

Neural correlates of spontaneous deception in a non-competitive interpersonal scenario: A functional near-infrared spectroscopy (fNIRS) study

Xiaohong Allison Lin^{a,b,*}, Chongxiang Wang^{a,1}, Jie Zhou^a, Liyang Sai^{a,b}, Genyue Fu^{a,b,c,*}

^a Institutes of Psychological Sciences, Hangzhou Normal University, Hangzhou, China

^b Zhejiang Key Laboratory for Research in Assessment of Cognitive Impairments, Hangzhou Normal University, Hangzhou, China

^c Department of Psychology, Zhejiang Normal University, Jinhua, China

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ABSTRACT

This study aims to examine neural correlates of spontaneous deception in a non-competitive interpersonal situation, and the difference in neural correlates between spontaneous deception and instructed deception using functional near-infrared spectroscopy (fNIRS). We used a modified poker game in which participants freely decided whether sending a piece of truthful/deceptive information to other participants. In the instructed session, participants sent truthful/deceptive information per the instructions. In this non-competitive interpersonal situation in the orbitofrontal cortex (OFC) and dorsolateral prefrontal cortex (DLPFC), deception produced higher neural activities than truth-telling. In addition, spontaneous deception exhibited higher neural activities than instructed deception in the frontopolar area, DLPFC, and frontal eye fields. Spontaneous truth-telling produced higher neural activities than instructed truth-telling in frontal eye fields and frontopolar area. This study provides evidence about neural correlates of spontaneous deception during non-competitive interpersonal scenarios and the difference between spontaneous deception and instructed deception.

1. Introduction

Deception is a common occurrence in any social interaction, such as politics, business, and economics, and could lead to dangerous consequences like catastrophic economic loss or national security problems. Per the Association of Certified Fraud Examiners (Association of Certified Fraud Examiners (ACFE), 2018), approximately 2690 real cases of occupational fraud were reported in 2018, accounting for over \$7 billion loss in total. An even serious scenario is when terrorists deceive the national security system and cause uncountable price of human lives all over the world. All such events have highlighted the significance of comprehending deceptive behavior.

Recent progress of neuroscience has made it feasible for researchers to investigate the neural mechanism underlying deception with neuroimaging techniques (fMRI; Greene & Paxton, 2009; Sip et al., 2010, 2012; Sun et al., 2015). Initially, most of the studies used differentiation of deception paradigm (DDP) to examine “instructed deception” in which participants were instructed to lie (e.g. Ganis et al., 2009;

Langleben et al., 2002). However, in real life, people typically lie spontaneously with certain motivation or expect to profit from it (Sip et al., 2008), but rarely to lie under others’ instructions. Owing to this limitation, a number of studies have started to explore neural correlates of spontaneous deception (Abe et al., 2014; Abe & Greene, 2014; Ding et al., 2013; Greene & Paxton, 2009; Pornpattananangkul et al., 2018; Yin et al., 2016). For instance, Greene and Paxton (2009) used a computed coin-flip task to examine neural correlates of the spontaneous deception. In their task, participants could get money by precisely predicting the outcomes of coin-flips. In the “No-Opportunity” condition, participants predicted the outcomes in advance; however, in the “Opportunity” condition, participants reported their prediction after the actual outcomes of coin-flips, which provided an opportunity to misreport their predictions to get money. They found that participants who lied about their outcomes displayed increased activity in the dorsolateral prefrontal cortex (DLPFC) when they choose to lie than when they choose to tell the truth. As the DLPFC is typically related to executive control, such as inhibition, or working memory (Abe et al., 2008; Barbey

* Corresponding authors at: Institutes of Psychological Sciences, Hangzhou Normal University, Hangzhou, China.

E-mail addresses: zhulin24show@hotmail.com, xiaohonglin@hznu.edu.cn (X.A. Lin), fugenyue@hznu.edu.cn (G. Fu).

¹ These authors contributed equally to this work.

et al., 2013; Courtney et al., 1998; Gamer et al., 2007; Greene & Paxton, 2009; Spence, 2008; Sun et al., 2015; Yin et al., 2016; Yin & Weber, 2019), these findings suggest that spontaneous deception requires more executive control than spontaneous truth-telling.

However, all the studies mentioned above examined spontaneous deception in a situation where no concrete receiver was involved. Based on the interpersonal deception theory (Buller & Burgoon, 1996; Burgoon et al., 1994; Vrij, 2008), deception comprises three elements—a liar, a receiver, and deliberate deceptive intention (Abe, 2011; Buller & Burgoon, 1996; Levine & Knapp, 2018; Vrij, 2008). Deception usually happens in an interactive context with information exchanging between liars and receivers; driven by this theory, many studies examined the neural correlates of spontaneous interpersonal deception using interactive paradigms (e.g. Sip et al., 2008, 2012; Volz et al., 2015). For example, Volz et al. (2015) adopted a sender–receiver game to examine neural correlates of spontaneous interpersonal deception. Their studies had two players—a sender and a receiver; the sender was informed about two different options (one was blue, and the other was red) corresponding to different monetary, and the sender had to send a message telling the receiver which option is more profitable for the receiver. As only the sender knew which option was more profitable, the sender could send a false message to mislead the receiver; however, the receiver could choose to believe or not what the sender sent. Thus, the sender could also send truthful messages to mislead the receiver (truth-telling with a deceptive intention). The findings revealed that both truth-telling with deceptive intentions and deception were associated with increased activity in the right temporoparietal junction (rTPJ), the dorsal anterior cingulate cortex (ACC), the (pre) cuneus (CUN), and the anterior frontal gyrus (aFG) than truth-telling without deceptive intentions (also see Volz et al., 2020). Using a similar paradigm, Sip et al. (2008) reported that both truth-telling with deceptive intentions and deception are associated with activity in the frontopolar cortex (BA10) than truth-telling without deceptive intentions. Despite different results across different paradigms, these findings suggested that both deception and truth-telling needs high executive strategies such as the theory of mind and inhibitory control in interpersonal situations.

However, the fMRI technique requires participants to lie in a boisterous and narrow space, as well as remain absolutely still, which is far away from real interaction scenario. Instead, the functional near-infrared spectroscopy (fNIRS) technique can offer the brain imaging insight while enabling participants to sit, stand, walk, and even run during the signal acquire period (Beurskens et al., 2014; Lee et al., 2014; Naseer & Hong, 2015), thereby making fNIRS a better brain imaging technique to explore spontaneous deception in real interpersonal scenarios (Li et al., 2015; Zhang et al., 2016). To date, only limited studies have used fNIRS to explore spontaneous interpersonal deception (Ding et al., 2014; Liu et al., 2017; Tang et al., 2018; Zhang et al., 2017). For example, Ding et al. (2014) used a hide and seek paradigm with fNIRS to examine neural correlates of spontaneous deception in an interpersonal scenario. In their study, participants played a competitive game with an experimenter in which participants hid a coin in one of their hands, and the experimenter guessed which hand the coin was hid. Participants won a reward if the experimenter did not correctly guess where the coin was. Before guessing, the experimenter asked participants which hand the coin was hid. As participants were aware that the experimenter might not believe what they said, participants can either tell the truth or lie to mislead the experimenter. Corroborating previous fMRI studies, they reported that both spontaneous deception and truth-telling with deceptive intention in the interpersonal situations elicited higher oxygenated hemoglobin (HbO) changes in the prefrontal cortex (the right superior frontal gyrus, BA6) than truth-telling without deceptive intention. Moreover, spontaneous deception elicited higher neural activities in the right middle frontal gyrus than spontaneous truth-telling with a deceptive intention. Tang et al. (2018) used an adapted ultimatum game and demonstrated that spontaneous deception involved higher activation in the right DLPFC than spontaneous truth-telling

during face-to-face interactions. Furthermore, they found that the right DLPFC activity during deception diminished while the deception magnitude escalated, indicating the role of the right DLPFC in the slippery-slope effect of deception (i.e., the escalation of small lies over time). Of note, these fNIRS findings provide evidence about neural correlates of spontaneous deception in a more real interpersonal situation.

Although the studies mentioned above have shed light on neural correlates of deception in an interpersonal situation, most studies have examined interpersonal deception in a highly competitive situation. In this situation, the receiver is aware of deceiver's intention; thus, the deceiver could also tell the truth to mislead the receiver. Although such deception is common in certain situations, such as negotiation and wars, deception with a specific receiver in a non-competitive situation is also common in real life. In a competitive situation, as the receiver are aware of the deceptive intention and could choose not to believe what the deceiver sent, to deceive successfully, the deceiver has to track the receiver's mental states and plan a strategy. In this situation, both truth-telling and lie-telling serves to deceive. However, in a non-competitive situation where a receiver have to accept what the deceiver sent, to lie to a receiver, the deceiver confronts conflicts between telling the truth to maintain their positive self-concept and telling a lie to get money (Mazar et al., 2008). Meanwhile, telling a lie also implies hurting the receivers, which also violates the intuitive prosocial rules (Köbis et al., 2019; Zaki & Mitchell, 2013). Currently, it remains unknown about neural correlates underlying such interpersonal deception. Thus, the first aim of this study is to examine neural correlates of spontaneous interpersonal deception in a non-competitive situation. Another aim is to explore the neural differences between spontaneous deception and instructed deception during interpersonal scenario. Although a few studies have examined spontaneous deception, to the best of our knowledge, only limited studies have explored the difference between spontaneous deception and instructed deception during interpersonal scenarios (Ding et al., 2014).

To address the questions raised above, this study adopted an interpersonal gambling task, which includes two sessions—spontaneous deception session and instructed deception session. During the spontaneous deception session, both participants and their partners were dealt with a poker card, and whoever got the bigger point received a reward in the trial. The participant could see the outcomes of both cards and was asked to send a message to his/her partner about who won in this trial, thereby providing an opportunity for participants to send a deceptive message for monetary reward. During the instructed deception session, participants sent truthful or deceptive messages as instructed. We recorded participants' brain activities in the prefrontal cortex regions using fNIRS.

Based on the relevant literature, we hypothesized that spontaneous deception in this non-competitive situation involves higher activities in control-related brain regions, such as DLPFC than spontaneous truth-telling, because spontaneous deception requires participants to inhibit the truthful response compared with spontaneous truth-telling (Abe et al., 2008; Köbis et al., 2019; Lisofsky et al., 2014). When deciding to deceive, or to tell a truth during a spontaneous session, participants need to consider the previous decisions to maintain a balance in the conflict between getting rewards and maintaining a positive self-concept, for example, to deceive for monetary reward but as much as possible to keep their own self-concept (Mazar et al., 2008), thus spontaneous deception/truth-telling would involve higher activity in the frontopolar area than instructed deception/truth-telling (Sip et al., 2010).

2. Materials and methods

2.1. Participants

We enrolled 24 participants (11 males; $M_{\text{age}} = 20.33$ years; $SD = 0.92$ years), who had no reported history of neurological or psychiatric

disorders and were all right-handed, with normal or corrected-to-normal visual activity. All participants provided written informed consent to participate and comply with the experimental procedures. This study was approved by the Ethics Committee of Zhejiang Normal University.

2.2. Procedures

During the experiment, the participants were seated in front of a computer screen in a quiet room. After reading the instructions, the participant was asked to play a poker game with a partner who was sitting in another room; they could not see each other until the end of the experiment.

In this poker game, two pokers with their points 1–13 were randomly selected by a computer; while one was for participants, the other one was for their partners. At this time, both could not see the points in the two pokers. Participants were told that their partners always picked one first; thus, the other one is for themselves. If participants got higher points in their pokers than their partners, the participants won the trials. After both picked one poker, participants could see the points, and thus knew who won in each trial. Participants were told that their partners could not see the points; thus, they needed to send messages to tell them who won for this trial by pressing the buttons. To win the game, participants had an opportunity to deceive their partners (e.g., tell their partners that they won when their partners won). At the beginning of each trial, there were three reward categories for winners in each trial (0.5, 1, or 2 RMB; 1 RMB = 15 cents). Moreover, we encouraged participants to try to win the game as many as they can by giving them extra bonus.

After the instructions, the participants were seated about 1-m away from the PC monitor. Each trial began with a 500-ms fixation. After the computer deal for 1000-ms, the partner picked his/her poker first, following which the participant got to see his/her poker for 1000 ms. Then, both participants' poker and the partners' poker were shown on the screen for 2000 ms. After another 4000-ms blank baseline data collection, the "pass the result" appeared, following which the participants pressed the "I win" or "you win" button as quickly and precisely as possible to send the result to their partner. Finally, an 11,000-ms blank was shown. There were 40 trials for this spontaneous deception session.

Every card appearing in the game was pseudo-randomized. Participants could only get the bigger poker point 10 times. Thus, there were 30 trials in which the poker points a participant got was smaller than their partner's, providing the participant with an opportunity to lie to get more reward. For each trial, participants could choose spontaneously to pass the partners the "real" result or the "false" one (see Fig. 1 for an example of one trial).

In addition, an instructed deception session was included, which was similar to the spontaneous deception session, except that the participant made decisions according to the instructions. During the computer deal, the participants received the message of "truth" or "lie"; participants were told to tell a lie or tell the truth based on the instructed messages. There are 30 trials in the instructed deception session had 30 trials, including 10 trials where participants got the bigger points, and 20 trials where they got the smaller point in which participants were instructed to lie in 10 trials and tell the truth in the other 10 trials.

2.3. fNIRS recordings

We used a 24-channel continuous wave system (ETG-4000; Hitachi Medical Co., Japan; Fig. 2a). The probes of the NIRS machine were fixed using one 9 cm × 9 cm rubber shell over the frontal areas. The shell was covered with a nylon-net to keep it attached to the head. The shell of 16 probes, with 4 × 4 arrays, including 8 light emitters and 8 detectors, could measure the relative concentrations of hemoglobin at 24 locations. The lowest probes were positioned along the Fp1–Fp2 line according to the international 10–20 system. The inter-optode distance was 30 mm, which enabled measuring neural activities approximately 15–25 mm beneath the scalp. In addition, we collected optical data from individual channels at two different wavelengths (695 and 830 nm) and analyzed using the modified Beer–Lambert Law for a highly scattering medium (Cope & Delpy, 1988). The sampling rate was set at 10 Hz.

We used a 3D-magnetic space digitizer (EzT-DM401; Hitachi Medical Co., Japan) to record the 3D locations of each optode on each participant's scalp. Furthermore, we used the probabilistic registration method (Singh et al., 2005) to obtain an estimation of each channel's corresponding location in the Montreal Neurological Institute (MNI) space. Fig. 2b and c shows the locations of 24 NIRS channels on the

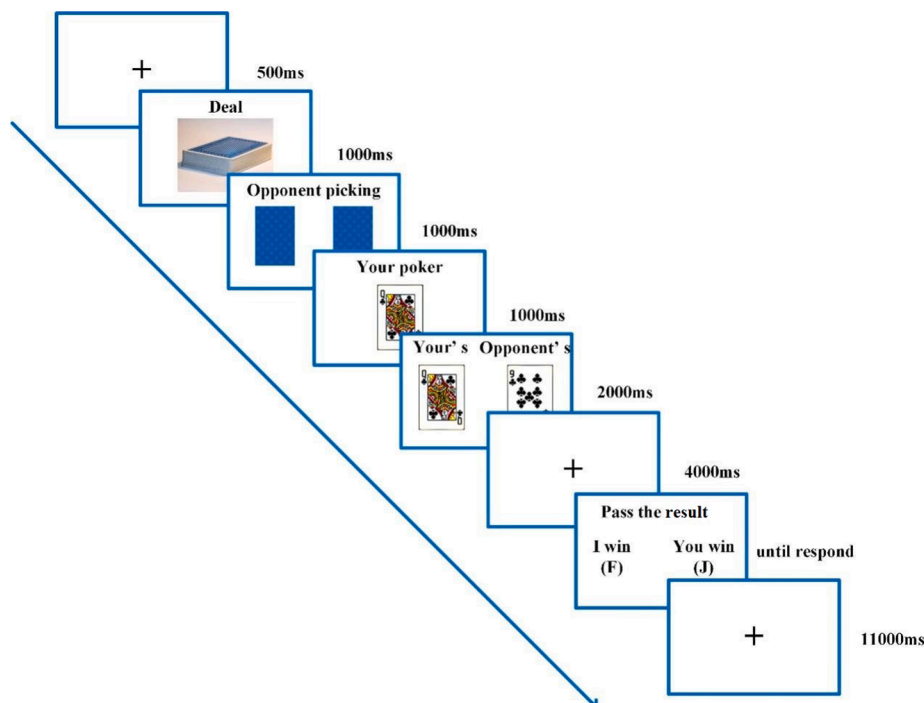


Fig. 1. An example of a trial in the spontaneous session.

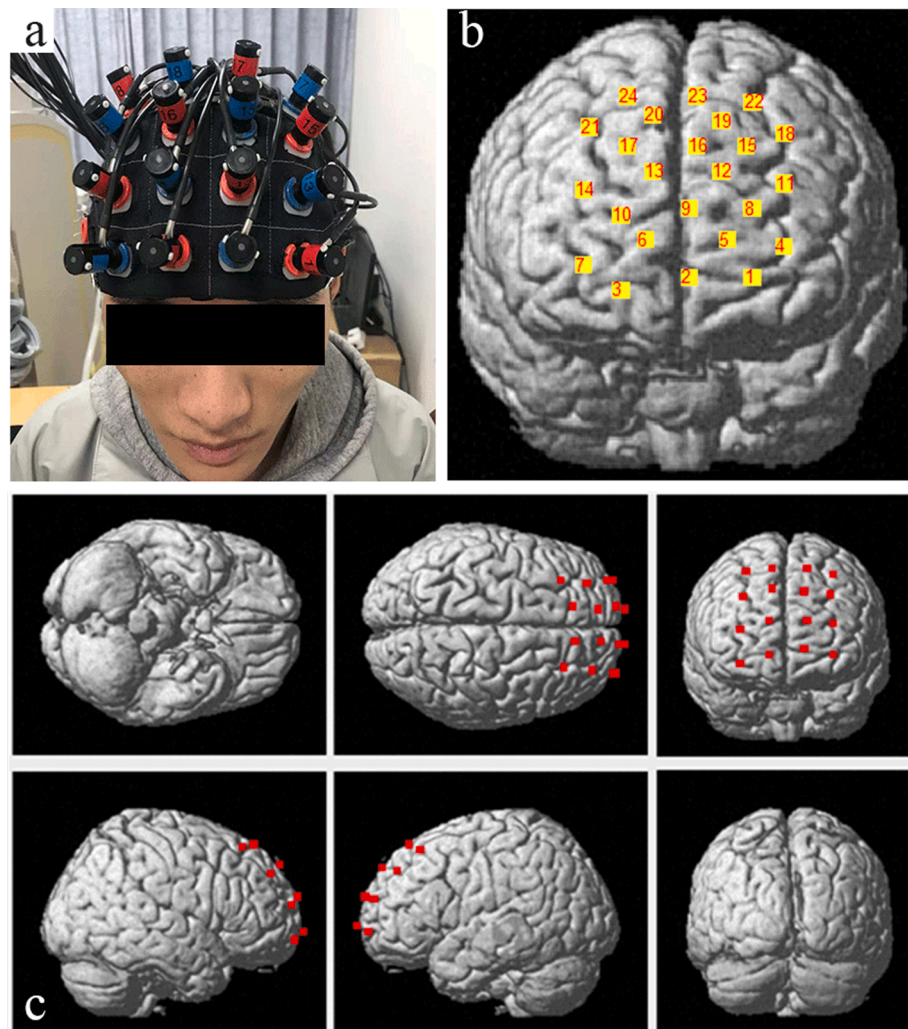


Fig. 2. (a) The arrangements of optodes and electrodes along the cap. (b) The estimated cortical locations of the 24 NIRS channels. (c) The estimated cortical locations of the 4×4 array of sources and detectors.

cortex.

2.4. NIRS data analysis

In this study, we only examined HbO changes because HbO is the most sensitive indicator of the regional cerebral blood flow activities, whereas HbR signals are noisy and unreliable (Homae et al., 2007; Lin et al., 2018). Several steps were needed to analyze the raw times series data and to remove baseline drifts and pulsation because of the heart-beat, the raw hemoglobin continuous data was filtered with a high-pass filter of 0.01 Hz and a low-pass filter of 0.3 Hz. Then, we segmented the data by different marks; the marks were obtained from the participants when they pressed the button while responding to “pass the result.” There were two types of marks in the spontaneous/instructed deception session—lying or truth-telling. Then, the baseline was calculated using the least-squares model fitting procedure according to the activities in the pre-stimulus and post-stimulus period. For each epoch of each channel, a first-degree baseline fit to the mean of the 2-s pre-stimulus and 11-s stimulus and recovery period was performed. After baseline correction, we computed the mean and standard deviation of each channel for each participant and converted the raw time course value to Z scores. Then, we averaged all event epochs for the channel of a particular trial type to derive a grand averaged time-course waveform of the channel for the trial type (Ding et al., 2013, 2014; Fu et al., 2014; Sai et al., 2014). Moreover, the peak values of averaged HbO changes were

extracted from each channel of each participant for further statistical analysis. Furthermore, the P values were corrected by false-discovery rate (FDR < 0.05; Singh & Dan, 2006).

3. Results

3.1. Behavioral results

Spontaneous deception session comprised 10 trials of participants win and 30 trials of participants lose; all participants told the truth when they won in these 10 trials. While, for the 30 trials of participants lose, participants lied on 15 trials on average (SD = 3.59), while told the truth on 15 trials on average (SD = 3.59). The one-sample *t*-test revealed no significant difference between hypothesized and observed lying trials ($p > 0.05$, Cohen’s $d = -0.01$). In the instructed deception session, all participants completed 10 trials of lying and 10 trials of truth-telling as required.

3.2. fNIRS results

3.2.1. Spontaneous deception vs. Spontaneous truth-telling in the spontaneous deception session

To examine the neural correlates underlying the spontaneous deception, we used the paired *t*-test to compare the spontaneous deception and the spontaneous truth-telling condition (Table 1). We

Table 1The paired *t*-test results about oxygenated hemoglobin (HbO) of the hemodynamic activities.

Channel	x	y	z	Brain region (Brodmann's area)	Probability	oxy	C1	C2
Spontaneous deception compared spontaneous truth-telling								
Ch3	21	72	-5	Orbitofrontal area (Right SFG, BA11)	0.74	$t = 2.564^*$	0.225	0.161
Ch16	-4	56	43	Dorsolateral prefrontal cortex (Left SFG, BA9)	0.95	$t = 2.373^*$	0.224	0.152
Spontaneous deception vs. instructed deception								
Ch4	-32	65	9	Frontopolar area (Left SFG, BA10)	0.88	$t = 3.901^{**}$	0.194	0.103
Ch7	32	68	4	Frontopolar area (Right SFG, BA10)	0.66	$t = 2.757^*$	0.193	0.103
Ch11	-32	55	30	Dorsolateral prefrontal cortex (Left MFG, BA46)	0.97	$t = 3.801^{**}$	0.278	0.175
Ch14	31	58	28	Dorsolateral prefrontal cortex (Right MFG, BA46)	0.77	$t = 4.208^{***}$	0.236	0.134
Ch18	-31	39	47	Dorsolateral prefrontal cortex (Left MFG, BA9)	0.95	$t = 2.744^*$	0.21	0.139
Ch20	10	49	51	Dorsolateral prefrontal cortex (Right MFG, BA9)	0.84	$t = 3.074^*$	0.233	0.127
Ch22	-22	34	57	Frontal eye fields (Left SFG, BA8)	0.75	$t = 4.856^{***}$	0.23	0.09
Spontaneous truth-telling vs. instructed truth-telling								
Ch4	-32	65	9	Frontopolar area (Left SFG, BA10)	0.88	$t = 3.543^*$	0.176	0.078
Ch22	-22	34	57	Frontal eye fields (Left SFG, BA8)	0.75	$t = 4.076^{***}$	0.193	0.082

C1, condition 1; C2, condition 2; BA, Brodmann area; SFG, superior frontal gyrus; MFG, middle frontal gyrus.

* $p < 0.05$.** $p < 0.01$.*** $p < 0.001$.

found that spontaneous deception elicited significantly higher HbO changes than spontaneous truth-telling in channel 3 ($t_{23} = 2.564$, $p = 0.017$, Cohen $d = 1.069$; FDR-uncorrected) and channel 16 ($t_{23} = 2.373$, $p = 0.026$, Cohen $d = 0.990$; FDR-uncorrected) (see representative channel 3 in Fig. 3a).

3.2.2. Spontaneous deception vs. Instructed deception

To analyze the difference of neural correlates underlying spontaneous deception and instructed deception, we used the paired-sample *t*-test to compare the spontaneous and instructed deception (Table 1). The results revealed that spontaneous deception elicited significantly higher HbO concentration changes than instructed deception in channels 4, 7, 11, 14, 18, 20, and 22 ($t_s \geq 2.744$, $p_s \leq 0.044$; channel 4: $t_{23} = 3.901$, $p = 0.008$, Cohen $d = 1.627$; channel 7: $t_{23} = 2.757$, $p = 0.044$, Cohen $d = 1.150$; channel 11: $t_{23} = 3.801$, $p = 0.006$, Cohen $d = 1.585$; channel 14: $t_{23} = 4.208$, $p < 0.001$, Cohen $d = 1.755$; channel 18: $t_{23} = 2.744$, $p = 0.041$, Cohen $d = 1.144$; channel 20: $t_{23} = 3.074$, $p = 0.024$, Cohen $d = 1.282$; channel 22: $t_{23} = 4.856$, $p < 0.001$, Cohen $d = 2.025$; FDR-corrected; see representative channel 7 in Fig. 3b).

3.2.3. Spontaneous truth-telling vs. Instructed truth-telling

To analyze the difference in neural correlates underlying, we used the paired-sample *t*-test to compare spontaneous truth-telling and instructed truth-telling (Table 1). We found that spontaneous truth-telling elicited higher HbO changes than instructed truth-telling in channel 4 ($t_{23} = 3.543$, $p = 0.024$, Cohen $d = 1.478$; FDR-corrected) and channel 22 ($t_{23} = 4.076$, $p < 0.001$, Cohen $d = 1.700$; FDR-corrected; see representative channel 4 in Fig. 3c).

3.3. Correlations between neural responses and participants' deception frequency

To explore the correlation between participants' deceptive behavior and their neural responses, we performed Pearson correlations between participants' deception frequency and their HbO changes (peak value) during spontaneous deception. The results revealed that participants' deception frequency negatively correlated with HbO changes in channel 14 (Fig. 4a) and channel 17 during spontaneous deception (Fig. 4b).

4. Discussion

This study investigated neural correlates of spontaneous deception in a non-competitive interpersonal scenario, as well as neural differences between this spontaneous interpersonal deception and instructed deception. We found that spontaneous deception exhibited higher HbO changes than spontaneous truth-telling in the orbitofrontal area (right SFC, BA11) and DLPFC (left SFG, BA9). In addition, we found that spontaneous deception was associated with increased HbO changes in the frontopolar area (anterior prefrontal cortex, bilateral SFG, BA10), DLPFC (bilateral MFG, BA9 and 46), and frontal eye fields (left SFG, BA8) than instructed deception; spontaneous truth-telling elicited higher HbO changes in frontal eye fields (left SFG, BA8) and frontopolar area (anterior prefrontal cortex, left SFG, BA10) than instructed truth-telling. These findings provide evidence about neural correlates of spontaneous deception in a non-competitive interpersonal situation.

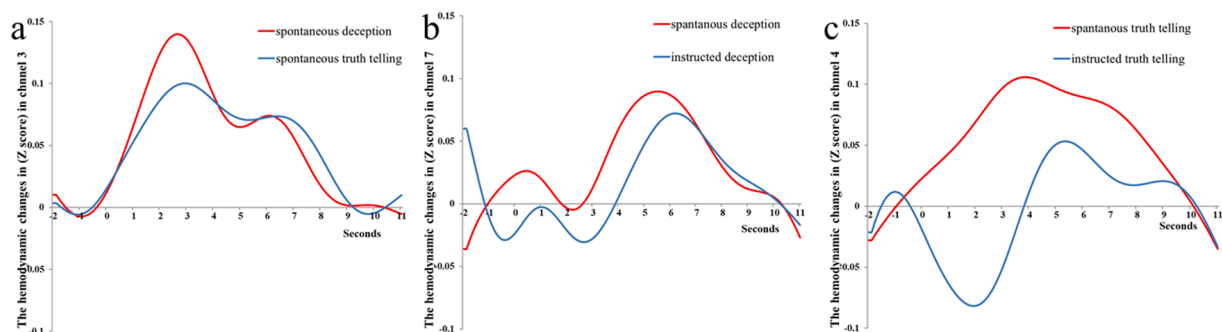


Fig. 3. (a) The time courses of the mean hemodynamic changes (Z-value) of spontaneous deception and spontaneous truth-telling in channel 3. (b) The time courses of the mean hemodynamic changes (Z-value) of spontaneous deception and instructed deception in channel 7. (c) The time courses of the mean hemodynamic changes (Z-value) of spontaneous truth-telling and instructed truth-telling in channel 4.

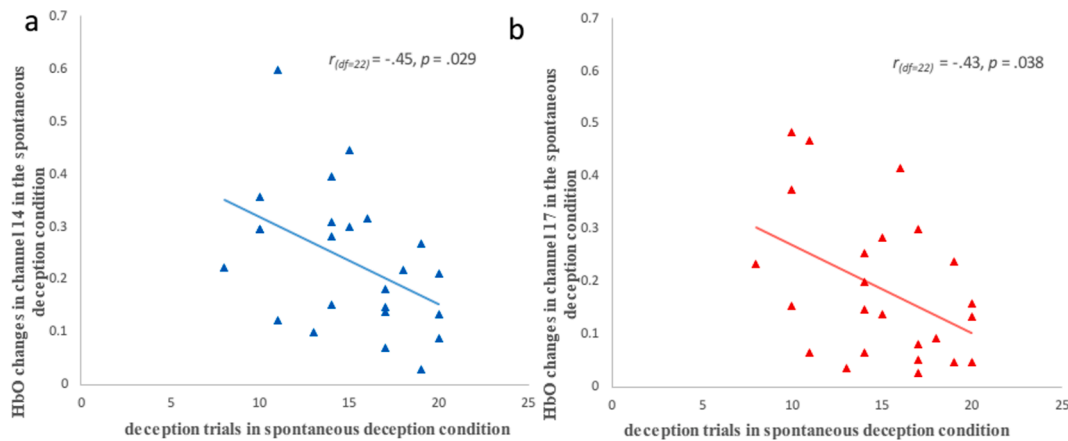


Fig. 4. The scatters plot of correlations between HbO changes and participants' deceptive behaviors. (a) The correlation between HbO changes in channel 14 and deception frequency in spontaneous deception session. (b) The correlation between HbO changes in channel 17 and deception frequency in spontaneous deception session.

4.1. Spontaneous deception vs. Spontaneous truth-telling

Compared with spontaneous truth-telling, spontaneous deception elicited stronger HbO changes in the orbitofrontal area (left SFG, BA11) and DLPFC (right SFG, BA9). Reportedly, DLPFC was associated with tasks which require cognitive control (Aron et al., 2014; Christ et al., 2008). In this study, when participants sent a deceptive message, they needed to inhibit the truthful message and make a false response, which involved higher cognitive control than they sent a truthful message, and thus spontaneous deception was associated with higher DLPFC activity; this finding was consistent with many previous studies which also found that deception was associated with and increased activity in DLPFC than truth-telling (Christ et al., 2008; Lisofsky et al., 2014).

Inconsistent with our prediction, we found that spontaneous deception elicited higher HbO changes in the orbitofrontal area than spontaneous truth-telling. The orbitofrontal cortex is considered to play a crucial role in value-based decision-making (Bechara et al., 2000; Padoa-Schioppa & Conen, 2017; Rolls, 2000), which could lead individuals to choose the preferred one consistently and flexibly during variable circumstances (Padoa-Schioppa & Conen, 2017). In this study, spontaneous deception and truth-telling were two options for participants to choose in which spontaneous deception could lead to reward, but not truth-telling. Thus, the activation in the orbitofrontal cortex associated with deception, which might reflect monetary value evaluation during spontaneous deception.

4.2. Spontaneous deception vs. Instructed deception

We found that the frontopolar area (anterior prefrontal cortex, bilateral SFG, BA10), DLPFC (bilateral MFG, BA9, and 46), and frontal eye fields (left SFG, BA8) exhibited higher HbO changes associated with spontaneous deception compared with instructed deception.

Consistent with our prediction, we found that the frontopolar area was more activated in the spontaneous deception than instructed deception. The frontopolar area was associated with high-level executive control in action selection (Koechlin & Summerfield, 2007). Previous studies suggested that it is especially crucial to the construction of deception to consider into the past and upcoming decisions. (Abe et al., 2006; Sip et al., 2010). During our task, when participants decided to whether or not to deceive, they could consider their previous action and upcoming action then decided to lie or tell the truth. To balance the positive self-concept they maintained and the monetary reward they got, participants could keep lying to get more monetary reward when they can maintain the positive self-concept, whereas when the negative self-concept appeared, they needed to give up the reward and stop lying to

get the positive self-concept back. (Mazar et al., 2008). While during instructed deception, participants only needed to follow the instruction to tell the truth or lie. Thus, higher activation of the frontopolar area was observed in spontaneous deception compared with instructed deception.

Unexpectedly, we found that spontaneous deception elicited greater DLPFC than instructed deception. As discussed earlier, DLPFC plays crucial roles in cognitive control (Christ et al., 2008; Kerns et al., 2004; Yin et al., 2016). Thus, there would be no difference for DLPFC between spontaneous deception and instructed deception because both need to inhibit the truthful response. However, some recent studies suggested that DLPFC also associated with decision to be honest or dishonest (Greene & Paxton, 2009). In this study, both spontaneous deception and instructed deception involved cognitive control to inhibit the truthful response during the executive stage. However, during the decision stage, spontaneous deception also required participants to use cognitive control to resolve conflict between the desire to get a reward and the desire to maintain a positive self-concept (Mazar et al., 2008), which might elicit more activity in DLPFC during spontaneous deception. Of note, our finding is also consistent with a finding from Yin et al. (2016), who reported that spontaneous deception correlated with increased activity in DLPFC than instructed one.

In addition, the frontal eye fields exhibited higher HbO changes in spontaneous deception than instructed deception, which is consistent with our expectation. Some previous studies reported that frontal eye fields correlated with the degree of uncertainty. In particular, higher activation of frontal eye fields associated with a high degree of uncertainty (Volz et al., 2005). In this study, in the spontaneous deception session, when participants lose, they could tell the truth to lose by passing the real result or telling a lie to win by passing the false result; thus, spontaneous deception condition involved with more uncertainty with two options. Comparatively, participants had to follow certain instructions to lie in instructed deception condition. Thus, compared with instructed deception, spontaneous deception induced higher activation in frontal eye fields.

4.3. Spontaneous truth-telling vs. Instructed truth-telling

We found that spontaneous truth-telling elicited higher HbO changes in the frontopolar area (left SFG; BA10) and frontal eye fields (left SFG; BA8) than instructed truth-telling.

Consistent with our hypothesis, spontaneous truth-telling involves higher activity in the frontopolar area than instructed truth-telling. To date, numerous studies have suggested that spontaneous truth-telling may also need cognitive resources (Gunia et al., 2012; Shalvi et al., 2012). As mentioned earlier, the frontopolar area was associated with

high-level executive control in action selection (Koechlin & Summerfield, 2007). When we have the opportunity to lie or tell the truth, we also need to refer our previous and upcoming actions to maximize the benefits and, at the same time, maintain positive self-concept. To tell a truth, participants need to inhibit the reward temptation, and balance the conflict between the desire to get a reward and the desire to maintain a positive self-concept (Mazar et al., 2008). In this study, when participants lose in the spontaneous deception session, participants told a lie to get reward, which would lower the positive self-concept they try to maintain. As lying increases, more damage was done to the positive self-concept, which could lead to the negative self-concept appeared. Then, participants had to tell the truth to give more reward to the partner to elevate their self-concept. However, the instructed truth-telling only required participants to follow the specific order to tell the truth, they did not need to choose or consider the past or upcoming options. Hence, spontaneous truth-telling induces a higher brain activity in the frontopolar area than instructed truth-telling.

In addition, the frontal eye fields exhibited higher HbO changes in spontaneous truth-telling than instructed truth-telling. Similar to spontaneous deception and instructed deception, when participants lose, spontaneous deception session included both spontaneous deception condition and spontaneous truth-telling condition involved with more uncertainty, as they could choose freely to lie or tell the truth. In comparison, participants had to follow a certain instruction to lie or tell the truth during instructed deception session. Thus, compared with instructed truth-telling, spontaneous truth-telling also induced higher activation in frontal eye fields (Volz et al., 2005).

4.4. The correlation between neural responses and behavior results

We found that the number of trials in which participants deceived negatively correlated with HbO changes in DLPFC (right MFG, BA9 and 46), suggesting that greater activation in DLPFC was found in participants who lied infrequently. As DLPFC is considered to be associated with cognitive control (Aron et al., 2014; Christ et al., 2008), this study suggested that when deciding to deceive, participants who lied less need more cognitive control. One possible explanation is that participants who lied less frequently valued honesty more than participants who lied frequently; thus, when making a deceptive decision, they need more cognitive control to keep balance between two conflict—the desire to get reward and the desire to maintain a honest self-concept (Mazar et al., 2008).

4.5. Limitations

This study has several limitations. First, we only focused on the role of the prefrontal cortex on spontaneous interpersonal deception in the non-competitive situation; however, other brain areas, like TPJ (Abe et al., 2014; Sip et al., 2012), could also play a crucial role in this spontaneous deception. Besides, as the fNIRS technique can only access the cortical surface, some regions such as ACC, which could play a crucial role in conflict detection and emotional processing (Abe, 2011; Kerns et al., 2004; Phan et al., 2002), could not be investigated in this study. Thus, further study should continue to examine this issue by using fMRI.

4.6. Conclusions

This study examined the neural correlates of spontaneous deception in non-competitive interpersonal interactive scenarios. We adopted a modified poker game that allowed participants to interact with a partner during spontaneous and instructed deception sessions. We found that spontaneous deception produced higher HbO changes than spontaneous truth-telling in the orbitofrontal area and DLPFC during this non-competitive interpersonal situation. Furthermore, we found that spontaneous deception was associated with increased HbO changes in the

frontopolar area, DLPFC, and frontal eye fields compared with instructed deception. In addition, spontaneous truth-telling elicited higher HbO changes in the frontal eye fields and frontopolar area than instructed truth-telling. Overall, this study provides evidence about neural correlates of spontaneous deception during non-competitive interpersonal scenarios.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.bandc.2021.105704>.

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