RESEARCH ARTICLE

The neural correlates of incidental self-processing induced by handwritten negative words

Lei Zhu · Li Zheng · Menghe Chen · Xiuyan Guo · Jianqi Li · Luguang Chen · Zhiliang Yang

Abstract Behavioral studies revealed that people were less likely to endorse negative information as self-descriptive. Neuroimaging studies have tapped on the neural mechanism underlying intentional self-processing of negative information using self-reflection tasks. Given that human self-processing occurring in our daily life is more likely to be captured by tasks involving incidental self-processing (automatic associations between the self- and external stimuli), rather than tasks involving intentional self-processing, it could be presumed that the relationship between self- and negative emotion might be better reflected during incidental self-processing. The present functional magnetic resonance imaging study aimed to explore incidental self-processing of negative information. To induce participants' incidental self-processing, we adopted negative and neutral words written by themselves or others as materials. They were scanned during judging whether the handwritten words were negative or neutral (additional non-self-task). Results revealed that incidental self-processing of negative information relied on the activation of left anterior insula, whereas medial prefrontal cortex activity was associated with incidental self-processing of neutral information.

Keywords Incidental self-processing · Self-handwriting · Negative emotion · MPFC · AI

Introduction

Within the past decade, researchers have made great efforts to investigate the neural basis underlying self-processing. Numerous neuroimaging studies have consistently demonstrated medial prefrontal cortex (MPFC) activation during self-reflection tasks which intentionally and consciously required participants to evaluate whether an item was self-descriptive (D'Argembeau et al. 2008; Fossati et al. 2003; Heatherton et al. 2006; Johnson et al. 2002; Kelley et al. 2002; Sajonz et al. 2010). Investigations subdividing participants' responses further revealed that items judged to be self-relevant were associated with greater MPFC activity than items judged to be irrelevant to the self (Macrae et al. 2004; Moran et al. 2006, 2009; Zhu et al. 2012).

However, such kind of intentional self-processing is relatively unusual in our daily life. In most social contexts, self-processing is usually relatively automatic associations between the self- and external stimuli (Rameson et al. 2010), which are not necessarily intentional. These automatic associations might be better reflected by incidental links between the self- and external stimuli (Cloutier and Macrae 2008; Cunningham et al. 2008; Turk et al. 2008). For example, when carrying out helping behaviors, one never directly asks "Am I kindhearted to save a drowning

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child"? Instead, incidental self-processing predicts such actual behaviors in an automatic way (Perugini and Leone 2009). Thus, for exploring human self-processing occurring in our daily life and its underlying neural basis, it seems to be more ecological for researchers to adopt the tasks involving incidental self-processing.

To our knowledge, several functional magnetic resonance imaging (fMRI) studies have investigated incidental self-processing by requiring participants to do a non-self-task (e.g., to respond when self-relevant words or self-irrelevant words were shown in green rather than white font, Moran et al. 2009; Rameson et al. 2010). These studies revealed greater activities in MPFC during processing self-relevant items (e.g., one's own name or self-schema) than self-irrelevant items even without intentional evaluation of self-relatedness. In addition to the stimuli used in the above-mentioned studies, one's own handwriting is another common kind of self-relevant information in everyday life. It is well known that handwriting characteristics can reflect one's own internal mental world and personality characteristics (Ren and Feng 2001; van Rooij and Hazelzet 1997). And the activation of self-concept by handwriting is mainly through visual features (Chen et al. 2008). Thus, in the present study, employing self-handwriting (vs. other-handwriting) materials was considered as a useful method to elicit incidental self-processing.

Further, a separate but critical issue regarding self-processing is "negative bias." Specifically, people are especially sensitive to and preferentially process negative information relative to neutral or positive information (Carreti'e et al. 2001; Huang and Luo 2006). At the neural level, several emotional areas including anterior insula (AI, Akitsuki and Decety 2009; Gu et al. 2010), anterior cingulate cortex (ACC, Cheng et al. 2010; Guo et al. 2012) and amygdala (Sergerie et al. 2008; Williams et al. 2004) have been extensively observed during negative stimuli processing by numerous fMRI studies.

With regard to intentional self-processing of negative information, behavioral studies revealed that people were less likely to endorse negative information as self-descriptive (Alicke 1985; Brown 1986) and were also more scared to see self-relevant negative outcomes and tended to judge them to be less foreseeable (Mark et al. 2003). Several fMRI studies have already tapped on the neural mechanism underlying intentional self-processing of negative information (Fossati et al. 2003; Moran et al. 2006; Yoshimura et al. 2009). Fossati et al. (2003) found that, when judging the self-relatedness of negative personality traits versus judging whether the word contained a specific target letter, MPFC was significantly activated, and no activations were found in AI, ACC or amygdala. Moran et al. (2006) observed stronger activities in dorsal ACC when judging negative traits to be high in self-relevance. Yoshimura et al.

(2009) revealed the engagement of both MPFC and right amygdala during intentional self-processing of negative words relative to semantic processing of negative words.

Considering that human self-processing occurring in our daily life is more likely to be captured by tasks involving incidental self-processing, rather than tasks involving intentional self-processing, it could be presumed that the relationship between self- and negative emotion might be better reflected during incidental self-processing. Thus, the present study tried to investigate incidental self-processing of negative information and its underlying neural mechanism by adopting handwriting materials and a non-self-task. Specifically, before the experiment, participants' handwritings of negative and neutral words were collected. Then, participants were scanned when they judged whether the words written by themselves or others were neutral or negative (Fig. 1a). It is predicted that the more activities in emotional areas might be observed during incidental self-processing of negative versus neutral words.

Materials and methods

Participants

Eighteen right-handed volunteers from the university community with normal or corrected-to-normal vision (four males, aged from 20 to 30, $M = 22.11$, $SD = 2.59$) participated in this experiment. None of the participants reported significant abnormal neurological history. All the participants were paid 50 RMB for their participation and gave informed consent before scanning.

Materials

One hundred words were selected from affective norms for English words (ANEW, Bradley and Lang 1999), and all of them were translated into 100 two-character Chinese nouns by two English experts. Emotional valence, arousal and dominance of these Chinese nouns were rated by 20 volunteers (not participants of the fMRI experiment) on a 9-point scale. Then, these nouns were divided into two lists which were counterbalanced for the ratings of valence, arousal and dominance. Each list contained 25 negative words and 25 neutral words. The valence and arousal of the negative words were significantly different from that of neutral words (ts > 12.33, ps < .01). One list served as self-handwriting materials, and second served as other-handwriting materials. And then, both of them were written by all the participants. Each participant was required to write down each word as big as he or she could in a 4 cm × 1.5 cm rectangle. The handwriting for each word was then scanned and saved as a picture. The handwriting materials from two participants were paired

Fig. 1 **a** Experimental procedure. For each trial, a 0.5 s fixation cross was presented at first, followed by a 2.0 s word. Participants were asked to judge whether the given word was negative or neutral. The words in the *solid rectangles* were written by one participant, and the words in the *dashed rectangles* were written by the other. **b** Regions showing interaction between incidental self-processing and emotion. Left AI showed greater contrast values (i.e., the difference of beta estimates between self and other trials) for negative words than neutral words, whereas MPFC showed greater contrast value for neutral words than negative words. *Error bars* indicate s.e.m. **c** Simple effects analyses. Results revealed MPFC activation was found when comparing self-handwritten neutral words with other-handwritten neutral words
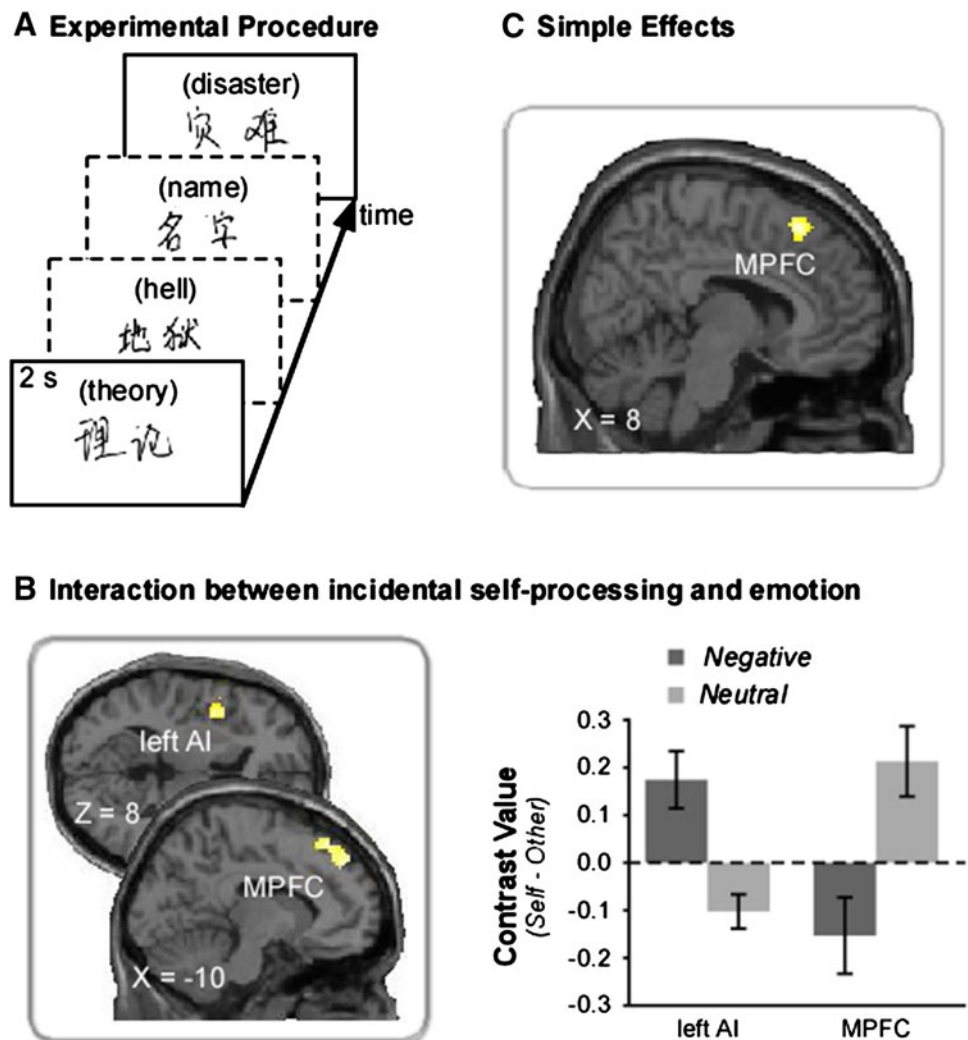
together. In order to rule out the influence of memory, all the participants were required to write all the 100 words before the experiment. We then paired 50 of 100 words written by one participant (List One) and the other 50 of 100 words written by another participant (List Two) together. Thus, during experiment, 50 presented words (from one list) were participant's own handwriting and the other 50 words were his (her) partner's handwriting (from the second list). Thus, words that appeared as self-handwriting for one participant appeared as other-handwriting for the other participant.

Procedure

Before the experiment, participants were told that they were presented all the 100 words they have written several days ago during the experiment, 50 of them were presented in their own handwritings, whereas the other 50 words were presented in another student's handwritings.

During scanning, 100 words were presented randomly (Fig. 1a). For each trial, a 0.5 s fixation cross was presented

at first, followed by a 2.0 s word. Participants were asked to judge whether the given word was negative or neutral. Responses were given via a magnet-compatible button box below participants' right hands. The experimental trials were intermixed with 2.5 s null trials (30 trials in all), during which a black fixation cross was presented. All the trials were presented with jittered inter-stimulus intervals (a fixation cross) from 0 to 1 s.

After the experiment, participants were inquired about whether the stimuli brought their episodic memory in the experiment (e.g., whether they retrieved whether they have written these words; whether they recalled how they wrote every stroke at that time). All the participants reported "NO".

fMRI imaging

Imaging was carried out on a 3T Siemens scanner at the functional MRI lab (East China Normal University, Shanghai). Functional images were acquired using a gradient

echo-planar imaging (EPI) sequence (TR = 2,200 ms, TE = 30 ms, FOV = 220 mm, matrix size = 64 × 64). Thirty-five slices paralleled to the AC–PC line (slice thickness = 3 mm, gap = 0.3 mm) were acquired and covered the whole brain. The first five TRs acquired were discarded to allow for T1 equilibration. Before the functional run, a high-resolution structural image was acquired using a T1-weighted, multiplanar reconstruction sequence (MPR) (TR = 1,900 ms, TE = 3.42 ms, 192 slices, slice thickness = 1 mm, FOV = 256 mm, matrix size = 256 × 256).

fMRI data analysis

Data preprocessing and statistical analyses were performed with statistical parametric mapping (SPM5, Wellcome Department of Cognitive Neurology, London). During data preprocessing, all volumes were corrected for differences in slice acquisition timing and realigned spatially to the first volume of the first time series. Then, the resulting images which were re-sampled to 2 × 2 × 2 mm voxel size were spatially normalized to a standard echo-planar imaging template based on the Montreal Neurological Institute (MNI) reference brain and smoothed with an 8-mm full-width, half-maximum (FWHM) isotropic Gaussian kernel.

Statistical analyses were performed using the general linear model implemented in SPM5. Trials with correct responses were classified into four conditions according to handwriting and emotion: (1) SNeg: negative words written by self; (2) SNeu: neutral words written by self; (3) ONeg: negative words written by other; (4) ONeu: neutral words written by other. Each trial was modeled using a canonical hemodynamic response function and its temporal derivative according to four conditions. RT for each correct trial was additionally included in the model as a parametric regressor, to rule out the possibility that neural activities during different conditions were associated with imbalanced difficulties among conditions indicated by different levels of behavioral performance. Trials with incorrect or no responses, six regressors modeling movement-related variance and one modeling the overall mean, were also employed in the design matrix as covariates of no interest. Parameter estimates for each regressor of interest at the single subject level were submitted to the second-level group analysis. Each participant's beta estimates for the four conditions were entered into a flexible factorial ANOVA.

Brain activations associated with incidental self-processing were defined using (SNeg + SNeu)–(ONeg + ONeu) contrast. Brain activations associated with emotion were identified by (SNeg + ONeg)–(SNeu + ONeu) contrast. Then, the (SNeg − ONeg)–(SNeu − ONeu) and reverse contrasts were tested to extract specific regions showing effects of incidental self-relevance for negative and neutral materials. To further test how emotion affects brain activations associated with incidental self-processing, specific activations identified in the contrasts testing interaction were used to compute regions of interest (ROIs). Specifically, all the significant voxels within the 6-mm spherical regions centered on the peak coordinates of the activated clusters were included in each ROI. Parameter estimates across ROIs were extracted to calculate BOLD signal changes associated with incidental self-relevance for negative and neutral materials for further statistics using the MarsBaR toolbox in SPM5 (Eickhoff et al. 2005). At last, the (SNeg − ONeg) and (SNeu − ONeu) contrasts and their reverse contrasts were also computed, respectively. A cluster-level threshold of $p < .05$ (FWE) and a voxel-level threshold of $p < .001$ (uncorrected) were used to define activations.

Results

Behavioral results

The participants' behavioral performance is shown in Table 1. A 2 incidental self-processing (Self vs. Other) × 2 emotion (Neutral vs. Negative) repeated-measures ANOVA for accuracy without no-response trials (accounting for 0.3 percent of all trials) revealed no significant effects. Turning to reaction time (RT), restricted to correct trials, applying a similar repeated-measures ANOVA, we observed a significant effect of incidental self-processing ($F(1, 17) = 10.08$, $p < .01$), indicating participants responded faster for self-handwriting than for other-handwriting. No other main effects or interactions were statistically reliable.

fMRI results

Main effect of incidental self-processing

To identify regions associated with main effects of incidental self-processing, we searched for voxels where

Table 1 Means (± *SD*) of accuracy and RTs (ms) for different conditions

	Self-handwriting		Other's handwriting	
	Accuracy	RT	Accuracy	RT
Negative	0.96 ± 0.04	902.57 ± 177.68	0.94 ± 0.05	919.90 ± 173.58
Neutral	0.96 ± 0.03	890.73 ± 147.42	0.96 ± 0.04	921.06 ± 162.07

self-handwritings elicited greater activity than other-handwritings. No regions survived from the analysis. The reverse contrast [(ONeg + ONeu)–(SNeg + SNeu)] also revealed no significant activation.

Main effect of emotion

The (SNeg + ONeg)–(SNeu + ONeu) contrast revealed significant activations in left AI, conforming to previous arguments for the role of AI on processing negative stimuli (Akitsuki and Decety 2009; Cheng et al. 2007, 2010; Gu et al. 2010). Additional activations were also observed in left supplementary motor area, left inferior parietal lobule, left middle frontal gyrus, bilateral middle temporal gyrus and right pallidum. The reverse contrast revealed significant activations in right angular gyrus, right precuneus, left postcentral gyrus, right superior frontal gyrus and right inferior temporal gyrus (Table 2).

Interaction

The interaction between incidental self-processing and emotion defined by (SNeg − ONeg)–(SNeu − ONeu) contrast revealed greater activations in left AI. Activation in right supplementary motor area was additionally observed. The reverse contrast revealed greater activation in MPFC (Table 3; Fig. 1b).

Participants' beta estimates in four conditions were extracted from ROIs in left AI (−40 4 8) and MPFC (−10 46 42). In order to examine the self-processing effects for neutral and negative words separately, several t tests were carried out. It is revealed that during negative trials, AI responded more strongly to self-handwriting than

other-handwriting ($t(17) = 2.90$, $p = .01$), whereas MPFC showed no activity difference for two kinds of handwritings. In contrast, during neutral trials, MPFC showed greater activity for self-handwriting than other-handwriting ($t(17) = 3.07$, $p < .01$), whereas AI responded more strongly for other-handwriting than self-handwriting ($t(17) = 3.05$, $p < .01$).

We further computed the (SNeg − ONeg) and (SNeu − ONeu) contrasts and their reverse contrasts, respectively, to identify brain activations associated with incidental self-processing for negative or neutral materials. Results revealed that no activated regions were observed during processing self-handwritten negative words relative to other-handwritten negative words, whereas compared with other-handwritten neutral words, self-handwritten neutral words significantly activated MPFC (Fig. 1c). The reverse contrasts revealed no significant activation.

Discussion

The present study aimed to investigate incidental self-processing of negative information using fMRI. We employed a novel type of stimuli—participants' own handwritings to elicit incidental self-processing. To exclude intentional self-processing, a non-self-task without self-relevant judgment was used. Results revealed that incidental self-processing of negative information relied on the activation of left AI, whereas MPFC activity was associated with incidental self-processing of neutral information.

Stronger AI activity observed during emotional judgments of handwritten negative words compared with handwritten neutral words conformed to prior demonstration

Table 2 Regions showing main effect of emotion

Region	Lat.	Peak Activation			T Value	Voxels
		X	Y	Z		
(SNeg + ONeg)–(SNeu + ONeu)						
Insula	L	−34	6	4	8.39	756
Supplementary motor area	L	−12	4	68	7.32	4,085
Inferior parietal lobule	L	−58	−50	38	7.22	1,188
Middle frontal gyrus	L	−46	12	44	6.05	762
Middle temporal gyrus	R	50	−28	−4	4.63	156
Middle temporal gyrus	L	−54	−32	−4	4.60	169
Pallidum	R	18	6	4	4.59	494
(SNeu + ONeu)–(SNeg + ONeg)						
Angular gyrus	R	40	−70	36	6.81	3,062
Precuneus	R	6	−66	46	5.94	1,301
Postcentral gyrus	L	−44	−26	58	5.50	949
Superior frontal gyrus	R	22	34	36	5.07	196
Inferior temporal gyrus	R	58	−54	−10	4.09	245

Coordinates (mm) are in MNI space

L left hemisphere, *R* right hemisphere

All clusters survived correction for multiple comparisons at the cluster level (FWE, *p* < .05, *p* < .001, uncorrected at the voxel level)

Table 3 Regions showing interaction and simple effects

Region	Lat.	Peak Activation			T Value	Voxels
		X	Y	Z		
(SNeg − ONeg)–(SNeu − ONeu)						
Insula	L	−40	4	8	4.98	172
Supplementary motor area	R	6	−8	54	4.21	152
(SNeu − ONeu)–(SNeg − ONeg)						
Superior frontal gyrus	L	−12	38	56	4.56	436
Medial prefrontal gyrus	L	−10	46	42	4.29	
Medial prefrontal gyrus	R	8	28	52	4.21	
SNeg − ONeg						
No regions						
ONeg − SNeg						
No regions						
SNeu − ONeu						
Medial prefrontal gyrus	R	8	26	54	4.93	209
Medial prefrontal gyrus	L	−8	28	54	3.80	
ONeu − SNeu						
No regions						

Coordinates (mm) are in MNI space

L left hemisphere, *R* right hemisphere

All clusters survived correction for multiple comparisons at the cluster level (FWE, $p < .05$, $p < .001$, uncorrected at the voxel level)

of AI activity in processing negative stimuli (Akitsuki and Decety 2009; Gu et al. 2010; Guo et al. 2012). When we focused on the interaction between incidental self-processing and emotion, stronger AI activity was found during emotional judgment of self-handwritten negative words compared with other-handwritten negative words, suggesting that incidental self-processing of negative information might rely on the activation of a specific region implicated in processing negative emotion, that is, AI. In addition, AI activation during incidental self-processing of negative versus neutral words might be also related to arousal of negative words. Future study can be done to test this assumption involving negative, neutral and positive handwritings as materials.

Results of the present study also revealed that MPFC was engaged in incidental self-processing of neutral information, but not negative information. These findings stand in marked contrast to a previous set of studies demonstrating MPFC contributions to intentional self-processing of negative information (Fossati et al. 2003; Yoshimura et al. 2009). This raises the question of why, in the present study, MPFC activation was only associated with self-processing of neutral materials. A plausible answer is that the neutral words themselves were more canonically self-relevant than the negative words. Moran et al. (2009) showed that only highly self-relevant information activates MPFC during implicit self-processing. Lots of work on self-serving bias (Alicke 1985; Brown 1986; Campbell and Sedikides 1999, Campbell et al. 2000) demonstrated that people were inclined to relate positive or neutral information to themselves, but reluctant to relate negative information to

themselves. Thus, MPFC engagements following incidental self-processing of neutral information, but not negative information, just indicate high self-relevance of neutral words. On the other hand, combined the neutral and negative words, the presence of own versus others' handwritings might not confer strong self-relevance to the stimuli, inducing null results on main effects of self-processing.

It was worth noting that incidental self-processing for neutral materials activated dorsal MPFC, not ventral MPFC which was repeatedly reported to be associated with self-processing in previous studies (Johnson et al. 2002; Kelley et al. 2002; Macrae et al. 2004). A double dissociation has been found that ventral MPFC responded more strongly during processing self and a similar other than processing a different other, whereas dorsal MPFC showed a trend in the opposite direction, that is, dorsal MPFC responded more strongly during processing self and a different other than processing a similar other (Mitchell et al. 2006). In the current study, participants knew that other-handwritten words were obtained from other students who were similar to themselves, for example, similar age and the same university. Thus, we argue that the dorsal MPFC activity might have resulted from the comparison between self and a similar other in the present study.

Last, comparing own versus others' handwritings in the present experiment might be not a test of source or even recognition memory because of the following reasons. First, in order to rule out the influence of memory, all the participants were required to write all the 100 words before the experiment. We then paired 50 of 100 words written by one participant (List One) and the other 50 of 100 words

written by another participant (List Two) together. Participants knew that they were presented all the 100 words they have written several days ago during the experiment. The only difference is that 50 of them were presented in their own handwritings, whereas the other 50 words were presented in another student's handwritings. Second, after the experiment, none of the participants reported that the stimuli brought their episodic memory in the experiment (e.g., whether they retrieved whether they have written these words; whether they recalled how they wrote every stroke at that time). Third, previous studies revealed that handwriting discrimination rarely relies on episodic memory (Knoblich and Flach 2003; Knoblich et al. 2002).

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