Research Report

Brain activation and adaptation of deception processing during dyadic face-to-face interaction

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ABSTRACT

Though deception is consistently characterized by the slippery-slope effect, i.e., the escalation of small lies over time, differing interactive situations and interacting processes may influence the trajectories of deception. To explore this influence, we investigated naturalistic face-to-face (FF) and computer-mediated face-blocked (FB) interactions using functional near-infrared spectroscopy (fNIRS). Pairs of participants acted as deceivers and receivers in an adapted ultimatum game while brain activity in the right dorsolateral prefrontal cortex (rDLPFC) and temporoparietal junction (rTPJ) was recorded. Comparison of deception in the two types of interactions showed that the FF interactions resulted in more successful deception, as well as acceptance of deception, and prompted more neural activation in the rDLPFC than the FB interactions. We found that the deception magnitude escalated in both FF and FB interactions, but rDLPFC activity during deception diminished over time only in the FF interactions but not in FB interactions, suggesting that the deceivers behaviourally adapted to deception over time in both types of interactions, but the neural adaptation occurred only in the FF interactions. Furthermore, neural adaptation in FF interactions was associated with behavioural switching after deception, indicating that the rDLPFC contributes to deception adaptation and the control of switching between deception and honesty. The FF interactions were also characterized by activity in the rTPJ, which showed an adaptation to deception. These findings highlight the importance of interactive situations in dyadic naturalistic settings for deception and the role of the rDLPFC and rTPJ in the slippery-slope effect in deception.

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1. Introduction

Deception is common in social interactions but changes across social contexts (DePaulo, Kashy, Kirkendol, Wyer, & Epstein, 1996; Zimbler et al., 2011); specifically, small lies can easily escalate to lies of greater magnitude in many interactive situations, incurring great cost and injury. However, our understanding of the behavioural and neural substrates underlying the variability in deception across interactive situations and the interaction process is limited (Buller and Burgoon, 1996; Cappelen, Sørensen, & Tungodden, 2013; DePaulo et al., 2003; Welsh, Ordóñez, Snyder, & Christian, 2015). The development of information technology has expanded the forms of media for deception beyond the dyadic face-to-face (FF) interaction, e.g., computer- or phone-mediated communication, thereby complicating deception and its consequences.

Compared to FF interactions, computer-mediated interactions are considered less interactive because it lacks a range of social cues, such as eye contact, facial expressions, and body gestures (Buller and Burgoon, 1996). However, whether the enhanced interactivity of FF interactions facilitates deception is unclear: while research has found that FF interactions encourage liars to engage in more deception (George and Carlson, 2005; Van Swol et al., 2017), other studies have observed no differences in deception rates between these two types of interactions (George and Robb, 2008; Van Swol, Braun, & Kolb, 2015), and still other investigations have reported more frequent instances of deception in computer-mediated interactions (Whitty et al., 2008; Zimbler et al., 2011).

There are at least two possible explanations for these inconsistencies. One might assume that the rich social cues in FF interactions could increase the deceivers' cognitive effort or cost since the deceivers need to manage their behaviours in a more complex manner to avoid being caught, which requires more cognitive resources (Burgoon, Stoner, Bonito, & Dunbar, 2003; Hu et al., 2015; Van Swol et al., 2015; Vendemia, Buzan, & Green, 2005). Another possibility is that deceivers might engage in more deception by evolving and adapting to the deception in FF interaction as the interaction proceeds. This is because they may accommodate and adjust their ways of talking, nodding, and/or gesturing to the receivers (Burgoon, Stern, & Dillman, 1995), and they may exploit social cues with strategies that distract the receivers (Van Swol et al., 2015). These two premises seemingly oppose each other but may work together to influence deception in naturalistically repeating interactions, as practice and training can reduce the cognitive cost of the deception (Hu, Chen, & Fu, 2012; Van Bockstaele et al., 2012). To test these hypotheses, the current study investigated the behavioural and underlying neural mechanisms of deception and changes in deception over time in repeated FF and computer-mediated interactions.

Numerous imaging studies have shown that brain activity in the dorsolateral prefrontal cortex (DLPFC) reflects an index of cognitive effort or cost in deception. The DLPFC is mainly active in executive control in deception, including the knowing engagement in dishonest behaviour, the inhibitory control of honest responses, and the switching between truthful and deceptive responses (Christ, Van Essen, Watson, Brubaker, & McDermott, 2009; Lisofsky, Kazzer, Heekeren, & Prehn, 2014; Spence et al., 2004). For instance, left DLPFC activity increased when participants were instructed to falsify honest responses by an interrogator relative to when they were required to tell the truth but secretly deceived the interrogator (Abe, Suzuki, Mori, Itoh, & Fujii, 2007). In a non-interactive coin-flipping situation, behaving dishonestly spontaneously recruited more bilateral DLPFC activity than did behaving honestly (Greene and Paxton, 2009). Spontaneous deception in natural, non-interactive and interactive coin-flipping situations increased activity in the bilateral DLPFC relative to honest behaviour (Ding et al., 2013, 2014). Specifically, the right DLPFC (rDLPFC) has been associated with strategic deception in two-person interactive bargaining (Bhatt, Lorenz, Camerer, & Montague, 2010) and is reportedly more sensitive to deception than the left DLPFC (Karton, Rinne, & Bachmann, 2014; Maréchal, Cohn, Ugazio, & Ruff, 2017).

The right temporoparietal junction (rTPJ) is also activated during deception, especially in interactive situations (Lisofsky et al., 2014). Regarded as a critical region for theory of mind (Saxe and Powell, 2006), the rTPJ is involved in the mentalization of others' intentions and the generation of deceptive strategies in interactions (Bhatt et al., 2010; Tang et al., 2016, 2017; Volz, Vogeley, Tittgemeyer, von Cramon, & Sutter, 2015; Zhang, Liu, Pelowski, & Yu, 2017). Disrupting the function of the rTPJ with transcranial magnetic stimulation (TMS) interrupts the capacity to refer to others' mental states, as well as strategic behaviours (Hill et al., 2017). Spontaneous activity in either the DLPFC or TPJ informs the linear prediction of an individuals' deception (Tang et al., 2018). These studies compared the differences between deception and honesty in non-interactive situations or in one type of interactive situation. How these two regions are involved and associated with each other in deception in different dyadic interactive situations remains unknown.

Several studies have elucidated how deception changes over time; to the best of our knowledge, one behavioural study studied changes in deception in a non-interactive situation (Welsh et al., 2015), and one imaging study studied these changes in a computer-mediated interactive situation (Garrett, Lazzaro, Ariely, & Sharot, 2016). Both of these studies observed a slippery-slope effect: the magnitude of the dishonesty increased, and the dishonesty in situations with relatively less initial dishonesty escalated with repetition. The imaging study showed that activity in the amygdala decreased as the magnitude of deception increased: this has been referred to as dishonesty adaptation (Engelmann et al., 2016; Garrett et al., 2016). However, due to limited findings from naturalistic interactions with feedback, a complete understanding of the nature and impact of dishonesty adaptation in different real-life interactive situations has yet to be achieved (White and Burgoon, 2001).

To measure deception in naturalistic FF and computer-mediated face-blocked (FB) interactions, the present study used a revised ultimatum game with feedback: deceivers were allocated a lump sum of money at the beginning of each trial and the amount was unknown to the receivers. The deceivers

could choose to deceive the receivers by misreporting the total and make a lower offering, with the hope of increasing the receivers' acceptance and obtain more money. To measure dynamic changes in deception, we provided truthful feedback at the end of each trial. The pairs of anonymous participants sat across tables in either the FF or FB interactions and maintained the same physical distance during their interactions. To further simulate deception in real life, the deceivers could verbally communicate the total and the offer in the FF interaction but could only type in the FB interaction. We recorded participants' brain activities in the rDLPFC and rTPJ regions via functional near-infrared spectroscopy (fNIRS). Although fNIRS features a lower spatial resolution than magnetic resonance imaging (MRI), its portability and adequate temporal resolution allowed for the recording of neural activity in naturalistic dyadic interactions (Cui et al., 2011, 2012).

Thus, we investigated whether FF and FB interactions would differentially alter deception and, hence, activity in the rDLPFC and rTPJ. We also aimed to examine and characterize the behavioural and neurobiological correlates of dishonesty escalation across time and the influence of repeated interactions with feedback. We hypothesized that if deceptive behaviour during FF interactions required increased cognitive effort, FF interactions would result in more rDLPFC activity than FB interactions. Moreover, if the deceivers adapted to the deception, the resultant slippery-slope effect would diminish neural activity in the rDLPFC.

2. Materials and methods

2.1. Participants

We reanalysed the data from our previous study (Tang et al., 2016), which included 202 college students grouped in 101 pairs (FF interaction: 53 pairs with 29 female pairs, age [mean $(M) = 22.68$, standard deviation $(SD) = 2.07$]; FB interaction: 48 pairs with 24 female pairs, age $(M = 22.20, SD = 2.18)$. Same-sex pairs were recruited to control for sex effects on the interactive process (Cheng, Li, & Hu, 2015; Pan, Cheng, Zhang, Li, & Hu, 2017; Zhang et al., 2017). Data from two male pairs from the FF interaction and one female and one male pair from the FB interaction were excluded due to either high noise caused by poor contact of the probes on the head during fNIRS recording or poor task comprehension and/or execution.

We examined the neural differences between deception and honesty, the changes in deception over time, and the relationship between activity of the rDLPFC and rTPJ in the two types of interactions. We performed two steps to extract the samples for analysis to avoid insufficient deceptive or honest trials for comparison and modelling: (1) participants who behaved honestly or deceived in less than four trials were excluded; (2) we calculated the M and SD of the deception rates of all the valid participants in this study, i.e., 51 pairs in the FF condition ($M = .26, SD = .28$) and 46 pairs in the FB condition ($M = .29, SD = .24$), to ensure that the participants' deception rates were within 2 SD of the mean deception rate. Thus, pairs whose deception rate was between 7.4% and 77.8% were analysed, resulting in a final dataset of 27 same-sex pairs [12 female pairs, age ($M = 23.41, SD = 2.14$)] in FF interactions and

30 same-sex pairs [15 female pairs, age ($M = 22.13, SD = 2.61$)] in FB interactions. All participants signed written informed consent. The study was approved by the Institutional Review Board of the State Key Laboratory of Cognitive Neuroscience and Learning at BNU.

2.2. Procedure

Pairs of participants repeatedly played as fixed deceivers or receivers in a revised ultimatum game in either FF or FB interactions (Güth, Schmittberger, & Schwarze, 1982; Tang et al., 2016) (Fig. 1A). The entire experiment consisted of 54 trials separated into three blocks. The procedure in Fig. 1B denotes what the players would see in each trial. Each trial began with a 1-sec fixation and contained four parts (Fig. 1B). First, the deceiver finished the choice stage of being deceptive or honest (12 sec) in three stages: 1) learning the true total amount available, which was randomly extracted from 4, 6, 8, 10, 12, or 14 monetary units (MU), for allocation in this trial (2 sec); 2) reporting the true or false total amount to the receiver (5 sec); and 3) making an offer based on the reported total to the receiver (5 sec). For example, if the true total available to the deceiver was 10, he/she could either say that the total was 10 (honesty) and offer 5 to the receiver; or lie and say that the total was 8 (deception) and offer 4 to the receiver. In FF interactions, the deceiver was required to look at the receiver's eyes and orally communicate the total amount and offer, and enter them into the computer during each trial. In FB interaction, the deceiver and receiver were separated by a board and communicated the total and offer by pressing buttons on the computer. We added the voice report to make the interactions in the FF conditions ecologically valid as previous studies did (Babiloni et al., 2007b, 2007a; Ding et al., 2014). To control the effects of the voice report on the comparisons between FF and FB conditions, the deceivers were prohibited from conveying any other information than the total amount and the offer. They entered the numbers into the computer, and then both players would see it on their computer screens. Second, both players predicted each other's behaviour, in which the deceiver predicted whether the receiver would accept or reject the offer, and the receiver guessed whether the deceiver had stated the true total or not (5 sec). Third, the receiver decided to accept or reject the offer (5 sec). If the receiver accepted, then both of them received the money units according to the deceiver's allocation; otherwise, both of them gained nothing. Finally, the payoffs for both sides based on the true total were revealed, in which the deceiver would see the response of the receiver and the receiver would know the truth (5 sec). Therefore, over repeated interactions, the deceiver needed to consider the effect of being deceptive or honest in the current trial on the receiver's choice in both the current and subsequent trials. The players entered the amounts and their choices using the same button presses in the FF and FB interactions. They were paid according to their choices during the game and received compensation for participation. Note that the players were strangers to each other in both the FF and FB interactions. The players in the FB interactions never met each other throughout the whole experiment and were not given the identity of, or any information about, each other.
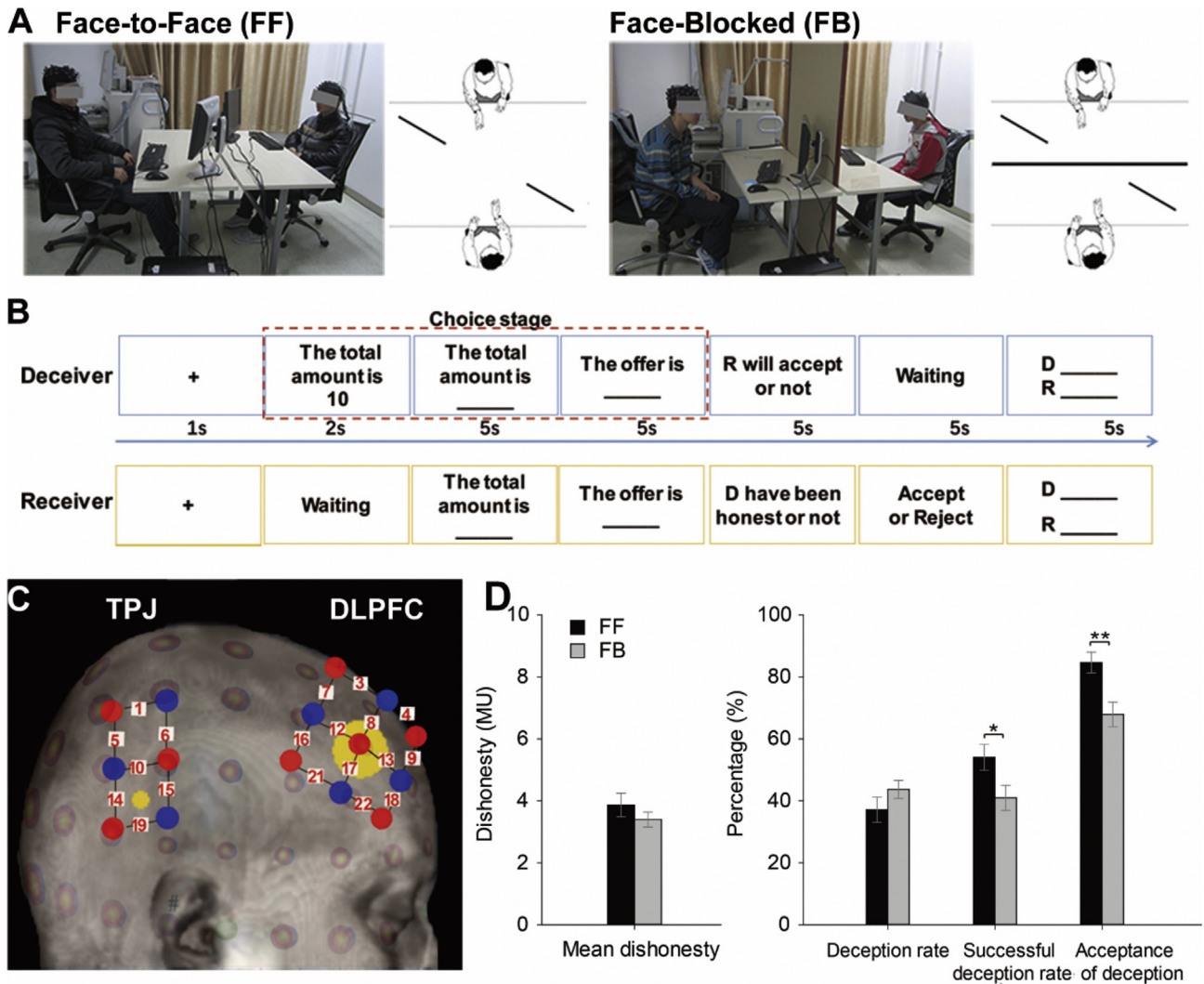
Fig. 1 — A) Face-to-face (FF) and computer-mediated face-blocked (FB) interactions that participants played as either the deceiver (D) or receiver (R). B) Experimental procedure. D sees the true total amount then reports a total and makes an offer to R (Choice stage, red dotted line frame) and predicts the behaviour of R. R sees the reported total and offer provided by D, predicts the behaviour of D, then makes a choice. The true allocation was revealed to both D and R at the end of each trial. C) fNIRS measurement. NIRS probes were set up over the rDLPFC and rTPJ localized by the international 10–20 system, leading to 19 measured channels (CH) marked with red numbers. The rDLPFC (Christ et al., 2009; Greene and Paxton, 2009) and rTPJ (Redcay et al., 2010; Saxe and Powell, 2006) were marked (yellow) based on MNI coordinates from previous studies. D) Behavioural results of deception. The deceivers in FF interactions have a higher successful deception rate and acceptance of deception than those in the FB interactions (*p < .05, **p < .01). Error bars indicate standard errors of the mean.

2.3. fNIRS data acquisition

The fNIRS data were collected by an ETG-4000 optical topography system (Hitachi Medical Company) with a sampling rate of 10 Hz. A 3×5 optode probe set (30 mm optode distance) with eight emitters and seven detectors was positioned on the deceivers' heads with two 3×3 holders (Fig. 1C). There were 19 recording channels (the measurement area between emitters and detectors) in total. A flexible swimming cap was used to fix the probes and place them on the head based on the international 10–20 EEG system. We used F4 as the reference to locate channels (CH) over the rDLPFC, which included CH 3, 4, 7, 8, 9, 12, 13, 16, 17, 18, 21, and 22; and used P6 as the reference

to locate channels over the rTPJ [covering the regions between P6 and CP6 (Santiesteban, Banissy, Catmur, & Bird, 2012)], which included CH 1, 5, 6, 10, 14, 15, and 19 (Jurcak, Tsuzuki, & Dan, 2007). The rTPJ and rDLPFC were marked according to coordinates informed by previous studies (Christ et al., 2009; Greene and Paxton, 2009; Redcay et al., 2010; Saxe and Powell, 2006) (Fig. 1C). Two wavelengths (695 and 830 nm) of near-infrared light were used to measure each channel's optical data. Changes in concentrations of oxyhemoglobin (HbO) and deoxyhemoglobin (HbR) were determined by the modified Beer–Lambert law (Cope and Delpy, 1988). A 30-sec resting state was measured before each experimental block to obtain stable signals.

2.4. Data analyses

2.4.1. Behavioural analysis of deception

To test the behavioural differences related to deception between the FF and FB interactions, we compared the following between the two conditions: dishonesty magnitude (mean dishonesty: mean of the true total amount minus the reported total amount in the deceptive trials), deception rate, successful deception rate (percentage of deception trials that was not detected by receivers), acceptance of deception (percentage of trials in which receivers accepted deception), and offers (the amount that deceivers offered to receivers) in deception and honesty trials. In addition, deception reportedly requires more cognitive effort than honesty, which can be measured by differences in reaction time (RT, millisecond) between deception and honesty trials (Spence et al., 2004; Suchotzki, Verschuere, Van Bockstaele, Ben-Shakhar, & Crombez, 2017). Thus, we compared the RT during the choice stage when the deceivers reported the total amount and made the decision in the deceptive and honesty trials with a 2 (Choice: Deception vs Honesty) × 2 (Condition: FF or FB) mixed ANOVA.

2.4.2. Neural activation analysis of deception

First, the deceivers' NIRS data (HbO) was processed with NIRS-SPM implemented in MATLAB (The Mathworks, USA) with wavelet minimum description length (wavelet-MDL) detrending and hemodynamic response function (HRF) low-pass filtering (Jang et al., 2009; Tak et al., 2011; Ye, Tak, Jang, Jung, & Jang, 2009). Next, HbO in the choice stage, from when the deceiver saw the true total to when she/he finished entering the offer (response-locked, Fig. 1B) during the choice stage, a period that lasted for approximately 7−12 sec, in deceptive and honest trials were modelled as events with a general linear model (GLM). The basis function with time and dispersion derivatives (Dubois et al., 2016; Lindquist, Loh, Atlas, & Wager, 2009) were used to model rapid event-related activity and allow variable shapes of the HRF. The HbO beta values during deception and honesty in the GLM model at each channel were analysed with Choice (Deception vs Honesty) × Condition (FF vs FB) mixed ANOVAs. Pearson correlations between the neural differences of deception and honesty, and the behavioural dishonesty magnitude were calculated to assess brain-behaviour associations of deception in the FF and FB interactions.

2.4.3. Behavioural analysis of changes in deception over time

First, we calculated the correlation between the dishonesty magnitude per deceptive trial of all participants (resulting in 484 and 670 values in the FF and FB interactions, respectively) with their absolute trial number (the number of past trials in the whole experiment) to test for trends between deception and time (Garrett et al., 2016). Next, we analysed how the dishonesty magnitude changed over time and how this change differed between the FF and FB interactions. Since the dishonesty magnitude was not normally distributed and transformations could not make it normal, a generalized linear mixed model (GLMM) based on the penalized quasi-likelihood (PQL) approach for non-normal distributions (Bolker et al., 2009) was used in this analysis. We used the glmmPQL function for gamma distribution with the MASS package implemented in R (https://cran.r-project.org/web/packages/MASS) to run the GLMM (B. D. Ripley et al., 2002; Breslow et al., 1993; Schall, 1991; Wolfinger et al., 1993), in which the dishonesty magnitude in each deceptive trial was treated as the dependent variable, the relative trial number (Trial) of the deceptive trial was nested within the subjects, the Condition (FF vs FB) was treated as a predictor, and the subject was entered as a random factor [the R code was: glmmPQL (Dishonesty magnitude $_t$ ~ Trial * Condition, random = ~1| sub ID, family = Gamma(link = "log"), data = data)]. In this model, the estimates of Trial denoted the changes in deception over time; the more positive the estimate of Trial was, the higher the dishonesty magnitude was if the deception occurred later relative to it occurring earlier in the interactions, i.e., the dishonesty magnitude escalated over time, indicating that participants adapted to dishonesty. To control for the effects of RTs on behavioural changes in deception over time, we added RTs when making decisions in the trials as covariates in the GLMM. We also tested whether successful deception and acceptance of deception changed over time and whether their changes differed between the FF and FB interactions with GLMMs for binomial distribution; in these analyses, we treated the categorical responses that receivers detected and accepted the deception (or not) as the dependent variables, the Trial and Condition as predictors, and the subject as the random factor. In addition, we examined how deceivers changed their strategies by switching behaviours. The switching behaviour rate, i.e., the percentage of trials that the deceiver switched to being honest after the current deceptive or honest trial was analysed with a 2 (Current trial: Deception, Honesty) × 2 (Condition: FF, FB) ANOVA. Cohen's d and partial eta squared (η_p^2) were calculated as the effect sizes for t-tests and ANOVAs.

2.4.4. Neural analysis of changes in deception over time

For the neural data, the data collected from the deceiver's deception stage in each trial were treated as an event (Garrett et al., 2016) and estimated with a GLM model. We applied the GLMMs with the glmmPQL approach to the activation from each deceptive trial across channels to examine how the brain activities changed over time from two different perspectives: (1) The beta obtained from the GLM on deceptive trials were used as the dependent variables, the relative trial number (Trial) was nested within subjects and the Condition was used as the predictors. (2) We divided the beta of the relative deceptive trial by the magnitude of dishonesty in the trial (Garrett et al., 2016), applied the brain activity per unit of dishonesty as the dependent variables, and used the Trial and Condition variables as the predictors. We also added RTs as covariates in the GLMMs to control for the effect of RTs on neural changes associated with deception over time. In addition, to exclude the possibility that the neural changes in deception observed over time were caused by habituation to the experimental paradigm, we also applied the GLMMs with the glmmPQL approach to the honest trials; the beta of the relative honest trials were the dependent variables and the relative trial number in the honest trial (Trial) and the Condition were used as the predictors.

2.4.5. Neural changes associated with deception over time and switching behaviours

To explore whether deceivers showed neural adaptation to dishonesty, we examined the relationship between dynamic changes in brain activity in the deception trials and the deceivers' strategic behaviours. We conducted the GLMMs to test this link: the beta of the relative deceptive trial was used as the dependent variable and the overall switching behaviour rate (switching to be honest) after a deceptive trial prior to the current deceptive trial (Switching), the relative trial number (Trial), and the Condition were used as the predictors. We focused on the estimates of the interactions of Trial × Switching and the interactions of Trial × Switching × Condition; the more negative the former estimates, the greater the contribution of switching behaviours in the neural dishonesty adaptation, and the larger the latter estimates, the greater the difference in the influence of switching behaviours on the neural adaptation between the FF and FB conditions.

The false discovery rate (FDR) correction was used to correct p values ($p_{FDR} < .05$) of the fNIRS data across channels for multiple comparisons in the activation analyses, analyses of neural changes over time, and analyses of the relationship between neural changes over time and switching behaviours. We applied the Benjamini-Hochberg procedure in MATLAB (https://ww2.mathworks.cn/matlabcentral/fileexchange/27418-fdr_bh) (Benjamini and Hochberg, 1995, Benjamini and Yekutieli, 2001, Benjamini and Yekutieli, 2005) to implement these corrections. Since we focused only on analysing the correlation between behavioural dishonesty magnitude and differential betas for deception and honesty in channels whose activation was significantly different between deception and honesty, we did not correct p values for the correlation analyses.

3. Results

3.1. Behavioural differences in deception

The mean dishonesty magnitude and deception rate showed no difference between the FF and FB interactions ($ts < 1.34$, $ps > .19$). FF interactions had higher successful deception rates [$t (55) = 2.25$, $p = .028$, d (Cohen's d) = .60], and higher acceptance of deception [$t (55) = 3.16$, $p = .003$, $d = .84$] than FB interactions (Fig. 1D). The offers presented in deception were significantly lower than those conveyed honestly in both the FF ($M_{deception} = 4.07$, $SD = .66$; $M_{honesty} = 3.99$, $SD = .51$) and FB interactions ($M_{deception} = 4.14$, $SD = .53$; $M_{honesty} = 3.83$, $SD = .36$), $F(1, 55) = 5.19$, $p = .027$, $\eta2 p = .09$. The main effect of Condition and the interaction of Choice × Condition were not significant, $F(1, 55) = 1.70$, $p = .20$; $F(1, 55) = .25$, $p = .62$.

Regarding the RT when reporting the total amount, the main effect of Choice [$F(1, 55) = 31.66$, $p < .001$, $\eta2 p = .37$] and interaction of Choice × Condition [$F(1, 55) = 4.62$, $p = .036$, $\eta2 p = .08$] were significant (Table 1). The main effect of Condition was not significant [$F(1, 55) = 1.52$, $p = .22$]. Post hoc tests showed that the RTs in deception trials were significantly longer than those in honesty trials in both FF [$F(1, 26) = 9.75$, $p = .004$, $\eta2 p = .27$] and FB [$F(1, 29) = 23.33$, $p < .001$, $\eta2 p = .45$] interactions. The RTs in deception trials showed a trend to be shorter in the FF interaction than those in the FB interactions

Table 1 — Deceivers' reaction time (RT; ms) in the decision stage.

	Reporting total amount		Making divisions	
	Deception	Honesty	Deception	Honesty
FF	1315	1183	1922	1862
FB	1546	1250	1409	1272

[$F(1, 55) = 2.88$, $p = .096$, $\eta2 p = .05$], and the RTs in the honesty trials did not differ between conditions [$F(1, 55) = .34$, $p = .57$]. For the RTs while making divisions, the main effect of Choice [$F(1, 55) = 5.12$, $p = .03$, $\eta2 p = .09$] and Condition [$F(1,55) = 30.08$, $p < .001$, $\eta2 p = .35$] were significant, and the interaction of Choice × Condition was not [$F(1, 55) = .79$, $p = .38$]. That is, the RTs when making divisions were longer in the deception than in the honesty trials in both FF and FB interactions, and they were longer in the FF than in the FB interactions.

3.2. Neural differences in deception

The effects of Choice revealed that the deceivers' rDLPFC was significantly more active in the deception trials than in the honesty trials in the FF interactions [CH8: $F(1,26) = 14.41$, $p_{FDR} = .005$, $\eta2 p = .36$; CH 12: $F(1,26) = 18.46$, $p_{FDR} < .001$, $\eta2 p = .42$; CH 13: $F(1,26) = 8.37$, $p_{FDR} = .01$, $\eta2 p = .24$], and rDLPFC activity was marginally significant in the FB interactions [CH8: $F(1,29) = 6.62$, $p = .016$, $p_{FDR} = .08$, $\eta2 p = .19$; CH 12: $F(1,29) = 6.58$, $p = .016$, $p_{FDR} = .08$, $\eta2 p = .19$; CH 13: $F(1,29) = 8.65$, $p = .006$, $p_{FDR} = .08$, $\eta2 p = .23$] (Fig. 2A). Significant interactions of Choice × Condition on the rDLPFC activity [CH8: $F(1,55) = 8.60$, $p_{FDR} = .03$, $\eta2 p = .14$; CH 12: $F(1,55) = 12.09$, $p_{FDR} = .009$, $\eta2 p = .18$; CH13: $F(1,55) = 3.72$, $p = .06$, $p_{FDR} = .096$, $\eta2 p = .06$] indicated that this region was more active during deception in the FF interactions than in the FB interactions (Fig. 2B). The post hoc tests also showed that the activation in deceptive trials per se tended to be greater in the FF interactions than in the FB interactions [CH8: $t (55) = 1.8$, $p = .08$, $p_{FDR} = .29$, $d = .66$; CH 12: $t (55) = 2.08$, $p = .04$, $p_{FDR} = .29$, $d = .54$; CH 13: $t (55) = .34$, $p = .73$, $p_{FDR} = .87$, $d = .09$]. Differential betas between deception and honesty trials were positively correlated with behavioural dishonesty magnitude only in the FF interactions (CH8: $r = .66$, $p < .001$; CH12: $r = .47$, $p = .01$; CH13: $r = .61$, $p = .001$) but not consistently significant in the FB interactions (CH8: $r = .42$, $p = .02$; CH12: $r = .23$, $p = .23$; CH13: $r = .23$, $p = .22$) across channels. A comparison of correlation coefficients showed that these correlations tended to be greater in FF than in FB interactions (CH8: $z = 1.23$, $p = .11$; CH12: $z = .98$, $p = .16$; CH13: $z = 1.69$, $p = .046$). The activity of the rTPJ did not differ between deception and honesty trials in FF interactions [CH10: $F(1,26) = 3.82$, $p = .06$, $p_{FDR} = .08$, $\eta2 p = .13$; CH15: $F(1,26) = 3.28$, $p = .08$, $p_{FDR} = .09$, $\eta2 p = .11$; CH19: $F(1,26) = 3.23$, $p = .08$, $p_{FDR} = .09$, $\eta2 p = .11$] or in FB interactions ($Fs < 1.42$, $ps > .24$), and this activity showed no difference between the two conditions ($Fs < 2.71$, $ps > .11$). The differential beta in the rTPJ was not positively correlated with behavioural dishonesty magnitude in the two conditions ($rs < .29$, $ps > .14$).
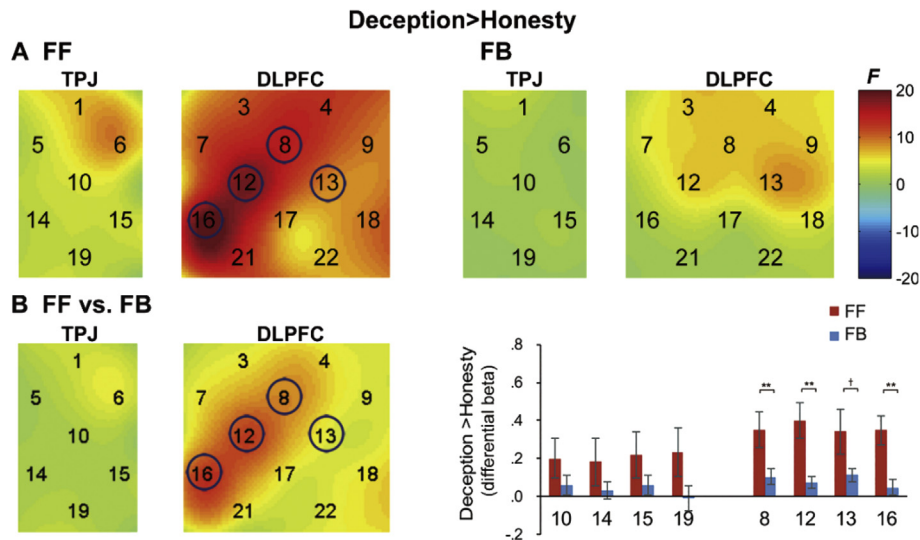
Fig. 2 — The fNIRS results for deception and honesty on HbO. A) The main effects of Choice display the comparison between deception and honesty trials (F-map). The rDLPFC (CH 8, 12, 13, 16) was more active in deception than in honesty trials in the FF interactions and was marginally significant in the FB interactions. B) The interactions between Choice and Condition found that only the rDLPFC (CH 8, 12, 13, 16) demonstrated greater activity with deception in the FF than the FB interactions [**$p < .01$, *$p < .05$,+$p < .07$ ($p_{FDR} < .1$)]. Error bars indicate standard errors of the mean.

3.3. Behavioural dishonesty adaptation

The dishonesty magnitude significantly increased over time in the FF interactions ($r = .15$, $p = .001$) and marginally in the FB interactions ($r = .07$, $p = .06$) (Fig. 3A and B). The results of the GLMM found a significant main effect of Trial (estimate = .01, $t = 2.81$, $p = .005$) and no significant effects of Condition (estimate = .07, $t = .62$, $p = .54$) and the interaction of Trial × Condition (estimate = .002, $t = .47$, $p = .64$), indicating that the dishonesty escalation in the FF interactions did not significantly differ from that in the FB interactions. Adding the RTs as covariates showed similar results: Trial (estimate = .01, $t = 3.14$, $p = .002$), Condition (estimate = .03, $t = .31$, $p = .76$), interaction of Trial × Condition (estimate = .002, $t = .51$, $p = .61$). These findings indicated that the behavioural dishonesty adaptation was not explained by the shared variance with the RTs. Successful deception and acceptance of deception decreased over time (Trial: estimate = −.06, $z = −4.46$, $p < .001$; estimate = −.04, $z = −2.50$, $p = .01$, respectively), but did not differ between the FF and FB interactions (Trial × Condition: estimate = .002, $z = .12$, $p = .91$; estimate = .007, $z = .40$, $p = .69$, respectively). Furthermore, the interaction of Current trial × Condition on the switching behaviour rate after deception [$F(1, 55) = 4.47$, $p = .04$, $\eta2$ $p = .08$] showed that the deceivers switched to being honest more often after a deception trial than after an honesty trial only in the FF interactions [$F(1, 26) = 6.72$, $p = .02$, $\eta2$ $p = .21$] but not in the FB interactions [$F(1, 29) = .80$, $p = .38$, $\eta2$ $p = .03$] and that the deceivers switched to being honest more often after a deception trial in the FF interactions than in the FB interactions [$F(1, 55) = 7.45$, $p = .008$, $\eta2$ $p = .12$] (Fig. 3C).

3.4. Neural dishonesty adaptation

The results of the GLMMs which treated the brain activity in each deceptive trial as the dependent variable showed that the rDLPFC showed significant dishonesty adaptation (i.e., the more negative the estimates of Trial were, the more brain activity during deception decreased over time) only in the FF interactions (CH12: estimate = −.003, $t = −2.33$, $p_{FDR} = .048$; CH13: estimate = −.004, $t = −2.97$, $p_{FDR} = .015$) but not in the FB interactions (CH12: estimate = −.001, $t = −.78$, $p = .44$, $p_{FDR} = .83$; CH13: estimate = −.00, $t = −.25$, $p = .80$, $p_{FDR} = .83$) (Fig. 4A). The interaction of Trial × Condition showed that dishonesty adaptation in the rDLPFC was marginally greater in the FF than in the FB interactions (CH12: estimate = −.003, $t = −1.55$, $p = .12$, $p_{FDR} = .22$; CH13: coefficient = −.004, $t = −2.49$, $p = .013$, $p_{FDR} = .08$) (Fig. 4B). The rTPJ also showed a similar pattern of dishonesty adaptation in the FF interactions (CH19: estimate = −.005, $t = −4.26$, $p_{FDR} < .001$), and this effect was greater in the FF than in the FB interactions (CH19: estimate = −.004, $t = −2.99$, $p_{FDR} = .038$). Adding RTs as covariates showed similar patterns (Fig. S1), indicating that the neural dishonesty adaptation was not explained by the shared variance with the RTs. The results of the GLMMs that treated the brain activity per unit of dishonesty in each deceptive trial as the dependent variable also showed a significant level of dishonesty adaptation in the rDLPFC in the FF interactions (CH12: estimate = −.001, $t = −1.63$, $p = .10$, $p_{FDR} = .18$; CH13: estimate = −.003, $t = −2.92$, $p_{FDR} = .03$) and not in the FB interactions (CH12: estimate = −.001, $t = −1.69$, $p = .10$, $p_{FDR} = .28$; CH13: estimate = −.001, $t = −1.24$, $p = .21$, $p_{FDR} = .41$), and the interaction of Trial × Condition was not
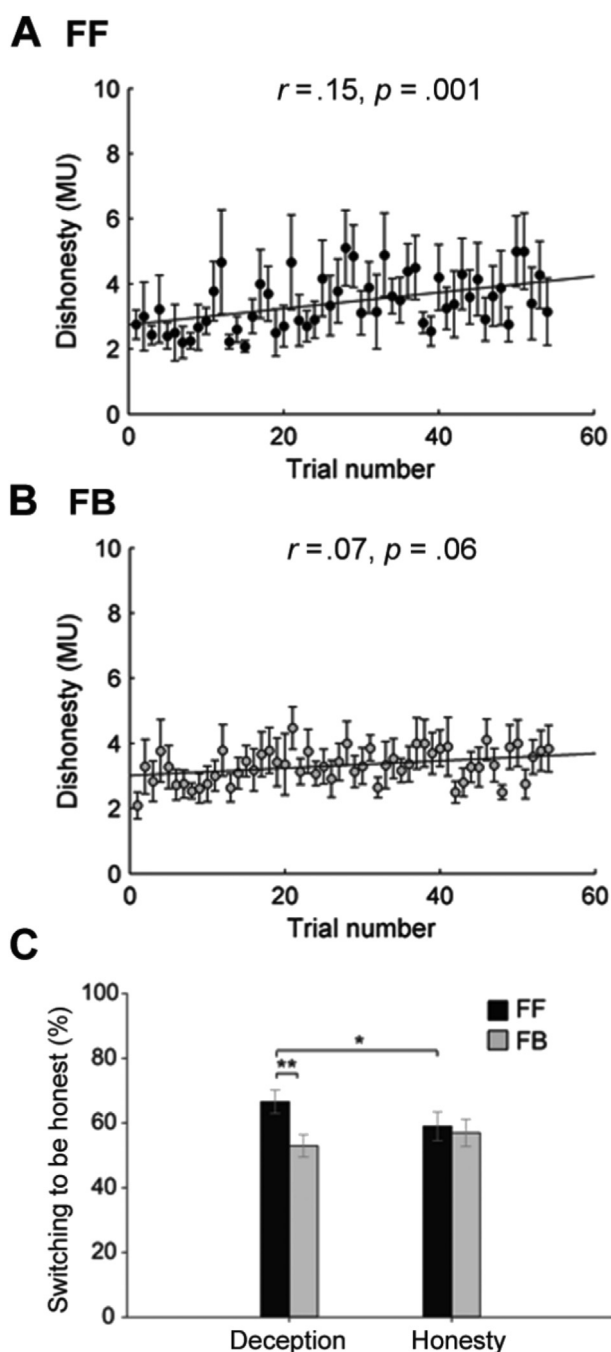
A FF

B FB

C

Fig. 3 — Behavioural dishonesty adaptation. A and B) Dishonesty magnitude in all deceptive trials across participants showed a greater escalation over time in the FF interactions and a trend in the FB interactions. C) Switching to being honest on the subsequent trial after a deception trial was more likely in the FF than in the FB interactions (*p < .05, **p < .01). Error bars indicate standard errors of the mean.

significant (CH12: estimate = −.00, t = −.43, p = .67, p_{FDR} = .85; CH13: estimate = −.002, t = −1.52, p = .13, p_{FDR} = .61) (Fig. S2).

In addition, the results of the GLMM on the activation during honesty did not find that the activation of the rDLPFC or rTPJ changed over time in either the FF or FB interactions

(ts < 2.04, ps $_{FDR}$ > .1) (Fig. S3). The interaction of Trial × Condition was not significant either. These findings gently suggested that the observed dishonesty adaptations in the brain were not simply explained by habituation to the experimental paradigm over time.

3.5. Neural dishonesty adaptation and switching behaviours

The dishonesty adaptation in the rDLPFC was significantly associated with switching behaviours in the FF but not in the FB interactions (Trial × Switching at CH12; FF: estimate = −.03, t = −2.90, p_{FDR} = .038; FB: estimate = −.003, t = −.54, p = .59, p_{FDR} = .82) (Fig. 5A). The interaction of Trial × Switching × Condition showed that this association was marginally greater in the FF than in the FB interactions (CH12: estimate = −.02, t = −2.20, p = .028, p_{FDR} = .09) (Fig. 5B and C). That is, the more the deceivers switched to being honest after a deception trial in the FF interactions, the greater the neural dishonesty adaptation in the rDLPFC. Although the interaction of Trial × Switching × Condition was marginally significant in the rTPJ at CH15 (estimate = −.02, t = −2.59, p = .01, p_{FDR} = .06), the effects of Trial × Switching was not significant in either the FF interactions (CH15: estimate = −.01, t = −1.77, p = .08, p_{FDR} = .21) or FB interactions (CH15: estimate = .01, t = 1.86, p = .07, p_{FDR} = .75), showing no significant association between dishonesty adaptation and switching behaviours in the rTPJ.

4. Discussion

The present study investigated the behavioural and neural differences in deception and changes in deception over time between dyadic FF and FB interactions. By using a repeated interactive deceptive game with feedback, we compared (1) whether FF interactions led to a higher or lower dishonesty magnitude, deception rate, success of deception, or acceptance of deception than FB interactions; (2) whether deception in FF interactions required more cognitive effort or cost which was represented by greater activation of the rDLPFC; (3) whether deceivers showed greater behavioural and neural adaptation of dishonesty in the rDLPFC and rTPJ in FF than in FB interactions; and (4) how the neural adaptation was associated with switching behaviours between deception and honesty.

We did not find a significant difference in the frequency or magnitude of deception between the FF and FB interactions, rejecting assumptions that deception would be increased or decreased in an FF interaction. Previous studies have suggested that the lack of differences in the frequency of deception in FB interactions may result from FF interactions being emulated by FB interactions due to the increasing use of computers in daily life, which diminished the difference between the two situations (George and Robb, 2008). Alternatively, some researchers have found that differences in deception manifest in different strategies, such as using different types of deception, rather than the frequency of deception (Van Swol et al., 2015). In line with this finding, our results revealed that FF interactions facilitated the success and acceptance of deception, in which the deceivers changed
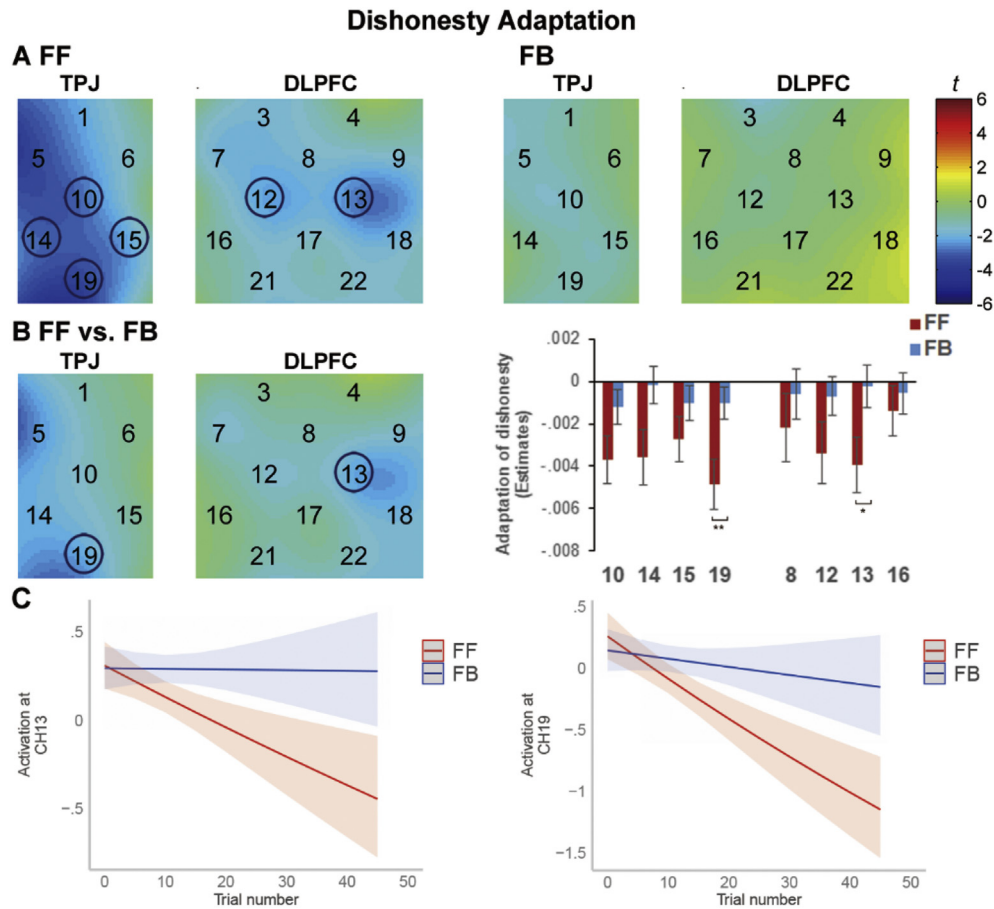
Fig. 4 — Neural dishonesty adaptation based on the GLMM analysis which treated the brain activity in deceptive trials as the dependent variable. A) Magnitude of the reduction in oxyhemoglobin (HbO) in deception trials over time was significant for the rDLPFC and rTPJ in the FF but not in the FB conditions. B) Comparisons of neural dishonesty adaptations between conditions showed that the adaptation in the rDLPFC and rTPJ was greater in the FF than in the FB conditions [*$p < .05$ ($p_{FDR} < .1$), **$p < .01$]. C) An illustration of the Trial × Condition interaction effect on activation in deceptive trials in the GLMM analysis, in which the shaded areas indicate the 95% confidence interval of the estimated values. Error bars indicate standard errors in the estimates from the GLMM.

their strategies by switching to being honest after deception, especially after their deceptive offer was rejected.

We found a large RT difference between the deception and honesty trials in both the FF and FB interactions. Deception has been found to have higher cognitive costs than honesty, which could be reflected by the RT deception effect (i.e., RT in deception trials was greater than that in honesty trials) (Spence et al., 2004). However, the RT deception effect has been long considered to be small and non-significant in natural interview situations (DePaulo et al., 2003; Zuckerman, DePaulo, & Rosenthal, 1981). A recent meta-analysis suggested that precise RT measurements, designs that require participants to make decisions immediately after they see the stimuli, and a sufficient number of deceptive and honest trials could result in a large RT difference between deception and honesty, but these criteria might not be generalizable to FF interactions (Suchotzki et al., 2017). Our results provided empirical evidence for the RT deception effect in naturalistic FF interactions. However, it is hard to directly compare the RT deception effect between the FF and computer-mediated FB interactions in the current study, since the deceivers reported

their choices through voice and button presses in the FF interactions but the deceivers in the computer-mediated FB interaction only reported their choices through button presses. Future studies controlling these factors might provide direct evidence for whether the RT deception effect differs across the two types of interactions.

The neural findings provided insight into the underlying mechanisms related to deception in FF and FB interactions. Previous studies have consistently found that activity in the DLPFC was correlated with the degree of deception indexed by either deception magnitude or frequency in both non-interactive and interactive situations (Abe et al., 2009; Greene and Paxton, 2009; Tang et al., 2018), and stimulating the DLPFC with transcranial direct current stimulation (tDCS) decreased deception magnitude (Maréchal et al., 2017). In line with these findings, our results showed that deception recruited greater activation of the rDLPFC than did honesty in the FF interactions, and this effect was more prominent in the FF interactions than in the FB interactions, providing neural evidence that the deceivers required more cognitive effort to control their untruthful demeanour in the FF interactions
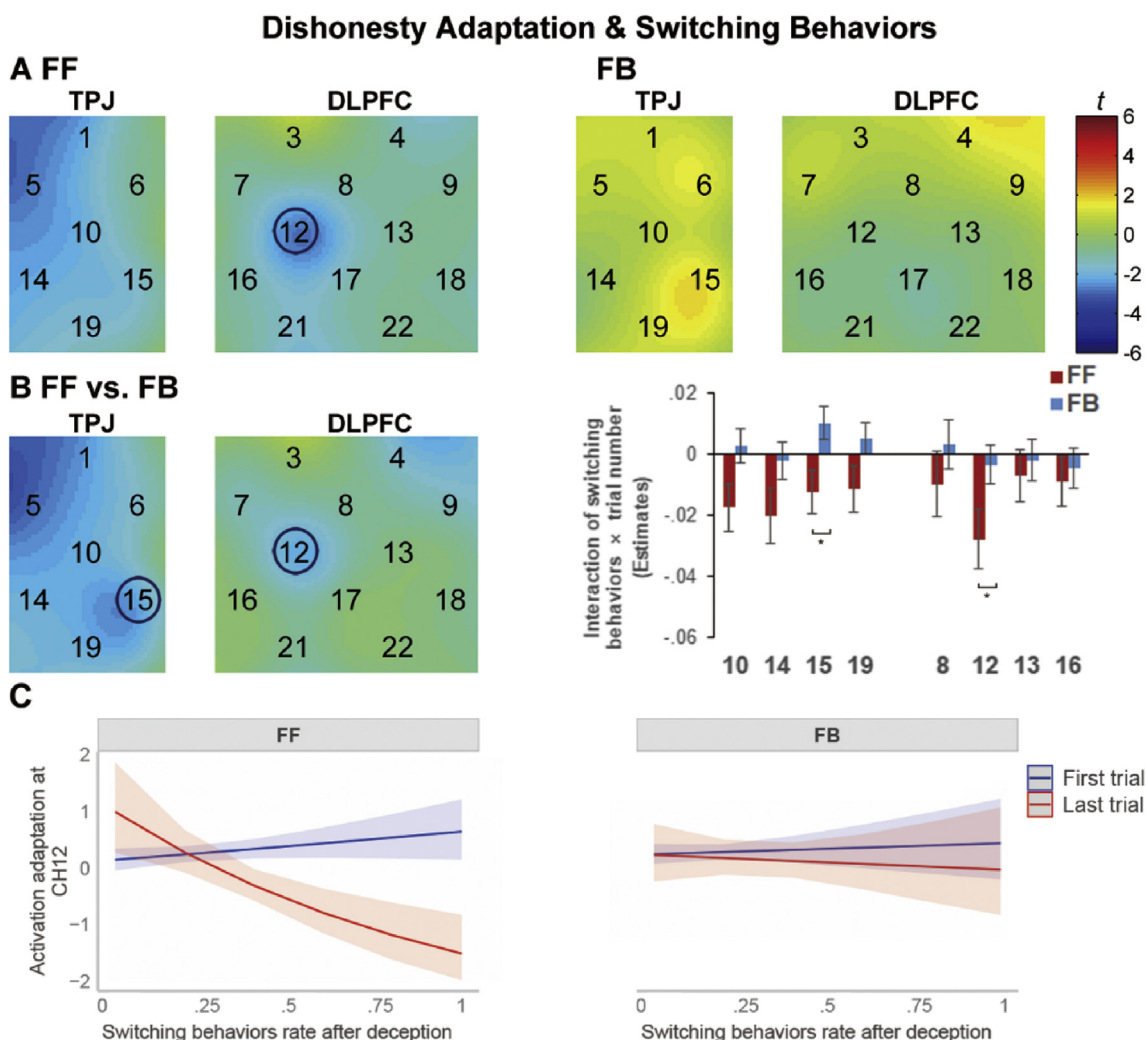
Dishonesty Adaptation & Switching Behaviors

Fig. 5 – The link between neural dishonesty adaptation and switching behaviours based on the GLMM analysis. The switching behaviours indicated the switching behaviour rate after deception prior to the current deceptive trial. A) Neural dishonesty adaptation in the rDLPFC was significantly associated with switching behaviours in the FF but not in the FB interactions. B) Comparisons between the two conditions showed that this link in the rDLPFC was greater in the FF than in the FB interactions [*$p < .05$ ($p_{FDR} < .1$)]. C) An illustration of the Trial × Switching × Condition interaction effect on activation in deception from the GLMM analysis, in which the shaded areas indicate the 95% confidence interval of the estimated values. It shows that the decrease in activation in the rDLPFC over time was more significant if the deceivers switched to being honest more often after deception. Error bars indicate standard errors in the estimates of the GLMM.

(Burgoon et al., 2003; Van Swol et al., 2015). However, it is unclear why the greater activation in the rDLPFC did not lead to greater deception in the FF than in the FB interactions, and what role the rDLPFC plays in deception in these two types of interactions; the prefrontal cortex could be associated with either remembering the truth when the person is being deceptive, engaging inhibitory control over a truth, or switching between deceptive and honest responses (Christ et al., 2009).

The answer may be rooted in the behavioural and neural adaptations of dishonesty in the FF interactions. Consistent with previous studies reporting that people cheated with small magnitudes in the beginning but gradually increased the dishonesty magnitude over time (Garrett et al., 2016; Welsh et al., 2015), we also found such an escalation of the dishonesty magnitude in the FF and FB interactions. Furthermore, the brain activity in the rDLPFC showed dishonesty adaptation in the FF interactions but not in the FB interactions, which suggested that the cognitive effort for deception was reduced over time in the FF interactions. The DLPFC is an essential region for adapting to novel or difficult circumstances (Spence et al., 2004). Specifically, it is engaged in conflict adaptation in preparation for an upcoming conflict based on the experience of previous conflicts (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Kan et al., 2013; Oehrn et al., 2014). The deceivers in the FF interactions might exploit the behavioural feedback, facial expressions, and body gestures of the receivers based on their history of interactions to prepare for the next deception. Thus, these deceivers showed neural adaptation during deception in the rDLPFC.

Interestingly, we found that this adaptation was driven by switching behaviours between being deceptive and being honest. The more likely the deceivers switched to being honest after a deception, the better they adapted to deception over time. These results corroborated previous findings that the rDLPFC was continuously involved in strategic behaviours in interactions such as bargaining (Bhatt et al., 2010), and especially in situations involving switching between deception and honesty (Christ et al., 2009).

We did not find differential activation of the rTPJ between the FF and FB interactions during deception. The rTPJ contributes to the understanding of others' intentions (Saxe and Powell, 2006) and mentalizing processes about future behaviours related to interactions (Carter, Bowling, Reeck, & Huettel, 2012; Teufel, Fletcher, & Davis, 2010). It is causally engaged in referring to how the outcomes of one's current behaviours influence partners' responses in future dynamic interactions, and interrupting its function could decrease strategic behaviours (Hill et al., 2017). Thus, this current result might have been caused by the deceiver needing to continuously infer the receiver's intention and the consequences of actions in both deceptive and honest trials in the two types of interactions, which increased the activity in the rTPJ in the FB interactions thereby diminishing the differences between the two interactions. However, the rTPJ adapted to dishonesty over time in the FF interactions. This could be due to the deceivers' adjustments in judging receivers' intentions being greater in the FF interactions than in the FB interactions. Alternatively, the absence of a difference in activation of the rTPJ between both types of interactions and its significant adaptation in the FF interactions might also have been caused by adaptation of attention or reorientation for social stimuli (Teufel et al., 2009). In dynamic interactions, the reorientating system is highly engaged when responding to novel and unexpected stimuli and then redirecting attention to information relevant to the goals of actions (Corbetta, Patel, & Shulman, 2008; Geng et al., 2013). As a key region in this system, the TPJ has been shown to be activated in response to behaviourally relevant distractors and deactivated during focused attention (Serences et al., 2005; Shulman et al., 2003). In our study, the deceivers needed to reorient their attention to the receivers' response to deception and honesty in both the FF and FB interactions, which might have decreased the difference in the activity of the TPJ between the FF and FB interactions. Furthermore, the deceivers adapted to the stimuli and responses of the receivers in the FF interactions, which might have resulted in a decreased demand for the reorientating system over time.

To our knowledge, this is the first study to investigate how deception dynamically changes over time in dyadic naturalistic interactions. Our results show both similarities and differences to the first study about neural adaptation in deception (Garrett et al., 2016). In Garrett et al.'s study, participants could gain benefits by sending dishonest advice to mislead anonymous estimators to make wrong estimates. Behaviourally, we replicated their findings and found dishonesty adaptation in both the FF and FB interactions, supporting the slippery-slope of dishonesty effect. At a neural level, they did not find dishonesty adaptation in the DLPFC but did in the amygdala, a brain region associated with emotion processing. Consistent with their findings, we found that the

dishonesty adaptation in the rDLPFC was not significant in the FB interactions (the situation in their study resembled the FB interactions in our study). However, this effect was significant in the FF interactions and was greater in the FF than in the FB interactions, suggesting that the rich social cues in FF interactions play important roles in the neural adaptation of dishonesty in the rDLPFC in naturalistic interactions. In contrast, we were limited to recording activity in the brain regions close to the brain surface, as the limit of the depth that fNIRS can measure is 3 cm. Thus, in the current study, we could not measure activity in subcortical regions related to deception, such as the amygdala, insula, and anterior cingulate cortex (Lisofsky et al., 2014). Future studies measuring changes in emotion and whole-brain activity could provide more evidence for the interaction between cognitive and affective brain networks in interactive deception. In addition, we found successful deception or acceptance of deception did not increase but it decreased over time in the current study. These findings might be caused by the deceivers being controlled in sending their messages by simple voice report and button presses in the laboratory. Compared to the uncontrolled ways in which others are deceived in daily life, these restraints imposed in the present study might have decreased the effects of dishonesty adaptation on the outcome of deception. Future studies which allow deceivers to freely interact with others might contribute to the understanding of how dishonesty adaptation influences the success or failure of deception.

There are several limitations in the current study. First, we recorded the activity of only the rDLPFC and not the bilateral DLPFC; therefore, our results and explanations might not be generalizable to the left DLPFC. Second, we investigated only the effects in same-sex dyadic interactive pairs. As different-sex pairs might have different strategies, they might show differences in both brain activation and adaptation in deception (Cheng et al., 2015; Pan et al., 2017; Zhang et al., 2017). Third, previous studies which investigated neural correlates underlying naturalistic interactions with voice report in games found that deception elicited greater activation in the prefrontal cortex than honesty, and did not reveal any effect of verbally reporting on deception or other decision making in the games (Babiloni et al., 2007b, 2007a; Ding et al., 2014). Although their findings and our results with RTs suggest that voice report about simple rules of games might not affect the behavioural and neural difference between deception and honesty, we cannot completely exclude the effect of voice report on the neural findings in our study. Finally, we did not directly record the rich social cues in the FF interactions. Future studies, which measure the rich social cues, such as body gestures or attention, may provide direct evidence for their involvement in the deception.

In summary, our study provided evidence that FF interactions could facilitate successful deception and dishonesty adaptation over time by decreasing activity in the rDLPFC and rTPJ. The neural adaptations in the rDLPFC were driven by switching behaviours after deception. These findings contribute to understanding how small unethical transgressions such as deception escalate to larger ones (Welsh et al., 2015) and shed light on how the brain adapts to deception in naturalistic interactions that include feedback.

Conflict of interest

The authors declare no competing financial interests.

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CRediT authorship contribution statement

Honghong Tang: Conceptualization, Formal analysis, Investigation, Writing - review & editing, Writing - original draft. **Shen Zhang:** Methodology, Software, Formal analysis, Validation, Project administration. **Tao Jin:** Data curation, Methodology, Software, Formal analysis, Writing - review & editing. **Haiyan Wu:** Visualization, Investigation, Project administration. **Song Su:** Writing - review & editing, Supervision, Resources, Validation, Funding acquisition. **Chao Liu:** Conceptualization, Writing - review & editing, Supervision, Validation, Funding acquisition.

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Supplementary data

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