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The correlation between Emotional Intelligence and gray matter volume in university students

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ABSTRACT

A number of recent studies have investigated the neurological substrates of Emotional Intelligence (EI), but none of them have considered the neural correlates of EI that are measured using the Schutte Self-Report Emotional Intelligence Scale (SSREIS). This scale was developed based on the EI model of Salovey and Mayer (1990). In the present study, SSREIS was adopted to estimate EI. Meanwhile, magnetic resonance imaging (MRI) and voxel-based morphometry (VBM) were used to evaluate the gray matter volume (GMV) of 328 university students. Results found positive correlations between Monitor of Emotions and VBM measurements in the insula and orbitofrontal cortex. In addition, Utilization of Emotions was positively correlated with the GMV in the parahippocampal gyrus, but was negatively correlated with the VBM measurements in the fusiform gyrus and middle temporal gyrus. Furthermore, Social Ability had volume correlates in the vermis. These findings indicate that the neural correlates of the EI model, which primarily focuses on the abilities of individuals to appraise and express emotions, can also regulate and utilize emotions to solve problems.

1. Introduction

As proposed by Salovey and Mayer in 1990, Emotional Intelligence (EI) represents the ability of an individual to manage and exploit his/her feelings and emotions to guide his/her thinking and actions (Salovey & Mayer, 1990). The publication of "Emotional Intelligence" by Goleman (1995) increased the public interest toward the applications and implications of EI over the past 20 years. Some researchers considered EI as a series of trait-like abilities that can be assessed by self-reporting (Bar-On, 2004), while other researchers argued that EI must be measured by demonstrable abilities in solving emotional problems (Mayer, Salovey, Caruso, & Sitarenios, 2002). Nevertheless, many studies had examined both trait and ability EI measures as valuable predictors of important outcomes for individuals, including social relationships, mental and physical health, work performance, and academic achievement (Brackett et al., 2013).

Studies on the neurological substrates of EI have begun to emerge recently. Two clinical studies reported that patients with lesions in the so-called somatic marker circuitry (SMC) or "body loop" exhibit a significantly lower EI than that of the control group (Bar-On, Tranel, Denburg, & Bechara, 2003; Krueger et al., 2009). The "body loop" was hypothesized to integrate the emotional signals originating from the body ("somatic markers"), with conscious cognitions to guide the decision-making process toward optimal outcomes (Damasio, Tranel, & Damasio, 1991). The circuitry covers several brain regions, including the amygdala, insular cortex, somatosensory cortex, and orbitofrontal (ventromedial prefrontal) cortex (Damasio, 1998). New techniques, such as MRI, have enabled non-invasive investigations into the human brain. For example, one functional MRI study corroborated the role of the "body loop" in EI (Killgore & Yurgelun-Todd, 2007). In addition, the researchers found that the activities of other brain regions, such as the middle temporal gyrus (MTG), occipital gyrus, fusiform, cuneus, precuneus, parahippocampus, and cerebellum, were related to EI when the subjects were asked to respond to a presentation of fearful faces.

Three structural brain imaging studies investigated the correlations between EI and the voxel-wise gray matter (GM) in the brain by VBM (Killgore et al., 2012; Koven, Roth, Garlinghouse, Flashman, & Saykin, 2010; Takeuchi et al., 2011), and all the results corroborated the role of SMC in individual EI. For example, Takeuchi et al.

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(2011) found that EI is associated with the GM density of the brain regions involved in SMC and in the social cognition network; Killgore et al. (2012) also supported the role of the ventromedial prefrontal cortex (VMPFC) and insula as key regions in the EI circuitry. However, several differences were detected in these three studies. Takeuchi et al. (2011) investigated the relationship between EI and gray matter density (GMD), whereas the other two structural imaging studies examined the relationship between EI and GMV, which may account for the discordance in the direction of their reported correlations. However, the relationship between GMD and GMV remains unclear. More importantly, the differences in the results may be due to the different EI scales that have been used in these studies and the relatively small sample that has been recruited. The utilized scales implicate different dimensions according to different EI models. The Emotional Intelligence Scale (EIS) that was used by Takeuchi et al. (2011) comprises three factors, namely, an intrapersonal factor, an interpersonal factor, and a situation management factor, which evaluate the ability of an individual to appraise as well as to cope with his/her self, with others, and with situations, based on the EI model of Bar-On (1997). However, the anatomy of the human brain may be structured according to different functions rather than according to intrapersonal and interpersonal abilities. The Trait Meta Mood Scale (TMMS) that was used by Koven et al. (2010) is capable of assessing EI, with specific attention given to emotions, clarity of emotions and mood repair. Attention to emotions measures the degree to which an individual pays attention to subjective feelings. Clarity of emotions measures the ability of an individual to perceive and understand subjective feelings. Lastly, mood repair measures the ability of an individual to manage emotions and repair negative feeling states (Koven et al., 2010). However, an increasing number of emotional theories claim that negative feelings are helpful and must not always be repaired (Ochsner, Silvers, & Buhle, 2012). The Bar-On Emotional Quotient Inventory (EQ-i) that was used by Killgore et al. (2012) is similar to EIS. The three previously mentioned scales are all trait measures that can be assessed by self-reporting. Killgore et al. (2012) also used the Mayer–Salovey–Caruso Emotional Intelligence Test (MSCEIT), which measures abilities based on the EI model of Mayer and Salovey (1997) and could yield an Experiential EI score as well as a Strategic EI score (Mayer & Salovey, 2007). Similar to the Monitor of Emotions aspect (see Emotional Intelligence Scale in Section 2) in the present study, Strategic EI indicates the ability of an individual to understand personal subjective feelings and those of others and to effectively regulate such feelings. Similar to the Utilization of Emotions aspect (see Emotional Intelligence Scale in Section 2) in this study, Experiential EI indicates the ability to discriminate personal emotions, those of others, and various inanimate stimuli as well as to use emotional information to facilitate problem-solving (Killgore et al., 2012). Killgore et al. (2012) only investigated the territory regions-of-interest (ROI) in the SMC, which was the potential cause of their failure in observing a correlation between GMV and Experiential EI. To the best of our knowledge, no study has yet examined the correlations between brain structure and trait EI assessed by the Schutte Self-Report Emotional Intelligence Scale (SSREIS), which includes specific EI abilities according to the theoretically cohesive and comprehensive EI model of Salovey and Mayer in 1990 (Schutte et al., 1998). The EI model focuses on the abilities of individuals to appraise and express emotions as well as to regulate and utilize emotions to solve their problems. These capabilities are widely accepted by the public and correspond to the basic capacities that can be mapped to the human brain (Salovey & Mayer, 1990). Although the process-oriented model of Mayer and Salovey (1997) was also revised. Schutte et al. (1998) argued that the original model developed in 1990 could better conceptualize the current state of EI development facets of an individual than the revised model. Most dimensions of the revised model can also be integrated into the original model.

Given that the three previously mentioned structural studies recruited relatively small samples and ignored the EI model of Salovey and Mayer (1990), the current study gathered a relatively large sample of local university students to evaluate the correlations between each dimension of the EI model and GMV. The VBM method was implemented to detect regional differences in GMV on a voxel basis across the entire brain (Mechelli, Price, Friston, & Ashburner, 2005). A Chinese version of the SSREIS was adopted, which included all four EI domains, namely, Monitor of Emotions (which means the ability to regulate effectively subjective emotions), Utilization of Emotions (which means the ability to utilize emotions in solving problems), Social Ability (which means the ability to use emotions in social activities), and Appraisal of Emotions in Others (which means the ability to appraise the emotions of others through verbal or non-verbal information) (Huang, Lu, Wang, & Shi, 2008).

In the light of the previous EI studies described earlier, especially the three structural studies, we predicted that volume correlates would appear in emotion-associated brain areas, including the VMPFC, somatosensory cortex, insular cortex, MTG, occipital gyrus, fusiform, cuneus, precuneus, hippocampus, parahippocampal gyrus (PHG), and cerebellum. We further hypothesized that the GMV correlates of Monitor of Emotions would comprise of regions within the SMC. Based on the results of Strategic EI studies, we expect these regions would include the VMPFC or orbitofrontal cortex (OFC), the insular cortex (Killgore et al., 2012), and an anatomical cluster that extends from the cuneus to the precuneus, which is a correlate of the Intrapersonal factor, as indicated in the study of Takeuchi et al. (2011). The Utilization of Emotions is expected to have a VBM correlate in the PHG, a region found to be correlated with emotional utilization in patients with early-stage schizophrenia (Wojtalik, Eack, & Keshavan, 2013). We also expected that the volume correlates of Utilization of Emotions would involve several regions in the temporal lobe because such regions were suggested to be related to emotional semantic coding and learning processes (Jefferies, 2012; Whitney, Kirk, O'Sullivan, Lambon Ralph, & Jefferies, 2010). We postulated that the volume correlates of Social Ability would include several regions of the "social brain", such as the adjacent anterior cingulate cortex, the temporoparietal junction (Amodio & Frith, 2006; Samson, Apperly, Chiavarino, & Humphreys, 2004), and the cerebellum, which was recently introduced in the "social brain" literature (Takeuchi et al., 2011). We also hypothesized that the GM correlates of the Appraisal of Emotions in Others aspect would emerge in the regions that were involved in social perception, such as the superior temporal sulcus, which was found to be correlated with the Interpersonal factor in the EI model of Bar-On (Takeuchi et al., 2011).

2. Methods

2.1. Subjects

A total of 335 right-handed, healthy volunteers from the local community of Southwest University in Chongqing participated in the study as part of our ongoing project to examine the associations between brain imaging, creativity and mental health. Participants were screened through a self-report questionnaire survey before the scanning to make sure of their healthy development. Thus, the participants who had a history of neurological or psychiatric illness, had received mental health care or had taken psychiatric medications were not included. Written informed consent was obtained from all participants prior to the experiment, in accordance with the Declaration of Helsinki (1991). This study was approved by the Southwest University Institutional Review Board. The participants all completed the Chinese version of the SSREIS (Schutte et al., 1998). Two participants were excluded due to missing items. Another five participants were removed from further analyses because of extraordinary motion artifacts or having abnormal brain structures. Thus, 328 (173 women and 155 men; mean age = 20 yrs) participants remained in further analyses.

2.2. Emotional Intelligence Scale

The SSREIS is a credible self-report assessment device built to measure EI (Schutte et al., 1998), with each response using a 5-point scale ranging from "not true of me" to "very often true of me". According to the study of Huang et al. in 2008, the item-level factor structure of the SSREIS in the Chinese version is a little different from the western version (Optimism/Mood Regulation, Utilization of Emotions, Social Ability and Appraisal of Emotions) (Petrides & Furnham, 2000; Saklofske, Austin, & Minski, 2003): Monitor of Emotions consists of 5 items that measure one's ability to regulate subjective emotions effectively (e.g. "I know why my emotions change"); items about optimism were removed from the Chinese revision due to the Chinese interdependent culture. Utilization of Emotions contains 5 items that measure one's ability to utilize emotions in solving problems (e.g. "When I am in a positive mood, I am able to come up with new ideas"), which is similar to the subscale in the western version. Social Ability contains 5 items that measure the degree to which an individual uses emotions in social activities (e.g. "I help other people feel better when they are down"), which is similar to the subscale in the western version. Finally, Appraisal of Emotions in Others has 4 items that measure the ability to appraise the emotions of others through verbal or non-verbal information (e.g. "I am aware of the non-verbal messages other people send"); items about the Appraisal of Emotions in self were removed from the Chinese revision due to their double load (Huang et al., 2008).

2.3. Magnetic resonance image data acquisition

Magnetic resonance (MR) images were acquired using a 3.0-T Siemens Trio MRI scanner (Siemens Medical, Erlangen, Germany). T1-weighted anatomical images with high resolution were collected through a magnetization-prepared rapid gradient echo (MPRAGE) sequence (resolution matrix = 256 × 256; repetition time (TR) = 1900 ms; inversion time (TI) = 900 ms; echo time (TE) = 2.52 ms; flip angle = 9°; thickness = 1.0 mm; slices = 176; voxel size = 1 × 1 × 1 mm).

2.4. Voxel-based morphometry analysis

The MR images were processed in SPM8 (http://www.fil.ion.ucl.ac/spm) implemented in Matlab 7.8 (MathWorks Inc., Natick, MA, USA). Firstly, each T1-weighted anatomical image was displayed in SPM8 to screen for gross anatomical abnormalities. For better registration, the MR images were manually reoriented to set them to the anterior commissure. Segmentation of the images into GM and white matter was conducted with the new segmentation in SPM8. Subsequently, Diffeomorphic Anatomical Registration through Exponentiated Lie (DARTEL) algebra in SPM8 was used to spatially normalize the segmented images (Ashburner, 2007). Additionally, the image intensity of each voxel was modulated by the Jacobian determinants to ensure regional differences in the total amount of GM were conserved. Then, the registered images were transformed to Montreal Neurological Institute (MNI) space using affine spatial normalization. Finally, the normalized modulated GM images were smoothed with an 8-mm full-width at half-maximum (FWHM) isotropic Gaussian kernel to increase the signal to noise ratio.

To examine any correlations between regional GMV and behavioral scores, multiple regression analysis was used, controlling for age, gender and total brain GM. An absolute threshold masking of 0.2 was used to avoid edge effects around the borders between GM and white matter, which meant that voxels with a GM possibility lower than 0.2 were removed from the analyses. Clusters were considered significant at the combined voxel-extent threshold of an uncorrected voxel level of $P < 0.005$ and cluster extent >316 voxels, which corresponded to a corrected $P < 0.05$. The AlphaSim correction (cluster radius connection: rmm = 5 and number of Monte Carlo simulations = 10,000) was conducted using the AlphaSim program in the REST software (http://www.restfmri.net), which applied a Monte Carlo simulation to calculate the probability of false positive detections by taking both the individual voxel probability threshold and cluster size into consideration (Chao-Gan & Yu-Feng, 2010).

3. Results

3.1. Behavioral data

The averages, standard deviations (SD) and inter correlations of scores on the four factors of the SSREIS are presented in Table 1. There were significant positive associations among all factors of the SSREIS.

3.2. Correlations between regional GMV and the Monitor of Emotions factor of EI

After controlling for age, sex and whole brain GM, multiple regression analysis revealed that scores on the Monitor of Emotions factor of EI were positively correlated with the GMV in several anatomical clusters that included the left insula, the right OFC and the left superior parietal lobule (SPL). Conversely, the scores were significantly negatively correlated with the GMV in the left cuneus (Fig. 1).

3.3. Correlations between regional GMV and the Utilization of Emotions factor of EI

After controlling for age, sex and whole brain GM, multiple regression analysis revealed that scores on the Utilization of Emotions factor of EI were positively correlated with the GMV in the right PHG. Conversely, the scores were significantly negatively correlated with the GMV in three anatomical clusters that included the right fusiform gyrus (FG), the left MTG and the left superior temporal gyrus (STG) (Fig. 2).

3.4. Correlations between regional GMV and the Social Ability factor of EI

After controlling for age, sex and whole brain GM, multiple regression analysis revealed that scores on the Social Ability factor

Table 1
Average (SD) and inter correlations of scores on four factors of SSREIS.

	Average (SD)	ME	UE	SA	AEO
ME	3.56 (0.51)		.308**	.402**	.434**
UE	3.83 (0.55)			.284**	.239**
SA	4.13 (0.43)				.330**
AEO	3.57 (0.65)				

Abbreviations: SD: standard deviations; ME: Monitor of Emotions; UE: Utilization of Emotions; SA: Social Ability; AE: Appraisal of Emotions in Others; SSREIS: Schutte Self-Report Emotional Intelligence Scale.
** $p < .01$.

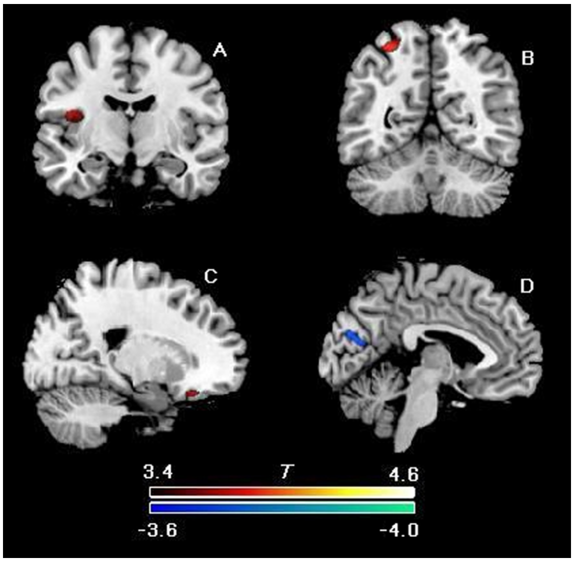

Fig. 1. Brain regions with significant correlations between GMVs and scores on the Monitor of Emotions factor in the Schutte Self-Report Emotional Intelligence Scale. The GMVs of the left anterior insula (A), the left superior parietal lobule (B) and the right orbitofrontal cortex (C) were positively correlated with scores on the Monitor of Emotions factor. The GMVs of the left cuneus (D) were negatively correlated with scores on the Monitor of Emotions factor. Color scales represent *T* values using one-way ANOVAs ($p < 0.005$, AlphaSim corrected). *Abbreviations:* GMV: gray matter volume. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

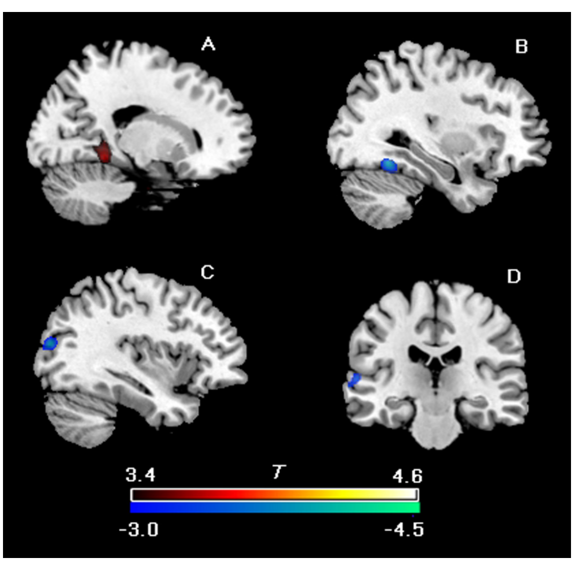

Fig. 2. Brain regions with significant correlations between GMVs and scores on the Utilization of Emotions factor in the Schutte Self-Report Emotional Intelligence Scale. The GMVs of the right parahippocampal gyrus (A) were positively correlated with scores on the Utilization of Emotions factor. The GMVs of the right fusiform gyrus (B), the left middle temporal gyrus (C) and the left superior temporal gyrus (D) were negatively correlated with scores on the Utilization of Emotions factor. Color scales represent *T* values using one-way ANOVAs ($p < 0.005$, AlphaSim corrected). *Abbreviations:* GMV: gray matter volume.

of EI were positively correlated with the GMV in the right vermis (Fig. 3).

3.5. Correlations between regional GMV and the Appraisal of Emotions in Others factor of EI

After controlling for age, sex and whole brain GM, multiple regression analysis revealed that there were no significant correlations between scores on the Appraisal of Emotions in Others factor of EI and any regional GMV in the brain. These results are shown in Table 2.

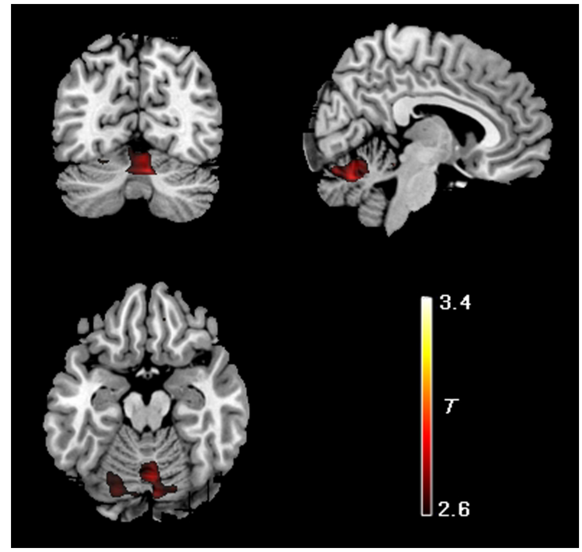

Fig. 3. Brain regions with significant correlations between GMVs and scores on the Social Ability factor in the Schutte Self-Report Emotional Intelligence Scale. The GMVs of the right cerebellum were positively correlated with scores on the Social Ability factor. Color scales represent *T* values using one-way ANOVAs ($p < 0.005$, AlphaSim corrected). *Abbreviations:* GMV: gray matter volume. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

4. Discussion

Compared with the sample in previous studies on the neural correlates of EI, we recruited a relatively large sample of participants to achieve a more comprehensive understanding of the diverse neural correlates of EI. We adopted the Chinese version of the SSREIS, which is based on the EI model of Salovey and Mayer in 1990 (Schutte et al., 1998). We speculated that different brain regions are involved in emotional perception, emotional monitoring, Social Ability and emotional utilization. By VBM, we found that at least three dimensions of EI (i.e., Monitor of Emotions, Utilization of Emotions and Social Ability) have distinctive associations with regional GMVs across the large sample of adult participants. Although we found the GMV correlates in brain regions that were identified in previous EI research (Killgore et al., 2012; Koven et al., 2010; Takeuchi et al., 2011; Wojtalik et al., 2013), including the OFC, insular, cuneus and PHG, our findings suggest that several other areas were associated with separate facets of EI. GM correlates were not factitious because of demographic or psychological variables, such as age and gender that we statistically controlled, as well as those participants who had a history of neurological or psychiatric illness, which we excluded. The large sample may help mitigate the conceptually difficult rationale of looking at the GMV correlates of complex psychological traits, such as the subcomponents of the EI scale. Our results show the neural correlates of the EI model developed by Salovey and Mayer in 1990. However, the novel elements of our results must be investigated further to justify their correlations with EI.

The positive and negative correlations that were reported in previous structural studies on EI emphasized the complexity of the relationship between function and structure. This matter remains an open question, at present. Sowell et al. (2003) found a rapid decline in gray matter density over the dorsal frontal and

Table 2
Brain regions with significant correlations between regional GMVs and the scores of each factor in the SSREIS.

Area	Brodmann's area	Size (voxels)	*T* score	MNI coordinates		
				x	*y*	*z*
Monitor of Emotions (GMV-positive)						
Insula	13	630	3.9	−44	−9	18
Superior parietal lobule	7	435	4.6	−29	−57	59
Orbitofrontal cortex, middle frontal gyrus	11	421	3.4	18	27	−18
Monitor of Emotions (GMV-negative)						
Cuneus	18	647	3.69	−6	−80	23
Utilization of Emotions (GMV-positive)						
Parahippocampal gyrus, Lingual Gyrus	30	1176	3.8	17	−45	−9
Utilization of Emotions (GMV-negative)						
Fusiform gyrus	37	343	4.4	32	−54	−14
Middle temporal gyrus, Middle occipital gyrus	19	441	4.3	−36	−83	17
Superior temporal gyrus	22	382	3.1	−63	−20	2
Social Ability (GMV-positive)						
Vermis		1084	3.3	8	−68	−24

Abbreviations: GMV: gray matter volume; SSREIS: Schutte Self-Report Emotional Intelligence Scale; MNI: Montreal Neurological Institute.
Note: the *T*-score and coordinates reflect peak correlation within a cluster.

parietal association cortices among individuals aged between 7 and 60 years old. However, this phenomenon was not the case for the posterior temporal or occipital cortices, which were found to have a more protracted course of maturation from childhood to adulthood than the dorsal frontal and parietal association cortices (Sowell et al., 2003). Furthermore, the increments in intracortical myelination may lead to high-speed nerve conduction as well as a decrease in regional GMV (Paus, 2005). Therefore, we suppose that the diminished GMV in the regional visual and auditory cortices is associated with the heightened EI-related abilities among adults. However, this is merely a speculation and the details of this phenomenon remain unclear.

4.1. Monitor of Emotions

The SSREIS Monitor of Emotions subscale confines the degree to which an individual efficiently adjusts his/her own emotions to become more adaptive in daily life. As predicted, we found that a more intensive Monitoring of Emotions is correlated with a higher GMV in the left insula, the left SPL, and the right OFC. A negative correlation was also found between the scores on the Monitor of Emotions subscale and the GMV in the left cuneus.

Among the positive correlations, the observed associations between the scores on the Monitor of Emotions subscale of the SSREIS and the structure of the insula and OFC conformed to the somatic marker hypothesis, which proposes that emotions and feelings have important roles in decision-making on daily life matters. Emotions are mostly expressed by the changes in the representation of the body state, and the results of emotions are projected from the brainstem and hypothalamus to the cerebral cortex (Damasio, 1998). Several studies presented evidence of the role of the insular cortex in monitoring somatic and visceral states (Craig, 2003, 2009; Critchley, Mathias, & Dolan, 2002; Critchley et al., 2005; Dunckley et al., 2005; Jabbi & Keysers, 2008; Reiman et al., 1997; Saarela et al., 2007; Singer, Critchley, & Preuschoff, 2009; Takeuchi et al., 2011). OFC has also been considered important in sensory integration, in representing the emotional value of outcomes, and in making decisions and predictions (Kringelbach, 2005). Several studies indicated that OFC is an essential part of the cognitive control system that adjusts emotional outputs by evaluating the emotional value of the stimuli and/or by learning to associate emotional responses with the stimuli (Ochsner & Gross, 2005; Roelofs, Minelli, Mars, van Peer, & Toni, 2009; Rudebeck et al., 2008). These findings consolidate the importance of the insula and OFC in the somatic marker circuitry that serves EI.

The cuneus has been rarely discussed in social cognition literatures, with the exception of a study that reported about pathological gamblers having high levels of activity in the dorsal visual processing stream, including the cuneus, relative to controls (Crockford, Goodyear, Edwards, Quickfall, & el-Guebaly, 2005). Platek and Kemp (2009) recently confirmed that the cuneus is active during facial discernment tasks such as comparing the faces of relatives to those of friends and suggested that the cuneus represents a computational process on facial familiarity and identity. Another study showed that the GMV in the cuneus is associated with better inhibitory control among patients with bipolar depression (Haldane, Cunningham, Androutsos, & Frangou, 2008). More importantly, two studies on the neural substrates of EI both reported correlations between EI and GM in the cuneus (Koven et al., 2010; Takeuchi et al., 2011). Therefore, we suggest that the cuneus not only plays a traditional role as a basic visual processing site, but is also engaged in social cognition processing as well as EI. The negative correlation that we have observed is consistent with the proposal that a diminished GMV in the regional visual and auditory cortices related to a more efficient behavior among adults.

In addition to the hypothesized regions, we found an unexpected cluster in the left SPL that was correlated with the EI scores. The left SPL is assumed to be involved in processing the spatial configuration of our bodies and supplying appropriate information to the frontal premotor cortices to facilitate actions (Felician et al., 2004). A case study on a patient with an SPL lesion found that the SPL played a role in sensorimotor integration by maintaining an internal representation of the body state (Wolpert, Goodbody, & Husain, 1998).

4.2. Utilization of Emotions

The SSREIS Utilization of Emotions subscale assesses the degree of emotional utilization in problem solving. Emotions drive us to focus on more pressing needs (Salovey & Mayer, 1990) and positive emotions may affect cognitive organization and inclusively relate more materials to produce diverse ideas (Nowicki, 1987; Rowe, Hirsh, & Anderson, 2007). We found a positive correlation between the scores on the Utilization of Emotions subscale and the GMV in the right PHG. Negative correlations were also found between the Utilization of Emotions scores and GMV in the right FG, the left MTG, and the left STG. These negative correlations were consistent with the proposal that a diminished GMV in the regional visual and auditory cortices is related to a more efficient behavior among adults.

The association between the Utilization of Emotions scores and the PHG volumes was consistent with the findings of a study on the structural neurobiological correlates of the Mayer–Salovey–Caruso Emotional Intelligence Test performance of patients with early-stage schizophrenia (Wojtalik et al., 2013). Rankin et al. (2009) revealed that the right PHG could play a crucial role in identifying social context, hence enabling the facilitation of emotions in diverting our attention toward more pressing needs depending on social clues. They also suggested that the right PHG enabled people to notice sarcasm (Rankin et al., 2009). The role of the posterior PHG in emotional memory is gradually being emphasized (Murty, Ritchey, Adcock, & LaBar, 2010). The developmental trajectory of the PHG is different from that of the other parts of the temporal lobe (Sullivan, Marsh, Mathalon, Lim, & Pfefferbaum, 1995), hence producing a positive relationship rather than a negative relationship between the PHG volume and the Utilization of Emotions subscale.

Evidence from MRI studies suggests that the FG plays a special role in face processing (Furl, Garrido, Dolan, Driver, & Duchaine, 2011; Garrido et al., 2009; Kanwisher, McDermott, & Chun, 1997; Sugiura et al., 2005). The fusiform face area (FFA) is differentially activated by faces that exhibit different emotions. One study argued that the FFA was strongly activated by fearful faces than neutral faces (Guyer et al., 2008). Therefore, the FFA may have several functions in processing emotions.

Previous studies found that a positive affect could facilitate creative problem solving by relating stimuli more inclusively (Ashby & Isen, 1999; Estrada, Isen, & Young, 1994; Nowicki, 1987; Rowe et al., 2007). In particular, the left posterior MTG controlled semantic cognition (Jefferies, 2012; Whitney, Kirk, O'Sullivan, Lambon Ralph, & Jefferies, 2010), and was involved in semantic associations (Visser, Jefferies, Embleton, & Ralph, 2012). A recent functional neuroimaging study found that providing the participants with a list of positively valence metaphors activated their left STG (Subramaniam, Beeman, Faust, & Mashal, 2013). Based on the developmental trajectory of the temporal cortex, we propose that the diminished GMV of the left MTG and the left STG underpins broader semantic associations, which are critical in creative problem solving processes that are facilitated by positive affects.

4.3. Social Ability

The SSREIS Social Ability subscale measures the degree to which an individual uses their emotions in social activities. We found a positive correlation between the Social Ability scores and the GMV in the right cerebellum, especially the vermis, which is situated in the midline of the cerebellum.

The cerebellum has been considered for a long time as the primary regulator of motor functions. However, anatomical studies found that patients with cerebellar damage showed demonstrated several deficits in their personality, executive function, and affective regulation (Riva & Giorgi, 2000; Schmahmann & Sherman, 1998). Recent MRI studies also found a positive correlation between the activity in the cerebellum and the interpersonal factor of EI (Killgore & Yurgelun-Todd, 2007). The vermis found in this study was termed *limbic cerebellum* for its role in emotional and cognitive processes (Schmahmann, 2004; Schmahmann, Weilburg, & Sherman, 2007). Several structural MRI studies also reported a reduction in vermian size in some emotional disorders (Baldaçara et al., 2011; Gothelf et al., 2008; Ichimiya, Okubo, Suhara, & Sudo, 2001; Monkul et al., 2008; Yucel et al., 2013). When considered with the above-mentioned research on the role of vermis in affect and cognition as well as on its traditional role in complex motor coordination, our data indicate that the vermis may also be an important structure in complex cognitive and affective process coordination, which may directly influence the EI level of an individual.

4.4. Appraisal of Emotions in Others

The SSREIS Appraisal of Emotions in Others subscale evaluates the ability of an individual to appraise the emotions of others through verbal or non-verbal information. However, similar to the results of an EI-VBM study among patients with early-stage schizophrenia and those of Koven et al. (Wojtalik et al., 2013; Koven et al., 2010), we failed to find the neural base of such ability. A null finding from a brain imaging study did not necessarily indicate that GMV was unrelated to the ability of individuals to appraise the emotions of others. Our null finding may be due to the fact that the VBM method was the only technique we adopted for testing our hypotheses. Given that using whole-brain VBM methods may miss several crucial results, future studies must employ both VBM and ROI methods to test whether other results may appear (Giuliani, Drabant, Bhatnagar, & Gross, 2011; Qiao et al., 2013). However, some complex human traits are not expected to have correlates in as vague a measure as VBM in healthy individuals. Additionally, all the participants in this study were at the same stage of adulthood. Therefore, the neurological substrates that underlie the ability of an individual to appraise the emotions of people from a wider population must be investigated further.

4.5. Limitations

VBM has been extensively used in the exploration of the brain structures that underpin all kinds of behaviors. However, this technique cannot differentiate the potential influence of the amount of regional GM, such as the number and size of neurons and glias, the level of synaptic pruning and the level of myelination (Draganski et al., 2004; May & Gaser, 2006). Therefore, the relationships throughout the brain are not simple or qualitatively linear. Likewise, the VBM results must be directed to the trajectories of cortical development. This study also has other restrictions aside from the drawbacks of VBM. Firstly, the correction for the Type I error has raised concerns on the Type II error. However, this error can often be overcome by using a large sample. Secondly, the factor structure of the SSREIS remains controversial. Thirdly, our use of young healthy subjects with high education background has led to a relatively narrow sample. Neglecting the full intellectual capability of individuals is a common hazard when recruiting samples from the college student population. The average scores on the four EI factors in our study were all higher than their average levels in the total population. The generalizability of our findings across the wider population can only be established by replicating our findings using highly representative samples.

4.6. Conclusions

By employing VBM in a relatively large sample of Chinese university students, this study provided an analysis of the brain-wide relationships between GMV and specific dimensions of EI based on the model of Salovey and Mayer (1990). Three out of the four facets demonstrated distinct sets of correlations. Monitor of Emotion was related to the somatic marker circuitry, Utilization of Emotions was related to the cerebral regions that were involved in social perception and semantic association, and Social Ability was related to the cerebellum. However, EI was found to be an extremely sophisticated phenomenon that was associated with complicated brain network functions. When an individual efficiently engages the entire network, s/he has a better capability to cope with his/her personal and social life as well as exhibit a higher level of EI.

Further studies must be performed to explore the functional connectivity and the brain networks within or outside the neurobiological models of the relevant constructs of EI.

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