to produce a deceptive response it is hypothesized that either an additional area of the brain would be marshaled to produce such a response, or perhaps a different activation of the same area would be needed to construct the deception. In producing a deceptive response, inhibition or concealment of the truth is obviously a key aspect of the construction. It is this step in the process of deception that has been the focus of intense study using fMRI since this is the unique cognitive function in the process of lying. There is some consensus among the investigators that the prefrontal cortex as an area involved in planning a deception response and inhibiting the truth^(19-23, 24, 11, & 13). Some fMRI studies of deception demonstrated activation of the anterior cingulate cortex⁽¹²⁻¹⁴⁾ and areas of the right hemisphere^(13, 14). The final component of producing a deceptive or truthful statement involves motor response. These responses may include speaking a truthful or deceptive utterance, or simply pushing a “yes” or “no” response key in the scanner. Such a response utilizes the motor system in the frontal lobe⁽²⁰⁾.

The purpose of this study was to investigate the regions of brain activation during truth telling and deception using blood oxygenation level dependent (BOLD) functional magnetic resonance imaging (fMRI) at 1.5 Tesla and an ecologically valid task (e.g., one that would mimic real life). We hypothesized that 1) there would be unique areas associated with deception and truth telling and 2) according to our hypothetical model there would be multiple areas of the brain involved in these two different processes. We

also hypothesize 3) that there would be more areas of the brain activated during the deceptive process.

Methods and Materials:

To test these hypotheses, we recruited twelve subjects for this the study. Of the twelve, one subject's data was eliminated due to acceptance of guilt prior to the start of the study, even though the subject was instructed to lie and try to beat the test. The experiments were performed on eleven (11) healthy volunteers screened for drug use, neurological and neuropsychiatric illness, and contraindications with MRI using a standard 1.5T Siemens scanner (5 females & 6 males, mean age: 28.9 years). Ten (10) subjects were right handed and one was left-handed. All subjects gave written informed consent and the Institutional Review Board of Drexel University approved the study. All subjects underwent an initial preparation phase, an interview phase, a polygraph test and an fMRI study. The order of the fMRI and the polygraph tests were randomized. In the preparation phase the subjects were given the following instructions:

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

Scenario 2: Non-guilty subjects: Someone fired a gun today inside the hospital. The researchers that will interview you and test you via the polygraph and fMRI have been told that you are a suspect in the shooting because someone who looks like you appeared on a video surveillance system in the area around the time of the shooting. Your role is to be co-operative and truthful, since you did not fire the gun. You want to do well in the interview and testing and demonstrate to them you are innocent.

The relevant situation used in this study was a mock shooting using a starter gun with blank bullets within a testing room in the functional neuroimaging center. The subjects were informed prior to the study about gun safety and how to fire a gun with blank bullets. None of the subjects recruited reported experiencing any significant distress or upset feelings. They were asked to wear goggles for eye protection. The fMRI lab is a safe environment and care was taken as not to affect other medical projects. This was followed by an interview phase utilizing the Forensic Assessment Interview technique ⁽²⁴⁾, where the subjects were asked about their involvement in the study and basic demographic information was gathered. The fMRI scanning and polygraph testing were performed following the interview.

Of the eleven subjects, five were asked to tell the truth (Scenario #2), that is, they were not involved in the relevant situation, and six were asked to deliberately lie and deny their involvement in the relevant situation (Scenario #1). We pooled the subjects who were asked to lie and refer to them in this study as guilty subjects (GS) and the subjects who were asked to tell the truth as not guilty subjects (NGS). The subjects were informed that they would be rewarded \$25 for correctly following the experimenter's instructions.

Polygraph measurements:

A certified polygraph examiner and an investigator in this study (N.J.G.) performed the interviews and polygraph measurements on all the subjects. The physiological responses from the healthy subjects were measured by using a four-channel computerized LX-4000 polygraph instrument. Three different types of physiological responses were measured. The rate and the depth of respiration were measured by two different pneumographs secured around the chest and the abdomen. A blood pressure cuff placed around the bicep of the subject was used to measure cardiovascular activity. The galvanic skin conductance (GSC), a measure of electrical conductivity related to perspiration, was measured with electrodes attached to the index and forefinger of the volunteers. All the polygraph signals were digitally recorded and the responses were displayed on a moving chart of a laptop computer using the software provided by the Lafayette Instrument Company, Lafayette, Indiana.

Functional MRI (fMRI):

The functional MRI experiment used a boxcar type block design for collecting images. The order of the fMRI and polygraph procedure was randomized across subjects. The subjects were instructed to stay still during the scanning. The auditory stimulus was controlled from outside the scanner using Presentation software (NeuroBehavioral Systems; www.neurobs.com) and delivered through headphones that were compatible for use in the MRI environment. Subjects listened to digitally recorded questions read by the investigator who performed the interviews and polygraph tests. The same voice was used

across all the subjects and recordings of the questions, which were matched as closely as possible for length, volume, and clarity. All questions were designed to be answered using Yes or No and subjects were instructed to respond using designated keys on a MR compatible response box (Resonance Technology, Inc). The question format that was used in this study followed a modified positive control polygraph questioning technique.

Initially a high-resolution (256*256) T1-weighted spin echo sequence was used to acquire anatomical images. Twenty-five (25) contiguous axial images were positioned and aligned parallel to the AC-PC (anterior commissure and posterior commissure respectively) line covering the entire brain ⁽²⁵⁾. Later, functional images were acquired with echo planar (EPI-FID) sequence in the same plane as the structural images. The imaging parameters were: matrix size = 128*128; field of view (FoV) = 22 cm; slice thickness = 5mm; TR=4s; TE=54 ms; and NEX=1. The in-plane image resolution was 1.72x1.72x5 mm.

The subjects were presented with 5 separate blocks of control and relevant questions alternating with rest period blocks. During each block (24 sec long), 6 volumes of EPI images were acquired, yielding a total of 120 EPI volumes. It was expected that the subjects denying their involvement in the relevant situation would produce a greater autonomic response to the relevant question (Figures 2 & 3) than to control questions. Continuous scanning was performed until all the 20 blocks were completed. Two separate fMRI experiments were conducted. The first session named “Lie Only Condition, (LOC)” was carried out to compare the brain activity during “known lie” to control questions and subjective lie to relevant questions. This was followed by another session named “Truth Only Condition, (TOC)”, where the brain activity during “known

truth” to control questions and subjective truth to relevant questions were compared. The questions were randomized and repeated between different blocks. At the end of the study all the subjects were debriefed about the study and their participation.

Image Processing

The post-acquisition preprocessing and statistical analysis was performed using SPM2 (Statistical Parametric Mapping, Wellcome Department of Cognitive Neurology, University College of London, UK ⁽²⁶⁾ run under the Matlab® (The Mathworks, Inc., Natick, MA) environment. Images were converted from the Siemens format into the ANALYZE (AnalyzeDirect, Inc., Lenexa, KY) format adopted in the SPM package. A 3D automated image registration routine (six-parameter rigid body, sinc interpolation; second order adjustment for movement) was applied to the volumes to realign them with the first volume of the first series used as a spatial reference. All functional and anatomical volumes were then transformed into the standard anatomical space using the T2 EPI template and the SPM normalization procedure ⁽²⁷⁾. This procedure uses a sinc interpolation algorithm to account for brain size and position with a 12 parameter affine transformation, followed by a series of non-linear basic function transformations seven, eight, and seven nonlinear basis functions for the x, y, and z directions, respectively, with 12 nonlinear iterations to correct for morphological differences between the template and given brain volume. Next, all volumes underwent spatial smoothing by convolution with a Gaussian kernel of 8 cubic mm full width at half maximum, to increase the signal-to-noise ratio (SNR) and account for residual intersession differences.

Subject-level statistical analyses were performed using the general linear model in SPM2. The scans corresponding to the relevant and control conditions in the two trials

(LOC & TOC) in the two groups of subjects (GS & NGS) were modeled using a canonical hemodynamic response function. Contrast maps were obtained through the following linear contrasts of event types: relevant vs. control (GS, LOC: Lie effect), control vs. relevant (GS, TOC: Lie effect), (relevant + control) vs. baseline (NGS, LOC: Lie effect), (relevant + control) vs. baseline (NGS, TOC: Truth effect). Next, group-level random effects analyses for main effects were accomplished by entering whole brain contrasts into one-sample t-tests. A significance threshold based on spatial extent using a height of $t \geq 3.00$ and cluster probability of an uncorrected $p \leq 0.001$ was applied to the effects of interest and surviving voxels were retained for further analyses (spatial extent threshold ≥ 10 voxels). Statistical parametric maps (SPM {t}) were generated to show visual representation of the areas in the brain wherein statistically significant differences between BOLD contrast during truth-telling and deception conditions are present. The analysis scheme that was performed in this study and sample questions are shown in Figures 2 & 3.

Results:

Polygraph data results

Table 1 shows the polygraph results analyzed using three different methods of polygraph scoring methodologies: Polyscore⁽²⁸⁾, developed by Johns Hopkins University Applied Science Laboratory; Objective Scoring System⁽²⁹⁾, developed by Donald Krapohl, and ASIT POLY SUITE⁽³⁰⁾ developed at the Academy for Scientific Investigative Training. Details of the above mentioned scoring systems is beyond the scope of this manuscript, however can be obtained from the above-mentioned references.

Eleven subjects completed this study; 6 subjects belonged to the GS category; and 5

subjects belonged to the NGS category. The polygraph scores irrespective of the techniques used showed 100% correlation in the GS category (Table 2). However in the NGS category, accuracy varied across the three scoring methodologies. Using the data from three polygraph charts, Polyscore and the Objective Scoring System properly identified 3 out of 5 NGS subjects, while two subjects showed inconclusive polygraph results. ASIT POLY SUITE properly identified 4 out of the 5 NGS subjects as truthful, with one subject showing inconclusive polygraph results. The accuracy for the NGS group ranged from 60% to 80% (Table 2).

fMRI results

Tables 3-5 show the group results for the main effect, lying in the three different conditions. Significant areas of activation ($p < 0.001$, spatial extent threshold > 10 for lie condition 1 and $p < 0.005$, spatial extent threshold > 10 for lie conditions 2 and 3) were seen in the all the three conditions. In condition 1 activation were seen in left lingual gyrus, left middle occipital gyrus, bilateral sub-lobar insula, right fusiform gyrus, left precentral, right anterior cingulate and left caudate body. During condition 2, activations were seen in right inferior parietal lobule, left inferior frontal gyrus, left medial frontal gyrus, right sub-lobar/thalamus/anterior nucleus, left lingual gyrus, left caudate body and left caudate tail. During condition 3, activations were seen in right hippocampus, left precuneus, right middle temporal, right paracentral lobule, right precentral gyrus, bilateral precuneus and left posterior cingulate areas. Figure 4 shows the areas of activation observed across all three-lie conditions.

Table 6, and Figure 5 shows the significant areas of activation during the truth experiment in the NGS subjects ($p < 0.005$, spatial extent threshold > 10). Activations were seen in left subcallosal gyrus, left sub-lobar/lentiform nucleus, right precuneus, left inferior temporal, left parietal lobule, left posterior cingulate gyrus and right precentral gyrus.

In summary, during the deception process there were fourteen regions to be significantly active. The results show areas of frontal lobe (left medial, left inferior and bilateral precentral gyri) [BA 9, 10, 6], temporal lobe (right hippocampus, and right middle temporal gyrus [BA 19], parietal lobe (bilateral precuneus, right inferior parietal lobule [BA 40], occipital lobe (left lingual gyrus) [BA 18], anterior, posterior cingulate, right fusiform gyrus, and right sub-lobar insula & thalamus regions to be significantly active during the deception process. During truth telling there were seven regions to be significantly active. These activation regions were seen in the frontal lobe (right precentral, left subcallosal Gyrus/Lentiform nucleus) [BA 46, 10], temporal lobe (left inferior temporal gyrus) [BA20], parietal lobe (right precuneus, left inferior parietal lobule), and posterior cingulate gyrus. Overall there were more regions of the brain activated during the deceptive process compared to the truth telling scenario. These experimental results concur with our hypothesis and suggest that there may be unique areas involved in the deception or truth telling that can be measured using fMRI. The brain regions that were shown to be active from our study are highlighted in bold lettering in the theoretical model shown in Figure 1. The polygraph results correlated well with the deceptive subjects. However, during truth telling in two subjects the polygraph result were inconclusive.

Discussion:

Identification of areas and patterns of brain activation associated with deception using non-invasive neuroimaging methods is in the early stages of development. Several groups have shown few areas of brain activated in association with deception, however have not shown areas that are activated during the process of truth telling, which may be less cognitively challenging than deception. If one assumes that one process is the antipode of the other, in other words lying and truth telling are complimentary processes there should be brain areas that might be overlapping in these two processes as well as areas unique to these individual processes. Hence in our study we used stimulus paradigms and conditions, which simulate these two processes to map out their individual areas of activation using BOLD fMRI.

The most challenging task in designing such a study is the selection of an appropriate task. Several groups that have studied the deception process to date have used tasks varying from card sorting⁽¹³⁾, guilty knowledge testing⁽¹³⁾, digit memory testing⁽¹²⁾ and other neuropsychological testing^(11,14&15) methods. One of the common problems associated with such tasks is the simulation of real life situations in laboratory settings. This imposes several constraints on arousal and emotional experience associated with deception. In this study, we used a starter gun with blank bullets as an exciting stimulus. This stimulus elicits sensory activation (visual, tactile, auditory, and olfactory) and has emotional content (fear, anxiety, and apprehension). We hypothesized that this would simulate the natural environment of committing a crime and would activate essential emotional components involved in the process of deception and truth telling. We also utilized the knowledge and techniques that have been used in polygraph studies, the

current gold standard method and implemented these procedures and techniques to collect the fMRI data. There are a number of paradigms that have been used in polygraph testing to elucidate deception. They include the Comparison Question Techniques, the Positive Control Questioning Technique, and Peak of Tension Tests. This study used the Integrated Zone Comparison Technique for the polygraph procedure and implemented a modified version of the Positive Control Technique to examine the brain regions activated during deception and truth telling. The “Positive Control” concept in the detection of deception involves dichotomous answers to identical questions, one of which must be truthful and one of which must be a lie ^(31, 32). Adaptation of a modified version of this dichotomous answer to identical questions in two separate block experiments was implemented in this study. The use of the polygraph test in this study helped us to verify and validate whether the subjects participated in this study were lying or telling the truth. The results of the polygraph test showed good correlation to the actual event when the subjects were asked to lie, however, were not as conclusive for truthful subjects (See Table. 1).

It is likely that the subject cannot mask fMRI brain activation patterns. The brain areas active during deception will always be active when the subject lies. The same areas will always be inactive when the subject tells the truth. A subject can attempt to create a false negative (deceptive person determined erroneously to be truthful) outcome by attempting countermeasure techniques to irrelevant or comparison questions in the polygraph examination. The cognitive aspects of telling the lie are not measured by a polygraph since it only measures the anxiety expressed by the limbic system. It does not

measure the result of activity in the frontal lobe that is presumably working to inhibit the truth and construct a lie.

Fourteen areas of brain activation were seen active during the deceptive process across all the three different lie conditions. The lingual gyrus of the left hemisphere associated with differentiating language was seen active. The lingual, middle occipital, of the left hemisphere and fusiform gyri of the right hemisphere have been associated with silent reading of sentences; probably associated with the linguistic processing of the sentences as well as the mental sequencing associated with sentence structure and meaning. Sub-lobar Insula areas have been shown to be associated with feeling of disgust and nausea. Anterior Cingulate is involved in a number of processes, but attention and response inhibition are the probable cause of activation in this study. Inferior parietal lobe in the right hemisphere and inferior frontal gyri in the left hemisphere may be part of the so-called mirror neuron system involved in mentally representing one's own behaviors, as well as similar behaviors in others. Inferior parietal lobe in the right hemisphere is also involved in representations of the self-concept in the mind; so patients who have lesions to this area, especially in the right hemisphere experience misidentification syndromes where they no longer believe the left half of their body belongs to them (hemibody neglect syndrome). Medial frontal gyrus has been associated with social cognition, or thinking about other people's thought, social interactions, and the consequences of such actions. Caudate is part of the basal ganglia involved in motor controls. Hippocampus, which is primarily associated with memory and emotions, was seen active during the deceptive process. Precuneus is involved in autobiographical memory, expert memory for past behaviors the person has been

involved in, as well as making determinations about mental imagery – whether one’s mental imagery is correct/incorrect. Posterior cingulate is attributed to some emotional processing and similar functions as the precuneus. Posterior cingulate may also be associated with internal feelings of discomfort. During truth telling among the seven regions activated the only new activation that was seen in addition to some of the above mentioned activation areas was the inferior temporal lobe in the left hemisphere which has been associated with memory/storage of faces, also may be involved in spatial and temporal encoding of events in memory; i.e. when, where, and how events occurred.

A major limitation of this study was that one of the investigators had knowledge about all phases in the study, which was necessary to co-ordinate the group role assigned to each subject (GS or NGS), and thus establishes “ground zero” truth to measure the accuracy of the polygraph and fMRI procedures that were to follow. The other experimenters were blind to subject condition. Future studies should be completely blinded to all investigators to eliminate any bias as well as use a larger sample size and age and sex matched controls.

In summary, the results of this study show that there are unique areas of brain function that may be able to dissociate the processes of deception and truth telling. There were overlapping as well as unique areas involved underlying these two processes. In comparison of our results with the hypothetical model of deception shown in figure 1, there were many areas in the planning, inhibition, and emotion that may be involved in the process of deception. Our results show that deceptive process is associated with activations of the limbic system, parts of the frontal lobe that are probably involved in suppressing or inhibiting the truth, and parts of temporal lobe which might be involved in

memory encoding and retrieval. Furthermore there is presumably anxiety associated with deception, which is reflected in the activation of the limbic system. However, when a subject is telling the truth, there is minimal to far less anxiety and an alternative cognitive thought process does not have to be inhibited. This is seen by a smaller number of brain areas to be active in the frontal and limbic system during the truth telling process.

These results are preliminary and it is too early to predict whether fMRI will replace other methods of examining deception, either in conjunction with other techniques or as a stand-alone procedure. Future fMRI studies involving large sample size, and conventional reliability and validity methods, are required to establish the utility of the methods as a test of deception.

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Tables

Table 1. Polygraph results for individual subjects.

Subject (Condition)	PolyScore (Ref#28)	Objective Score Sys (Ref#29)	ASIT POLY SUITE (Ref#30)
1 (GS)	DI probability > .99	DI probability >.99	DI -39
2 (GS)	DI probability > .99	DI probability > .99	DI -40
3 (NGS)	NDI probability>.99	NDI probability>.99	NDI +26
4 (NGS)	INC probability DI .78	INC	INC +5
5 (NGS)	NDI probability>.99	NDI probability>.99	NDI +36
6 (NGS)	INC probability DI .94	INC	NDI+16
7 (Deleted)	No polygraph performed		
8 (GS)	DI probability > .99	DI probability.99	DI -24
9 (GS)	DI probability > .99	DI probability > .99	DI -58
10 (GS)	DI probability > .98	DI probability > .98	DI -23
11 (GS)	DI probability > .99	DI probability > .99	DI -32
12 (NGS)	NDI probability>.99	NDI probability>.99	NDI +54

DI = Deception indicated; NDI= No deception indicated; INC = Inconclusive; GS = Guilty subject; NGS = Not guilty subject.

Table 2. Accuracy of algorithms used to interpret the polygraph studies. This table shows overall accuracy of the three algorithms utilized for the interpretation of data collected on three polygraph charts. GS: Guilty subjects; NGS: Not guilty subjects.

	Polyscore	Objective Scoring System	ASIT POLY SUITE
GS	100%	100%	100%
NGS	60%	60%	80%
% Accuracy	80%	80%	90%

Table 3. Local maxima of BOLD changes in guilty subjects during Lie experiment in GS. (Control questions > Relevant questions, *Lie condition#1*). Cluster detection corrected $p < 0.001$ except where indicated. (spatial extent threshold > 10)

Region	Hemisphere	x	y	z	Z-score
Lingual gyrus (BA 18)	L	-17	-83	-6	4.56
Middle Occipital gyrus (BA19)	L	-35	-85	8	4.40
Sub-Lobar, Insula (BA 13)	R	39	-9	19	4.05
Fusiform gyrus (BA 37)	R	28	-47	-10	4.04
Sublobar, Insula, (BA 13)	L	-38	15	17	4.00
Precentral, (BA 4)	L	-52	-1	15	3.86
Precentral, (BA 43)	L	-52	-9	12	3.15
Anterior Cingulate (BA 32)	R	6	39	-5	3.62
Caudate body	L	-20	-18	23	3.99

Table 4. Local maxima of BOLD changes during in guilty subjects during truth experiment in GS. (Control questions < Relevant questions, *Lie condition#2*) Cluster detection corrected $p < 0.005$ except where indicated. (spatial extent threshold > 10)

Region	Hemisphere	x	y	z	Z-score
Inferior parietal lobule (BA 40)	R	36	-48	45	4.25
Inferior frontal gyrus (BA 9)	L	-56	15	25	4.06
Medial frontal gyrus (BA 9)	L	-4	54	38	3.92
Sub-lobar/Thalamus/Anterior Nucleus	R	6	-5	13	2.83
Lingual Gyrus (BA 18)	L	0	-88	-4	3.41
Caudate body	L	-6	4	9	3.34
Caudate Tail	L	-14	-20	20	3.14

Table 5. Local maxima of BOLD changes ((Control questions + relevant questions) > baseline, *Lie condition#3*) in non-guilty subjects during lie experiment in NGS. Cluster detection corrected $p < 0.005$ except where indicated. (spatial extent threshold > 10)

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

Table 6. Local maxima of BOLD changes in non-guilty subjects during truth experiment in NGS. ((Control questions + relevant questions) > baseline), *Truth condition*. Cluster detection corrected $p < 0.005$ except where indicated. (spatial extent threshold > 10)

Region	Hemisphere	x	y	z	Z-score
Subcallosal gyrus (BA 47)	L	-16	17	-9	4.11
Sub-lobar/Lentiform Nucleus	L	-22	19	-3	3.88
Precuneus (BA 7)	R	20	-50	54	3.74
Inferior temporal (BA 20)	L	-65	-22	-16	3.52
Parietal lobule (BA 40)	L	-48	-40	48	3.50
Cingulate gyrus	L	-4	-26	33	3.45
Precentral gyrus (BA 6)	R	42	-1	37	3.00

Figure Legends

Figure 1. Hypothetical model of deception. Highlighted are regions we found active during fMRI in our study.

Figure 2. fMRI Analysis strategy for Guilty Subjects (GS).

Figure 3. fMRI Analysis strategy for Non-Guilty Subjects (NGS).

Figure 4. Significant areas ($p < 0.001$, spatial extent threshold > 10 for lie condition #1 and $p < 0.005$, spatial extent threshold > 10 for lie conditions #2 and 3) of activation that are seen across all the three different lie conditions. (A) anterior cingulate, (B) left inferior frontal gyrus, (C) left precentral, (D) precuneus, (E) inferior parietal lobule, (F) sub-lobar insula/thalamus, (G) posterior cingulate (arrow), (H) left lingual gyrus (arrow), (I) right fusiform gyrus (arrow), (J) left medial frontal gyrus, (K) right hippocampus, (L) right middle temporal.

Figure 5. Significant areas ($p < 0.005$, spatial extent threshold > 10) of activation that are seen during the truth condition. (A) precentral gyrus, (B) subcallosal gyrus/lentiform nucleus, (C) inferior temporal, (D) precuneus, (E) posterior cingulate, (F), Parietal lobule.

Figures

Figure 1.

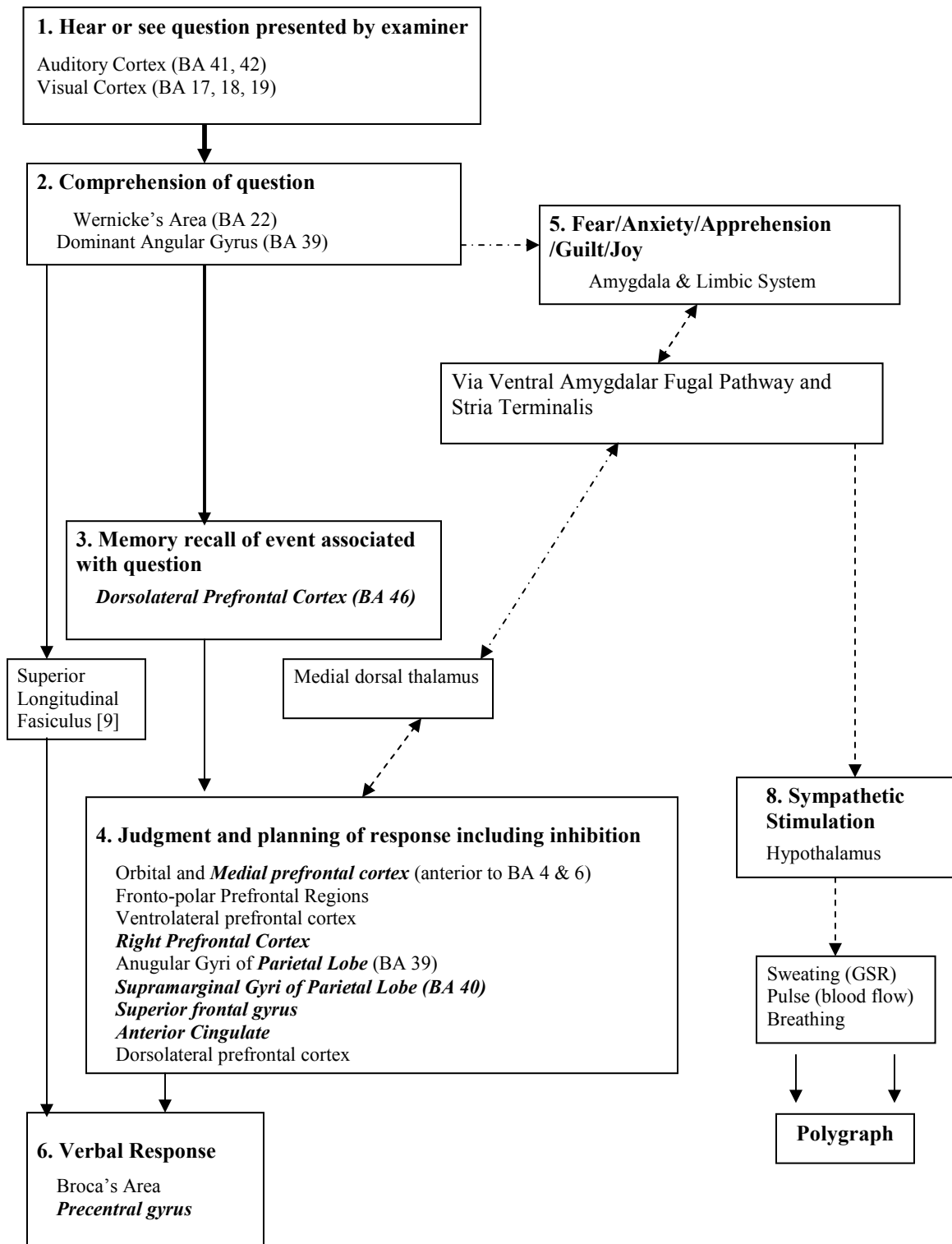


Figure 2.

Subjects Fired Gun

Subjects instructed to lie on the Relevant Questions (GS)

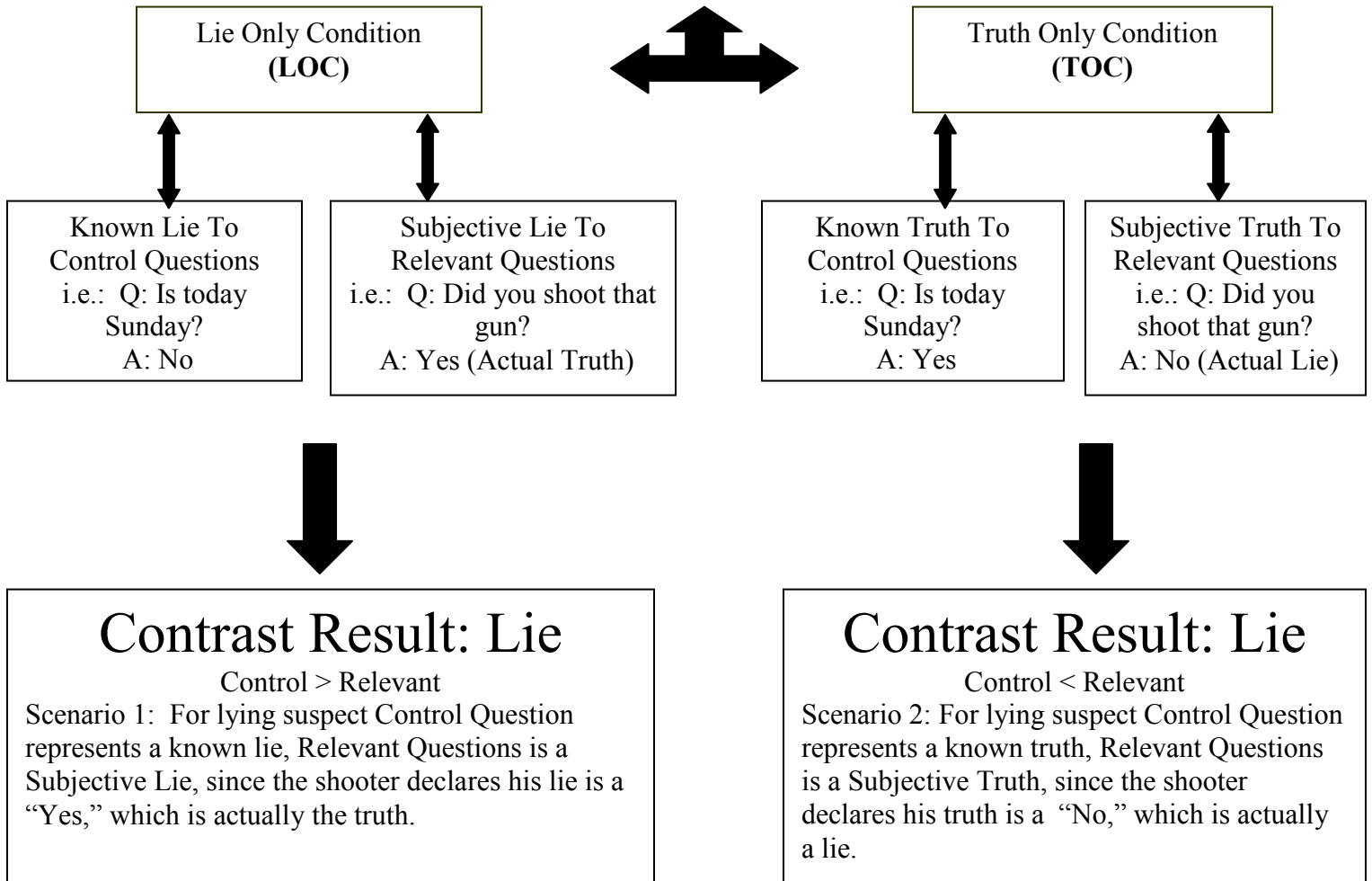


Figure 3.

Subjects Did Not Fire Gun

Subjects instructed to tell the truth on the Relevant Questions (NGS)

