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Neural correlates of envy: Regional homogeneity of resting-state brain activity predicts dispositional envy

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ABSTRACT

Envy differs from common negative emotions across cultures. Although previous studies have explored the neural basis of episodic envy via functional magnetic resonance imaging (fMRI), little is known about the neural processes associated with dispositional envy. In the present study, we used regional homogeneity (ReHo) as an index in resting-state fMRI (rs-fMRI) to identify brain regions involved in individual differences in dispositional envy, as measured by the Dispositional Envy Scale (DES). Results showed that ReHo in the inferior/middle frontal gyrus (IFG/MFG) and dorsomedial prefrontal cortex (DMPFC) positively predicted dispositional envy. Moreover, of all the personality traits measured by the Revised NEO Personality Inventory (NEO-PI-R), only neuroticism was significantly associated with dispositional envy. Furthermore, neuroticism mediated the underlying association between the ReHo of the IFG/MFG and dispositional envy. Hence, to the best of our knowledge, this study provides the first evidence that spontaneous brain activity in multiple regions related to self-evaluation, social perception, and social emotion contributes to dispositional envy. In addition, our findings reveal that neuroticism may play an important role in the cognitive processing of dispositional envy.

Introduction

Envy is a powerful emotion that "arises when a person lacks another's superior quality, achievement, or possessions and either desires it or wishes that the other lacked it" (Parrott and Smith, 1993). Envy is a "painful emotion" associated with inferiority, anxiety, or resentment (Aristotle, 1981). Envy has widespread effects on an individual's mental health (Smith et al., 2008), life satisfaction (Smith et al., 1999), and moral behavior (Polman and Ruttan, 2012; Gino and Pierce, 2009). Therefore, envy has always been a hot topic of intense study in multiple fields. Simultaneously, theoretical studies have shown that personality is closely related to envy (Habimana and Massé, 2000; Smith et al., 1999). Although the concept of dispositional envy has garnered significant attention, the precise neural correlates of dispositional envy remain unclear. Therefore, in this study, we explored the neural correlates underlying individual differences in dispositional envy and the role of personality in these associations.

Several researchers have explored the neural correlates of episodic envy via task-based functional magnetic resonance imaging (fMRI). For example, using a face emotion task, Shamay-Tsoory et al. (2007) found that, compared to a normal group, the individual with ventromedial prefrontal cortex (VMPFC) impairment was unable to distinguish the emotion of envy. Takahashi et al. (2009) adopted a scenario method to elicit envy, and the results showed that the degree of envy elicited was positively correlated with activity in the dorsal medial prefrontal cortex (DMPFC), which has been implicated in the execution of social emotion (Singer et al., 2004; Kerns et al., 2004). These findings indicate that the medial prefrontal cortex (MPFC) may be important for episodic envy in a particular task. However, fMRI based tasks have an obvious drawback: a particular task only activates particular regions. According to the definition of envy provided by Parrott and Smith (1993), envy involves the complex synthesis of various negative emotions. Therefore, the cognitive process of envy may be related to several brain regions. Additionally, the display of envy is not permitted in society, as it is considered a negative emotion. Individuals with stronger feelings of envy need to allocate a significant amount of psychological resources to control their emotions. Thus, brain regions involved in emotion regulation and cognitive control are likely to be activated during recruitment of these psychological resources. Previous neuroimaging studies have indicated that the lateral prefrontal cortex (LPFC) plays a crucial role in regulating or processing negative emotion. For example, Kühn et al. (2013) found

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that unwanted thoughts were negatively associated with the dorsolateral prefrontal cortex (DLPFC), which is associated with the control of negative emotions; this finding was consistent with those of several other studies (Papousek et al., 2012; Cacioppo and Gardner, 1999; Davidson, 1998; Kemp et al., 2010; Lopez-Duran et al., 2012). In addition, Wang et al. (2014) further explored the relationship between the LPFC (including the DLPFC and ventrolateral prefrontal cortex [VLPFC]) and conflict adaptation, and found that both the DLPFC and VLPFC are positively associated with the ability to adapt to conflict. According to one concept of envy, envy is elicited by social comparison of oneself to others (Parrott and Smith, 1993; Smith et al., 1999; Smith and Kim, 2007). Therefore, envy often reflects self-conflict or a threat to an individual's concept of self (Tesser and Collins, 1988; Takahashi et al., 2009). That is, from the perspective of conflict control, the LPFC (including the DLPFC and VLPFC), which is associated with cognitive conflict or cognitive adaptation, may be a crucial region for envy processing. Therefore, we assume that the LPFC may also be associated with dispositional envy. Based on previous findings, in the present study, a standard measure of regional homogeneity (ReHo) was used to explore the neural basis of dispositional envy. ReHo explores regional brain activity at rest by examining the degree of regional coherence in a resting-state fMRI (rs-fMRI) time course. Previous research has defined ReHo as an index reflecting the synchronization of activity in different brain regions (Zang et al., 2004), and increased ReHo reflects neural hyperactivity in a specific brain area, indicating increased blood supply to cope with chronic hypoxia (Yan et al., 2010). Furthermore, many previous studies have demonstrated that ReHo is associated with different psychological traits, such as intelligence (Wang et al., 2011), personality (Hahn et al., 2013), and psychological resilience (Kong et al., 2015a). Therefore, ReHo may be an effective index reflecting the neural basis of dispositional envy. Based on a review of the neural basis of episodic envy, we predicted that ReHo in the prefrontal cortex (PFC), including the MPFC and LPFC, would be significantly related to dispositional envy.

Moreover, many studies have revealed some core emotional characteristics of envy, such as feelings of injustice, inferiority, depression, and anxiety (Aristotle, 1981; Parrott and Smith, 1993; Smith et al., 1999). Of all these emotions, inferiority is very typical for envy. Smith et al. (1999) proposed that a sense of inferiority was a typical characteristic of neuroticism. Furthermore, using measures of neuroticism from different personality scales, including the NEO Personality Inventory, Big Five Personality Test, and the Eysenck Personality Inventory, they demonstrated a positive association between dispositional envy and neuroticism with correlations ranging from 0.41 to 0.56. This finding is consistent with other studies that have shown positive associations between neuroticism and other complex negative emotions such as anxiety, self-consciousness, and irritability (Watson et al., 2008; Costa and McCrate, 1992). In addition, envy has also been demonstrated to be a blended synthesis of multiple negative emotions (Lazarus, 1991; Parrott, 1991; Smith, 1991). Based on these findings, we hypothesized that several personality traits, especially neuroticism, may mediate the relationship between brain activity and dispositional envy.

Thus, the present study explored the neural basis of dispositional envy and how personality mediated the effect of the PFC, particularly the MPFC or LPFC, on dispositional envy. Firstly, we computed the correlation between envy and ReHo across the whole brain. We hypothesized that individual differences in dispositional envy would be significantly correlated with ReHo in some regions of the PFC (e.g., MPFC and LPFC), which have been linked to self-evaluation and negative emotion processing. Secondly, we explored which personality traits were significantly associated with dispositional envy. According to previous studies (Watson et al., 2008; Costa and McCrate, 1992; Smith et al., 1999), we predicted that neuroticism would be significantly correlated with dispositional envy. Thirdly, after identifying the dimension most closely associated with dispositional envy and the neural basis of dispositional envy, we explored how specific personality traits would affect regions of the PFC in envy.

Methods

Participants

Forty-one healthy students from South China Normal University participated in this study (17 men; mean age = 21.37 years; standard deviation [SD] = 1.99). All participants were Chinese and right-handed with normal or corrected-to-normal vision. No participants had a history of mental or neurological illness. This study was approved by the Imaging Center Institutional Review Board of South China Normal University. All participants were asked to provide written informed consent before engagement in this research.

Behavioral assessments

Dispositional envy

The dispositional envy scale (DES), which was proposed by Smith et al. (1999) and consists of 8 items, was used to assess the degree of envy. Examples of statements include, “I feel envy every day,” and “Feelings of envy constantly torment me.” Each item was scored on a 5-point Likert-type scale, in which 1 = strongly disagree, 2 = moderately disagree, 3 = neither agree nor disagree, 4 = moderately agree, and 5 = strongly agree. Previous studies have demonstrated that the DES has high reliability and has been used widely to assess envy (McCullough et al., 2002; Froh et al., 2011). To ensure the reliability and validity of the Chinese translation of the scale in the present study, we implemented the following procedure: first, two English major specialists translated the DES to Chinese; second, 10 students evaluated the semantic clarity, cultural appropriateness, and grammatical aspects of the items; and third, the translated version was discussed within the group of researchers and the final version was derived. A total score was calculated, of which higher scores represented greater degrees of envy. In this study, the scale showed adequate internal reliability ($\alpha = 0.79$).

NEO Personality Inventory

We adopted the Revised NEO Personality Inventory (NEO-PI-R) with five dimensions: neuroticism, extraversion, openness to experience, agreeableness, and conscientiousness (Costa and McCrate, 1992). Each dimension is measured by 24 items, and the scale includes 120 items in total. The NEO-PI-R was scored using a 5-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). Some items were reversely coded before further analysis. Several studies have demonstrated the high reliability and validity of the scale in Chinese culture (Kong et al., 2015b; Li et al., 2014; Yang et al., 1999). In this study, Cronbach's alphas ranged from 0.79 to 0.89.

MRI data acquisition

The rs-fMRI scan was executed by a 3.0-T scanner (Siemens Magnetom Trio, A Tim System) equipped with a 12-channel phased-array head coil at South China Normal University. Resting-state scanning consisted of 240 contiguous echo-planar imaging (EPI) images (TR = 2000 ms; TE = 30 ms; flip angle = 90°; slices = 32; matrix = 64×64; FOV = 220×220 mm^2; thickness/gap = 3.5/0.8 mm). Simultaneously, high-resolution T1-weighted structural images were collected using a MPRAGE sequence (TR/TE = 1900/2.52 ms; flip angle = 9; matrix = 256×256; slice thickness = 1.0 mm; sagittal slices = 176). During resting-state fMRI, all participants were asked to relax, keep their eyes closed, and stay awake.

Data preprocessing

EPI data was preprocessed by DPARSF (Data Processing Assistant for Resting-State fMRI software; http://www.restfmri.net/forum/DPARSF) (Yan and Zang, 2010), using Statistical Parametric Mapping 8 (SPM8) on the MATLAB platform (The MathWorks, Natick, MA, USA). Special processing included the following steps: (1) checking the scanning image quality for each participant and transforming the DICOM file format into the nifti file format; (2) removing the first 10 time points, which include instability of the initial MRI signal; and (3) computing the slice time with the 33th slice as the reference, realigning the images, normalizing the images using standard Montreal Neurological Institute (MNI) templates with a resolution of $3 \times 3 \times 3$ mm^3, and detrending and filtering the data with residual signals within 0.008–0.08 Hz to discard bias from high-frequency physiological noise and low-frequency drift. Three subjects with head motion >2.5 mm or 2.5° in any of the six parameters were excluded.

Calculation of ReHo

We measured ReHo of the time-series of a given voxel with the nearest 26 neighboring voxels in a voxel-wise manner using Kendall's coefficient of concordance (KCC). The formula used to calculate the KCC has been reported elsewhere (Zang et al., 2004). The procedures used to obtain individual ReHo maps were implemented using REST software. For standardization purposes, each ReHo map was divided by the global mean ReHo of each participant. Then, the data were smoothed with a Gaussian kernel of 4-mm full-width at half maximum (FWHM).

Statistical analysis

Data analysis was performed using SPM8. In the whole-brain analyses, a multiple linear regression was applied using dispositional envy as the variable of interest to identify regions where ReHo was correlated with individual differences in the level of dispositional envy after controlling for possible confounding variables, such as age and sex. The AlphaSim program was performed to correct for multiple comparisons in AFNI (10,000 interactions) using the REST software. The smoothing kernel was calculated with 3dFWHMx on the ReHo maps, and the estimated size of spatial smoothness was larger than origin (origin: 6, 6, and 6 mm; new: 8,8, and 8 mm, cluster connection radius = 5 mm). Using the new smooth size for multiple comparison correction, a corrected cluster threshold of $p < 0.05$ (single voxel $p < 0.005$, Cluster size ≥ 25) was set.

Furthermore, to test whether some personality traits mediated the association of dispositional envy and some brain regions, a mediation analysis was performed using the PROCESS macro programmed by Preacher and Hayes (2008).

Results

Table 1 reports the mean, SD, skewness, and kurtosis for the DES and NEO-PI-R scales. All scores for kurtosis and skewness ranged from −1 to +1, indicating normality of the data (Marcoulides and Hershberger, 1997). No significant sex difference was observed in the envy scores [$t(39) = 0.006$, $p = 0.995$], and no significant correlation between envy scores and age ($r = -0.03$, $p = 0.85$) was observed.

To explore the neural correlates of envy, we correlated the envy scores with the ReHo value of each voxel across the whole brain. After controlling for age and sex, the envy scores were significantly and positively associated with two whole-brain clusters located in the inferior/middle frontal gyrus (IFG/MFG) and the DMPFC, respectively (see Table 2 and Fig. 1 and Fig. 2). No other significant relationships were observed.

After identifying the neural correlates of dispositional envy, we further examined the role of personality traits in these associations. Firstly, we explored the relationship between personality and envy scores. Results showed that among the five personality traits, only neuroticism had a significant correlation with dispositional envy scores ($r = 0.43$, $p < 0.01$). The 'Enter' regression analysis revealed that neuroticism accounted for 18.5% of the variance in dispositional envy [$R^2 = 18.1\%$, $F(1,39) = 8.596$, $p = 0.006$]. Secondly, we further explored whether neuroticism had a significant correlation with the neural correlates of envy. The results showed that ReHo of the IFG/MFG had a significant correlation with neuroticism ($r = 0.33$, $p = 0.039$).

To explore whether the neuroticism personality trait mediated the relationship between the ReHo of the IFG/MFG and envy, a mediation analyses was performed. We tested the effect of the relationship between ReHo of the IFG/MFG and envy without controlling for neuroticism. The result showed that ReHo of the IFG/MFG ($\beta = 0.69$, $p < 0.001$) significantly predicted envy. After controlling for neuroticism, the effect of the IFG/MFG ($\beta = 0.53$, $p < 0.001$) on envy was reduced, but remained significant. A bootstrap simulation (n = 10,000) further confirmed that this reduction was statistically significant (95% confidence interval = [0.010, 21.03], $p < 0.05$).

Discussion

The present study used rs-fMRI to explore the potential contribution of spontaneous brain activity to dispositional envy in young healthy individuals. Results of the ReHo-behavior analysis showed that dispositional envy scores were positively correlated with ReHo in the IFG/MFG and DMPFC, indicating that these two regions were associated with dispositional envy. Furthermore, we found that neuroticism mediated the relationship between the IFG/MFG and dispositional envy.

These results revealed that dispositional envy scores were significantly positively correlated with ReHo in the DMPFC, including part of the dorsal anterior cingulate (dACC). Previous studies have revealed that the MPFC is an important region for self-evaluation and self-knowledge processing (Van Overwalle, 2009; Kelley et al., 2002; Gillihan and Farah, 2005; Amodio and Frith, 2006). Furthermore, previous studies have indicated that the emotion of envy is linked to negative self-evaluation (Sullivan, 1956; Aristotle, 1981) when one is aware of another's superior quality, achievement, or possessions (Tesser and Cornell, 1991). Therefore, in the present study, the result that ReHo in the MPFC predicted envy significantly may reflect a stable relationship between envy and negative self-evaluation. Previous studies have shown that increased ReHo is regarded as a compensatory mechanism to cope with a functional decrease or impairment in some brain regions (e.g. Chen et al., 2012; Guo et al., 2012). Consequently, we can speculate that this correlation may reflect a functional decrease or impairment in

Table 1
Descriptive statistics for envy and personality factors (n = 41).

	Means (SD)	Range	Skewness	Kurtosis	Correlation with envy
Dispositional envy	19.76 (7.72)	8–39	0.79	0.26	/
Neuroticism	73.39 (9.01)	54–92	−0.16	−0.52	0.43**
Extraversion	75.10 (7.21)	58–94	−0.29	0.72	0.14
Openness	80.61 (9.29)	61–100	−0.37	−0.21	0.02
Agreeableness	82.85 (6.92)	68–96	−0.11	−0.57	−0.11
Conscientiousness	78.78 (9.96)	58–93	−0.52	−0.82	0.16

"/" means the correlation between envy and envy. Therefore, we replace 1.00 with character "/".
** $p < 0.01$ (Bonferroni-corrected).

Table 2
Significant associations between brain regions and envy scores.

Brain regions	Hemisphere	MNI coordinates			Number of voxels in the cluster	Peak T-value
		x	y	z		
IFG/MFG	R	48	30	18	50	4.608*
DMPFC	R	3	21	42	57	4.645*

IFG/MFG = inferior/middle frontal gyrus; DMPFC = dorsal medial prefrontal cortex.
* $p < 0.05$.

the ability to self-evaluate among individuals with higher dispositional envy. This finding is consistent with the increased ReHo observed in the MPFC of patients with depressive disorder, which is characterized by negative self-evaluation (Liu et al., 2013; Lai and Wu, 2012). In summary, ReHo in the MPFC is positively correlated with dispositional envy scores, which suggests that self-information or self-evaluation plays a crucial role in coping with dispositional envy. In addition, Takahashi et al. (2009) found that the DMPFC, especially the dACC, was activated in episodic envy, which is partially consistent with our current study. Previous studies have demonstrated that the dACC is associated with self-conflict (Kerns et al., 2004), reflecting a type of social pain (Eisenberger and Lieberman, 2004). Therefore, this result may also apply to dispositional envy, which like episodic envy is a social pain.

We also found that dispositional envy was positively linked with ReHo in the IFG/MFG. Previous studies have indicated that the PFC (including the IFG/MFG) is involved widely in cognitive-emotion processing, especially in emotion regulation (Kalisch, 2009; Pessoa, 2008) and social cognition (Forbes and Grafman, 2010; Rilling and Sanfey, 2011). Some researchers have demonstrated that individuals with PFC damage may exhibit abnormal emotional regulation, such as self-control obstacles, flattened affect, and depression (Hugdahl, 1998). Other studies also have demonstrated that the PFC, especially the DLPFC, may play a crucial role in social cognition. For example, researchers have indicated that the individuals with impairment in the DLPFC exhibit social cognition disorder, which includes poor interpersonal relationships and difficulty in correctly understanding other's emotion (Braver and Bongiolatti, 2002; Rahman et al., 2001). Dispositional envy, as a complex social emotion, has two typical affective components including the chronic sense of inferiority and feeling of ill will according to previous studies (Parrott and Smith, 1993; Smith, 1991), formed in the long life. However, the former was closely related to threaten self-concept, the latter tended to violate social rule. Whatever affective components, they all need to be controlled or inhibited for individuals. Therefore, the result that DLPFC (including the IFG/MFG) predict significantly the dispositional envy may reflect a decrease in emotional regulation ability or the presence of social cognition disorder. In addition, using task fMRI, the previous studies also demonstrated the DLPFC implied the function of conflict adaptation and conflict resolution (Egner and Hirsch, 2005; Botvinick et al., 2001). Therefore, from evolutionism perspective on survival instinct need, to protect self in social interaction, the DLPFC (including IFG/MFG) may play a crutial role in controlling some social negative emotions or adjusting behavior to adapt to the society for the dispositionally envious person.

Furthermore, previous studies on rest-fMRI have also confirmed our deduction. For example, Wang et al. (2014) showed that increased ReHo in the DLPFC was associated with better conflict adaptation ability (Wang et al., 2014), i.e., better emotional conflict adaptation or emotional regulation. However, in that study, this effect was observed in the left DLPFC, whereas findings from the current study were observed in the right DLPFC (including IFG/MFG). Previous studies have demonstrated that the left and right PFC have different functions in regulating positive and negative emotion, respectively (Davidson, 1998; Harmon-Jones et al., 2010). Using rest electroencephalogram (EEG) and transcranial direct current stimulation (tDCS), researchers have found that the right PFC plays a crucial role in negative emotional processing, whereas the left PFC reacts mainly to positive emotion (Papousek et al., 2014). Studies on patients with mental illness (e.g., anxiety or depression) also found abnormalities in right PFC activation, including the DLPFC and VLPFC, compared to healthy control subjects (Davidson, 1998; Kemp et al., 2010; Lopez-Duran et al., 2012), which further confirmed the role of the right PFC in regulating negative emotion. These studies indicated that the right LPFC (including the IFG/MFG) may play a specific role in regulating negative emotion, abnormalities of which may lead to an individual's failure to restrain negative emotion. Using ReHo as the measurement index, previous studies also found that the degree of ReHo increase in the LPFC (including the IFG/MFG) positively correlated with the degree of mental illness (Wu et al., 2011; Zhang et al., 2011). Based on previous findings, the positive relationship between ReHo of the right IFG/MFG and dispositional envy in the present study may not only reflect abnormality of

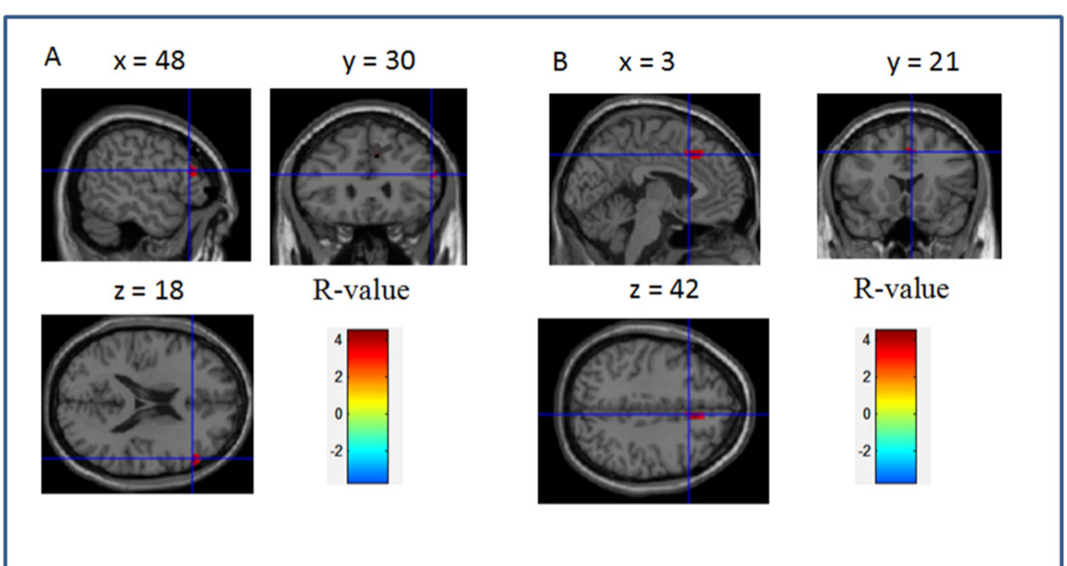

Fig. 1. Brain regions that were positively correlated with dispositional envy. ReHo of the right inferior/middle frontal gyrus (IFG/MFG) (A) and dorsal medial prefrontal cortex (DMPFC) (B) was positively correlated with dispositional envy. All correlations were based on whole-brain analysis.

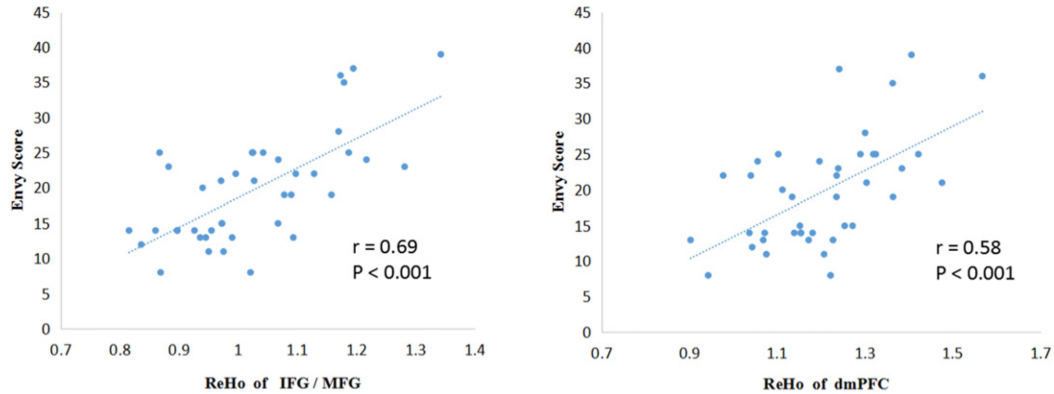

Fig. 2. The left panel showed correlation between dispositional envy scores and inferior/middle frontal gyrus (IFG/MFG); the right panel showed correlation between dispositional envy scores and dorsal medial prefrontal cortex (DMPFC).

emotional regulation and social cognition but also suggest that higher dispositional envy is associated with less ability to regulate negative emotions, even in mental illness.

Interestingly, we found that neuroticism mediated the effect of the IFG/MFG on dispositional envy. Previous studies have found that neuroticism is correlated with the experience of negative emotion, anxiety, and irritability (Watson et al., 2008; Costa and McCrate, 1992). Using fMRI, previous studies have shown that the neural basis of neuroticism overlaps with some regions, such as the DLPFC, that are related to threats to self-concept, punishment, and other negative information processing (Eisenberger and Lieberman, 2004; Gray and McNaughton, 2000; Macrae et al., 2004; Adelstein et al., 2011; Li et al., 2014). These findings indicate that the neural basis of neuroticism is closely associated with negative emotion regulation, which is consistent with the neural basis of dispositional envy. Therefore, this result suggests that neuroticism may serve as an underlying mechanism that explains the ReHo of IFG/MFG on individual differences in dispositional envy. The reason for this association may be attributed to the fact that both dispositional envy and neuroticism contribute to negative emotion regulation.

In summary, the present study provides the first evidence that dispositional envy is linked to regions associated with self-processing, emotional regulation, and social cognition from a spontaneous brain activity perspective. Furthermore, this study provides the first evidence that neuroticism acted as a mediational mechanism underlying the association between ReHo of the IFG/MFG and dispositional envy.

Conflict of interest

The authors declare no competing interests.

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