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ORIGINAL RESEARCH

The important role of dACC in shyness

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Abstract

Shyness is often characterized by the avoidance of social contact, the fear of other people's evaluations and a lack of self-esteem. Generally, individuals with high levels of shyness are more likely to suffer from psychosomatic stress and social anxiety. However, the structural brain basis of individual shyness among healthy people has not yet been investigated with DTI (diffusion tensor imaging). Thus, in this study, we investigated the relationship between FA (fractional anisotropy), WMV (white matter volume), GMV (gray matter volume) and shyness in a large healthy sample of 318 college students. Multiple regression was used to analyze the correlations among regional FA, WMV, GMV and shyness, adjusting for age, sex, and total intracranial volume. The results showed that shyness was significantly, negatively associated with FA, WMV and GMV in a cluster that included the dACC (dorsal anterior cingulate cortex) and the MCC (middle cingulate cortex) and was significantly positively associated with the GMV in the IPL (inferior parietal lobule), an effect that may have been related to the weaker ability to regulate emotion in these participants and their state of being overly worried about others' evaluations. Finally, mediation analyses revealed that the correlation between shyness and psychosomatic stress was mediated by a region including the dACC and the MCC.

Keywords Shyness · Diffusion tensor imaging · Dorsal anterior cingulate cortex · Inferior parietal lobule

Introduction

Shyness is a core dimension of personality traits or temperaments that describes discomfort or hesitation in responding to social situations, especially those involving evaluations by authority figures, as well as inhibition and discomfort in interpersonal situations (Buss 1986; Henderson and Zimbardo 1998). It is a ubiquitous trait that over 90% of the population is reported to have experienced at some point in their lives. Although for many people shyness occurs only during childhood, 10–25% of the population still have an enduring temperament of shyness (Cheek and Melchior 1990; Battaglia et al. 2005). Findings from numerous longitudinal studies have indicated that shyness is one of the stable and heritable constructs that can predict important life outcomes in adulthood, such as occupational attainment, interpersonal relations, and psychopathology (Dennissen et al. 2008). In the present study, we wanted to investigate the neural basis of shyness among healthy adults. We used the NEO-PI-R (Neuroticism-Extraversion-Openness Personality Inventory Revised) to measure individual levels of shyness. The NEO-PI-R is the most widely used measure of the FFM (five factor model) of personality structure, having comparatively high reliability and validity (Costa and McCrae 1992a, b). The fourth subdimension (N4) of neuroticism measures individual levels of self-consciousness, and the core part of self-consciousness in the NEO PI-R is shyness; in addition, people with high N4 scores are shyer and more socially anxious (Costa and McCrae 1992a, b).

According to a student life survey administered by the University of Alberta campus, 45% of the college students reported that they were troubled with shyness, and approximately 50% of the students reported that they were afraid of public speaking (comfort and phobia). Most people feel shy because they worry about other people's evaluation. However, if this worry becomes persistent, it will disrupt their daily lives and may lead to the use of drugs or alcohol to facilitate their social skills or to the avoidance of opportunities that require public speaking, and all of those are signs of social anxiety (Beidel and Turner 2007). Social anxiety is described as a widespread fear of social situations in which an individual

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might experience humiliation or scrutiny. Approximately 20% of the general population has diagnosable social anxiety (Comfort and Phobia n.d.). According to previous studies, there is a strong relationship between shyness and social anxiety; the prevalence of social phobia was found to be significantly higher among shy individuals (18%) than among non-shy individuals (3%) (Heiser et al. 2003). In addition, Ward and Tracey found that shy people reported more trouble with face-to-face relationships (Ward and Tracey 2004). Chak and Leung found that shyness was associated with Internet addiction (Chak and Leung 2004). Specifically, a computer addict tends to be a shy, full-time student who spends longer amounts of time online per session and is online more times during the week than less shy individuals (Ebeling-Witte et al. 2007). Therefore, given the important role of shyness in mental health, it is important to explore the neural basis of individual differences in shyness.

To date, numerous task-related neuroimaging studies and resting-state studies have been conducted on shyness and social anxiety. Most of these studies indicated that shyness was related to emotion regulation and to the specific brain regions involved in emotion regulation. For example, fMRI studies have revealed that shyness is associated with hyperresponsivity to social stimuli in the amygdala (Schwartz et al. 2003; Beaton et al. 2008, 2009) and the frontal cortex (Beaton et al. 2010). A recent study by Kagan's group found greater amygdala activation in response to novel faces in young adults who were classified as shy versus non-shy as children using fMRI (Schwartz et al. 2003). Another study indicated that correlations between functional connectivity and shyness were found among the superior temporal gyrus, the parahippocampal gyrus and the frontal gyrus; among the insula, the precentral gyrus and inferior parietal lobule; and between the cerebellum and precuneus (Yang et al. 2013).

In addition, some studies have investigated the structural basis of shyness. For example, a study by Xun Yang found positive correlations between relative regional density and shyness in the bilateral superior temporal gyri and the parahippocampal gyrus, and in the right insula and the left posterior lobe of the cerebellum (Yang et al. 2013). Another study indicated that there was a significant shyness-by-sex interaction in the dACC, the right insula, the right ventral anterior cingulate cortex and the ventral medial prefrontal cortex (Yang et al. 2015). Unlike the previous study, which investigated the structural basis of shyness in a relatively small sample, we collected a large sample of 318 pieces of neuroimaging data and behavioral data. Furthermore, in this study, we combined the TBSS (tract-based spatial statistics) method and VBM (voxel-based morphometry) to measure the neural basis of individual differences in shyness. DTI (Diffusion tensor imaging) can provide a meaningful measure of fiber tract organization (Pierpaoli et al. 1996; Beaulieu 2002) by assessing FA, which describes the directional selectivity of the random diffusion of water molecules (Basser 1994; Uluğ et al. 1995; Conturo et al. 1996; Pierpaoli and Basser 1996). Higher FA values (maximum theoretical value is 1.0) are observed along heavily myelinated WM tracts. The structure of the axonal cell membranes and myelin sheaths hinders the diffusion of water molecules in all but the direction of the fiber tract, thereby producing highly anisotropic water diffusion (Pierpaoli and Basser 1996). In contrast, a tissue where the motion of the water molecules is random and isotropic, such as in CSF, has FA values that are close to zero. Absolute WM FA values are sensitive to many parameters, including regional myelination levels, the degree of intra-voxel fiber crossing, axonal density and average axonal diameter (Beaulieu 2002; Kochunov et al. 2012).

Drawing upon findings from previous neuroimaging studies, we hypothesized that shyness might be associated with the FA, WMV and GMV of brain regions involved in emotion regulation (e.g., especially the ACC, which plays a central role in the limbic system). To some extent, this structural imaging study of individual differences in shyness can contribute to a comprehensive understanding of the neural substrates of shyness and shyness-related mental disorders.

Methods

Subjects

This study was approved by the local ethics committee of Southwest China University and the Institutional Human Participants Review Board of the Southwest University Imaging Center for Brain Research. The methods were conducted in accordance with approved guidelines. All participants provided written informed consent prior to taking part in the study. This study was conducted as part of an ongoing project to examine the association among brain imaging, creativity, and mental health. In total, 318 healthy right-handed college or postgraduate students were recruited from the local community of Southwest University (China). None of the subjects reported a prior history of neurological or psychiatric disease or substance abuse.

The big five personality test

The NEO-PI-R is the most widely used measure of the FFM of personality structure. It is a 240-item questionnaire that was developed through rational and factor analysis methods. Each of the five factors (neuroticism, extraversion, openness,

agreeableness, and conscientiousness) is represented by six specific traits, or facets (Costa and MacCrae 1992a, b).

Psychosomatic tension relaxation inventory

The PSTRI (psychosomatic tension relaxation inventory) was developed to measure the psychosomatic stress of individuals. It contains 50 items. The total score on the PSTRI is between 0 and 200. Higher scores indicate higher levels of psychosomatic stress (Chen et al. 2002).

Imaging data acquisition

The MRI (magnetic resonance imaging) scans were obtained on a 3-T Siemens Magnetom Trio scanner (Siemens Medical, Erlangen, Germany). High-resolution T1-weighted anatomical images were acquired using a magnetization-prepared rapid gradient echo (MPRAGE) sequence (repetition time [TR]/echo time [TE]/inversion time = 1900 ms/2.52 ms/900 ms; flip angle = 9°; slices = 176; slice thickness = 1.0 mm; resolution matrix = 256 × 256; and voxel size = 1 × 1 × 1 mm). The diffusion tensor data for each subject were obtained using a diffusion-weighted, single shot, spin-echo, EPI sequence (TR/TE = 11,000/98 ms, matrix = 128 × 128, 60 axial slices, 2.0-mm slice thickness, b value 1 = 0 s/mm2, and b value 2 = 1000 s/mm2) in 30 directions.

Voxel-based morphometry analysis

The MRI scans were processed using the Statistical Parametric Mapping software (SPM8; Wellcome Department of Cognitive Neurology, London, UK (www.fil.ion.ucl.ac.uk/spm/) implemented in Matlab 7.8 (MathWorks Inc., Natick, MA, USA). The MRI scans were first displayed in SPM8 to screen for artifacts or gross anatomical abnormalities. For better registration, the reorientation of the images was manually set to the posterior commissure. The images were segmented into gray matter, white matter, and cerebrospinal fluid using the new segmentation tool in SPM8. We then utilized Diffeomorphic Anatomical Registration Through Exponentiated Lie Algebra (DARTEL) in SPM8 for registration, normalization, and modulation [30]. To ensure that the regional differences in the absolute amount of gray matter were conserved, the image intensity of each voxel was modulated by the Jacobian determinants. Then, the registered images were transformed to the MNI (Montreal Neurological Institute) space. Finally, the normalized modulated images (gray and white matter images) were smoothed with a 10 mm FWHM (full-width at half-maximum) Gaussian kernel to increase the signal-to-noise ratio.

Statistical analyses of the GMV (gray matter volume) and WMV (white matter volume) data were performed using SPM8. In the whole-brain analyses, we used multiple linear regression to identify regions where the WMVs and GMVs were associated with individual differences in shyness. The N4 scores were used as the variable of interest in these analyses. Previous studies indicated that some aspects of brain asymmetries interact with gender (Hiscock et al. 1994; Kulynych et al. 1994). Although the participants' ages only ranged from 17 to 26 years old in the present study, we included age as a covariate in the analysis since age has an appreciable effect on brain morphology (Good et al. 2002). Thus, to control for possible confounding variables, age, sex and global volumes of white matter (gray matter) were entered as covariates into the regression model. We also applied explicit masking using the population-specific masking toolbox in SPM8 in order to restrict the search volume within the gray matter and the white matter (http://www.cs.ucl.ac.uk/staff/g.ridgway/masking/). This approach was used instead of absolute or relative threshold masking in order to reduce the risk of false negatives caused by overly restrictive masking, in which potentially interesting voxels are excluded from the statistical analysis (Ridgway et al. 2009).

DTI analysis

We used the PANDA (Pipeline for Analyzing Brain Diffusion images) toolbox (Cui et al. 2013) (http://www.nitrc.org/projects/panda/) to preprocess the DTI data. The steps included skull-stripping, simple-motion and eddy-current correction; diffusion tensor/parameter calculation; and spatial normalization. The resulting maps contained voxelwise parameter estimates for FA in individual space.

The TBSS method, distributed as a part of the FMRIB Software Library (FSL) package, was used for tract-based analysis of the diffusion anisotropy (Smith et al. 2006). First, FA (fractional anisotropy) images were created by fitting the diffusion tensor to the raw diffusion data (Smith 2002). In the next step, all FA images were spatially normalized on the global level and then nonlinearly aligned to a group-wise, MDT (minimal deformation target) brain. The global spatial normalization was performed using a method distributed with the FSL package (FLIRT) (Smith et al. 2006) with 12 degrees of freedom. This step was performed to reduce the global inter-subject variability in brain volumes prior to non-linear alignment. The group's MDT brain was identified by warping all individual brain images in the group to each other (Kochunov et al. 2001). The MDT was selected as the image that minimized the amount of the required deformation from other images in the group. Next, the individual FA images were averaged to produce a group-average anisotropy image. This image was used to create a group-wise skeleton of the

WM tracts. The skeletonization procedure is a morphological operation that extracts the medial axis of an object. This procedure is used to encode the medial trajectory of the WM fiber tracts with one-voxel thin sheaths. An FA threshold of ≥0.2 was chosen to minimize the effects of incidental tracts and partial voluming. Finally, the FA values of each image were projected onto the group-wise skeleton of the WM structures. This step accounted for residual misalignment among the individual WM tracts. The FA values are assigned to each point along the skeleton using the peak value found within a designated range perpendicular to the skeleton.

Tract-based t statistic regression analyses were then performed to correlate FA with N4. The statistical analyses were performed using FSL Randomize, a nonparametric permutation procedure. TFCE (Threshold-free cluster enhancement) was applied to proceed whole brain regression analyses to obtain cluster-wise statistics, corrected for multiple comparisons (Smith & Nichols, 2009). The statistical threshold was set at $P < 0.05$, FWE (familywise error)-corrected, via permutation testing with 5000 permutations. We prepared an FA template according to the procedure described by Smith et al. (2006), which was then overlaid with the statistically significant SPM clusters using the MRIcro software for graphical presentation in neurological convention (R = R). The MNI coordinates of the peak voxels were used to determine the FA values in these peak voxels in each subject's dataset and to depict these data in scatter plots.

Mediation analysis

To test whether the regional GMV could explain the relationship between young adults shyness and psychosomatic stress, we performed a mediation analysis. A mediating variable (M) if a variable that is part of the causal pathway by which an independent variable (X) affects a dependent variable (Y). Mediation analyses were conducted by the indirect macro designed for SPSS (Preacher and Hayes 2008). In the present study, X is the shyness measured by the NEO-PI-R, Y is the psychosomatic stress, and M is the GMV of the ACC. First, we saved our VBM results as separate ROIs (region of interest); then we extracted the three separate ROI signals (the volume of each ROI) from each participant using the SPM8 toolbox. Age and sex were used as covariates in the model. This macro used bootstrapped sampling to estimate the indirect mediation effect. In this analysis, 2000 bootstrapped samples were drawn, and bias corrected 95% bootstrap CI (confidence intervals) were reported. CI that did not include zero indicated a significant indirect effect of the independent variable on the dependent variable through the mediators (Preacher and Hayes 2008).

Results

Descriptive statistics

The demographic data and behavioral results are shown in Table 1. The mean N4 score for the current sample was 26.22 (SD = 4.53). There was no significant difference between males and females in terms of the N4 scores ($p > 0.05$, $t = 0.904$, two-tailed t-test), a finding that was consistent with those of previous studies (Cheek and Buss 1981). The kurtosis (−0.115) and skewness (−0.205) of the N4 variable were acceptable for an assumption of normality (this ranges between −1 and + 1 (Marcoulides & Hershberger, 1997) (Table 2).

Correlations between the FA and N4 scores

In the present study, we found that decreased FA values in the right CB were associated with N4 scores after correcting for age, sex ($p < 0.05$, FWE-corrected). However, no other significant associations were found (See Fig. 1).

Correlations between WMV and N4 scores

After correcting for age, sex and global white matter volumes, the N4 scores exhibited significant, negative associations with the WMVs in the dACC and the MCC [Left: MNI coordinates: 3, 3, 31; $t = -3.69$; cluster size = 2609; $p < 0.005$], corrected for multiple comparisons at the cluster-level of $p < 0.05$ with alphasim correction and an underlying voxel level of $p < 0.005$ (See Fig. 2).

Correlations between GMV and N4 scores

After entering age, sex and global volumes of gray matter as covariates into the regression model, a multiple regression analysis revealed that the N4 scores had significant, positive associations with the GMV in the left inferior parietal lobule [Left: MNI coordinates: −57, −48, 45; $t = 4.34$; cluster size = 1247; $p < 0.005$], corrected for multiple comparisons at the cluster-level of $p < 0.05$ with alphasim correction and an underlying voxel level of $p < 0.005$(See Fig. 3). In addition, the N4 scores exhibited significant, negative associations with the

Table 1 Demographic data

	Males ($n = 147$)			Females ($n = 171$)		
Measure	Mean	SD	Range	Mean	SD	Range
Age	22.22	1.30	19–26	19.73	0.92	17–24
Shyness	25.80	4.23	17–37	26.58	4.77	16–38
Psychosomatic stress	46.66	24.07	3–123	48.79	21.07	3–103

SD standard deviation

Table 2 Brain regions with significant association between brain structures and PNI score

Brain regions		MNI coordination			Cluster size (mm^2)	Peak T-value
		X	Y	Z		
GMV						
dACC and MCC	R	7.5	12	22.5	1089	−4.15*
IPL	L	−57	−48	45	1247	4.34**
WMV						
dACC and MCC	R	3	3	31	2026	−3.69*

GMV gray matter volume, *WMV* white matter volume

* Alphasim p (corrected) < 0.005

** Non-stationary correction p (corrected) < 0.05

GMVs in the right dACC and the MCC [Right: MNI coordinates: 7.5, 12, 22.5; $t = -4.15$; cluster size = 1089; $p < 0.005$], corrected for multiple comparisons at the cluster-level of $p < 0.05$ with alphasim correction and an underlying voxel level of $p < 0.005$ (See Fig. 4).

Mediation results

Indirect mediation effects can be interpreted as the strength of the relationship between shyness and psychosomatic stress when accounting for mediating pathways. To test the significance of the indirect effect between shyness and psychosomatic stress, bootstrap resampling was used. Shyness-related influence in psychosomatic stress (c = 0.171, $p < 0.005$) were multiply mediated by the GMV of dACC and the MCC (a = −0.195, $p < 0.005$, b = −0.136, $p < 0.05$). The results showed a significant indirect effect (partial mediation effect, ab = 0.028, $p < 0.05$) between shyness and psychosomatic stress, CI [0.007, 0.658], through the volumes of the dACC and the MCC (See Fig. 5).

Discussion

In the present study, we combined FA, WMV and GMV to reveal the structural basis underlying individual differences in shyness in a large sample of healthy college students, which greatly differed from the samples of former studies. Consistent with previous studies, our behavioral results showed that there were no significant gender differences in terms of shyness

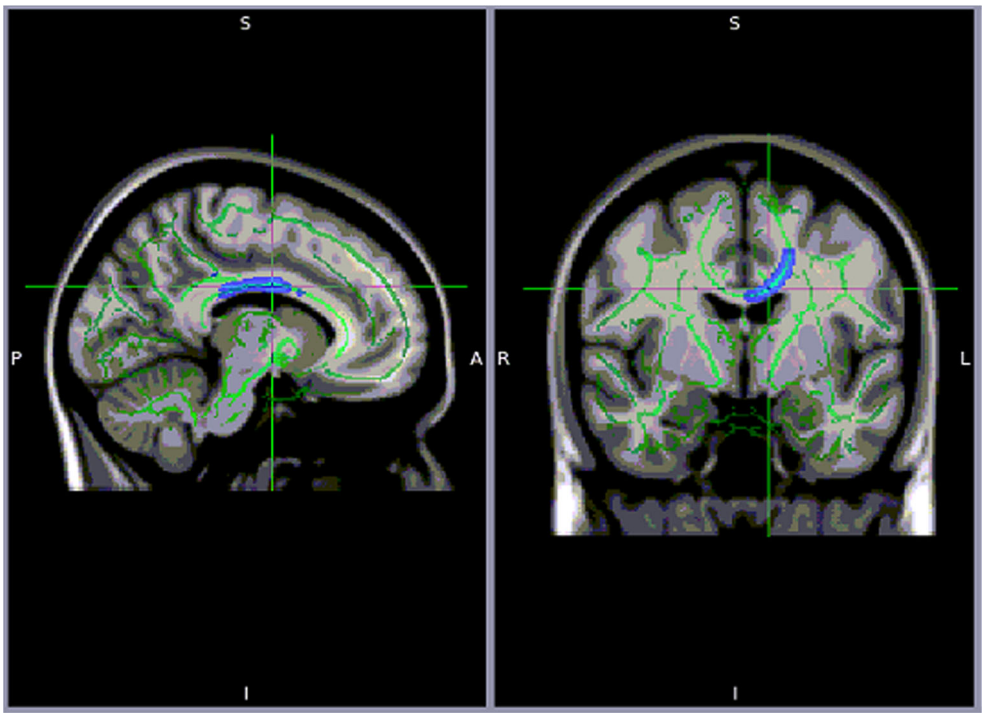

Fig. 1 Anatomical correlations with shyness. FA was negatively correlated with individual shyness in the right cingulum bundle. (B) Scatter plots of the relationship between shyness and FA values of the right cingulum bundle

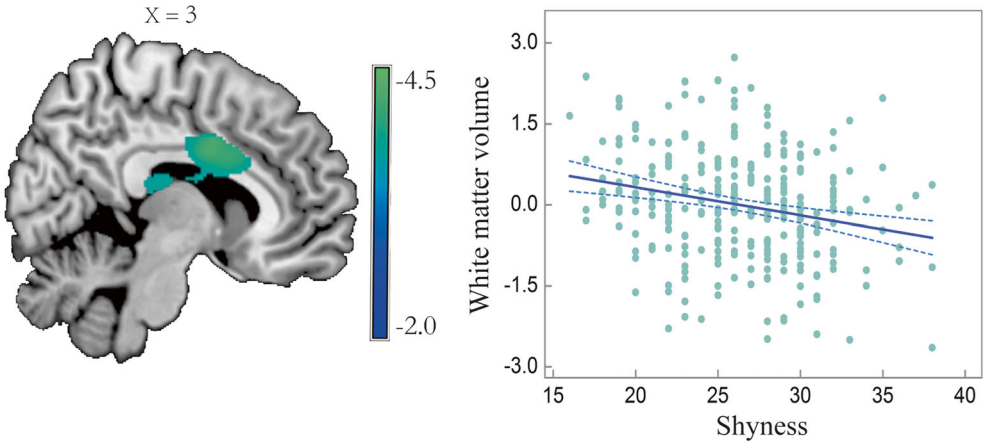

Fig. 2 Anatomical correlations with shyness. WMV was negatively correlated with individual shyness in the right dACC and MCC. (B) Scatter plots of the relationship between shyness and WMV values of the right dACC and MCC

(Cheek and Buss 1981). We found that decreased FA values in the cingulum bundle were associated with high levels of shyness. Subsequently, the structural data showed that shyness was positively correlated with the GMV in the IPL and negatively correlated with both the WMV and GMV in a cluster including the dACC and the MCC. The present study might provide key evidence of the structural brain basis of individual shyness. The following discussion will address the implications of these findings.

First, we found decreased FA values in the right CB (cingulum bundle), a finding that was consistent with the decreased WMVs in the right dACC and the MCC in our study. The CB, as mentioned previously, is the most prominent white matter fiber tract of the limbic system. It underlies the cingulate gyrus and remains the only communication route between the cingulate cortex and other areas of the brain, including the prefrontal, parietal, and temporal areas, as well as the thalamus (Domesick 1970). In this study, the decrease in diffusion anisotropy suggested a significant abnormality in the integrity of the fiber tracts interconnecting limbic structures. Many studies have shown that the limbic system plays a major role in emotion regulation (Hariri et al. 2000; Pessoa et al. 2002; Taylor et al. 2003; Etkin et al. 2006). In general, the hippocampus and anterior cingulate/prelimbic cortex inhibit stress-induced HPA activation (Herman et al. 2005). Several studies have suggested that shy persons experience significant emotional distress (Henriksen and Murberg 2009). For example, in a study asking students to rate five important aspects of their shyness, internal discomfort was ranked as the second most distressing experience of shyness (Pilkonis 1977). Thus, in the present study, the WMV variation in the right cingulate cortex might indicate weaker emotional regulation abilities in shy people.

Our results also indicated that decreased GMVs in the right dACC and the MCC were associated with higher level of shyness. The findings of previous studies indicated that the dACC was activated in response to an episode of social rejection and that the magnitude of dACC activity was correlated with the magnitude of self-reported social pain following exclusion (Eisenberger et al. 2003). In addition, social support appeared to diminish neural reactivity associated with social distress, such that greater levels of social support were associated with diminished levels of dACC activity and of the process of social evaluative threat involved in the neural activities of the ACC and the MCC (Eisenberger et al. 2007; Wager et al. 2009; Onoda et al. 2010). Other studies have demonstrated affective ACC and MCC abnormalities in depression and anxiety disorders, which might reflect a common pathophysiological mechanism related to altered emotion

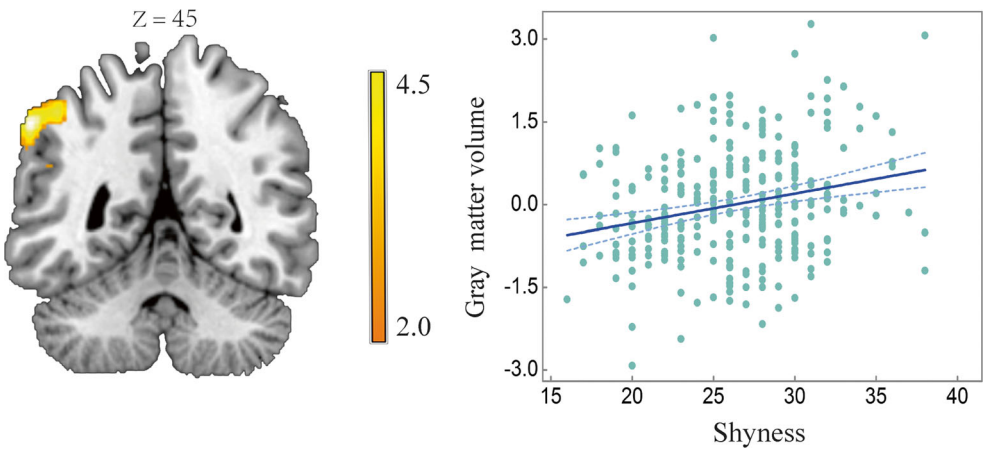

Fig. 3 Anatomical correlations with shyness. GMV was positively correlated with individual shyness in the right IPL. (B) Scatter plots of the relationship between shyness and GMV values of the right IPL

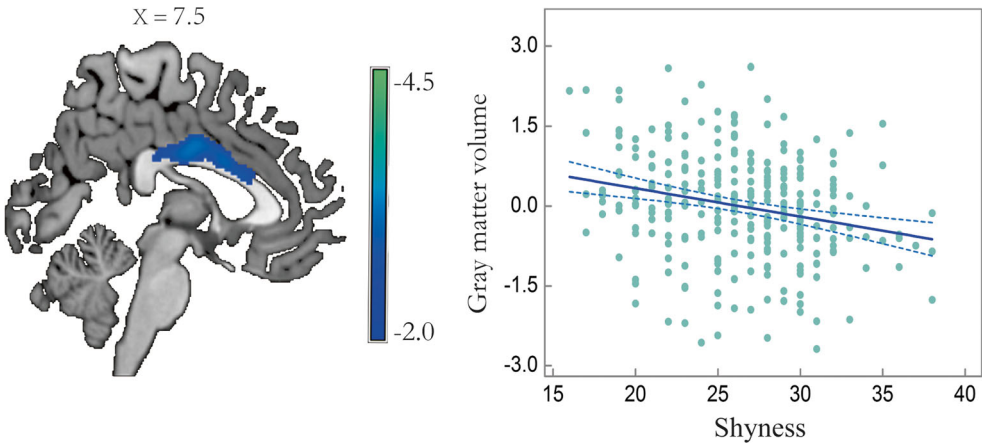

Fig. 4 Anatomical correlations with shyness. GMV was negatively correlated with individual shyness in the right dACC and MCC. (B) Scatter plots of the relationship between shyness and GMV values of the right dACC and MCC

processing (Drevets et al. 1997; Botteron et al. 2002; Tang et al. 2007; Asami et al. 2009; Yucel et al. 2009). A study investigating the relationship between ELS (early life stress) and the morphometry of adult brain structure indicated a negative correlation between ELS and the GMV of ACC (Cohen et al. 2006). The findings of the previous studies are interesting in light of the fact that the ACC and the MCC may perform compensatory roles in the regulation of emotion, especially negative emotion (Adamec 1997; Davidson et al. 1999; Davidson and Irwin 1999). For example, a study found that the ACC plays an important role in the regulation of negative emotion (Ochsner and Gross 2005), another study showed that the greater activation of the cingulate cortex was associated with the guilty feelings of individuals (Yu et al. 2013). Thus, the decreased GMV of the dACC and the MCC might have some negative influence on individuals' emotion regulation abilities, and then these people might have higher vulnerability to be in states of negative feelings in daily life.

Second, we found that higher N4 scores were associated with an increased GMV in the left IPL. The IPL has been implicated in processing verbal information related to the self (Kircher et al. 2000), attention (Culham and Kanwisher 2001), and the processing of working memory-associated emotional content (Rämä et al. 2001). For example, the IPL was found to be activated in response to facial stimuli, especially in response to fearful faces (Radua et al. 2010). Another study found increased cortical thickness in the frontal cortex and the parietal cortex in patients with social anxiety disorder, which could be associated with overactive and dysregulated attentional networks in anxiety disorders (Brühl et al. 2014). As the core region of mirror neuron system, the IPL has recently been shown to involved in understanding the intention of others (Fogassi et al. 2005). Shy people are sensitive and vulnerable to the judgments of others; in addition, they are good at perceiving other the emotions of others, especially in social settings. Thus, in the present study, the increased GMV in the IPL among the participants with higher levels of shyness might consequently be related to these participants being overly worried about others' evaluations.

Finally, in the present study, we investigated the neural basis of the relationship between shyness and psychosomatic stress in young healthy individuals. The behavioral results indicated that shyness was related to young adults' psychosomatic stress. The VBM results showed that shyness and

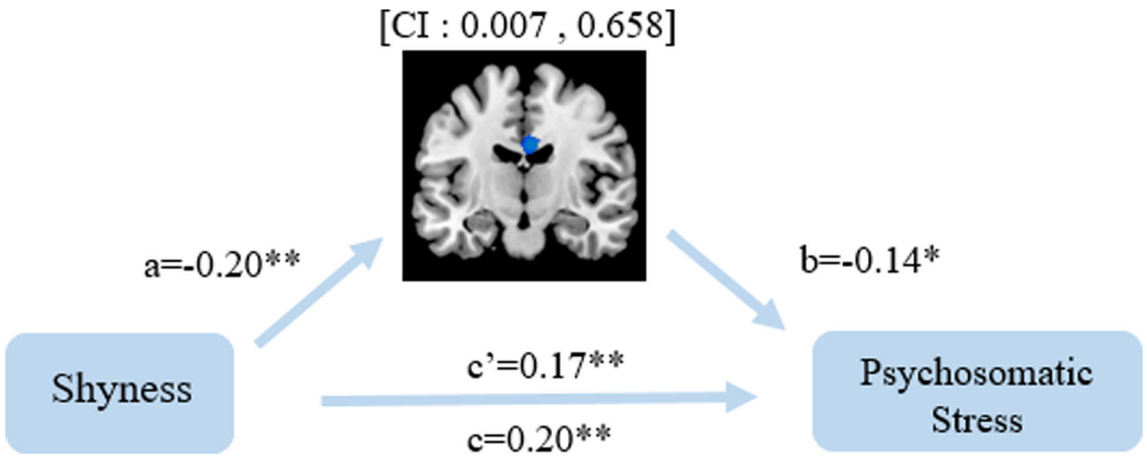

Fig. 5 The mediation results showed that the GMV of the dACC extending to MCC partly mediated the association between shyness and psychosomatic stress. *$p < 0.05$, **$p < 0.005$

psychosomatic stress were negatively correlated with the GMV of the dACC and the MCC. In addition, the mediation analysis showed that the volume of the ACC mediated the association between shyness and psychosomatic stress. It has been shown that shy people are more likely to perceive threats to a greater number of everyday events in their environment (Zimmermann and Stansbury 2004); thus, it is possible that shy people might suffer more psychosomatic stress. Taken together, our results suggested that the regions of the dACC and the MCC may play an important role in shyness.

There are some limitations in this study. One concern was that our sample consisted of highly educated, normal, healthy, young adults. While it is common to choose college students as participants (He et al. 2013), we failed to examine the effect of age on shyness and the developmental trajectory of shyness because of the narrow age range; this also certainly limited the generalizability of the results. However, the effect of age on individual brain structure was adjusted for by including age as a covariate in the correlation analyses. Furthermore, the effect sizes of the results in the present study were small, which may have been caused by the relatively larger sample size and simple linear regression analysis method we used (Olejnik and Algina 2000), but the relationship between the two variables may not be just a simple linear correlation.

Conclusion

The present study explored the associations among FA, WMV, GMV and individual differences in shyness in a large healthy adult sample and found that structural variations occurring in the cingulate cortex and the IPL underlie shyness. To some extent, the present structural imaging study of individual differences in shyness can contribute to a comprehensive understanding of the neural substrates of shyness and shyness-related mental disorders. In the future, the methods of intervention and longitudinal analysis may be explored to investigate how brain networks influence the levels of shyness of individuals.

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Compliance with ethical standards This study was approved by the local ethics committee of Southwest China University and the Institutional Human Participants Review Board of the Southwest University Imaging Center for Brain Research. The methods were conducted in accordance with the approved guidelines. All participants provided written informed consent prior to taking part in the study.

Conflict of interest All authors declare that they have no conflict of interest.

Animal studies and human participants All procedures performed in the studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards.

Ethical approval This article does not contain any studies with human participants performed by any of the authors.

Informed consent Informed consent was obtained from all individual participants included in the study.

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