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Research Report

Temporal course of executive control when lying about self- and other-referential information: An ERP study

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ABSTRACT

Recent neuroimaging studies have been trying to investigate the neural correlates of deception. To explore the temporal course of neural activity underlying deception, we recorded event-related potentials (ERPs) while participants were performing the Differentiation of Deception Paradigm (DDP) task to self- and other-referential information. Results showed that lying was associated with increased N1 (parietal–occipital area), N2 (frontal–central area) and decreased P3 (frontal–central area). Moreover, self-referential information elicited larger P2 and P3 compared with other-referential information. Finally, the interaction between stimulus and response types on N2 and P3 suggested that lying about self-referential information is more difficult than lying about other-referential information. These results revealed a temporal course of neural activity regarding executive function underlying deception, which complemented the current understanding of deception from the spatial dimensions.

1. Introduction

Driven by national security concerns as well as by the potential commercializing value, psychophysiological detection of deception (PDD) has been a very active field in recent years. Generally, investigators employed comparison question test (also known as the control question test, CQT) (Podlesny and Raskin, 1977; Raskin and Honts, 2002) and concealed information test (CIT, also known as Guilty Knowledge Test, GKT) (Lykken, 1960; Lykken, 1979) as questioning techniques. However, although these techniques, especially the CIT, have received ever-increasing attention from scholars employing neuroscience methodologies (e.g. event-related potentials, ERPs (Lui and Rosenfeld, 2008; Rosenfeld et al., 2008), functional MRI (Gamer et al., 2007; Langleben et al., 2002; Langleben et al., 2005), or transcranial directed current stimulation, tDCS (Karim et al., 2010)), they do not investigate the mechanisms of deception. For instance, the CIT mainly measures the recognition of crime-relevant information and a strong effect can be achieved even without the existence of deception (Furedy and Benshakhar, 1991; Meijer et al., 2009). Another recent study demonstrated that the brain activation pattern discovered in fMRI–CIT studies may be ascribed to the process of memory retrieval of past knowledge instead of responding deceptively (Gamer et al., in press).

To investigate the deception as a psychophysiological process, a paradigm available here is Differentiation of Deception Paradigm (DDP) which was developed by Furedy et al. (1988; 1991). In the DDP, the same set of equally probable stimuli or questions will be answered twice, once truthfully

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and once deceptively. The questions used in the two blocks are exactly the same, which eliminates the possible confounds related to differential significance of questions. Meanwhile, honest and deceptive responses occur in equal proportion, 50%–50%, for participants answered the same question twice. This step is to control the possible confound of stimulus frequency. In sum, in the DDP, the only difference between the control and experimental conditions would be the presence or absence of deception.

Recently, a number of studies have employed the DDP to investigate the cognitive process and neural basis underlying deception. Results consistently show that deception will elicit the activation of a network including the prefrontal cortex (PFC), e.g. the dorsalateral prefrontal cortex (DLPFC), the ventralateral prefrontal cortex (VLPFC), the medial frontal cortex (MFC) and the anterior cingulate cortex (ACC) (Abe et al., 2006; Abe, 2009; Christ et al., 2009; Ganis et al., 2003; Spence et al., 2001). It is reasonable to hypothesize that deception involves the need to inhibit the automatic yet inappropriate truthful response, detect the conflict between competing response tendencies and execute the controlled yet willed deceptive response to create a false belief in the target-person. These processes would be reflected by the involvement of MFC, DLPFC and VLPFC (Aron et al., 2004; MacDonald et al., 2000; Ridderinkhof et al., 2004). In addition, manipulating two competing response tendencies (truthful and deceptive responses) simultaneously will increase the working memory load, as reflected by the increased activation of DLPFC (Reuter-Lorenz et al., 2000). Despite the progress in understanding brain activity underlying deception along the spatial dimension provided by fMRI and PET, it is still worthwhile to elaborate the cognitive processing and the corresponding neural activity in deception along the temporal dimension.

A series of ERP studies used a variety of materials (perceptual stimulus, memorized words, and personal attitudes) to explore the spatial–temporal course of the neural activity during deceptive responses (Johnson et al., 2008, 2003, 2004, 2005; Tu et al., 2009; Wu et al., 2009). For instance, the parietal late positive component (LPC), which occurs 500–700 ms after stimulus presentation, was reduced in deception probably due to a dual-task nature of deception (Johnson et al., 2003). Moreover, the medial frontal negativity (MFN), which occurs within 0–100 ms post-response, was more negative after deceptive than truthful responding. This component, which was located near ACC, was thought to reflect the processes of response monitoring and conflict detection (Johnson et al., 2004). Another response-locked component, the pre-response positive (PRP) potential, was also reduced during deception compared with truth during the 100 ms interval before the response (Johnson et al., 2004; Johnson et al., 2005). This was thought to reflect the strategic monitoring/conflict resolution before the response. Despite these important findings, the previous findings were largely about lying about the perceptual stimulus and memorized material and the analysis mainly focused on late ERP activities, e.g. LPC and MFN. Thus, the current study aimed to extend previous research to investigate the temporal processing of lying about personal knowledge. Particularly, we expected to observe a series of distinguishable ERP components from early attention/perception to late response monitoring and selection processes. For instance, as a task involves enhanced attention, how will deception modulate the early attention-related ERP components like N1 or P2? Moreover, will the executive function involved in deception be represented in the frontal–central N2, a component thought to reflect response monitoring? Furthermore, how would the following conflict resolution and response selection processes be reflected by neural activity following N2? We expected that the conflict monitoring and the subsequent response selection can be separated temporally and functionally by ERP activities.

Another aim of the current study was to examine the neural activity underlying two different types of lying: lying about self-referential knowledge vs. other-referential knowledge. Previous studies which investigated deception to different stimulus types, however, have yielded inconsistent results. Using memorized words as material, Johnson et al. (2003, 2004) did not find that lying about old words is different from lying about new words, both in terms of behavioral patterns and MFN or LPC activities. However, when people were lying about their attitudes (e.g. agreed or disagreed item), results showed that lying about an agreed item elicited more negative MFN and less positive LPC than lying about a disagreed item (Johnson et al., 2008). Similarly, one recent fMRI study, which adopted rate-limiting processes to predict behavioral performance, found that different subsets of the cingulate–insula–prefrontal brain region were modeled to predict self- and other-related lies. This result also supported the notion that distinguishable neural circuits were underlying different types of deception (Ganis et al., 2009). Here, we aimed to compare deception to self-referential vs. other-referential information. Previous studies have consistently shown that self-related memory is superior to other types of memory and special neural circuits may exist for self-referring information, e.g. the middle cortex system (Kelley et al., 2002; Northoff and Bermpohl, 2004; Rogers et al., 1977). Moreover, P300–CIT studies also show that the detection rate is higher when lying about self-related information than lying about other-related information, which was explained by the potency and meaningfulness of self-relevant information which outweighs other-relevant information even if the other-related information was learned to 100% accuracy (Rosenfeld et al., 2006). Nevertheless, the relationships between self-other processing and executive function, which was hypothesized as a core feature in deception, remains unclear. Thus, the current research tried to examine the neural activities underlying the interaction of honest/dishonest response and processing of self-/other-referential knowledge. Considering the superiority of self-related memory, as well as the aforementioned studies, we hypothesized that lying about one's own information would be more challenging than about other-related information and these two processes can be differentiated.

2. Results

2.1. Behavioral results

Since the effect of order of task as a between-subject variable did not reach significance in both RT and accuracy [$F(1,21)<1$,

$p > .05$], we focused the analysis on the 2 (stimulus: self vs. other) × 2 (response: honest vs. dishonest) within-subject ANOVA. Regarding RT, the result revealed a significant main effect on stimuli, $F(1,21) = 39.46$, $p < .001$, and response, $F(1,21) = 121.03$, $p < .001$. Specifically, response to self-related information (mean ± SE: 651.84 ± 18.82) was faster than other-related information (691.44 ± 21.08); deceptive responses (751.63 ± 24.56) were associated with slower RT than truthful responses (591.82 ± 16.76). The interaction between response and stimuli type was not significant ($F < 1$, $p > .3$) (see Fig. 1).

Analysis of error rate (mean ± SE) revealed a significant main effect on stimuli type [$F(1,21) = 4.51$, $p < .05$] and response type [$F(1,21) = 14.81$, $p < .001$]. Results showed that response to self-related information (.978 ± .005) was more accurate than other-related information (.965 ± .008), and honest response (.992 ± .003) was more accurate than deceptive response (.952 ± .01). Furthermore, the interaction between stimulus and response type was not significant: $F < 1$, $p > .3$ (see Fig. 1).

2.2. ERP results

2.2.1. Early processing reflected by N1 and P2

N1: A 2 (stimuli: self vs. others) × 2 (response: honest vs. dishonest) × 4 (scalp electrode zone: frontal, central, parietal and occipital) within-subjects ANOVA resulted in a significant main effect of response type [$F(1,21) = 16.67$, $p < .001$], as well as a significant main effect of electrode zones [$F(3,63) = 20.08$, $p < .001$]. Post hoc analysis showed that the deceptive response ($-3.25 \pm .275$ μV) elicited a more negative N1 than the truthful response ($-2.80 \pm .246$ μV). Concerning the main effect of area, N1 at parietal area was more negative than frontal area ($p < .001$); N1 at occipital area was more negative than at frontal, central and parietal area (all $p < .001$). No other main effect or interaction was found.

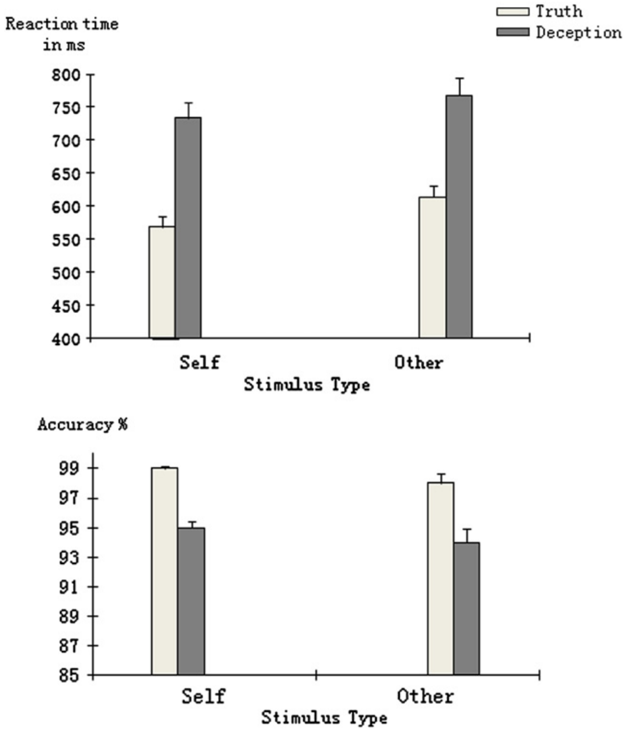

Fig. 1 – Behavioral performance of stimulus (self vs. other) and response type (truth vs. deception). Top: Reaction time; Bottom: Accuracy.

P2: The same ANOVA on P2 amplitude revealed a main effect of stimuli type [$F(1,21) = 5.46$, $p < .05$], suggesting that self-related stimuli (3.77 ± .351 μV) elicited larger P2 than other-related stimuli (3.32 ± .349 μV). No other main effect or interaction was found.

2.2.2. Late processing reflected by N2 and P3

N2: A 2 (stimulus: self vs. other) × 2 (response: honest vs. dishonest) × 4 (scalp electrode zones: frontal, central, parietal and occipital) within-subjects ANOVA showed a significant main effect on response type [$F(1,21) = 6.93$, $p < .05$], which meant that deceptive response ($-2.537 \pm .342$ μV) was associated with more negative N2 than honest response ($-1.948 \pm .324$ μV). There was also a strong trend of effect of the electrode zones [$F(3,63) = 3.4$, $p = .06$]. Post hoc analysis showed that the N2 was more frontal–central distributed, yet the difference is not significant at .05 level. No other main effect or interaction was found. Since the N2 is the frontal–centrally distributed, we further examined this N2 effect confined within the frontal–central area (including FCz, FC1, FC2, Cz and 7, 106, see Fig. 5). This re-analysis further confirmed the main effect of response type [$F(1,21) = 17.47$, $p < .001$], suggesting that deception was related to more negative N2 than honest responding. It also showed a main effect of stimuli [$F(1,21) = 7.82$, $p = .011$], which was indicated by more negative N2 for other-related stimuli than self-related stimuli. More importantly, the stimuli by response interaction was found [$F(1,21) = 4.72$, $p < .05$]. The follow-up simple effect test showed that more negative N2 associated with lying about self-related information (deceptive–honest (self) = -2.698 μV, $p = .003$) than lying about other-related information (deceptive–honest (other) = 0.774 μV, $p = .008$) (see Fig. 2).

P3: A 2 (stimuli: self vs. others) × 2 (response: honest vs. dishonest) × 4 (scalp electrodes area: frontal, central, parietal and occipital) within-subjects ANOVA revealed that the self-related stimuli had elicited larger P3 (3.51 ± .39 μV) than other-related stimuli (2.96 ± .38 μV) [$F(1,21) = 8.35$, $p < .01$]. Furthermore, a significant interaction between stimulus and response type was revealed [$F(1,21) = 4.61$, $p < .05$]. This interaction could be accounted for by the significantly more reduced P3 when lying about other-related information (honest–deceptive (other) = 0.616 μV) than lying about self-related information (honest–deceptive (self) = -0.152 μV). No other main effect or interaction was found. To be consistent with the N2 analysis, the P3 within the frontal–central area were re-analyzed. Results again showed a significant main effect stimuli type as evidenced by a larger P3 with self-relevant information (1.72 ± .41 μV) than other-related information (1.09 ± .45 μV) [$F(1,21) = 5.99$, $p < .05$]. Moreover, the response type also showed a significant main effect [$F(1,21) = 10.34$, $p < .05$], suggesting that deceptive response was associated with more decreased P3 (.96 ± .41 μV) than truthful response (1.86 ± .46 μV) was. Finally, the stimulus and response type interaction was again significant [$F(1,21) = 9.55$, $p < .01$]. A follow-up simple effect test showed that this interaction could be accounted for by the significantly more reduced

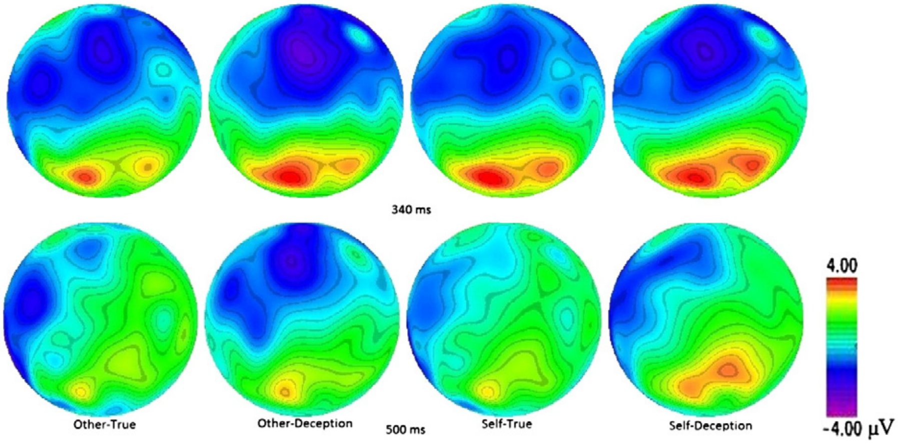

Fig. 2 – Top view of voltage distribution maps showing the whole brain activity about stimulus type (self vs. other) and response type (truth vs. deception). Top: the N2 voltage distribution at 340 ms. Bottom: the P3 voltage distribution at 500 ms.

P3 associated with lying about other-related information (deceptive–honest (other) = −1.604 µV, $p < .01$) than lying about self-related information (deceptive–honest (self) = −0.204 µV, $p > .6$). (See Fig. 2. For stimulus-locked waveforms at FCz, see Fig. 3.)

3. Discussion

3.1. *Behavioral results*

This study employed the Differentiation of Deception Paradigm and event-related potentials to investigate the neural activity underlying deception about self-/other-referring information. Consistent with previous results using a similar paradigm (Johnson et al., 2008, 2003, 2004, 2005; Nuñez et al., 2005; Spence et al., 2001), deception involved more conflict and control, as evidenced by prolonged RT and reduced accuracy. Moreover, self-referential information was retrieved more quickly and with higher accuracy than other-related information, suggesting that self-referential memory is more elaborated, processed more deeply and retrieved with more ease than other-referential knowledge (Craik et al., 1999; Kelley et al., 2002; Rogers et al., 1977; Symons and Johnson, 1997).

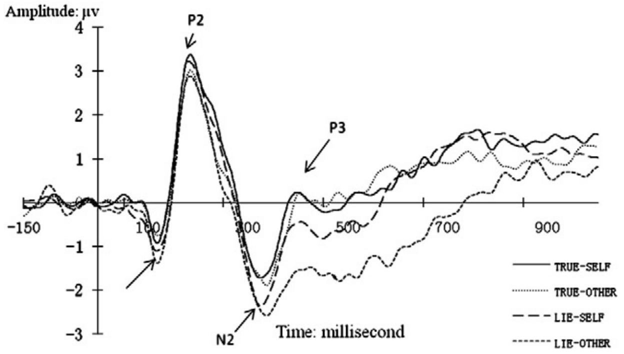

Fig. 3 – Grand average waveform of the stimulus-locked ERPs for N1, P2, N2 and P3 at FCz.

3.2. *ERP results*

ERP results revealed that the 80–180 ms parietal–occipital N1 was significantly larger in deception compared with truth, while the 180–280 ms frontal–central P2 was larger for self-related information than other-related information. Late components over the frontal–central area also distinguished deception and truth as suggested by the more negative N2 (280–400 ms) and the less positive P3 (400–600 ms) in deception. Moreover, stimulus type was differentiated from N2 and P3: self-referring information elicited significantly less negative N2 and more positive P3 than other-related information. Finally, the interaction between stimulus and response type reflected on frontal–central N2 and P3 indicated that different deceptive processes could be distinguished by ERP activities.

3.2.1. *The N1–P2 effect and early processing*

The occipital N1 was thought to reflect enhanced attention to attended or task-relevant stimuli (Hillyard et al., 1973; Hillyard and Anllo-Vento, 1998; Luck et al., 1990). Here, the deception-related N1 was larger than during truthful responses, suggesting that the stimuli in the deception task required more attention resources for subsequent information processing. On the contrary, being honest is regarded as a default response state during human interaction (Greene and Paxton, 2009), which does not require enhanced attention resources as deception does. Although no previous studies reported this deception-related N1 effect, we believed it is valid because deception required more attention to deal with later cognitive processing, e.g. stimuli evaluation, response monitoring etc. As a matter of fact, a number of fMRI-based deception studies had found that lying would recruit attention-control networks to execute this goal-directed response (Christ et al., 2009; Langleben et al., 2005).

The P2 component following N1 showed a significant effect of stimuli category: the self-related information elicited a larger P2 than other-related information. The P2 is usually suggested to play a role in perceptual processing (Chen et al., 2008b; Hillyard and Anllo-Vento, 1998). Given the stimulus feature here, self-referential information could be more arousing and attention-capturing for participants than other-referential information, which resulted in increased P2. This result is also consistent with a recent CIT study which showed an enhanced P2 to participants' own birth date compared with irrelevant dates (Meixner and Rosenfeld, 2010). It is worthy noting that early processing of stimulus as reflected by N1 and P2 warrants future studies exploring the ERPs correlated with deception and would illustrate how would one's behavior goal (e.g. deception) influence the early attention allocation stage in information processing (e.g. Bentin and Golland, 2002). In sum, the N1 and P2 effect on response type and stimulus type respectively may facilitate the following higher cognitive processing as indexed by late ERP components.

3.2.2. *The N2–P3 effect and the late processing*

The current study is among the first to show that the stimulus-locked N2 was associated with deception (Wu et al., 2009). Generally, N2 can be divided into a perceptual driven novel or mismatch N2 and a cognitive control related response monitoring and control N2 (for review, see Folstein and Van Petten, 2008). The N2 observed in the current study could be classified as the latter category for its involvement in deception, which requires cognitive control (Christ et al., 2009; Nuñez et al., 2005; Spence et al., 2004). Recent ERP–CIT studies also identified the enhanced N2 to probe than to irrelevant stimulus, suggesting the role of the orienting response or the response monitoring in the CIT task (Gamer and Berti, 2009; Matsuda et al., 2009). In the current study, the deception elicited significant larger frontal–central N2 than the honest responding in the 280–400 ms period. Given its spatial–temporal characteristics and its sensitivity to deception, the N2 here could reflect the response conflict and monitoring process involved in deception (Chen et al., 2008b; Nieuwenhuis et al., 2003; Veen and Carter, 2002; Wu et al., 2009). Based on previous studies which showed MFN was also involved in deception, it is possible that the stimulus-locked N2 and the response-locked MFN may both reflect the response monitoring process because (a) the N2 and MFN showed a similar medial central–frontal distribution as well as their sensitivity to deceptive responding; (b) previous response monitoring studies showed that N2 reflected response conflict on trials involving two competing response tendencies, e.g. incompatible flanker trials, and was thought to reflect the activity of ACC (Chen et al., 2008b; Veen and Carter, 2002; Yeung and Cohen, 2006). Studies on MFN or error-related negativity (ERN) also suggested its role in response monitoring and the MFN or ERN was suggested to be generated in or near ACC (Gehring and Willoughby, 2002; Johnson et al., 2008, 2004; Veen and Carter, 2002; Yeung and Cohen, 2006). Thus, it is possible that the N2 here represented the conflict generated from the competition between the controlled dishonest response and the automatic-activated honest response prior to the response, whereas MFN monitored the conflict occurred between the already executed deceptive response (incompatible with truth) and the still activating honest response (compatible with truth) after the response. Future studies are warranted to directly address this N2–MFN issue in deception tasks.

The P3 here first showed a main effect of stimulus type over the midline scalp area: personal information was larger than non-personal information. Since the stimulus frequency here was equalized, this larger P3 would be attributed to the meaningfulness of self-relevant information (Johnson, 1986). Although our paradigm was different from classic oddball paradigm which was used to elicit the classic parietal P3b (Polich, 2007), the P3 we obtained here, over the frontal–central and parietal area, still reflected the process of stimuli categorization and evaluation. Moreover, our result is also consistent with previous CIT studies which showed that autobiographical information evoked a larger parietal P3 compared with non-self-referring information or with incidentally acquired information (Rosenfeld et al., 2006, 2007). This result added further evidence that self-related information is processed more deeply and suggested the self-memory superiority effect along with other ERP studies (Chen et al., 2008a; Gray et al., 2004; Perrin et al., 2005). When focused on the frontal–central P3, the main effect of response type emerged: the P3 in the deception block was reduced than the P3 in the honest block. This effect could be ascribed to the elevated task demand in deception, especially the processes of conflict resolution and response selection after the conflict detection process. This higher workload would decrease the P3 (Chen et al., 2008b; Johnson et al., 2008; Tu et al., 2009). This explanation followed the model that the P3 varies as a function of task complexity (Johnson, 1986). Here, since the reduced P3 was following enhanced conflict-sensitive N2, we proposed that the P3 here reflected conflict resolution and response selection process (e.g. to select the goal-relevant deceptive response). This inverse relationship between N2 and P3 is consistent with another ERP study which found that the more negative N2 was associated with smaller P3 in the forced deceptive response instead of self-determined responses (Wu et al., 2009). Moreover, the current N2–P3 could be analogous to the result of Johnson et al. (2008, 2004) that deception involved larger MFN and reduced LPC. Given its temporal and functional implication, the N2–P3 relationship provided temporal evidence regarding conflict detection and control in deception tasks within one trial, which complemented the fMRI/PET studies' results that the activation of ACC and lateral PFC were underlying deception (Abe et al., 2006; Abe, 2009; Christ et al., 2009; Nuñez et al., 2005; Sip et al., 2008; Spence et al., 2001, 2004).

3.2.3. *Different types of deception and their corresponding neural activities*

In the current study, we designed two different kinds of deception: one was lying about self-related information and the other one was lying about other-related information. The interaction between stimulus and response type on frontal–central N2 and P3 suggested that these two types of lies could be differentiated via neural activity. Specifically, lying about self-referential information caused more conflict and was more difficult to execute, as evidenced by a more negative N2 and a less reduced P3, than lying about other-related information. The differential effect of deception regarding self-/other-referential information on P3 is consistent with recent P300–CIT studies which showed that deception could enhance the detection efficiency when the probe was the participants' own name but not when the probe was another's name, although the others' names were learned with 100% accuracy (Rosenfeld et al., 2006; Verschuere et al., 2009). Moreover, the interaction on frontal–central N2–P3 is consistent with the finding of Johnson et al. (2008) that lying about an agreed item elicited a more negative MFN and a more reduced LPC than lying about a disagreed item, which was explained in terms of the "denial of self" being more difficult than conformity. Similarly, Ganis et al. (2009) also found that different subsets of the interference-control network were involved in predicting behavioral performance regarding self- and other-related lies. Although some other studies failed to find this pattern of results, we argued that the inconsistency could be attributed to the difference of stimuli used in the various experiments: the studies that failed to find the difference used perceptual stimulus or memorized words (Johnson et al., 2003; Wu et al., 2009), whereas we and others used highly personal relevant information (e.g. personal names, attitudes). Compared with perceptual stimulus or memorized words, self-referring information is processed more deeply and, thus, is more difficult to lie about. Therefore it is reasonable to infer that the more personal relevance the stimulus is, the more difficult it is to lie about. Results from fMRI studies also corroborated this notion: Nuñez et al. (2005) found that the interference effect (as evidenced by enhanced activity in ACC and DLPFC) was more significant when lying about autobiographical information (e.g. Can you ride a bicycle?) than lying about a non-autobiographical or general information (e.g. Is New York in Ohio?) In addition, studies using PET or tDCS presented similar findings (Abe et al., 2006; Mameli et al., 2010; Priori et al., 2008). In sum, combining ERP, fMRI, PET and tDCS results suggests that the differential neural activity are involved by deception about stimuli that differ along the self-relevance or significance level.

3.3. *Conclusion*

Using a Differentiation of Deception Paradigm, our results showed a series of distinguishable ERP activities regarding deception and truth: the early N1 and P2 components were related to early attention allocation and stimulus evaluation; the late N2 and P3 components were implicated in conflict detection, stimuli categorization and response selection. Moreover, the interactions between stimulus and response on N2 and P3 activities consistently demonstrated that deception could be differentiated as the stimuli changed. Here, the liars experienced more interference when lying about self-referential information compared with other-referential information. This result again emphasizes that deception involves highly flexible behavior along various cognitive or emotional dimensions. Thus, further exploration of biological markers underlying different types of deception is warranted to increase our understanding of this universal behavior.

4. Experimental procedures

4.1. *Participants*

Twenty-two college students (9 males, average age = 19.3 years) were recruited via fliers on campus. They were given a monetary reward for their participation. All participants were right-handed and had normal or corrected-to-normal vision. Signed informed consents were obtained prior to the experiment.

4.2. *Stimuli and procedure*

The stimuli consisted of self-referential information (participant's full name, date of birth and hometown) and other-referential information (a stranger's full name, an irrelevant date and an irrelevant place). Each stimulus was presented fifteen times, resulting in $15 \times 3 \times 2 = 90$ trials. Stimulus was in white font on a black background lasting for 300 ms and the inter-trial-interval varied between 1500 and 2500 ms. Participants were seated approximately 90 cm from the monitor. According to different instructions, the experiment consisted of 2 blocks. One was the honest block, in which participants were asked to press "yes" for self-related information and "no" for the other-related information. The other was the dishonest block, in which participants were asked to press "no" to deny their own self-related information and "yes" to the other-related information as if they were someone else. The order of the two blocks was counterbalanced across participants. Since the second block required participants to reverse their responding, it was possible that participants would simply reverse the button-press without being deceptive or truthful. To avoid this, we employed additional 30 trials of "Honest" and "Dishonest" in each block. These trials were randomly presented among the 90 self-/other-information stimuli. Participants were told to press "yes" to "Honest" catch trial and to press "no" to "Dishonest" catch trial across honest and dishonest blocks. Thus, the responses to catch trials were consistent across two blocks to prevent participants from merely reversing the response mapping (for other catch trials, see Johnson et al., 2008). Moreover, these Honest/Dishonest catch trials reminded the participants that this was an honest/dishonest task rather than right/left button-press classification. The participants were warned that they would be excluded if they made 3 or more errors to those catch trials in each block.

4.3. *Electrophysiological recording and analysis*

The EEG was recorded from 128 sites using the 128-channel Geodesic Sensor Net. The impedance of all electrodes was kept below 40 KΩ (an acceptable setting for this system for its high-impedance amplifiers) (Tucker, 1993). All recordings were initially referenced to vertex (Cz) and re-referenced off-line against the average reference. EEG was recorded using 0.1–100-Hz bandpass on-line and filtered using 0.1–30-Hz off-line for subsequent analysis. Signals were sampled with 500-Hz digitization rate. Trials containing eye blink ($<50\ \mu V$) were rejected. ERPs epoch was 1150-ms long (including a 150-ms

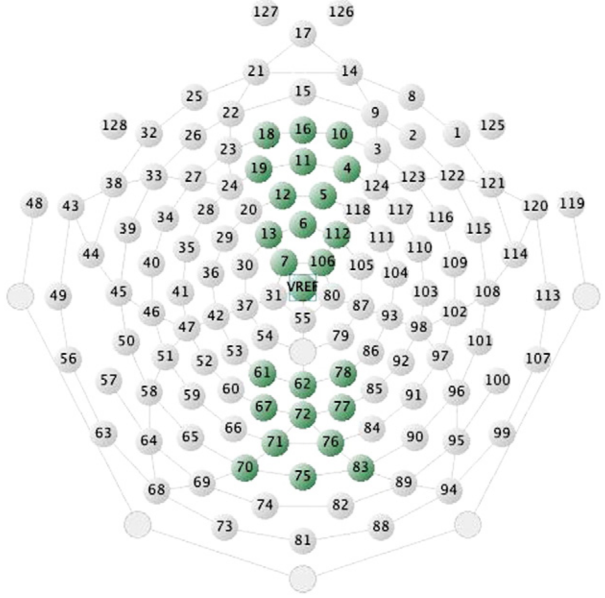

Fig. 4 – Electrode clusters: Frontal zone includes 4 (F2), 5, 10, 11 (Fz), 12, 16 (AFz), 18, 19 (F1); central zone includes 6 (FCz), 7, 13 (FC1), 106, 112 (FC2), VREF 129 (Cz); parietal zone includes 61, 62 (Pz), 67 (PO3), 72 (POz), 77 (PO4), 78 and occipital zone includes 70 (O1), 71, 75 (Oz), 76, 83 (O2).

baseline). After deletion of incorrect response trials and artifact, ERPs were averaged according to stimulus type (self vs. other) and response type (honest vs. dishonest) into four categories: honest-self, honest-other, dishonest-self and dishonest-other. If the correct and artifact-free trials in any category were less than 30, then the participant was excluded from subsequent analysis.

Electrode clusters were chosen along the midline for analysis: the frontal zone consisted of 4 (F2), 5, 10, 11 (Fz), 12, 16 (AFz), 18 and 19 (F1); the central zone consisted of 6 (FCz), 7, 13 (FC1), 106, 112 (FC2), 129 (Cz); the parietal zone consisted of 61, 62 (Pz), 67 (PO3), 72 (POz), 77 (PO4), 78 and the occipital zone consisted of 70 (O1), 71, 75 (Oz), 76, 83 (O2) (see Fig. 4). The ERPs were stimulus-locked and the time windows for each component were the following: N1, 80–180 ms; P2, 180–280 ms; N2, 280–400 ms and P3, 400–600 ms. The amplitude (baseline-peak) was defined as the mean amplitude of the electrode zone of an 80 ms epoch (±40 ms) around the peak of each component. The amplitude of each ERP component was then submitted in ANOVA with response type (honest vs. dishonest), stimulus type (self vs. other-referential information) and electrodes clusters (frontal vs. central vs. parietal vs. occipital) as within-subject variables and the order of task (first vs. second) as a between-subject variable. The effect of order was not reported for it did not reach significance for all dependent variables (all $p > .05$). Results were corrected with Greenhouse–Geisser (GG) if the $df > 1$.

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