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Research Report

Neural correlates of evaluations of lying and truth-telling in different social contexts

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ABSTRACT

The present study examined the neural correlates of evaluations of both lying and truth-telling in different social contexts using fMRI methodology. The results demonstrated the differentiation between lying and truth-telling and between different types of lying in a network of brain regions. These regions included bilateral superior frontal gyrus (SFG), bilateral inferior parietal lobule (IPL), bilateral cuneus, right lingual gyrus (LG), right precuneus, and left postcentral gyrus (PoCG). Additionally, we found that activations in the right LG, the left IPL and the left PoCG were correlated with the off-line evaluations of truthful and untruthful communications about good and bad acts in different social contexts. These results suggest that the judgments of lying and truth-telling involving a third party might not be emotion-arousing but involve rational processing. This study is among the first to demonstrate that evaluations of truthful and untruthful communications in different social contexts can be differentiated in terms of brain BOLD (blood-oxygen-level-dependent) activities.

1. Introduction

A lie is statement made by a speaker with the intention to instil a false belief into the mind of the listener (Chisholm and Feehan, 1977). Thus, lie-telling involves two parties: the lie-teller, and the lie-recipient who the lie-teller intends to deceive.

Over the last decade, there have been an increasing number of studies examining the neural activities associated with *lie-telling*. These studies have used a variety of methodologies such as functional magnetic resonance imaging (fMRI) (Ganis et al., 2003; Langleben et al., 2005; Mohamed et al., 2006; Phan et al., 2005; Spence et al., 2004), positron emission tomography (PET) (Abe et al., 2006), and transcranial direct current stimulation (tDCS) (Karim et al., 2006). All of the fMRI, PET and tDCS studies have shown that lying was specifically associated with the activation of several regions of the prefrontal cortex (PFC) (Abe et al., 2006; Karim et al., 2006; Langleben et al., 2005; Mohamed et al., 2006; Phan et al., 2005; for a metaanalysis, see Christ et al., 2009), as well as some posterior regions such as the superior temporal sulcus (STS) (Abe et al., 2006; Langleben et al., 2005; Phan et al., 2005).

In contrast, limited neuroimaging research has been conducted from the perspective of the lie-recipient. Extensive behavioural studies have shown that people tell lies regularly in their daily interaction with others (DePaulo and Kashy,

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1998). Thus, determining whether others have lied to us and how to respond appropriately to their lies or truths plays an important role in the success of our social interaction with others. When a person makes a statement to us, we must first determine whether the person has lied or told the truth. Then, we must appraise the dishonest or honest act. The appropriateness of the appraisal is extremely important because failure to appreciate the positivity or negativity of a dishonest or honest statement can have far-reaching consequences to our social relation with others. For example, failure to recognize another's dishonest statement (Vrij and Baxter, 1999) and associated negative moral valence may lead to inappropriate trust of the deceiver. Also, making dishonest statements, or lying, is not a homogenous concept. Not all types of lies automatically entail negative values (Lee, 2000; Talwar and Lee, 2008). One common type of lie involves individuals who after having done something socially undesirable (e.g., drawing pictures in a book from a library), intentionally make a false statement to deceive the lie-recipient to conceal the transgression (henceforth referred to as the bad-act lie). Such lies are eschewed universally and thus are typically judged morally wrong whereas telling the truth to confess one's own transgression (henceforth referred to as the bad-act truth) are typically judged morally right in almost all cultures (Fu et al., 2007; Fu et al., 2008; Fu et al., 2001; Lee et al., 1997; Lee et al., 2001; Xu et al., 2010).

In contrast, there are social contexts in some cultures where lies are often considered to be acceptable and truth-telling is in fact socially questionable. One example in the Western culture is the lie people tell in order to be polite and spare another person's feelings. Another example in the Eastern Asian societies, especially in the Chinese culture (Fu et al., 2001), is when individuals are encouraged to show humility about their personal achievements and good deeds (e.g., helping a needy person or saving another's life). When questioned, Eastern Asians are encouraged to be unsung heroes and not to tell the truth about themselves. Rather, in some situations, lying is condoned. Behavioral studies (e.g., Fu et al., 2001; Lee et al., 2001) have consistently shown that Eastern Asians rate telling the truth about one's own good deeds (henceforth referred to as the good-act truth) less positively than telling the truth about one's own antisocial acts. In contrast, they rate lie-telling about one's own good deeds (henceforth referred to as the good-act lie) less negatively than lie-telling about one's own antisocial deeds.

To date, it is entirely unclear whether such differences in evaluations also exist at the neural response level. Knowledge about the neural basis of the differential evaluations of the various kinds of lies and truths is important for several reasons. First, it will provide a deeper understanding of our evaluative behaviour concerning dishonesty and honesty. Second, it will show whether and how social contexts will affect not only our evaluative behaviour but also the brain activities associated with the evaluation of dishonesty and honesty. Third, such knowledge will also provide a normative basis for us to assess individuals with mental disorders, such as paranoid and pathological lying, who may have abnormal neural responses to others' lie- and truth-telling behaviours.

The present study, with the use of fMRI methodology, aimed to reveal the neural correlates of individuals' evaluations of lies and truths told in different social contexts. Specifically, we compared the BOLD (blood-oxygen-level-dependent) activities elicited by participants' evaluations of good-act lies and truths. The purpose was to assess whether we could capture the neural activity associated with the positive behavioral evaluation of lying in the good-act situation and the negative evaluation of lying in the bad-act situation and the reverse for truth-telling. Participants were shown stories in which a protagonist either lied or told the truth about his/her own good or bad deeds. Participants were asked to judge whether the protagonists' statements in the stories were good or bad.

We expected that similar to the behavioral evaluation differences between good- and bad-lies and -truths, the BOLD signals will also differ. Because the present study was the first to examine this issue directly, no firm predictions were made. Nevertheless, we believed it was reasonable to predict brain responses to the truth- or lie-telling stories in the present study based on the following three existing sets of findings.

First, because truth- and lie-telling in some situations violate social norms (e.g., lying about one's own bad act), they may automatically evoke negative reactions in participants. We thus speculated that reading such stories might elicit specific neural responses in areas that have been identified to be related to the processing of emotionally valenced information such as the amygdala and the lingual gyrus (LG) (Isenberg et al., 1999; Narumoto et al., 2000).

In addition, because lying by definition involves the intentional instillation of false beliefs into the mind of the lie-recipient and the ability to understand others' beliefs and intentions is at the core of theory of mind (ToM), it is possible that the LG, the inferior parietal lobule (IPL), the precuneus, the medial prefrontal cortex (MPFC), the superior temporal sulcus (STS), and the bilateral temporo-parietal junction (TPJ) may also be activated during the evaluations of lying as these areas have been implicated in ToM (Gallagher and Frith, 2003; Gobbini et al., 2007; Goldin and Gross, 2010; Vollm et al., 2006; Young and Saxe, 2008).

Further, because the present task was in essence a moral evaluation task, a number of areas that have been implicated in moral judgments such as the medial frontal gyrus (MFG), the superior temporal sulcus (STS), the precuneus, the dorsolateral prefrontal cortex (DLPFC) and the inferior parietal lobe (i.e., the so-called moral brain: for a review see Greene and Haidt, 2002) might be activated as well. However, as was suggested by Haidt (2001), moral judgments do not just contain a process of rational reasoning but also have an emotional process as well. Some moral judgments such as personal moral judgments are more emotion-arousing, while the other kinds such as impersonal moral judgments are more rational. These two kinds of moral judgments are thought to be associated with different brain areas (Greene et al., 2001). That is, certain regions of the "moral brain" (e.g., the MFG and the STS) tend to be activated to a larger extent when moral judgment tasks are highly emotionally charged (Greene et al., 2001; Greene and Haidt, 2002; Moll et al., 2002). In contrast, other regions of the "moral brain" (e.g., the DLPFC, the superior frontal gyrus, the inferior parietal lobe and the cuneus) tend to be activated to a larger extent when moral judgment tasks are rational but less emotional (Berthoz et al., 2006; Borg et al., 2006; Greene et al., 2001; Greene et al., 2004; Harenski and Hamann, 2006). In the present study, we expected that the participants might react with strong emotion to certain acts of lying or truth-telling because they might appraise the acts to be a grave violation of social norms. Alternatively, they might also be more rational but less emotional because the stories used in the present study involve a third party entirely unrelated to the participants. Thus, we were uncertain from the outset as to which of the "moral brain" regions would be specifically activated in the lie- or truth-telling in this study. Nevertheless, we expected that activations in these areas, if any, would be differentiated depending on the social context in which the lie or truth was told.

2. Results

2.1. *Behavioral results*

Off-line ratings from extremely bad to extremely good were coded as −3 to 3. Two-way ANOVA with repeated measures for participants' judgments of *truthfulness* (lying, truth-telling) and *act valence* (bad, good) showed a significant main effect of *truthfulness* [lying (−1.41) vs. truth-telling (1.95); $F(1,17)=94.08$, $p<0.01$], a significant main effect of *act valence* [bad act (−0.17) vs. good act (0.72); $F(1,17)=11.83$, $p<0.01$], and a significant interaction of *truthfulness* and *act valence* [$F(1,17)=58.40$, $p<0.01$] (see Fig. 2). Simple effects analyses showed that BL (−2.41) was rated lower than BT (2.07) [$F(1,17)=171.26$, $p<0.01$], GL (−0.40) was rated lower than GT (1.83) [$F(1,17)=30.18$, $p<0.01$], and BL was rated lower than GL [$F(1,17)=39.15$, $p<0.01$]. There was no difference between the two types of truth-telling [$F(1,17)=0.77$, $p=0.39$].

Additionally, we ran two-way ANOVA with repeated measures for response time (RT) of *truthfulness* (lying, truth-telling) and act valence (bad, good), the results showed a significant main effect of truthfulness [$F(1,17)=11.02$, $p<0.01$], a significant main effect of *act valence* [$F(1,17)=4.47$, $p<0.05$], and a significant interaction of *truthfulness* and *act valence* [$F(1,17)=7.91$, $p<0.05$]. Simple effect analyses showed that GT (867.49 ms) was judged faster than BT (966.66 ms) [$F(1,17)=16.17$, $p<0.01$], also, GT (867.49 ms) was judged faster than GL (1011.05 ms) [$F(1,17)=14.33$, $p<0.01$]. The results may reflect the fact that the participants might be more inclined to expect children to tell the truth about their good acts than to confess about their bad acts or lie about their good acts.

2.2. *fMRI results*

To identify the brain regions that were specifically activated during the judgment of each type of lying or truth-telling, a priori contrasts where activation while judging BL stories was greater than that of BT stories (BL>BT), and activation while judging GL stories was greater than that of GT stories (GL>GT)

Table 1 – Peak voxel and number of voxels for brain regions obtained for judgments of lying and truth-telling ($p<0.001$, uncorrected).

Region	BA [a]	Voxel	Z-score	Coordinate (MNI)		
				x	y	z
BL (bad act lie) minus BT (bad act truth)						
Right lingual gyrus	18	73	3.859	9	-87	-6
Left postcentral gyrus	5	[b]	3.615	-36	-45	63
Right precuneus	19	10	3.412	30	-72	39
Left inferior parietal lobule	40	21	3.669	-36	-60	45
	40	[b]	3.726	-48	-42	54
Right inferior parietal lobule	40	43	3.789	39	-51	54
	40	[b]	3.437	36	-54	45
	40	[b]	3.266	42	-60	48
GL (good act lie) minus GT (good act truth)						
No significant activation						
BL (bad act lie) minus GL (good act lie)						
Left superior frontal gyrus	9	36	4.062	-39	39	36
Left inferior parietal lobule	40	10	3.651	-51	-45	42
Left cuneus	18	19	3.399	-6	-93	6
	18	[b]	3.217	-6	-90	15
Right cuneus	18	15	3.277	6	-87	12
	18	[b]	3.149	6	-78	18
GL (good act lie) minus BL (bad act lie)						
Right superior frontal gyrus	10	11	3.739	18	54	24
Left superior frontal gyrus	10	10	3.633	-21	57	24

Z-scores reflect the statistical difference between the two conditions, as computed by SPM2. Coordinates refer to the MNI space.
[a] BA is according to the nearest grey matter of local maxima in the table.
[b] Clusters with more than one local maxima.

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were calculated (Table 1). The contrast of BL>BT showed significant activation in the right lingual gyrus (LG), bilateral inferior parietal lobule (IPL), left postcentral gyrus (PoCG), and right precuneus. The contrast of GL>GT did not show significant differential activations in any regions.

To determine the involvement of the *act valence* in lying, we compared the two types of lying using a priori contrasts where activation while judging BL stories was greater than that of GL stories (BL>GL), and activation while judging GL stories was greater than that of BL stories (GL>BL) (Table 1). The contrast of BL>GL showed significant activation in the left superior frontal gyrus (SFG), left IPL, and the bilateral cuneus, and the contrast of GL>BL showed significant activation in the bilateral SFG.

Two-way ANOVAs of *truthfulness* (lying vs. truth-telling) by *act valence* (bad vs. good) for all the six functional ROIs (left and right IPL, left and right SFG, left PoCG, and right LG) were carried out to further test the involvement of these regions in judgments of lying and truth-telling. The results revealed that percentage signal change increased during the judgments of lying relative to truth-telling in the left IPL [$F(1,17)=15.22$, $p<0.01$], the right IPL [$F(1,17)=6.67$, $p<0.05$], the left PoCG [$F(1,17)=21.96$, $p<0.01$], and the right LG [$F(1,17)=12.93$, $p<0.01$]. Further, percentage signal change increased during the judgments of good-act stories relative to bad-act stories in the left SFG [$F(1,17)=14.38$, $p<0.01$] and the right SFG [$F(1,17)=7.18$, $p<0.05$]. We also found that percentage signal change increased during the judgments of bad-act stories relative to good-act stories in the right LG [$F(1,17)=6.04$, $p<0.05$].

Further, a significant interaction of *truthfulness* and *act valence* was found in the right SFG [$F(1,17)=4.79$, $p<0.05$] and the right IPL [$F(1,17)=4.93$, $p<0.05$]. Simple effect analysis showed that percentage signal change in the bilateral IPL (Fig. 3C, D), left PoCG (Fig. 3E), and right LG (Fig. 3F) were significantly increased during the judgments of BL relative to BT. Percentage signal change in the bilateral SFG (Fig. 3A, B) was significantly increased during the judgments of GL relative to BL. Percentage signal changes in the right SFG (Fig. 3B), the left IPL (Fig. 3C) and the left PoCG (Fig. 3E) were significantly increased during the judgments of GL relative to GT. Also, percentage signal change in the left IPL (Fig. 3C) was significantly increased during the judgments of BL relative to GL.

2.3. *Relation between behavioral and fMRI results*

To assess the relative predictive power of regional neurophysiology on lie or truth judgments, correlation analyses were performed on all of the percentages of signal change for the six functional ROIs and the participants' evaluations of all four types of stories when they were not in the MRI scanner. The BOLD responses in the right LG ($r=-0.33$, $p<0.01$), left IPL ($r=-0.33$, $p<0.01$) and left PoCG ($r=-0.39$, $p<0.01$) were significantly related to the evaluations with the data from the four types of stories combined (Fig. 4). Also, correlation analyses were carried out between response time and the percentages of signal change of the six functional ROIs. No significant correlations were found.

To further delineate the above significant findings in these three brain regions concerning participants' evaluations, we conducted additional correlation analyses. To examine the effect of the act valence, correlation analyses were performed on the percentage of signal change for the three regions and the evaluations of bad-act stories and good-act stories respectively (with the lying and truth-telling stories combined). Results showed that off-line evaluations of bad-act stories were significantly related to the activations in the left IPL ($r=-0.33$, $p<0.05$) and the left PoCG ($r=-0.37$, $p<0.05$): the more negative the ratings of the bad acts, the greater were the percent signal changes in these regions. In contrast, off-line ratings of good-act stories were significantly related to activations in the right LG ($r=-0.36$, $p<0.05$) and the left PoCG ($r=-0.48$, $p<0.01$): the more positive the ratings of the good acts, the smaller the percentage signal changes in these regions. Altogether, these results suggest that activity in the left PoCG was associated with participants' off-line evaluations of both good and bad acts, whereas activity in the right LG was only associated with off-line evaluations of good acts and activity in the left IPL was only correlated with off-line evaluations of bad acts.

To examine the effect of truthfulness (lying or truth-telling), correlation analyses were also performed on percentage of signal change for the three regions and the ratings of lying and truth-telling stories respectively (with the good and bad act stories combined). Results showed that activation in these three regions were not related to the ratings of either lying or truth-telling stories, suggesting that when the social contexts were not considered, participants' off-line evaluations of lying and truth-telling were not associated with activation in the above three brain regions.

Additionally, we examined the correlations between the off-line evaluations of each of the four story types (BL, BT, GL, GT) and the percentage signal changes in the three brain regions. Only the percentage signal change in the left PoCG was significantly related to participants' off-line evaluations of lying about a good act ($r=-0.53$, $p<0.05$): the more activity in the left PoCG, the more negatively participants rated good-act lies (Fig. 5).

3. Discussion

Using fMRI techniques, we examined the neural correlates of evaluations of lying and truth-telling in different social contexts. More specifically, we compared the neural activities associated with the evaluations of lying and truth-telling about antisocial acts with those about prosocial acts. Our results revealed that evaluations of truthful and untruthful communication in different social contexts produced significant differences in terms of brain BOLD activities.

First, we found that activations were increased in the right lingual gyrus (LG), the postcentral gyrus (PoCG), the right precuneus, and the bilateral inferior parietal lobule (IPL) in judgments of bad-act lies relative to truth-telling. Second, the bilateral superior frontal gyrus (SFG), the bilateral cuneus, and the left IPL were activated differently between the good and bad-act lies. Third, activation in the right LG, the left PoCG, and the left IPL were negatively correlated with off-line evaluations of stories involving lie- or truth-telling in different social

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contexts. The left PoCG was specifically sensitive to the evaluations of lying about good acts: the activations were greater when participants rated it negatively off-line than when they rated it positively. We will discuss each of these three major findings below.

First, the increased activation in the LG and PoCG might be interpreted in terms of enhanced negative valence associated with bad-act lying relative to bad-act truth-telling. Isenberg and his colleagues suggested that the LG was involved in semantic encoding of threat-valenced words (Isenberg et al., 1999). Narumoto et al. also showed that the right LG was activated in an emotional task relative to either a rest condition or gender task (Narumoto et al., 2000). Another brain area which might be involved in the appraisal of valence information in lie judgments is the PoCG which has been suggested to be involved in basic emotion processing (Ruby and Decety, 2004). Since the bad-act lies in the present study violate social norms, it is reasonable to speculate that they may automatically evoke more negative reactions in participants than truth-telling. However, it should be noted that there were no activation differences between lie- and truth-telling stories in some brain areas that have been suggested to be involved in the processing of emotionally valenced information such as the amygdale (Isenberg et al., 1999; Narumoto et al., 2000). It is possible that although the stories used in the present might have evoked some levels of emotional reaction, the emotional valence of the stories might not have been as sufficiently strong as those used in the previous studies. After all, the present bad act stories all involved lying or truth-telling about minor transgressions by a third party.

Second, activation in the LG, the PoCG, the IPL and the precuneus from judgments of bad-act lies relative to bad-act truth-telling could be interpreted in terms of the involvement of theory of mind (ToM) reasoning in the judgments. The LG is an important area in ToM related reasoning about beliefs and intentions. It has been found that negative self-belief activated the LG relative to the control condition (Goldin and Gross, 2010) and Vollm et al. revealed that the LG was associated with both ToM and empathy (Vollm et al., 2006). Interestingly, Gobbini et al. found that not only the LG but also the IPL were activated more in false belief stories compared with control stories (Gobbini et al., 2007). Additionally, Young and Saxe (2008) suggested that the precuneus is recruited for processing beliefs during moral judgments. As for the left PoCG, previous studies have found that it was associated with participants' reasoning about social contracts (Fiddick et al., 2005). Therefore, activation in the LG, the IPL, the precuneus and the PoCG in the judgment of bad-act lies relative to bad-act truth-telling might be a result of participants' reasoning about the protagonists' intentions or beliefs in the stories of the present study. However, interestingly, some brain areas associated with ToM tasks such as the superior temporal sulcus (STS), and the temporal parietal junction (TPJ) were not activated. This is likely due to the fact that the TPJ has been suggested to be selective for belief attributions when protagonists' thoughts or beliefs are clearly described in the ToM stories (Saxe and Powell, 2006; Young and Saxe, 2008). The lie- and truth-telling stories in the present study did not explicitly describe protagonists' thoughts or beliefs. As for the STS, it has been found to be an important part of the ToM network with a specific function in representing the intentional actions of others through the detection of visual biological motion (Frith and Frith, 1999; Gallagher and Frith, 2003; Pelphrey et al., 2004; Saxe et al., 2004). Because we did not present participants with specific intentional visual information, it was reasonable to expect that the STS would not have been significantly activated in our task.

In addition to the above major findings in neural activations between bad-act lying and bad-act truth-telling, we also found that the neural activations between the bad-act lying and good-act lying were significant in the bilateral SFG, the bilateral cuneus and the left IPL. Existing research has suggested that the SFG is associated with cognitive processing of moral or immoral acts (Borg et al., 2006). In Berthoz et al.'s study, the SFG was activated in intentional violations relative to accidental violations of social norms (Berthoz et al., 2006). Greene and his colleagues found that activation of the SFG was significantly increased during utilitarian rational moral judgments (e.g., choosing to sacrifice one life in order to save five others) relative to non-utilitarian and more emotional moral judgments (Greene et al., 2004). They also found greater activation in the cuneus with easy personal moral judgments compared with difficult personal moral judgments (easy ones have less cognitive conflict than difficult ones), while the activation in the bilateral IPL was greater for difficult compared with easy moral judgments. Further, in a study by Harenski and Hamann (2006), both the SFG and cuneus were activated in the decrease moral condition (i.e., to intentionally decrease emotional responses when viewing moral violation pictures) relative to baseline conditon. These findings from previous studies suggest that the differential activations of SFG, IPL and cuneus in the judgments of two types of lying in the present study might be due to the fact that the two types of lying involved different cognitive processes. The good-act lies in the present study presented a cognitive conflict. On the one hand, lying violates the universal rule of communication that we must inform, not misinform our communicative paterners (Grice, 1975; Lee, 2000). On the other hand, the Chinese culture calls for individuals to be modest and not advertise their good deeds. In contrast, there was no cognitive conflict in the bad-act lie stories. Thus, these crucial differences between the two types of lies might have led to the differential activiations in the bilateral SFG, the bilateral cuneus, and the left IPL, which suggests that the good-lie stories might have enhanced participants' engagement in moral evaluations of lying.

It should be noted that the above brain regions have been suggested to be involved in the more rational aspect of moral judgments and reasoning (Berthoz et al., 2006; Borg et al., 2006; Greene et al., 2004; Harenski and Hamann, 2006). The present finding may suggest that our task has also mainly engaged the participants in rational judgments of lying and truth-telling, perhaps because the stories used in the present study involve a third party (children) entirely unrelated to the participants (adults) and the moral transgressions depicted in the stories were relatively minor. This might also explain why the brain activities in the present study were relatively low. Had we used stories depicting more grave moral violations or that were more relevant to the participants, the brain areas associated with emotional moral judgments such as MFG

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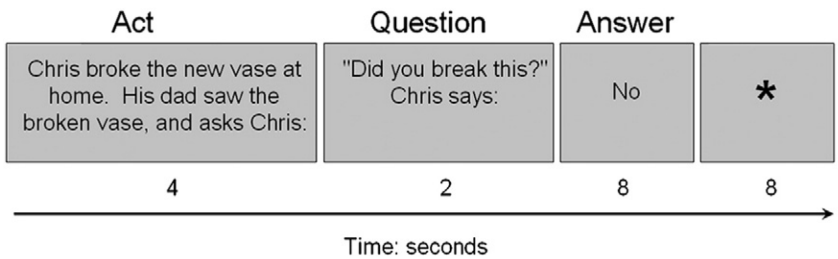

Fig. 1 – Stimulus sequence of one trial. Times under boxes represent stimulus duration. Answers were presented for 8 s and did not disappear after participants responded.

and the STS might have also been enhanced in the judgment of lying relative to truth-telling. Thus, future studies should use other types of stories to fully clarify the neural mechanisms of evaluations of lying or truth-telling.

The final major finding of this study concerned with individual differences in brain activities when participants were involved in evaluations of others' lie- or truth-telling. We found that the activations of the right LG, the left PoCG, and the left IPL were all negatively correlated with off-line evaluations of stories involving lie- or truth-telling in different social contexts. More specifically, the more negative participants rated lie- or truth-telling about the bad acts, the greater activations in these regions. The same was true for the lie- or truth-telling about the good acts: the more negative participants rated the acts, the greater activations in these regions. Further, we found that the left PoCG was even specifically sensitive to the evaluations of lying about good acts: when participants rated it negatively off line, their activations were greater than when they rated it positively.

The significant correlation between out-of-scanner behavioral ratings and in-scanner brain activations is of significant importance. This finding not only reflected individual differences but also could be used to interpret the nature of the differences between evaluations of lying and truth-telling as well as differences between lying in different contexts. As was discussed above, the left PoCG might be involved in the appraisal of valence information in lie judgments. That is, among the three brain areas, the PoCG might be the most sensitive to the positive-negative valence variance of the stories. Thus, not only the right LG, the left PoCG, and the left IPL were sensitive to group differences in the evaluation of lies and truths, they, the left PoCG in particular, appeared to be sensitive to individual differences in positive–negative valence evaluations. Future studies need to use different types of stories to assess whether these areas are unique to the positive–negative valence evaluations of truths and lies or more generally to the evaluations of any positively or negatively valenced acts.

4. Conclusions

The present fMRI study demonstrated a differentiation between lying and truth-telling and between different types of lying in a network of brain regions associated with rational and non-emotional evaluations. These regions contained bilateral superior frontal gyrus (SFG), bilateral inferior parietal lobule (IPL), bilateral cuneus, right precuneus, right lingual gyrus (LG), and left postcentral gyrus (PoCG). Additionally, we found that activations in the right LG, the left IPL and the left PoCG were correlated with off-line evaluations of truthful and untruthful communications about good and bad acts. This study was among the first to demonstrate that evaluations of truthful and untruthful communication in different social contexts can be differentiated in terms of brain BOLD activities.

5. Experimental procedures

5.1. *Participants*

Twenty right-handed healthy subjects (6 males, *M* age = 21.4 - years, range = 18–26 years) participated in this experiment. All of the participants were native Chinese with normal or corrected-to-normal vision and without history of neurological or psychiatric illness. A test of handedness showed that all of the participants were right handed. Data from one female participant were discarded because of a structural brain abnormality found after acquiring the high-resolution anatomical images and data from one male participant were discarded because of significant movement artefacts. The study was approved by the local ethics committee and written

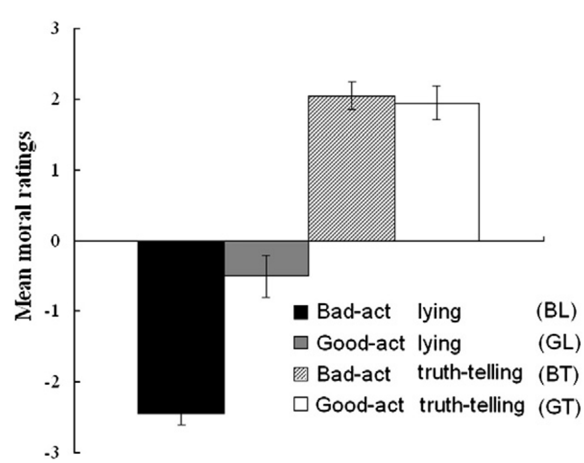

Fig. 2 – Mean off-line moral ratings (with standard errors) of the two types of lying and the two types of truth-telling (positive scores denoting "good" and negative sores denoting "bad").

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consent was obtained from each participant prior to the start of the session.

5.2. Materials and procedure

The session began with a practice section in which participants became familiarized with the procedure of the experiment, and then the fMRI session followed. The fMRI session contained 80 trials. Forty trials were stories where protagonists lied about their acts (the lying stories), and 40 trials were stories where protagonists told the truth about their acts (the truth-telling stories). In 20 of the lying stories, the protagonists committed a transgression and lied about it (e.g., Chris broke the new vase at home. His dad saw the broken vase, and asked Chris, "Did you break this?" Chris answered: "No"). This type of lying was defined as *bad-act lying* (BL). In the other 20 lying stories, the protagonists performed a good act but lied about it (e.g., Jim tidied up the classroom during recess. After seeing the tidy classroom, the teacher asked Jim, "Did you tidy up the classroom?" Jim answer: "No"). This type of lying was defined as *good-act lying* (GL). In 20 of the truth-telling stories, the protagonists told the truth after committing a transgression. This type of truth-telling was defined as *bad-act truth-telling* (BT). In the other 20 truth-telling stories, the protagonists told the truth after performing a good act. This type of truth-telling was defined as *good-act truth-telling* (GT).

All of the trials described everyday events and shared the same structure. They contained 3 parts. The Act part described the protagonist's act (e.g., Chris broke the new vase at home. His dad saw the broken vase and asked Chris). The Question part depicted another individual asking the protagonist about the act (e.g., "Did you break this?" Chris said…). The Answer part was the protagonist's answer ("Yes" or "No") to the above question. Participants were asked to read each story and then make a judgment as to whether the protagonist's answer in each story was "good" or "bad". The procedure is shown in

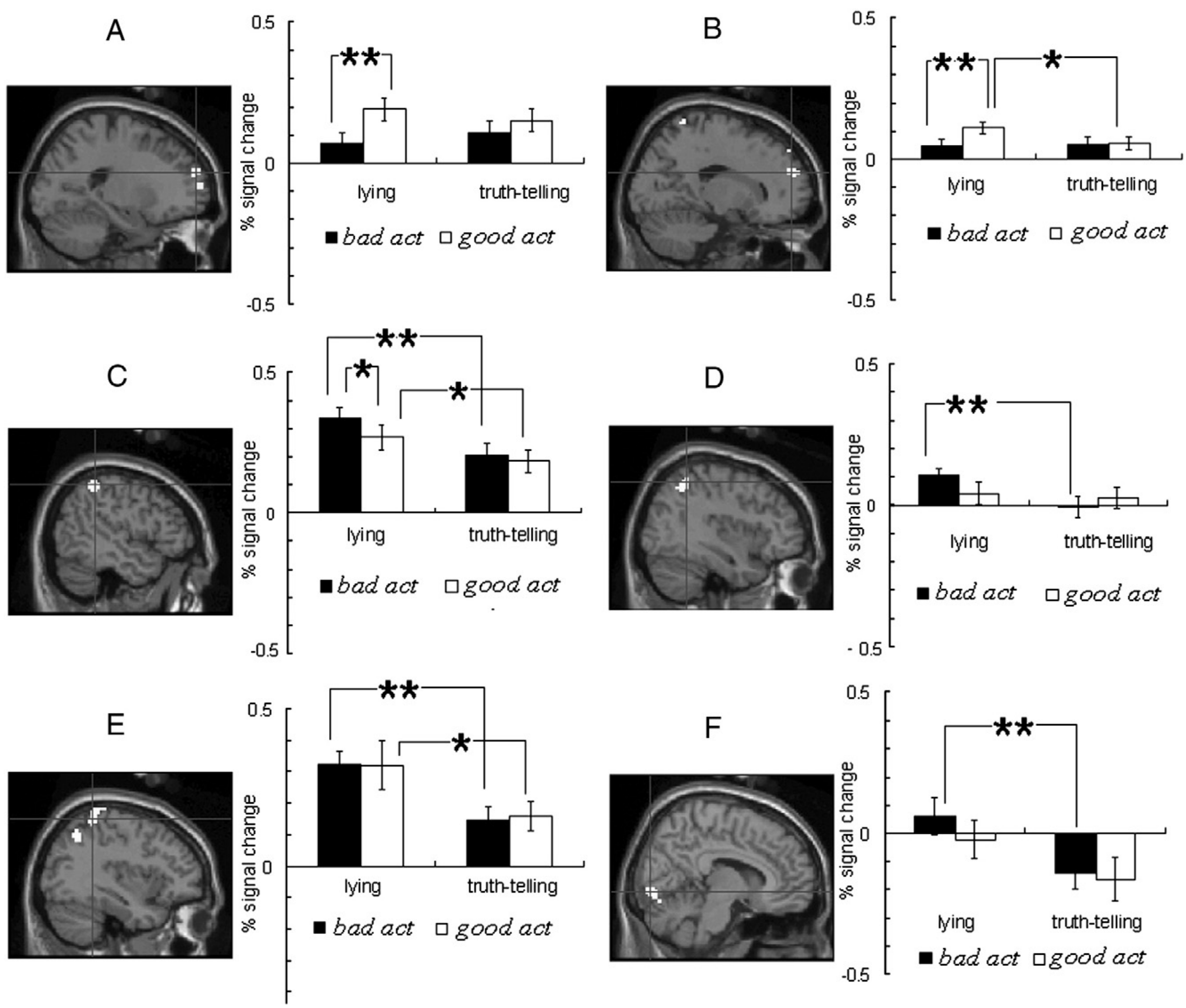

Fig. 3 – Group average activation for the six functional ROIs. Histograms show the percent of signal change at the local maxima (*$p<0.05$; ** $p<0.01$). A = the left superior frontal gyrus; B = the right superior frontal gyrus; C = the left inferior parietal lobule; D = the right inferior parietal lobule; E = the left postcentral gyrus; F = the right lingual gyrus.

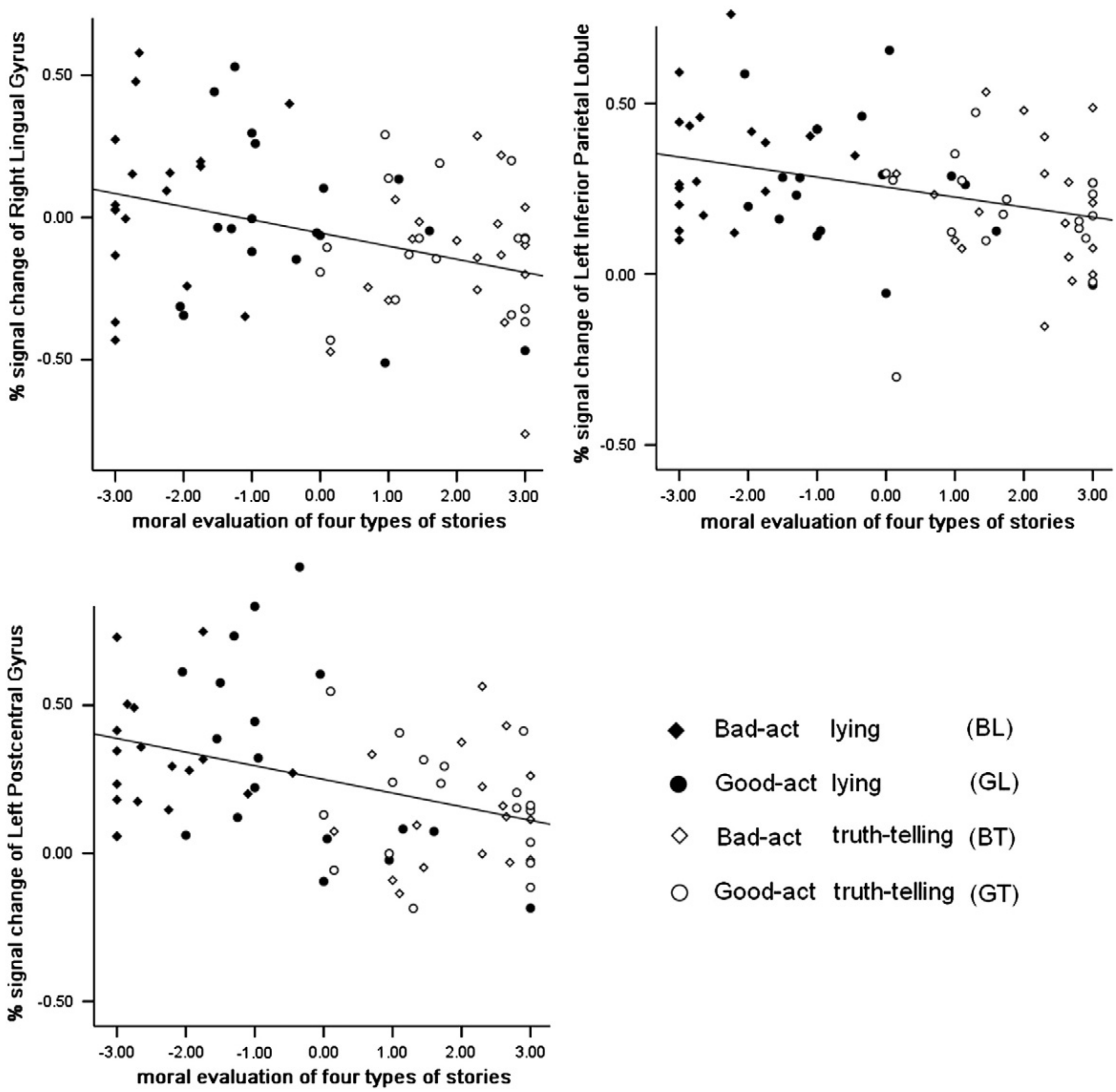

Fig. 4 – Significant correlations between the percentages of signal change in the right lingual gyrus (LG), left inferior parietal lobule (IPL), and left postcentral gyrus (PoCG) during the moral judgment task and the off-line moral ratings.

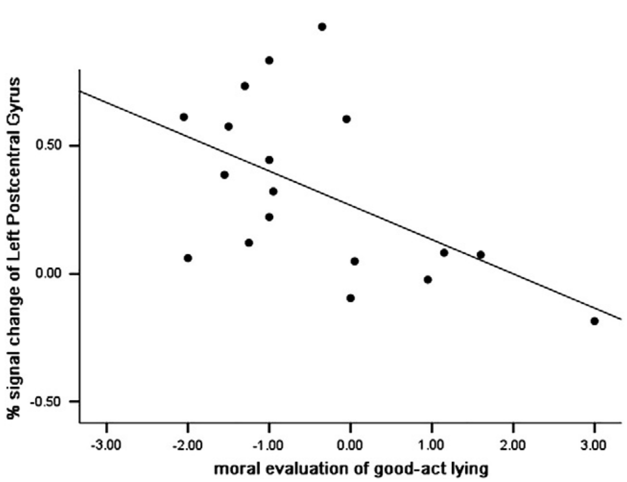

Fig. 5 – Significant correlation between the percentages of signal change in the left postcentral gyrus (PoCG) during the moral judgment task and the off-line moral ratings.

Fig. 1. First, the Act part of each story was presented on the screen for 4 seconds, and then the Question part followed for 2 seconds. Finally, the Answer part was shown for 8 seconds. Participants were asked to judge whether the answer was good or bad by pressing a key after the Answer part was shown. We used a long event related design to ensure that we could capture clear bold signals of judgments of lies or truth. A pilot study showed that participants were able to respond with a judgment within 8 seconds (with an average response time around 2 seconds). Thus, in our design, after the story presentation, there was an Answer part for 8 seconds and another 8-second ISI, which was sufficiently long to allow for capturing clear BOLD signals associated with a specific judgment of lying or truth-telling.

After the fMRI session, outside the MRI scanner, participants were asked to complete a questionnaire which contained the same stories presented during the fMRI task. They were asked to judge the protagonist's answer on a seven-point scale from very bad (rated as −3) to very good (rated as 3). The stories in the questionnaire were randomly ordered.

5.3. MRI data acquisition

We used a Siemens 3 T Trio MRI scanner to acquire whole-brain imaging data at BNU Imaging Center for Brain Research. Whole-brain functional images with blood-oxygenation-level-dependent (BOLD) contrasts were acquired using T2*-weighted gradient echo-planar imaging (EPI) sequences (TR = 2 s, TE = 30 ms, 64 × 64 matrix, 3.125 × 3.125 × 4 mm voxel size, 28 slices, slice thickness = 4 mm, interslice gap = 0.6 mm, flip angle = 90°, FOV = 200 × 200 mm). A total of 225 scans were obtained in each of the five fMRI runs. After the acquisition of functional images, whole-brain structural images were acquired using T1-weighted MPRAGE sequences (TR = 2530 ms, TE = 3.39 ms, FOV = 256 × 256 mm, 256 × 192 matrix, flip angle = 7°, 1.33 × 1 × 1.33 mm voxel size, 128 slices, slice thickness = 1.33 mm, interslice gap = 0 mm). Head movement was limited by the placement of padding.

5.4. fMRI data preprocessing

We used statistical parametric mapping (SPM2; Wellcome Department of Imaging Neuroscience, London, UK) implemented in MatLab 6.5 (Mathworks Inc., Sherborn, MA) to analyze the MRI data. Images were time-sliced and then realigned to the first volume of the five runs to correct for inter-scan movement. The images were then re-sampled as a 3 × 3 × 3 mm voxel size and spatially normalized using the EPI template. At the end of the preprocessing, the images were spatially smoothed using an 8 mm (FWHM) Gaussian kernel which was necessary to fulfill the statistical assumptions of the random-effect analysis.

5.5. Random-effect statistical data analysis

First, preprocessed data were analyzed at the individual level using the standard general linear model approach of SPM2. Convolving with a synthetic hemodynamic response function (HRF), the event-related responses for the four types of experimental stories were modeled. These models contained the movement parameters obtained from the realignment procedure to minimize the influences of movement artifacts. Low frequency noise was removed using a high-pass filter (128 s) (Holmes et al., 1997). Four t-contrast maps were calculated: BL versus BT; GL versus GT; BL versus GL; and GL versus BL. Second, at the group level, a voxel-by-voxel single sample *t*-test was performed to determine whether the contrast differed from zero. Clusters were considered significant only if there were 10 contiguous voxels, each with a statistical threshold of $p < 0.001$ (uncorrected). All coordinates were reported in MNI space. The coordinates were converted into Talairach space using an MNI2TAL program (Cognition and Brain Science Unit, Medical Research Council, Cambridge, UK), and anatomical labels were generated using the Talairach Daemon database (Lancaster et al., 1997).

5.6. Regions-of-interest (ROI) analysis

Using the toolbox MarsBar (Brett et al., 2002), we evaluated the GLM used for the group analysis for six ROIs and for each participant. Because a clear definition of functional regions was absent in the research of lie- and truth-telling judgments, the six ROIs were defined as a 6 mm × 6 mm × 6 mm box centered at the peak of the parametric activation. Estimates of the percentage of signal change during the judgment of BL, BT, GL, and GT stories were extracted for the six ROIs. Two-way ANOVAs of *truthfulness* (lying vs. truth-telling) by *act valence* (bad vs. good) were performed on the percentage of signal change. Finally, we performed correlation analysis to clarify whether the BOLD response was significantly related to participants' evaluations outside the MRI scanner.

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