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Can fMRI discriminate between deception and false memory? A meta-analytic comparison between deception and false memory studies

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ABSTRACT

Previous research has highlighted the potential of fMRI in discriminating between truth and falsehood. However, falsehoods may not necessarily represent a deliberate intention to deceive; they can be a result of false memory too. It is important to show that fMRI can discriminate between deception and false memory, before it can be applied in legal contexts for deception detection. To this end, we performed a meta-analytic comparison of brain activation between deception and false memory. Activation likelihood estimation meta-analyses were conducted separately on 49 deception (61 contrasts; N_{total} = 991) and 28 false memory (32 contrasts; N_{total} = 484) studies. The contrasts obtained from these meta-analyses were entered into subsequent conjunction and contrast analyses. Deception and false memory tasks activated several frontoparietal regions. Both tasks activated the left superior frontal gyrus. Deception, relative to false memory, was associated with increased activation in the right superior temporal gyrus, right insula, left inferior parietal lobule and right superior frontal gyrus. These results provide some evidence to suggest that fMRI can discriminate between deception and false memory.

1. Introduction

Deception is the deliberate act of providing misleading information to convince others to believe falsehood as truth. The study of deception detection has aroused considerable interest among researchers due to its implications in law enforcement and national security contexts (Haynes and Rees, 2006; Strömwall and Willén, 2011). With the advent of functional magnetic resonance imaging (fMRI), there have been several studies that have explored the possibility of using brain activation patterns to distinguish between falsehood and truth. Generally, in these studies the increased deception related activation in various brain regions are hypothesized to correspond to the increased cognitive effort required to engage in deception. Relatedly, deception can be a complex task that involves several cognitive mechanisms. To craft a lie, the deceiver needs to hold and manipulate the truth in their working memory (Mori et al., 2005). The deceiver also needs to assess if the lie is convincing. That is, it had to be coherent with other pieces of information and appear believable to the deceived. The cross-checking of the lie with other pieces of information would involve some reasoning processes and require more information to be held in the working memory (Ganis et al., 2003). The deceiver also needs to be in the shoes of the deceived to assess how convincing the lie would be; this would crucially involve theory of mind (Lisofsky et al., 2014). If the lie is premeditated long before its execution, the deceiver would need to retrieve it from their long term memory (Ganis et al., 2003). In executing the lie, the deceiver needs to hold the deception goal in his working memory, inhibit the 'truth' set of responses and switch to a different set of responses which are specific to the lying context (Priori et al., 2007). In general, the conception and execution of a lie would require high levels of executive control.

Several deception tasks were devised to contrast the brain activation patterns between truthful responses to false responses. Most of these

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involve deceptive recognition in which participants would require to falsely indicate one of the presented items as the truth. In such studies, various types of information were manipulated to generate false responses. These include information learnt during the experiment, such as stories or word lists (e.g., Abe et al. (2008)), or information not learnt during the experiment such as those relating to autobiographical memories (e.g., Nunez et al. (2005)) or daily activities (e.g., Spence et al., 2001). A few other deception tasks involve deceptive recall. Unlike deceptive recognition, participants were required to generate a lie spontaneously on the spot (e.g., Ganis et al. (2003)) instead of selecting one among multiple possible responses. Another group of deception fMRI paradigms involves decision making (Lisofsky et al., 2014). In these tasks, the subject would take the perspective of another person, read their intentions and make a conscious and morally reprehensible decision to deceive that person.

A great deal of research on the topic has emerged in the past two decades, culminating in two meta-analyses (Christ et al., 2009; Lisofsky et al., 2014). These meta-analytical findings revealed that deceptive responses were associated with increased brain activity in frontal regions (e.g., bilateral dorsolateral prefrontal cortex, bilateral ventrolateral prefrontal cortex, left middle frontal gyrus (MFG), bilateral anterior insula and right anterior cingulate cortex), parietal regions (e.g., bilateral inferior parietal lobule (IPL) and bilateral posterior parietal cortex (PPC)) and temporal regions (e.g., bilateral temporoparietal junction (TPJ) and bilateral temporal pole). Given that previous meta-analytical research have reported that executive control tasks (Niendam et al., 2012) and theory of mind tasks (Schurz et al., 2014) activated several frontoparietal regions and temporoparietal regions. The increased activation in these regions would be consistent with the high executive control and socio-cognitive demands of crafting a deceptive response.

These findings were however not good enough to warrant the use of fMRI for detecting deceptive responses in high stakes legal contexts. It is not enough to simply identify falsehoods. One needs to understand why these falsehoods were communicated. Falsehoods may not always be used deceptively; they are also likely to arise from false memories.

Indeed, our memory is far from infallible; recall and recognition errors can occur on a daily basis even among cognitively healthy populations (Carrigan and Barkus, 2016). False memories can be created intentionally (by others) or unintentionally in many different ways, such as via affective interferences (Kaplan et al., 2015), misleading suggestions (Bruck and Ceci, 1999), the misinformation effect (Ayers and Reder, 1998) and schemas (Webb et al., 2016). These false memories can be recalled vividly and confidently (Ceci and Loftus, 1994), making it difficult to differentiate between true and false memories behaviorally. A meta-analysis (Kurkela and Dennis, 2016) revealed that false memory retrievals were associated with increased activity in the IPL and several frontal regions such as the medial superior gyrus, bilateral inferior frontal gyrus (IFG), left precentral gyrus, and ventromedial prefrontal cortex. One could observe some overlap with the regions reported in deception meta-analyses. Regardless, the involvement of these regions was interpreted as the recruitment of top-down cognitive control resources to monitor memory judgments as they become less certain. Experimentally, false memories are typically elicited as false recognition. In these experiments, participants would first acquire some information (e.g., word lists, stories or visual stimuli) during a learning phase. Subsequently in the test phase, the participant would attempt to recognize this learnt information among other very similar distractors. As a result, it becomes easy to falsely recognize one of the distractors as the correct response.

Crucially, although both deceptive responses and false memories are incongruent with the truth, false memories carry no intention to deceive. This distinction is paramount in legal contexts. In the case of false memory, while the individual may satisfy 'actus reus' (i.e., the objectively incorrect information), he/she does not satisfy 'mens rea' (i.e., the ill-intention to deceive), consequently nullifying his/her criminal liability. The importance of this distinction can be vividly appreciated from the controversy surrounding false childhood sexual abuse allegations (Mikkelsen et al., 1992). These false allegations may have been deliberately fabricated to harm the accused (Ney, 2013) or the result of careless memory suggestions on the part of therapists (Pezdek and Banks, 1996). In such situations, both false-negative (attributing to false memories in the former) and false-positive (inferring malicious intent on the latter) judgments can lead to serious miscarriages of justice.

Given these serious implications, critics have advocated the need for fMRI paradigms to be able to discriminate between false memory and deception, before deception-related fMRI applications are ready for public use (Henry and Plemmons, 2012). To this end, there were only two fMRI studies that directly compared between the neural correlates of false memory and deception. In the first (Abe et al., 2008), participants were presented with semantically related word-lists during a study phase and instructed to either tell the truth or lie when indicating if the presented word was 'old' or 'new' in a subsequent test phase. The authors reported that correctly lying that an 'old' word was 'new', as compared to false recognition (truthfully indicated a 'new' word as 'old') and correct rejection (truthfully indicated a 'new' word as 'new') was associated with increased activation in the left MFG and left supramarginal frontal gyrus. In another study (Lee et al., 2009) with similar study and test phases, participants' responses were grouped as correct (truthful hits and correction rejections), incorrect (truthful misses and false rejections) and fake incorrect responses (correctly lying that an incorrect response is correct and vice versa). It was found that fake incorrect responses, relative to correct and incorrect responses were associated with increased activation in the left inferior frontal gyrus (IFG), right cingulate cortex, and left precuneus. Taken together, these findings suggest that lying recruits significant frontal-parietal resources to support response manipulation and this interpretation remains true even if lying was compared to false memories. Although these are certainly positive findings on the ability to differentiate between false memory and deception using fMRI paradigms, given the limited studies and sample sizes, further research is required to verify these findings.

Apart from carrying out experiments involving deception and false memory tasks simultaneously, another way of differentiating between the neural correlates of these tasks, albeit indirectly, is to carry out meta-analyses on fMRI studies of both paradigms separately and then compare the differences in their brain activation patterns. Although this approach does not allow us to directly examine the within-subject difference in neural correlates between deception and false memory, it would enable us to exploit the vast empirical evidence on both tasks that have accumulated over the past two decades to infer the differences in brain activation patterns.

In the current study, we first carried out separate activation likelihood estimation (ALE) meta-analyses on deceptive responses vs. truthful responses, and false memories vs. true memories. Following which, we compared the ALE maps derived from these meta-analyses, for regions of brain activations which were common to deception and false memory, as well as those unique to deception or false memory. Guided by previous findings (Abe et al., 2008; Lee et al., 2009), we hypothesized that deceptive responses (relative to truthful responses) and true memories (relative to false memories) are both associated with increased activation in various regions of the prefrontal cortex and parietal cortex, in their respective meta-analyses and a conjunction analysis of both. As for the primary research question on the difference in neural correlates between false memory and deceptive responses, we hypothesized that deceptive responses relative to false memories are associated with increased activation in various regions of the PFC and parietal cortex, alluding to the increased recruitment of cognitive resources for response manipulation on top of those required to monitor uncertain memory judgments.

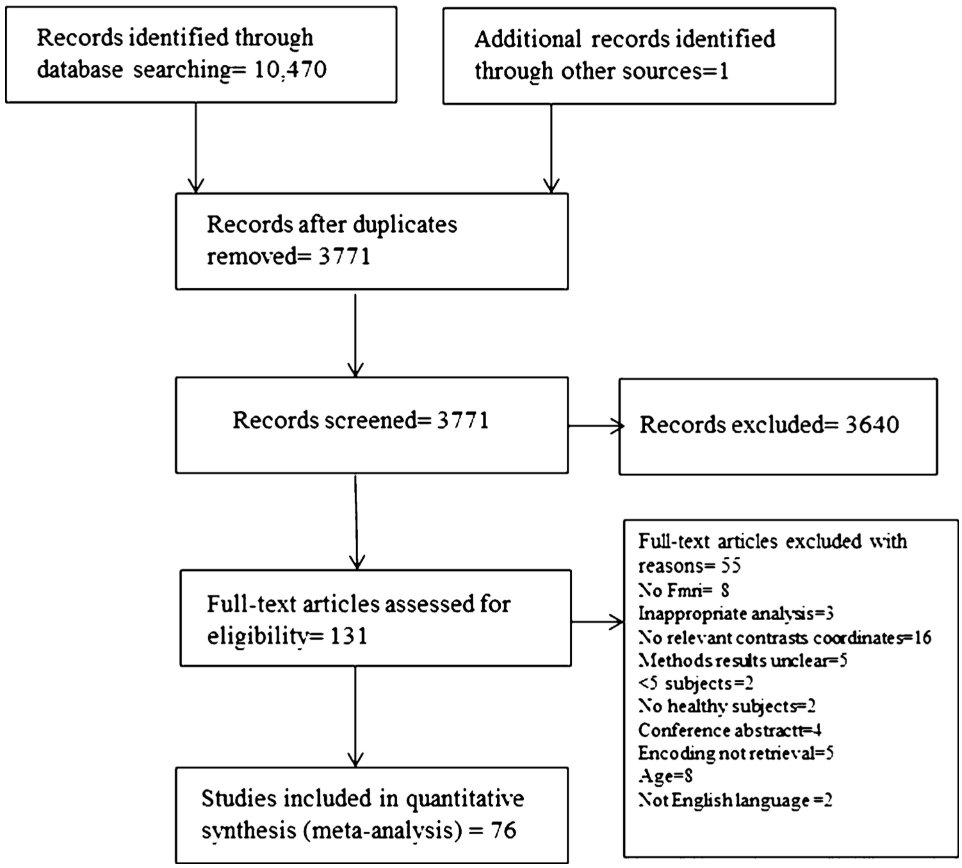

Fig. 1. Selection of studies.

2. Methods

2.1. Data sources and study selection

A search was carried out on PubMed and Web of Science for peer-reviewed articles published prior to 1st March 2018, according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Moher et al., 2009). The following keywords were used: [deception OR lying OR denial OR lie OR deceptive OR conceal OR malingering OR dishonest OR cheating OR false memory OR fake memory OR feigned memory] AND [fmri OR magnetic resonance imaging]. The reference list of relevant reviews (Langleben and Moriarty, 2013; Schauer, 2010; Spence, 2004; Wolpe et al., 2010) were also manually searched for potential studies. All potential studies were imported to EndNote X7. The titles and abstracts of potential studies were screened for relevance, and the inclusion of these studies was subsequently decided upon checking their full-texts. The detailed study selection process is shown in Fig. 1.

Articles were included in the current meta-analyses if they 1) carried out fMRI, 2) recruited healthy adult participants aged between 18–55, 3) reported relevant contrasts using conventional thresholds for whole brain analysis, 4) reported coordinates of significant clusters of activation in Montreal Neurological Institute (MNI) or Talairach space, 5) had a minimum of five participants in the final analyses and 6) had at least one contrast that sought to establish the neural correlates of deceptive vs. truthful responses or true vs. false recognition. Additionally, for studies on true vs. false recognition, only experiments reporting the neural correlates of retrieval-based processes (as opposed to encoding processes) were included. In cases where a study included multiple relevant and independent contrasts, all such contrasts were included. As for studies that contained multiple dependent contrasts, only the most relevant contrast was included. For instance in Ito et al. (2012), there were three relevant contrasts: a) Neutral lie > Neutral truth, b) Negative lie > Negative truth, and c) (Neutral lie + Negative lie) > (Neutral truth + Negative truth); among them c) was deemed to be the most relevant and thus included. Details of all included contrasts are presented in Tables 1 and 2 in the supplementary materials.

2.2. Data synthesis

Activation likelihood estimation (ALE; Eickhoff et al., 2009; Laird et al., 2005) meta-analyses were carried out using BrainMap GingerALE 2.3.6 (http://www.brainmap.org/ale/). Prior to carrying out the ALE meta-analyses, foci coordinates which were not reported in MNI space were transformed using Lancaster transformation (Lancaster et al., 2007). Four separate meta-analyses, relevant to our primary objectives, were carried out: 1) deceptive responses > truthful responses, 2) false recognition > true recognition, 3) conjunction analysis of (deceptive responses > truthful responses) and (false recognition > true recognition) and 4) contrast analysis of (deceptive responses > truthful responses) and (false recognition > true recognition). The meta-analyses of truthful responses > deceptive responses and true recognition > false recognition, which are of secondary importance to the current study, were also carried out and reported in the supplementary materials (See Table S1 in the supplementary materials).

For 1) and 2), these ALE meta-analyses identify regions consistently activated across experiments by computing anatomical maps for each experiment using the foci data. Specifically, it estimates activation likelihood by placing the foci as centers for 3-D Gaussian probability distributions and then calculating the union of these distributions to create modeled activation (MA) maps for each experiment. To determine the anatomical convergence across studies, the union of all MA maps was computed voxel by voxel. This approach considers both sample size and reproducibility by attributing greater weight to studies

Table 1
Studies included for the deception ALE meta-analysis.

No.	Reference	General	N	Foci	Contrast (as named in paper)	Deception Task Type	Stimuli Type
1	Abe et al. (2014)	T > LY	25	5	Honest > Dishonest	Decision making	Visually presented helpful/ harmful/ control stories
2	Abe et al. (2008)	LY > T	20	20	(Lying to truth- True recognition) + (Lying to New targets-Correct rejection)	Recognition	Auditory (encoding)/ visual words (retrieval)
3	Baumgartner et al. (2009)	LY > T	26	1	Dishonest > Honest	Computerized game/ Trust/Promise	N/A
4	Bhatt et al. (2009)	LY > T	18	9	Lie –truth (unfamiliar faces)	Recognition	Grayscale photos of familiar /unfamiliar faces
				4	Lie-truth (familiar faces)		
5	Browndyke et al. (2008)	LY > T	7	7	Malingered target miss > Normal target hits	Recognition/feigned memory impairment	Black and white line drawings of familiar/unfamiliar objects
				5	Malingered recognition false alarm errors > Normal recognition correct rejections		
		T > LY		4	Normal target hits > Malingered target miss		
				5	Normal recognition correct rejections > Malingered recognition false alarm errors		
6	Cui et al. (2014)	LY > T	16	4	Probes > Irrelevants	Mock murder/ Guilty Knowledge Test (modified)	Visually presented relevant/irrelevant words relating to crime
7	Ding et al. (2012)	LY > T	12	9	Identify faking > control condition	Recognition/ identity concealment	Visually presented Chinese names
				7	Identity concealment > control condition		
8	Gamer et al. (2007)	LY > T	14	7	Probes > Irrelevants	Guilty Knowledge Test	Playing cards/bank notes
9	Gamer et al. (2009)	LY > T	23	10	Probes > Irrelevants	Guilty Knowledge Test (modified)	Playing cards/bank notes
10	Ganis et al. (2003)	LY > T	10	11	Spontaneous-Isolated lies > Truth	Decision making/Recognition	Visually presented Autobiographical /memorized alternative scenarios
				7	Memorized-Scenario lies > Truth		
11	Ganis et al. (2009)	LY > T	14	19	Self-related deception- Honest responses	Recognition	Visually presented
				10	Other related deception-honest responses		True/false self- and other- related statements
12	Ganis et al. (2011)	LY > T	12	14	Probe > Irrelevant dates	Recognition/concealed information paradigm	Irrelevant and self-relevant dates (written in white against a black background)
13	Greene and Paxton, (2009)	LY > T	35	2	Opportunity Wins > No- Opportunity Wins	Computerized game/ moral judgement	Coin-flips
14	Ito et al. (2012)	LY > T	16	6	Lie > True	Recognition	Colored photos of living and nonliving things
15	Ito et al. (2011)	LY > T	25	9	Lie > True	Recognition	Colored negative and neutral pictures with scenery and human figures
16	Kireev et al. (2013)	LY > T	24	21	Deception Claim > Honest Claim	Computerized game/ Decision making	Upward-downward arrows
17	Kosheleva et al. (2016)	LY > T	22	3	Feigning > Not-feigning administrations	Recognition/ Feigned memory impairment	Target/New pictures
18	Kozel et al. (2009)	LY > T	14	30	Lie > True (Mock crime group)	Mock-crime	Questions (neutral, who picked up the envelop and committed the sabotage)
			21	15	Lie > true (No crime group)		
19	Kozel et al. (2005)	LY > T	31	14	Lie > True	Mock-crime	Questions (stolen items, control, neutral)
20	Kozel et al. (2004a)	LY > T	10	11	Lie > True	Recognition	Pictures of objects seen in the room previously
21	Kozel et al. (2004b)	LY > T	8	10	Lie > True	Recognition	Pictures of objects seen in the room previously
22	Kozel et al. (2009)	LY > T	29	28	Lie > True	Mock-crime	Questions (stolen items, control, neutral)
23	Langleben et al. (2005)	LY > T	26	4	Lie > True	Guilty Knowledge Test (modified)/ Card identity concealment	Photos of playing cards
		T > LY		39	True > Lie		
24	Langleben et al. (2002)	LY > T	18	6	Lie > True	Guilty Knowledge Test/ card identity concealment	Photos of playing cards
25	Lee et al. (2009)	LY > T	7	8	Intentional faked response > Truthful accurate response	Recognition/Feigned memory impairment	Visually presented Old/New words
		T > LY		1	Truthful accurate response > Intentional faked response		
26	Lee et al. (2002)	LY > T	5	26	Lie > Truth (Digit)	Recognition/Feigned memory impairment	Visually presented list of 3 digital numbers and autobiographical facts
				22	Lie > Truth (Autobiographic)		
27	Lee et al. (2010)	LY > T	13	11	Lie > True	Valence lying	Positive and negative emotion-eliciting pictures
		T > LY		6	True > Lie		
28	Lee et al. (2013)	LY > T	13	2	Main effect of cue (Lie > Truth)	Recognition	Grayscale photos of familiar and unfamiliar faces
29	Marchewka et al. (2012)	LY > T	29	13	Lie > Truth	Self-relevant	Visually presented personal and general questions
30	McPherson et al. (2012)	LY > T	13	8	Feigned > Correct (Tone listening task)	(Instructed lying without recognition) /Feigned hearing loss	Auditory words and tones
			14	6	Feigned > Correct (Word listening task)		
31	Mohamed et al. (2006)	LY > T	11	16	Lie > True	Mock shooting	Visually presented control and relevant questions
32	Nose et al. (2009)	LY > T	19	5	Critical > Standard	Modified oddball task	Six playing cards
33	Nunez et al. (2005)	LY > T	20			Self-relevant	

(*continued on next page*)

Table 1 (*continued*)

No.	Reference	General	*N*	Foci	Contrast (as named in paper)	Deception Task Type	Stimuli Type
				8	False > True (Non-autobiographical)		Auditory autobiographical and non-autobiographical yes/no questions
				7	False > True (Autobiographical)		
34	Ofen et al. (2016)	LY > T	17	13	Lie > True (execution)	Self-relevant	Visually presented episodic, belief, and opinion yes/no questions
				13	Lie > True (preparation)		
35	Phan et al. (2005)	LY > T	14	11	Lie > True	Modified card version of the Guilty Knowledge TestT	Playing cards
				8	Lie > Control		
36	Shao and Lee (2017)	LY > T	48	5	Dishonest > Truth	Modified directed lie paradigm	Photos of familiar and unfamiliar faces
37	Sip et al. (2013)	LY > T	17	3	False > True	Mock-theft	Auditory questions and visually presented objects
38	Sip et al. (2010)	LY > T	14	5	Claim falsely > control	Computerized version of Meyer	Dice
				1	Claim falsely > claim truthfully		
39	Spence et al. (2001)	LY > T	10	13	Lying response > truthful response	Self-relevant	Auditorily and visually presented daily life yes/no questions (YES and NO both in green or red)
40	Spence et al. (2008)	LY > T	17	7	Lie > True	Decision making/self-relevant	Auditory instructions and memory questions
41	Suchotzki et al. (2015)	LY > T	32	4	Deny > Admit	Mock-crime/CIT	Pictures of probe, target and irrelevant items
42	Sun et al. (2015a)	LY > T	20	5	Positive effect (Dishonest response > honest response)	Economic game/moral judgment	N/A
		T > LY		2	Negative effect (Honest response > dishonest response)		
43	Sun et al. (2015b)	LY > T	14	5	Lie > True	Self-relevant	Grayscale photos of participants' acquaintances and strangers
44	Sun et al. (2016)	LY > T	25	6	Dishonest > Honest	Economic game/moral judgment	N/A
45	Vartanian et al. (2012)	LY > T	15	7	Lie > True	Match/Mismatch task	Visually presented strings of identical digits (green and red used for T and L)
46	Vartanian et al. (2013)	LY > T	15	5	Lie > True	Match/Mismatch task	Visually presented Four- or six-digit string + 1 digit
47	Volz et al. (2015)	LY > T	29	8	Lie > True	Sender-Receiver game/moral judgment	N/A
48	Yin et al. (2017)	LY > T	42	2	Lie > True	Sender-receiver game/moral judgment	N/A
		T > LY		6	Lie < True		
49	Yin et al. (2016)	LY > T	42	11	Instructed lie (incorrect) > Instructed truth (incorrect)	Sic bo gambling game/decision making and instructed	Dice
		T > LY		16	Instructed lie (incorrect) > Instructed truth (correct)		
				1	Instructed lie (incorrect) < instructed truth (incorrect)		
				4	Instructed lie (incorrect) < instructed truth (correct)		

Note: LY, lying; T, truth.

Table 2
Studies included for the false memory ALE meta-analysis.

No.	Reference	General	*N*	Foci	Contrast (as named in paper)	False memory Task Type	Stimuli Type
1	Abe et al. (2013)	TR > FR	29	6	True recognition > false recognition	Remember-know-new (Perceptual related)	Color photographs of "living" and "non-living" objects
2	Abe et al. (2008)	TR > FR FR > TR	20	6 10	True recognition > False recognition False recognition > Correct recognition	Old/new (Semantically related)	Auditory (encoding)/ visual words (retrieval)
3	Atkins and Reuter-Lorenz, (2011)	FR > TR TR > FR	19	9 6 4 5	Related lure false alarms > Unrelated lure correct rejection Positive hit > Unrelated lure correct Recognition Positive hit > Lure false alarm Lure correct recognition > Lure false alarm	Yes/No (Deese/Roediger–McDermott (Semantically related)	Visually presented words
4	Cabeza et al. (2001)	FR > TR TR > FR	12	3 2	False-True True-False	Old/new (Semantically related)	Auditory presented words (via videotape)
5	Carpenter et al. (2016)	TR > FR	38	2	True memory > False memory	Multiple choice questions (Associative memory)	Slideshows of victim or perpetrator as in-group/out-group member
6	Dennis et al. (2012)	FR > TR TR > FR	17	14 17	Remember false alarms > Know false alarms Remember Hits > Know Hits	Remember-know-new (Perceptually related)	Visually presented colour pictures of objects
7	Dennis et al. (2014)	FR > TR TR > FR	18	12 10 28	False alarms > Correct rejection False alarm > Hit Hit > False alarm	Remember-know-new (Associative memory)	Visually presented colour photographs of faces and scenes
8	Garoff-Eaton et al. (2007)	FR > TR	14	18 1	Conceptual false > conceptual true Perceptual false > perceptual true	Remember-know-new (Semantic/ perceptual related)	Visually presented words
9	Garoff-Eaton et al. (2005)	FR > TR	11	4	Unrelated false recognition > (true recognition + related 10false recognition)	Same-similar-new (Perceptually related)	Visually presented 2D shapes
10	Giovanello et al. (2009)	TR > FR	15	12	Hits > Feature false alarm (younger adults)	Old/new (Associative memory)	Visually presented compound words
11	Gutchess and Schacter, (2012)	FR > TR TR > FR	9	12 10	False alarm > Hits Hits > False alarm	Yes/No (Semantically related)	Visually presented pictures of single objects
12	Heun et al. (2000)	FR > TR	14	3	False alarm > Hits	Target/distractor (Semantic related)	Visually presented list of words
13	Heun et al. (2004)	FR > TR TR > FR	15	1 2 1	False alarm > Correct Rejection False alarm > Hits Hits > False alarm	Target/distractor (Semantic related)	Visually presented list of words
14	Hofer et al. (2007)	FR > TR	21	3 5	False alarm > Rest Missed alarms > Rest	Previously seen/new (Perceptual related)	Visually presented grayscale photographs of unfamiliar faces
15	Iidaka et al. (2012)	FR > TR	19	2 164	False alarm lure > Correct rejection lure False alarm new > Correct rejection new	Surely old/maybe old/surely new/ maybe new (Perceptually related)	Visually presented color pictures of morphed faces
16	Iidaka et al. (2014)	FR > TR	19	3	False alarm Lure > Hit Old	Surely old/maybe old/surely new/ maybe new Perceptually related	Visually presented color pictures of morphed faces
17	Kensinger and Schacter, (2006)	FR > TR TR > FR	16	9 12 8 5	Word-picture misattributions ('no picture') > word-picture correct attributions ('picture') Word-only misattributions ('picture') > word-only correct attributions ('no picture') Word-picture correct attributions ('picture') > word-picture misattributions ('no picture') Word-only correct attributions ('no picture') > word-only misattributions ('picture')	Yes (word & photo)/ No (new words/words with no corresponding photo) (Reality monitoring)	Visually presented pairs of words and photos of objects or words alone
18	Kensinger and Schacter, (2007)	FR > TR TR > FR	19	1 14 30 32	False recognition > successful recognition (negative items) False recognition > successful recognition (neutral items) Successful recognition > false recognition (negative items) Successful recognition > false recognition (neutral items)	New/Similar/Same (Perceptual related)	Colored, negative/neutral photos of objects
19	Kim and Cabeza, (2007)	FR > TR TR > FR	11	6 3	False recognition > True recognition True recognition > False recognition	Sure old/Unsure old/Unsure new/ Sure new (Semantically related)	Visually presented word lists selected from category norms
20	Kuehnel et al. (2008)	FR > TR	12	6	Similars False alarm > Baseline	Known/Unknown (Film paradigm)	Visually presented mute film and sets of pictures
21	Marchewka et al. (2008)	FR > TR	16	6 3	False Recognition > Correct rejection False Recognition > Correct rejection	Old/New Associative memory/ (Divided-visual field paradigm)	Emotionally neutral and negative pictures
22	Moritz et al. (2006)	FR > TR TR > FR	17	1 4	False memory > Hits Hits > False memory	Confident/Rather confident/ Guessing old or new (Semantically related)	Visually presented word lists
23	Paz-Alonso et al. (2008)	FR > TR TR > FR	16	11 13	Critical lure false alarms > Unrelated Lure correct rejection's Hits > Misses	Yes/No (Adapted Deese/ Roediger–McDermott (DRM false memory effect task) (Semantically related)	Auditorily presented words (encoding and retrieval)
24	Slotnick and Schacter, (2004)	FR > TR TR > FR	12	11 18	False recognition > True recognition True recognition > False recognition	Old-left/Old-right/New (Perceptual related)	Visually presented shapes
25	Turney and Dennis, (2017)	FR > TR TR > FR	25	2 3	False > true True > false	Old/New (Perceptually related)	Pictures of adult faces

(*continued on next page*)

Table 2 (*continued*)

No.	Reference	General	*N*	Foci	Contrast (as named in paper)	False memory Task Type	Stimuli Type
26	Urgolites et al. (2015)	TR > FR	18	4	True > False	Definitely/Probably/Maybe new or old (Perceptual related)	Color photos of indoor/outdoor scenes
27	Von Zerssen et al. (2001)	FR > TR	10	10	(False alarm > Rest) > (Correct rejection > Rest)	Old/New (Semantically related)	Auditorily and visually presented categories of words (encoding)/ Visually presented (retrieval)
28	Webb et al. (2016)	FR > TR TR > FR	22	2 6	False > True (recollection) True > False (recollection	Remember-Know-New (Perceptually related)	Visually presented colored images of schematic scenes

Note: FR, false recognition, TR, true recognition.

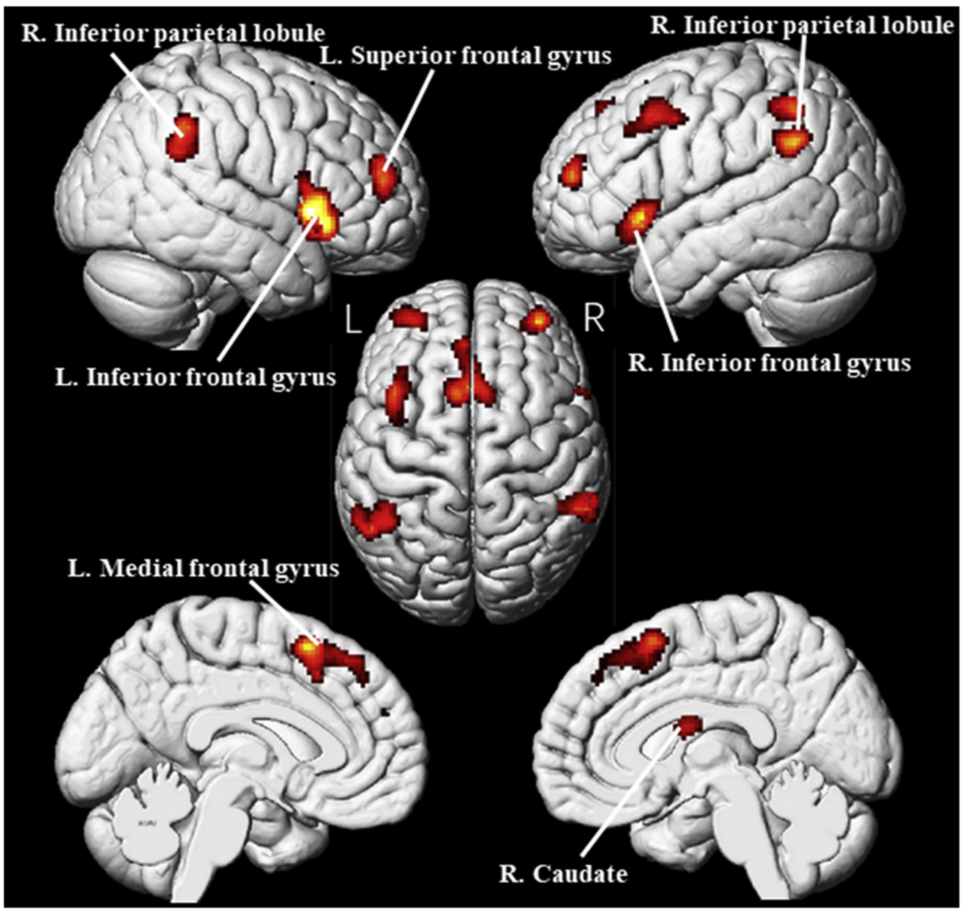

Fig. 2. Significant clusters of activation associated with deceptive responses > truthful responses.

with larger sample sizes and foci that converge across experiments. The resulting ALE image was thresholded using uncorrected $p < 0.001$ and a cluster-level inference threshold of $p < 0.05$ against a null-distribution generated by 5000 random permutation tests. The conjunction analysis of 3) identifies voxels in which significant effects were present in the ALE contrasts of deceptive responses > truthful responses and false recognition > true recognition. To compute the conjunction between these contrasts, we applied the conservative minimum statistic, which is equivalent to identifying the intersection between the two corrected results. Finally, for the contrast analysis of 4), we examined the distinct brain activations between deceptive responses > truthful responses and false recognition > true recognition, we computed the voxel-wise difference, in both directions, between both ALE contrasts. These voxel-wise differences were then subjected to a label-exchange permutation test (5000 times) and thresholded using a posterior probability of $p < 0.05$(Eickhoff et al., 2012). Surviving voxels represented the significant effect of the ALE analysis for the minuend.

2.3. Sensitivity analyses

Studies have indicated that the neural correlates of deception depend on the task and the stimuli (Christ et al., 2009; Lisofsky et al., 2014). To this end, we carry out sensitivity analyses on the different task types and stimuli modality. For the former, we identified 21 contrasts (212 foci) from deceptive recognition tasks, and seven contrasts (70 foci) from deceptive decision making tasks. As for the latter, we divided the tasks between the modalities of visual (37 contrasts; 400 foci) and auditory presentation (10 contrasts; 78 foci). For these two comparisons, we ran contrast analyses in a similar manner as described in the previous section.

Given the unbalanced number of contrasts for deception (61 contrasts) and false memory (32 contrasts) included in the meta-analysis, there is a possibility that it would a lot easier to obtain consistent areas of activation in the former than the latter. To assess such a possibility we randomly selected 32 deceptive responses > truthful responses contrasts to match the 32 contrasts for false memory > true memory.

We ran an ALE meta-analysis for the former. Then, similar to the main analyses, using the ALE contrasts from the meta-analyses of the 32 deceptive responses > truthful responses contrasts and 32 false memory > true memory contrasts, we examined the distinct and common brain activations between deceptive responses > truthful responses and false recognition > true recognition via contrast and conjunction analyses.

3. Results

3.1. Deceptive responses > truthful responses meta-analysis

We included 49 studies to examine the brain activation associated with deceptive responses > truthful responses. These studies (see Table 1 for details) consisting of 61 contrasts and 583 foci, had a combined sample of 991 participants. This meta-analysis revealed ten significant clusters primarily in the bilateral frontoparietal regions such as the IFG, superior frontal gyrus (SFG), MFG, insula, supramarginal gyrus, IPL and caudate. The details of these clusters are presented in Table 2 and Fig. 2.

3.2. False recognition > true recognition meta-analysis

We included 28 studies to examine the brain activation associated with false recognition > true recognition. These studies (see Table 3 for details) included a total of 32 contrasts and 210 foci, and had a combined sample of 484 participants. Four significant clusters were identified in this meta-analysis. These included activations in the left SFG, right MFG, left cingulate gyrus, left precuneus and left IPL (Table 4 and Fig. 3).

3.3. Common and distinct neural correlates of deceptive responses > truthful responses and false recognition > true recognition

Next, to identify clusters of activation which were common to deception and false memory, we carried out a conjunction analysis on the contrasts of deceptive responses > truthful responses and false recognition > true recognition as obtained in the previous two analyses. The results of this analysis revealed a significant cluster in the left SFG, which had commonly emerged in the deceptive responses > truthful responses and false recognition > true recognition contrasts (see Fig. 4 and Table 5).

To identify the clusters of activation which were unique to deception or false memory, a contrast analysis was carried out between the previously obtained contrasts of deceptive responses > truthful responses and false recognition > true recognition. This analysis revealed significant clusters in the right SFG, left IPL, right superior temporal gyrus (STG) and right insula for the contrast of (deceptive responses > truthful responses) > (false recognition > true recognition), as shown in Table 5 and Fig. 5; there were no significant clusters in the reverse contrast (i.e., (deceptive responses > truthful responses) < (false recognition > true recognition)).

3.4. Sensitivity analyses

The contrast analyses of deceptive decision making, deceptive recognition, visual and auditory presentation resulted in significant clusters of activation in all but the last contrast. These results are reported in table S4 and S5 in Supplementary. Importantly, the subsequent contrast analyses of deceptive decision making vs. deceptive recognition and visual vs. auditory presentation did not reveal any significant activation in any direction.

Next, the results of the contrast analysis involving 32 deceptive responses > truthful contrasts to match the 32 contrasts for false memory > true memory are largely similar to the original analyses. We found significant clusters of activation in the right SFG, left IPL, and right insula for the contrast of (deceptive responses > truthful responses) > (false recognition > true recognition). There was no significant clusters in the reverse contrast (i.e., (deceptive responses > truthful responses) < (false recognition > true recognition)) (See Table S6 in Supplementary).

Similar to the main analyses, we repeated the contrast and conjunction analyses to determine the common and unique neural correlates of deception and false memory within the context of this matched

Table 3
Results of deceptive responses > truthful responses meta-analysis

Cluster	K	Hemisphere	Region	BA	MNI coordinates			ALE (10^{-2})
					X	Y	Z	
1	922	R	Inferior Frontal Gyrus	47	46	24	−8	4.1
		R	Insula	13	46	20	−2	4
2	739	L	Superior Frontal Gyrus	6	−8	14	58	3.8
		R	Superior Frontal Gyrus	6	6	14	60	2.9
		L	Superior Frontal Gyrus	6	−2	18	50	2.8
		L	Superior Frontal Gyrus	8	−6	38	50	2.4
		L	Cingulate Gyrus	32	−6	20	42	1.9
		L	Superior Frontal Gyrus	8	−4	42	42	1.9
		L	Medial Frontal Gyrus	32	−12	20	42	1.7
3	574	L	Inferior Frontal Gyrus	47	−48	20	−2	2.8
		L	Insula	13	−36	22	−4	2.7
		L	Insula	13	−32	32	6	2.2
4	456	R	Inferior Parietal Lobule	40	54	−44	42	2.6
		R	Supramarginal Gyrus	40	58	−48	30	2.4
		R	Supramarginal Gyrus	40	42	−44	36	2.3
5	362	L	Middle Frontal Gyrus	6	−40	14	46	2.9
		L	Middle Frontal Gyrus	8	−36	26	40	1.8
6	298	R	Middle Frontal Gyrus	10	36	52	12	3
		R	Superior Frontal Gyrus	10	32	52	18	2.8
7	297	L	Superior Temporal Gyrus	39	−54	−56	34	3.6
8	256	L	Inferior Parietal Lobule	40	−46	−54	48	2.7
9	212	L	Superior Frontal Gyrus	10	−28	52	20	2.7
		L	Superior Frontal Gyrus	10	−36	54	16	2.5
10	105	R	Caudate		16	−2	18	2.6

Note. voxel size 2 × 2 × 2 mm^3.L = Left hemisphere; R = Right hemisphere; BA = Brodmann area.
K = number of voxels.

Table 4
Results of the false recognition > true recognition meta-analysis

Cluster	K	Hemisphere	Region	BA	MNI coordinates			ALE (10^{-2})
					X	Y	Z	
1	388	L	Superior Frontal Gyrus	8	−6	22	48	1.9
		L	Medial Frontal Gyrus	6	−6	38	32	1.8
		L	Medial Frontal Gyrus	8	−4	34	38	1.6
		L	Cingulate Gyrus	32	−8	30	36	1.5
2	122	L	Precuneus	19	−32	−66	48	1.6
3	121	L	Inferior Parietal Lobule	40	−32	−36	46	1.5
		L	Inferior Parietal Lobule	40	−32	−28	40	1.5
4	108	R	Medial Frontal Gyrus	11	4	34	−22	2
		R	Medial Frontal Gyrus	11	−6	32	−18	1.3

Note. voxel size 2 × 2 × 2 mm^3.L = Left hemisphere; R = Right hemisphere; BA = Brodmann area.
K = number of voxels.

analysis. The results were largely similar to the original results. A significant cluster in the left SFG had commonly emerged in the deceptive responses > truthful responses and false recognition > true recognition contrasts. As for the contrast analyses, significant clusters in the right SFG, left IPL, and right insula emerged in the contrast of (deceptive responses > truthful responses) > (false recognition > true recognition), but there were no significant clusters in the reverse contrast (i.e., (deceptive responses > truthful responses) < (false recognition > true recognition)) (See Table S7 in Supplementary). Taken together, these findings suggest that it is unlikely that the task type, stimuli modality or unbalanced number of deception and false memory contrasts would have a significant influence on the results.**Discussion**

Pooling together the results of 76 fMRI studies on deception and false memory, we sought to determine if fMRI data can distinguish between deception and false memory. This research goal was accomplished in a few steps. First, we carried out ALE meta-analyses on deception and false memory studies separately to obtain the ALE contrasts needed for subsequent analyses. These meta-analyses replicated previous meta-analyses in showing that both deception and false memory were largely associated with increased activation in the frontoparietal regions (Christ et al., 2009; Kurkela and Dennis, 2016). Then, using the contrasts obtained from these analyses, we put both sets of studies together to analyze the common and distinct clusters of activation. We found that both types of task paradigms had commonly activated a cluster in the left SFG. Furthermore, deception relative to false memory, was associated with increased activation in the right STG, right insula, bilateral IPL and right SFG. These results provide some evidence to suggest that fMRI can discriminate between deception and false

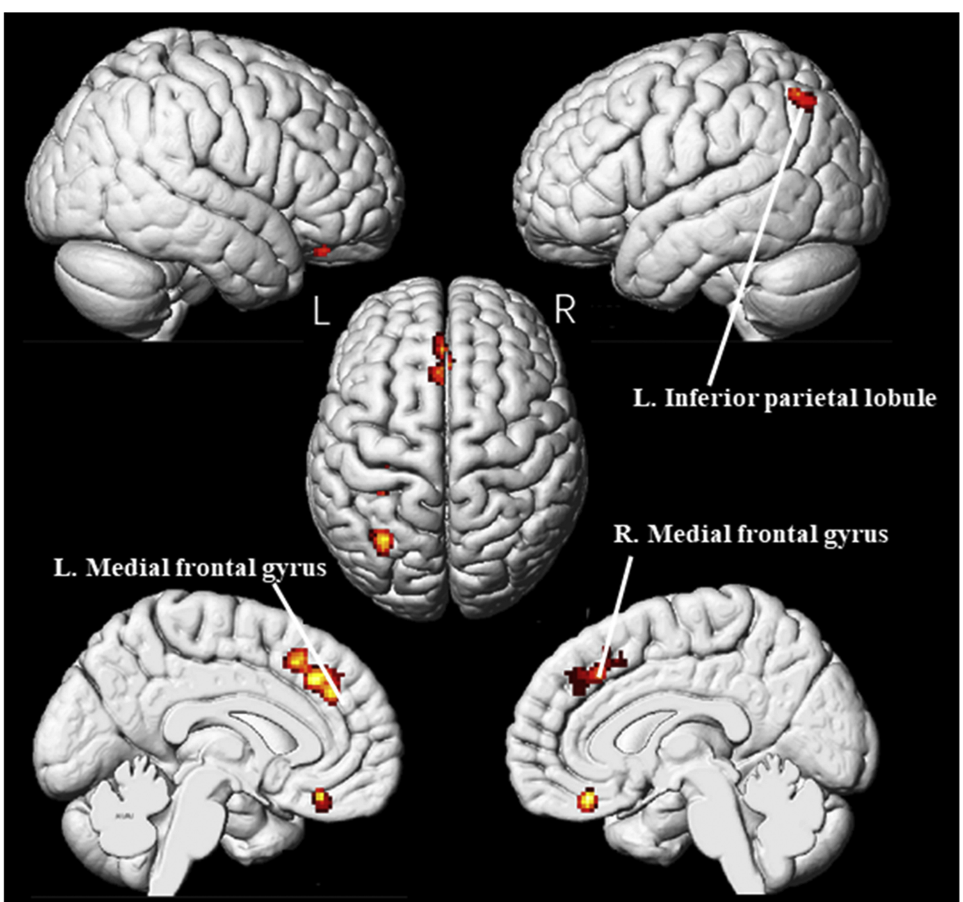

Fig. 3. Significant clusters of activation associated with false recognition > true recognition.

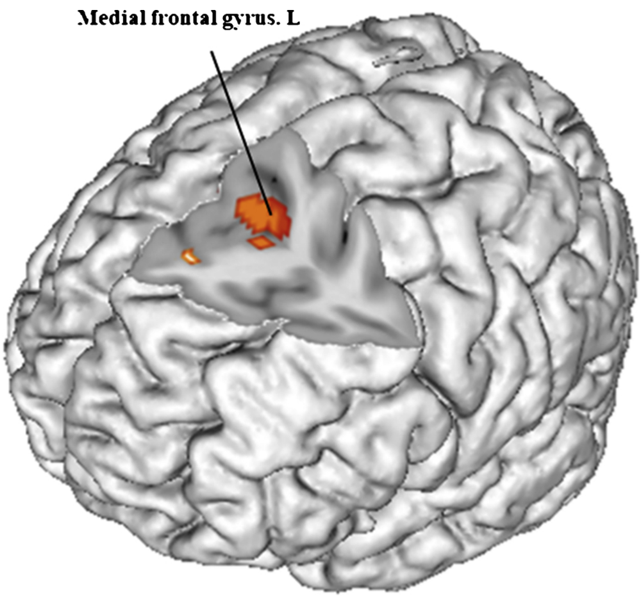

Fig. 4. Common neural correlates of deceptive responses > truthful responses and false recognition > true recognition.

memory.

As our contrast analyses have revealed, deception relative to false memory significantly activates several frontoparietal regions. This meta-analytic result is also generally consistent with within-study investigation of deception and false memory (Abe et al., 2008; Lee et al., 2009). These differences in activation may be explained by the differences in cognitive processes involved in both tasks. In most fMRI cue-deception paradigms, increased cognitive effort was required for the participants to inhibit the dominant 'truth' set of responses and switch to the 'false' set of responses as the cue changes from truth to lying, (Christ et al., 2009). Such increased inhibition and set-switching demands are perhaps absent in retrieving false memories. Consistent with this interpretation, the right SFG which was activated in the (deceptive responses > truthful responses) > (false recognition > true recognition) contrast, have been reported to be involved in inhibition (Hu et al., 2016) and task switching (Cutini et al., 2008). Furthermore, socio-cognitive processes are also engaged to craft deceptive responses (Lisofsky et al., 2014)— one has to be able to imagine others believing their false responses as truthful. It is thus not surprising that temporoparietal regions, previously found to be associated with theory of mind tasks, such as the IPL and STG (Schurz et al., 2017), were activated in deception responses, relative to false memory. This does not mean that these regions are not be involved in false memory retrievals, but that deception tasks may activate these areas more so than false memory retrievals. Relatedly, a more anterior and medial region of the left IPL was activated in the false recognition > true recognition contrast. Such activation was unlikely to be related to theory of mind processing; instead this IPL activity may occur within context of the parietal memory network, which relates to the familiarity of the recalled memories (McDermott et al., 2017). Relatedly, the conjunction analysis revealed that the brain activation patterns of both tasks only overlapped to a minor extent— only the left SFG was commonly activated. Given that previous research has associated the SFG with working memory-related processes (Boisgueheneuc et al., 2006), this common activation may allude to the common working memory demands of both tasks —the need to hold certain pieces of information online while manipulating such information. In deception tasks, this would mean keeping the truth in mind while crafting a false response; in false memory retrieval tasks, this would mean keeping the retrieved memory in mind while evaluating its accuracy. Nevertheless, it should be noted that SFG activity has also been associated with several other cognitive processes apart from working memory, such as response inhibition (Zhang et al., 2017), task switching (Cutini et al., 2008), visual attention (Salo et al., 2017) and theory of mind (Mossad et al., 2016). Hence, it is also likely that this common activation derived from the two tasks may relate to very different cognitive processes. For instance, the SFG activation in the deception task could be associated with inhibiting the truth set of responses, whereas in false memory tasks, such activation could be associated with holding the retrieved memory in the working memory.

Another interesting and important takeaway from our results would be the fact that significant clusters of activation had emerged in the (deceptive responses > truthful responses) > (false recognition > true recognition) contrast, but not the reverse contrast. This may suggest quantitative differences, in addition to qualitative differences in the cognitive processes employed in both tasks. It is possible that the deception tasks were much more cognitively demanding than those of false memory retrievals, hence the brain activation patterns of deception may have possibly overshadowed those of false memory retrievals but not vice versa (i.e., significant activation were observed only in one contrast but not the other). This raises some pertinent questions — how much of the differences in brain activation between both tasks relate to the differences in task difficulty rather than in the nature of the tasks? Is it possible to decrease and increase the difficulty of deception and false memory retrieval tasks respectively, to obtain null or even opposite results (i.e., significant frontoparietal activations only in the (deceptive responses > truthful responses) < (false recognition > true recognition) contrast)?

Across different individuals and real-world situations, conceiving a lie and recalling a false memory may vary tremendously in term of the level of difficulty, and consequently, the amount of cognitive effort required. More importantly, it has been shown that with repeated practice, individuals with high psychopathic tendencies can significantly decrease the difficulty of carrying out deceptive acts and reduce their lying-related neural signals (Shao and Lee, 2017). That

Table 5
Results of the conjunction and contrast analyses between deceptive responses > truthful responses and false recognition > true recognition.

Cluster	K	Hemisphere	Region	BA	MNI coordinates			Z value
					X	Y	Z	
Conjunction analysis: (deceptive responses > truthful responses)∩ (false recognition > true recognition)								
1	70	L	Superior frontal gyrus	8	−4	22	48	1.9
Contrast analysis: (deceptive responses > truthful responses) > (false recognition > true recognition)								
1	86	R	Superior temporal gyrus	22	57	14	0	3.72
		R	Insula	13	53	14	−6	3.54
2	75	L	Inferior parietal lobule	40	−50	−50	48	3.72
		L	Inferior parietal lobule	40	−46	−53	44	3.54
3	50	R	Superior frontal gyrus	9	33	50	24	3.24

Note. voxel size $2 \times 2 \times 2$ mm^3.L = Left hemisphere; R = Right hemisphere; BA = Brodmann area.
K = number of voxels.

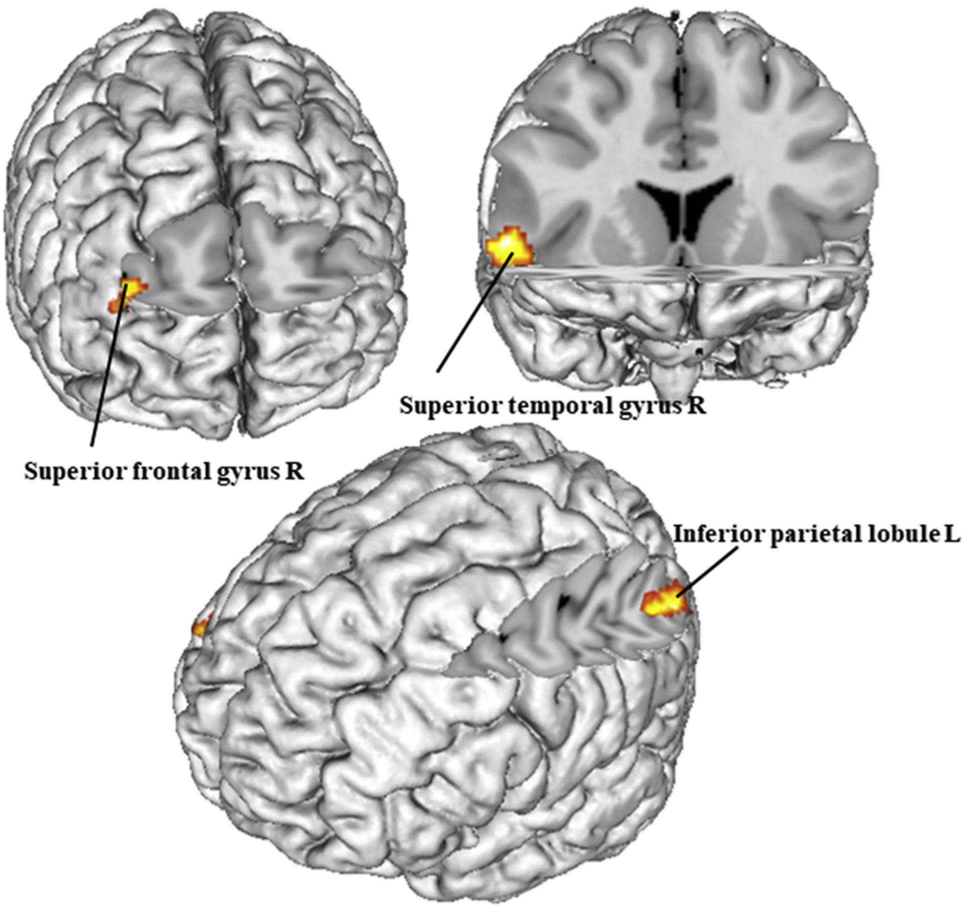

Fig. 5. Significant clusters of activation associated with (deceptive responses > truthful responses) > (false recognition > true recognition).

being said, if the differentiation between deception and false memory rests solely on the brain activation relating to the amount of cognitive effort, then criminals can easily fool such detection mechanism with repeated practice. Hence, from the standpoint of discriminating between deception and false memory, it is imperative to show that fMRI is sensitive to the qualitative differences, rather than quantitative differences, in the cognitive effort associated with performing the two different tasks. Unfortunately, this could not be adequately supported in the current work and literature. To this end, future research not only needs to execute both deception and false memory tasks within-study, but they should go one step further to vary the difficulty of both tasks systematically using parametric modulation designs.

Aside from this, there are other concerns that need to be addressed before such fMRI differentiation of deception and false memory can be implemented in the legal context. First, while the current study has shown that fMRI can differentiate deception from false memories at the meta-analytic level and studies have shown that both can be differentiated at the group level (Abe et al., 2008; Lee et al., 2009), it remains to be known if such fMRI differentiation can be reliably and accurately achieved at the single subject level. In this regard, there is a need for future studies to carry out multivoxel pattern analyses to classify responses as deceptive or false memories. Furthermore, in most of the deception studies included in this meta-analysis, deceptive responses were elicited via cues rather than spontaneously. It remains unclear how such fMRI differentiation would fare in real life legal contexts, where deceptive acts are driven by self-interest or the intention to harm, rather than in response to a cue.

The current meta-analytic comparison of deception and false memory is limited by the fact that both task paradigms were compared between studies rather than within studies. Thus, one cannot rule out the possibility that between-study differences in MRI acquisition- and participant-related variables might have had a confounding influence on the results.

The current work sought to investigate if deception and false memory can be differentiated using fMRI. First, we replicated previous meta-analyses in showing that both deception and false memory tasks were associated with increased activation in several frontoparietal regions. Then, we compared the contrasts obtained from these meta-analyses to identify common and unique neural correlates of both tasks. The left SFG was found to be activated in both tasks. Additionally, deception relative to false memory, was associated with increased activation in the right STG, right insula, left IPL, and right SFG. This increased activation could possibly be explained by the differences in the nature of both tasks and their task difficulty. These findings do support the notion that fMRI can discriminate between deception and false memory. Nevertheless, future work is needed to clarify that the basis of this differentiation lies with differences in the nature of the tasks rather than task difficulty, before we can advance the use of fMRI for detecting deception in high stakes legal contexts.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.neubiorev.2019.06.027.

References

Abe, N., Fujii, T., Ito, A., Ueno, A., Koseki, Y., Hashimoto, R., Hayashi, A., Mugikura, S., Takahashi, S., Mori, E., 2014. The neural basis of dishonest decisions that serve to harm or help the target. Brain Cogn . 90, 41–49. https://doi.org/10.1016/j.bandc.2014.06.005.

Abe, N., Fujii, T., Suzuki, M., Ueno, A., Shigemune, Y., Mugikura, S., Takahashi, S., Mori, E., 2013. Encoding-and retrieval-related brain activity underlying false recognition. Neurosci. Res . 76, 240–250.

Abe, N., Okuda, J., Suzuki, M., Sasaki, H., Matsuda, T., Mori, E., Tsukada, M., Fujii, T., 2008. Neural correlates of true memory, false memory, and deception. Cereb. Cortex 18, 2811–2819. https://doi.org/10.1093/cercor/bhn037.

Andrew Kozel, F., Johnson, K.A., Grenesko, E.L., Laken, S.J., Kose, S., Lu, X., Pollina, D., Ryan, A., George, M.S., 2009. Functional MRI detection of deception after committing a mock sabotage crime. J. Forensic Sci. 54, 220–231.

Atkins, A.S., Reuter-Lorenz, P.A., 2011. Neural mechanisms of semantic interference and false recognition in short-term memory. Neuroimage 56, 1726–1734.

Ayers, M.S., Reder, L.M., 1998. A theoretical review of the misinformation effect: Predictions from an activation-based memory model. Psychon. Bull. Rev. 5, 1–21. https://doi.org/10.3758/BF03209454.

Baumgartner, T., Fischbacher, U., Feierabend, A., Lutz, K., Fehr, E., 2009. The Neural Circuitry of a Broken Promise. Neuron 64, 756–770. https://doi.org/10.1016/j.neuron.2009.11.017.

Bhatt, S., Mbwana, J., Adeyemo, A., Sawyer, A., Hailu, A., VanMeter, J., 2009. Lying about facial recognition: An fMRI study. Brain Cogn . 69, 382–390. https://doi.org/10.1016/j.bandc.2008.08.033.

Boisgueheneuc, F. du, Dubois, B., Levy, R., Volle, E., Kinkingnehun, S., Seassau, M., Zhang, S., Duffau, H., Samson, Y., 2006. Functions of the left superior frontal gyrus in humans: a lesion study. Brain 129, 3315–3328. https://doi.org/10.1093/brain/awl244.

Browndyke, J.N., Paskavitz, J., Sweet, L.H., Cohen, R.A., Tucker, K.A., Welsh-Bohmer, K.A., Burke, J.R., Schmechel, D.E., 2008. Neuroanatomical correlates of malingered memory impairment: Event-related fMRI of deception on a recognition memory task. Brain Inj . 22, 481–489. https://doi.org/10.1080/02699050802084894.

Bruck, M., Ceci, S.J., 1999. THE SUGGESTIBILITY OF CHILDREN'S MEMORY. Annu. Rev. Psychol. 50, 419–439. https://doi.org/10.1146/annurev.psych.50.1.419.

Cabeza, R., Rao, S.M., Wagner, A.D., Mayer, A.R., Schacter, D.L., 2001. Can medial temporal lobe regions distinguish true from false? An event-related functional MRI study of veridical and illusory recognition memory. Proc. Natl. Acad. Sci. 98https://doi.org/10.1073/pnas.081082698. 4805 LP – 4810.

Carrigan, N., Barkus, E., 2016. A systematic review of cognitive failures in daily life: Healthy populations. Neurosci. Biobehav. Rev. 63, 29–42. https://doi.org/10.1016/j.neubiorev.2016.01.010.

Ceci, S.J., Loftus, E.F., 1994. 'Memory work': A royal road to false memories? Appl. Cogn. Psychol. 8, 351–364.

Christ, S.E., Van Essen, D.C., Watson, J.M., Brubaker, L.E., McDermott, K.B., 2009. The contributions of prefrontal cortex and executive control to deception: Evidence from activation likelihood estimate meta-analyses. Cereb. Cortex 19, 1557–1566. https://doi.org/10.1093/cercor/bhn189.

Cui, Q., Lei, X., Yang, W., Wang, Y., Zhang, Q., 2014. The Existence of Feedback Modulates the Neural Mechanism Underlying Deception. Sci. Sin. Vitae 44, 938–950. https://doi.org/10.1360/052013-59.

Cutini, S., Scatturin, P., Menon, E., Bisiacchi, P.S., Gamberini, L., Zorzi, M., Dell'Acqua, R., 2008. Selective activation of the superior frontal gyrus in task-switching: An event-related fNIRS study. Neuroimage 42, 945–955. https://doi.org/10.1016/j.neuroimage.2008.05.013.

Dennis, N.A., Bowman, C.R., Vandekar, S.N., 2012. True and phantom recollection: an fMRI investigation of similar and distinct neural correlates and connectivity. Neuroimage 59, 2982–2993.

Dennis, N.A., Johnson, C.E., Peterson, K.M., 2014. Neural correlates underlying true and false associative memories. Brain Cogn. 88, 65–72.

Ding, X.P., Du, X., Lei, D., Hu, C.S., Fu, G., Chen, G., 2012. The Neural Correlates of Identity Faking and Concealment: An fMRI Study. PLoS One 7, e48639.

Eickhoff, S.B., Bzdok, D., Laird, A.R., Kurth, F., Fox, P.T., 2012. Activation likelihood estimation meta-analysis revisited. Neuroimage 59. https://doi.org/10.1016/j.neuroimage.2011.09.017.

Eickhoff, S.B., Laird, A.R., Grefkes, C., Wang, L.E., Zilles, K., Fox, P.T., 2009. Coordinate-based activation likelihood estimation meta-analysis of neuroimaging data: a random effects approach based on empirical estimates of spatial uncertainty. Hum. Brain Mapp. 30. https://doi.org/10.1002/hbm.20718.

Gamer, M., Bauermann, T., Stoeter, P., Vossel, G., 2007. Covariations among fMRI, skin conductance, and behavioral data during processing of concealed information. Hum. Brain Mapp. 28, 1287–1301.

Gamer, M., Klimecki, O., Bauermann, T., Stoeter, P., Vossel, G., 2009. fMRI-activation patterns in the detection of concealed information rely on memory-related effects. Soc. Cogn. Affect. Neurosci . 7, 506–515.

Ganis, G., Kosslyn, S.M., Stose, S., Thompson, W.L., Yurgelun-Todd, D.A., 2003. Neural correlates of different types of deception: an fMRI investigation. Cereb. cortex 13, 830–836.

Ganis, G., Morris, R.R., Kosslyn, S.M., 2009. Neural processes underlying self- and other-related lies: An individual difference approach using fMRI. Soc. Neurosci. 4, 539–553. https://doi.org/10.1080/17470910801928271.

Ganis, G., Rosenfeld, J.P., Meixner, J., Kievit, R.A., Schendan, H.E., 2011. Lying in the scanner: covert countermeasures disrupt deception detection by functional magnetic resonance imaging. Neuroimage 55, 312–319.

Garoff-Eaton, R.J., Slotnick, S.D., Schacter, D.L., 2005. Not all false memories are created equal: the neural basis of false recognition. Cereb. Cortex 16, 1645–1652.

Garoff-Eaton, R.J., Kensinger, E.A., Schacter, D.L., 2007. The neural correlates of conceptual and perceptual false recognition. Learn Mem. 14, 684–692.

Giovanello, K.S., Schnyer, D., Verfaellie, M., 2009. Distinct hippocampal regions make unique contributions to relational memory. Hippocampus 19, 111–117. https://doi.org/10.1002/hipo.20491.

Greene, J.D., Paxton, J.M., 2009. Patterns of neural activity associated with honest and dishonest moral decisions. Proc. Natl. Acad. Sci. 106, 12506–12511.

Gutchess, A.H., Schacter, D.L., 2012. The neural correlates of gist-based true and false recognition. Neuroimage 59, 3418–3426.

Haynes, J.-D., Rees, G., 2006. Neuroimaging: decoding mental states from brain activity in humans. Nat. Rev. Neurosci. 7, 523.

Henry, S., Plemmons, D., 2012. Neuroscience, neuropolitics and neuroethics: the complex case of crime, deception and FMRI. Sci. Eng. Ethics 18, 573–591.

Heun, R., Jessen, F., Klose, U., Erb, M., Granath, D.-O., Grodd, W., 2000. Response-related fMRI analysis during encoding and retrieval revealed differences in cerebral activation by retrieval success. Psychiatry Res. Neuroimaging 99, 137–150.

Heun, R., Jessen, F., Klose, U., Erb, M., Granath, D.-O., Grodd, W., 2004. Response-related fMRI of veridical and false recognition of words. Eur. Psychiatry 19, 42–52.

Hofer, A., Siedentopf, C.M., Ischebeck, A., Rettenbacher, M.A., Verius, M., Golaszewski, S.M., Felber, S., Fleischhacker, W.W., 2007. Neural substrates for episodic encoding and recognition of unfamiliar faces. Brain Cogn. 63, 174–181.

Hu, S., Ide, J.S., Zhang, S., Li, C.R., 2016. The Right Superior Frontal Gyrus and Individual Variation in Proactive Control of Impulsive Response. J. Neurosci. 36, 12688–12696. https://doi.org/10.1523/JNEUROSCI.1175-16.2016.

Iidaka, T., Harada, T., Kawaguchi, J., Sadato, N., 2012. Neuroanatomical substrates involved in true and false memories for face. Neuroimage 62, 167–176.

Iidaka, T., Harada, T., Sadato, N., 2014. False memory for face in short-term memory and neural activity in human amygdala. Brain Res. 1591, 74–85.

Ito, A., Abe, N., Fujii, T., Ueno, A., Koseki, Y., Hashimoto, R., Mugikura, S., Takahashi, S., Mori, E., 2011. The role of the dorsolateral prefrontal cortex in deception when remembering neutral and emotional events. Neurosci. Res. 69, 121–128.

Ito, A., Abe, N., Fujii, T., Hayashi, A., Ueno, A., Mugikura, S., Takahashi, S., Mori, E., 2012. The contribution of the dorsolateral prefrontal cortex to the preparation for deception and truth-telling. Brain Res. 1464, 43–52. https://doi.org/10.1016/j.brainres.2012.05.004.

Kaplan, R.L., Van Damme, I., Levine, L.J., Loftus, E.F., 2015. Emotion and False Memory. Emot. Rev. 8, 8–13. https://doi.org/10.1177/1754073915601228.

Kensinger, E.A., Schacter, D.L., 2007. Remembering the specific visual details of presented objects: Neuroimaging evidence for effects of emotion. Neuropsychologia 45, 2951–2962.

Kensinger, E.A., Schacter, D.L., 2006. Amygdala Activity Is Associated with the Successful Encoding of Item, But Not Source, Information for Positive and Negative Stimuli. J. Neurosci. 6, 2570. https://doi.org/10.1523/JNEUROSCI.5241-05.2006. 2564 LP – 2570.

Kim, H., Cabeza, R., 2007. Trusting our memories: dissociating the neural correlates of confidence in veridical versus illusory memories. J. Neurosci 27, 12190–12197.

Kireev, M., Korotkov, A., Medvedeva, N., Medvedev, S., 2013. Possible role of an error detection mechanism in brain processing of deception: PET-fMRI study. Int. J. Psychophysiol. 90, 291–299.

Kosheleva, E., Spadoni, A.D., Strigo, I.A., Buchsbaum, M.S., Simmons, A.N., 2016. Faking bad: The neural correlates of feigning memory impairment. Neuropsychology 30, 377.

Kozel, F.A., Johnson, K.A., Mu, Q., Grenesko, E.L., Laken, S.J., George, M.S., 2005. Detecting deception using functional magnetic resonance imaging. Biol. Psychiatry 58, 605–613.

Kozel, F.A., Laken, S.J., Johnson, K.A., Boren, B., Mapes, K.S., Morgan, P.S., George, M.S., 2009. Replication of functional MRI detection of deception. Open Forensic Sci. 2, 6 J.

Kozel Andrew, F., Padgett, T.M., George, M.S., 2004a. A replication study of the neural correlates of deception. Behav. Neurosci. 118, 852.

Kozel, F. Andrew, Revell, L.J., Lorberbaum, J.P., Shastri, A., Elhai, J.D., Horner, M.D., Smith, A., Nahas, Z., Bohning, D.E., George, M.S., 2004b. A pilot study of functional magnetic resonance imaging brain correlates of deception in healthy young men. J. Neuropsychiatry Clin Neurosci. 16, 295–305.

Kuehnel, S., Mertens, M., Woermann, F.G., Markowitsch, H.J., 2008. Brain activations during correct and false recognitions of visual stimuli: implications for eyewitness decisions on an fMRI study using a film paradigm. Brain Imaging Behav. 2, 163.

Kurkela, K.A., Dennis, N.A., 2016. Event-related fMRI studies of false memory: An Activation Likelihood Estimation meta-analysis. Neuropsychologia 81, 149–167. https://doi.org/10.1016/j.neuropsychologia.2015.12.006.

Laird, A.R., Fox, P.M., Price, C.J., Glahn, D.C., Uecker, A.M., Lancaster, J.L., Turkeltaub, P.E., Kochunov, P., Fox, P.T., 2005. ALE meta-analysis: Controlling the false discovery rate and performing statistical contrasts. Hum. Brain Mapp. 25, 155–164. https://doi.org/10.1002/hbm.20136.

Lancaster, J.L., Tordesillas Gutierrez, D., Martinez, M., Salinas, F., Evans, A., Zilles, K., 2007. Bias between MNI and Talairach coordinates analyzed using the ICBM-152 brain template. Hum Brain Mapp 28. https://doi.org/10.1002/hbm.20345.

Langleben, D.D., Loughead, J.W., Bilker, W.B., Ruparel, K., Childress, A.R., Busch, S.I., Gur, R.C., 2005. Telling truth from lie in individual subjects with fast event-related fMRI. Hum. Brain Mapp. 26, 262–272.
Langleben, D.D., Moriarty, J.C., 2013. Using brain imaging for lie detection: Where science, law, and policy collide. Psychol. Public Policy, Law 19, 222.
Langleben, D.D., Schroeder, L., Maldjian, J.A., Gur, R.C., McDonald, S., Ragland, J.D., O'brien, C.P., Childress, A.R., 2002. Brain activity during simulated deception: an event-related functional magnetic resonance study. Neuroimage 15, 727–732.
Lee, T.M.C., Liu, H., Tan, L., Chan, C.C.H., Mahankali, S., Feng, C., Hou, J., Fox, P.T., Gao, J., 2002. Lie detection by functional magnetic resonance imaging. Hum. Brain Mapp. 15, 157–164.
Lee, T.M.C., Lee, T.M.Y., Raine, A., Chan, C.C.H., 2010. Lying about the valence of affective pictures: an fMRI study. PLoS One 5, e12291.
Lee, T.M.C., Leung, M., Lee, T.M.Y., Raine, A., Chan, C.C.H., 2013. I want to lie about not knowing you, but my precuneus refuses to cooperate. Sci. Rep. 3, 1636.
Lee, T.M.C., Au, R.K.C., Liu, H.L., Ting, K.H., Huang, C.M., Chan, C.C.H., 2009. Are errors differentiable from deceptive responses when feigning memory impairment? An fMRI study. Brain Cogn. 69, 406–412. https://doi.org/10.1016/j.bandc.2008.09.002.
Lisofsky, N., Kazzer, P., Heekeren, H.R., Prehn, K., 2014. Investigating socio-cognitive processes in deception: A quantitative meta-analysis of neuroimaging studies. Neuropsychologia 61, 113–122. https://doi.org/10.1016/j.neuropsychologia.2014.06.001.
Marchewka, A., Brechmann, A., Nowicka, A., Jednoróg, K., Scheich, H., Grabowska, A., 2008. False recognition of emotional stimuli is lateralised in the brain: An fMRI study. Neurobiol. Learn Mem. 90, 280–284.
Marchewka, A., Jednorog, K., Falkiewicz, M., Szeszkowski, W., Grabowska, A., Szatkowska, I., 2012. Sex, lies and fMRI—gender differences in neural basis of deception. PLoS One 7, e43076.
McDermott, K.B., Gilmore, A.W., Nelson, S.M., Watson, J.M., Ojemann, J.G., 2017. The parietal memory network activates similarly for true and associative false recognition elicited via the DRM procedure. Cortex 87, 96–107. https://doi.org/10.1016/j.cortex.2016.09.008.
McPherson, B., McMahon, K., Wilson, W., Copland, D., 2012. "I know you can hear me": Neural correlates of feigned hearing loss. Hum. Brain Mapp. 33, 1964–1972.
Mikkelsen, E.J., Gutheil, T.G., Emens, M., 1992. False sexual-abuse allegations by children and adolescents: Contextual factors and clinical subtypes. Am. J. Psychother. 46, 556–570.
Mohamed, F.B., Faro, S.H., Gordon, N.J., Platek, S.M., Ahmad, H., Williams, J.M., 2006. Brain mapping of deception and truth telling about an ecologically valid situation: functional MR imaging and polygraph investigation—initial experience. Radiology 238, 679–688.
Moher, D., Liberati, A., Tetzlaff, J., 2009. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. BMJ 339. https://doi.org/10.1136/bmj.b2535.
Mori, E., Yamaguchi, K., Suzuki, M., Itoh, M., Abe, N., Tsukiura, T., Fujii, T., 2005. Dissociable Roles of Prefrontal and Anterior Cingulate Cortices in Deception. Cereb. Cortex 16, 192–199. https://doi.org/10.1093/cercor/bhi097.
Moritz, S., Gläscher, J., Sommer, T., Büchel, C., Braus, D.F., 2006. Neural correlates of memory confidence. Neuroimage 33, 1188–1193.
Mossad, S.I., AuCoin-Power, M., Urbain, C., Smith, M. Lou, Pang, E.W., Taylor, M.J., 2016. Thinking about the thoughts of others; temporal and spatial neural activation during false belief reasoning. Neuroimage 134, 320–327. https://doi.org/10.1016/j.neuroimage.2016.03.053.
Ney, T., 2013. True And False Allegations Of Child Sexual Abuse: Assessment & Case Management. Routledge.
Niendam, T.A., Laird, A.R., Ray, K.L., Dean, Y.M., Glahn, D.C., Carter, C.S., 2012. Meta-analytic evidence for a superordinate cognitive control network subserving diverse executive functions. Cogn. Affect. Behav. Neurosci. 12, 241–268. https://doi.org/10.3758/s13415-011-0083-5.
Nose, I., Murai, J., Taira, M., 2009. Disclosing concealed information on the basis of cortical activations. Neuroimage 44, 1380–1386.
Nunez, J.M., Casey, B.J., Egner, T., Hare, T., Hirsch, J., 2005. Intentional false responding shares neural substrates with response conflict and cognitive control. Neuroimage 25, 267–277.
Ofen, N., Schwarzlose, R.F., Gabrieli, J.D.E., Whitfield-Gabrieli, S., Chai, X.J., 2016. Neural correlates of deception: lying about past events and personal beliefs. Soc. Cogn. Affect. Neurosci . 12, 116–127. https://doi.org/10.1093/scan/nsw151.
Pezdek, K.E., Banks, W.P., 1996. The recovered memory/false memory debate. Academic Press.
Phan, K.L., Magalhaes, A., Ziemlewicz, T.J., Fitzgerald, D.A., Green, C., Smith, W., 2005. Neural correlates of telling lies: A functional magnetic resonance imaging study at 4 Tesla1. Acad. Radiol. 12, 164–172.
Priori, A., Cogiamanian, F., Mameli, F., Tiriticco, M., Ferrucci, R., Marceglia, S., Mrakic-Sposta, S., Zago, S., Polezzi, D., Sartori, G., 2007. Lie-Specific Involvement of Dorsolateral Prefrontal Cortex in Deception. Cereb. Cortex 18, 451–455. https://doi.org/10.1093/cercor/bhm088.
Salo, E., Salmela, V., Salmi, J., Numminen, J., Alho, K., 2017. Brain activity associated with selective attention, divided attention and distraction. Brain Res. 1664, 25–36. https://doi.org/10.1016/j.brainres.2017.03.021.
Schauer, F., 2010. Neuroscience, lie-detection, and the law: Contrary to the prevailing view, the suitability of brain-based lie-detection for courtroom or forensic use should be determined according to legal and not scientific standards. Trends Cogn. Sci. 14, 101–103.
Schurz, M., Radua, J., Aichhorn, M., Richlan, F., Perner, J., 2014. Fractionating theory of mind: A meta-analysis of functional brain imaging studies. Neurosci. Biobehav. Rev. 42, 9–34. https://doi.org/10.1016/j.neubiorev.2014.01.009.
Schurz, M., Tholen, M.G., Perner, J., Mars, R.B., Sallet, J., 2017. Specifying the brain anatomy underlying temporo-parietal junction activations for theory of mind: A review using probabilistic atlases from different imaging modalities. Hum. Brain Mapp. 38, 4788–4805. https://doi.org/10.1002/hbm.23675.
Shao, R., Lee, T.M.C., 2017. Are individuals with higher psychopathic traits better learners at lying? Behavioural and neural evidence. Transl. Psychiatry 7, e1175.
Sip, K.E., Carmel, D., Marchant, J.L., Li, J., Petrovic, P., Roepstorff, A., McGregor, W.B., Frith, C.D., 2013. When Pinocchio's nose does not grow: belief regarding lie-detectability modulates production of deception. Front. Hum. Neurosci. 7, 16.
Sip, K.E., Lynge, M., Wallentin, M., McGregor, W.B., Frith, C.D., Roepstorff, A., 2010. The production and detection of deception in an interactive game. Neuropsychologia 48, 3619–3626.
Slotnick, S.D., Schacter, D.L., 2004. A sensory signature that distinguishes true from false memories. Nat. Nat. Neurosci. 7, 664.
Spence, S.A., 2004. The deceptive brain. J. R. Soc. Med. 97, 6–9.
Spence, S.A., Farrow, T.F.D., Herford, A.E., Wilkinson, I.D., Zheng, Y., Woodruff, P.W.R., 2001. Behavioural and functional anatomical correlates of deception in humans. Neuroreport 12, 2849–2853.
Spence, S.A., Kaylor-Hughes, C., Farrow, T.F.D., Wilkinson, I.D., 2008. Speaking of secrets and lies: the contribution of ventrolateral prefrontal cortex to vocal deception. Neuroimage 40, 1411–1418.
Strömwall, L.A., Willén, R.M., 2011. Inside Criminal Minds: Offenders' Strategies when Lying. J. Investig. Psychol. Offender Profiling 8, 271–281. https://doi.org/10.1002/jip.148.
Suchotzki, K., Verschuere, B., Peth, J., Crombez, G., Gamer, M., 2015. Manipulating item proportion and deception reveals crucial dissociation between behavioral, autonomic, and neural indices of concealed information. Hum. Brain Mapp. 36, 427–439. https://doi.org/10.1002/hbm.22637.
Sun, D., Chan, C.C.H., Hu, Y., Wang, Z., Lee, T.M.C., 2015a. Neural correlates of outcome processing post dishonest choice: An fMRI and ERP study. Neuropsychologia 68, 148–157. https://doi.org/10.1016/j.neuropsychologia.2015.01.013.
Sun, D., Lee, T.M.C., Chan, C.C.H., 2015b. Unfolding the spatial and temporal neural processing of lying about face familiarity. Cereb. Cortex 25, 927–936. https://doi.org/10.1093/cercor/bht284.
Sun, D., Lee, T.M.C., Wang, Z., Chan, C.C.H., 2016. Unfolding the spatial and temporal neural processing of making dishonest choices. PLoS One 11, e0153660.
Turney, I.C., Dennis, N.A., 2017. Elucidating the neural correlates of related false memories using a systematic measure of perceptual relatedness. Neuroimage 146, 940–950.
Urgolites, Z.J., Smith, C.N., Squire, L.R., 2015. True and false memories, parietal cortex, and confidence judgments. Learn Mem. 22, 557–562.
Vartanian, O., Kwantes, P., Mandel, D.R., 2012. Lying in the scanner: localized inhibition predicts lying skill. Neurosci. Lett. 529, 18–22.
Vartanian, O., Kwantes, P., Mandel, D.R., Bouak, F., Nakashima, A., Smith, I., Lam, Q., 2013. Right inferior frontal gyrus activation as a neural marker of successful lying. Front. Hum. Neurosci. 7, 616.
Volz, K.G., Vogeley, K., Tittgemeyer, M., von Cramon, D.Y., Sutter, M., 2015. The neural basis of deception in strategic interactions. Front. Behav. Neurosci. 9, 27.
Von Zerssen, G.C., Conscious recollection illusory recognit, Mecklinger, A., Opitz, B., Von Cramon, D.Y., 2001. ion: an event-related fMRI study. Eur. J. Neurosci. 13, 2148–2156.
Webb, C.E., Turney, I.C., Dennis, N.A., 2016. What's the gist? The influence of schemas on the neural correlates underlying true and false memories. Neuropsychologia 93, 61–75. https://doi.org/10.1016/j.neuropsychologia.2016.09.023.
Wolpe, P.R., Foster, K.R., Langleben, D.D., 2010. Emerging neurotechnologies for lie-detection: Promises and perils. Am. J. Bioeth. 10, 40–48.
Yin, L., Reuter, M., Weber, B., 2016. Let the man choose what to do: Neural correlates of spontaneous lying and truth-telling. Brain Cogn. 102, 13–25.
Yin, L., Hu, Y., Dynowski, D., Li, J., Weber, B., 2017. The good lies: Altruistic goals modulate processing of deception in the anterior insula. Hum. Brain Mapp. 38, 3675–3690.
Zhang, R., Geng, X., Lee, T.M.C., 2017. Large-scale functional neural network correlates of response inhibition: an fMRI meta-analysis. Brain Struct. Funct. 222, 3973–3990. https://doi.org/10.1007/s00429-017-1443-x.