Regional Gray Matter Density Associated With Emotional Intelligence: Evidence From Voxel-Based Morphometry

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Abstract: Emotional Intelligence (EI) is the ability to monitor one's own and others' emotions and the ability to use the gathered information to guide one's thinking and action. EI is thought to be important for social life making it a popular subject of research. However, despite the existence of previous functional imaging studies on EI, the relationship between regional gray matter morphology and EI has never been investigated. We used voxel-based morphometry (VBM) and a questionnaire (Emotional Intelligence Scale) to measure EI to identify the gray matter correlates of each factor of individual EI (Intrapersonal factor, Interpersonal factor, Situation Management factor). We found significant negative relationships between the Intrapersonal factor and regional gray matter density (rGMD) (1-a) in an anatomical cluster that included the right anterior insula, (1-b) in the right cerebellum, (1-c) in an anatomical cluster that extends from the cuneus to the precuneus, (1-d) and in an anatomical cluster that extends from the medial prefrontal cortex to the left lateral fronto-polar cortex. We also found significant positive correlations between the Interpersonal factor and rGMD in the right superior temporal sulcus, and significant negative correlations between the Situation Management factor and rGMD in the ventromedial prefrontal cortex. These findings suggest that each factor of EI in healthy young people is related to the specific brain regions known to be involved in the networks of social cognition and self-related recognition, and in the somatic marker circuitry. *Hum Brain Mapp* 32:1497–1510, 2011. © 2010 Wiley-Liss, Inc.

Key words: emotional intelligence; voxel-based morphometry; somatic marker; social cognition

INTRODUCTION

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Salovey and Mayer define Emotional Intelligence (EI) as the ability to monitor one's own as well as others' emotions, and to use that information to guide one's thinking and action [Salovey and Mayer, 1990]. EI is important for social interaction because emotions serve communicative and social functions, conveying information about people's thoughts and intentions and coordinating social encounters [e.g., Keltner and Haidt, 2001]. EI measures are valuable predictors of performance in employment, academic and life settings [for a meta-analysis, see Van Rooy and Viswesvaran, 2004].

Previous studies suggest the neural network involved in social cognition is one of the networks thought to be involved in EI. Given the relationship between EI and socially relevant outcome measures and knowing that the construct of EI includes the ability to interact with others in social life and to contend with social situations [Uchiyama et al., 2001], it is likely that EI is related to such neural networks of social cognition as theory of mind. Among regions relevant to social cognition, the medial prefrontal cortex and the superior temporal sulcus (STS) may play a key role in representing one's own and other people's mental states [Frith and Frith, 2001]. On the other hand, a recent functional imaging study [Reis et al., 2007] showed that brain activities while performing social reasoning were negatively correlated with EI in the left lateral fronto-polar cortex and temporal cortex, which are critical areas in social reasoning [Stone et al., 2002].

Previous neuroscientific studies have indicated that the "somatic marker" circuitry is another neural network which plays a key role in EI. The somatic marker hypothesis [Damasio et al., 1991] posits that emotion-based biasing signals arising from the body (somatic markers) are integrated in higher brain regions, in particular the ventromedial prefrontal cortex (VMPFC), to regulate decision making in situations of complexity, especially in the personal and social realms. Several regions, including the VMPFC, insula, amygdala, sensory cortices, and the nuclei in the brainstem are thought to belong to the somatic marker circuitry [Damasio, 1998]. These regions are rather (though, not completely) distinct from the regions involved in social cognition such as theory of mind, as described above. Brain activities during the perception of fearful faces were negatively correlated with EI in the somatic marker circuitry [Killgore et al., 2007]. Furthermore, previous lesion studies reported that lesions in the somatic marker circuitry [Bar-On et al., 2003] or the key node of the somatic marker circuitry, the VMPFC [Krueger et al., 2009] result in low emotional intelligence. These studies suggest that high EI is mediated by efficient processing in the somatic marker circuitry, especially in the key node of the circuitry, the VMPFC.

Results of previous functional imaging studies on EI, as described above, are in accord with the neural efficiency hypothesis which was originally introduced by Haier et al. [1988 and 1992]. On the basis of many functional imaging studies of learning, development and intelligence [e.g., Olson et al., 2006], the neural efficiency hypothesis posits that neural activity becomes more efficient (decreases during the task) and focused as individuals become more intelligent or acquire greater skills and experience [for review, see Neubauer and Fink, 2009]. Stone et al.'s [2007] study and Killgore et al.'s [2007] studies are congruent with such a hypothesis and reported negative correlation between EI and activities of the social cognition network and somatic marker circuitry respectively. One interesting question with regards to this issue is, "What is the anatomical basis of EI, which negatively correlated with brain

activities?" In studies of normal development, the gray matter of brain regions involving the frontal and parietal regions has been found to thin over time [Sowell et al., 2003]. This kind of cortical thinning has been supposed to underlie more focused functional activations during skill acquisition and increases in the efficiency of cognitive processes [Durton and Casey, 2006]. Thus, one possibility is that higher EI is associated with thinner cortices in relevant regions. However, because studies of intelligence often show that thicker cortices are associated with higher intelligence [e.g., Haier et al., 2004], there was a new hypothesis that more gray matter and thicker cortices resulted in greater efficiency of function [Jung and Haier, 2007], but so far there is no confirmation of this see Haier et al. [2009]. At present, this matter is an open question.

Nevertheless, the vast amount of attention given to EI lacks a study observing EI's relationship with regional gray matter density (rGMD) which is the purpose of our current investigation. Individual differences in EI play a role in building and maintaining a successful social life as described above. Investigating the neural bases underlying EI is important for gathering new insights as to how a successful social life is achieved. Structural imaging studies are especially suited for investigating the neural correlates of EI because, unlike functional MRI studies, the results of structural imaging studies (1) are not limited to the specific regions engaged in the task during scanning and include the regions involved in diverse social and emotional cognitive processes, (2) and need not take into account unusual situations mocking social and emotional activities in daily life. Furthermore, considering that gray matter structures are associated with theory of mind performance in patients with schizophrenia [Herold et al., 2009] as well as alexithymia which is associated with inferior EI [Borsci et al., 2009; Parker et al., 2001], gray matter structures may well be associated with EI in a nonclinical sample.

In this study, we used voxel-based morphometry (VBM) [Good et al., 2001] to assess rGMD. To assess EI, we used the Japanese version of the Emotional Intelligence Scale [Emotional Intelligence Scale; Fukunishi et al., 2001; Uchiyama et al., 2001] which has three factors (Intrapersonal factor, Interpersonal factor and Situation Management factor). A four-component model of EI [Salovey and Mayer, 1990] and a five-component model of EI [Bar-On, 1997] also exist. The model of EI developed by Bar-On [1997] consists of two major factors, intrapersonal and interpersonal, and several minor factors such as stress coping, adaptability and general mood. On the contrary, Otake et al. [2001] proposed that there is a third major factor known as "Situation Management" which is equal to the minor factors in Bar-On's model. Each of the three major factors of the Emotional Intelligence Scale evaluates, the ability to know and contend with one's self, others and situations [Uchiyama et al., 2001, see Methods for details].

We regressed each factor of EI against rGMD. On the basis of the previous neuroscientific studies described

above, we hypothesized that rGMD in brain regions of the somatic marker circuitry and the social cognition network is associated with each factor of EI. Specifically, we reasoned that the regions responsible for EI include the medial prefrontal cortex, the fronto-polar cortex, the right STS, and the VMPFC, because they are key nodes of the two networks and are suggested to play a key role in EI by the previous studies described above.

METHODS

Subjects

Fifty-five healthy, right-handed individuals (42 men and 13 women) participated in this study as part of our ongoing project to investigate the association between brain imaging, cognitive function, and aging. The data from the same subjects were used in other studies [see Takeuchi et al., 2010a,b]. All the subjects who took part in this study also became subjects of our intervention study in which working memory training was performed and the effects of the training were investigated. Psychological tests and MRI scanning not described in this study were performed together with the ones described in this study (psychological data and imaging data recorded before the intervention were used in this study). The mean age of subjects was 21.7 years (standard deviation [SD], 1.44). All subjects were university students or postgraduate students. The subjects were recruited using advertisements on bulletin boards at Tohoku University or using an emailed introduction of the study sent to subjects of our laboratory's previous experiments. All subjects had normal vision and none had a history of neurological or psychiatric illness. Handedness was evaluated using the Edinburgh Handedness Inventory [Oldfield, 1971]. Written informed consent was obtained from each subject for the projects in which they participated. The procedures for all studies were approved by the Ethics Committee of Tohoku University.

Emotional Intelligence Scale

The Japanese version of the EI scale (Emotional Intelligence Scale) [Fukunishi et al., 2001; Uchiyama et al., 2001] was used to assess EI. The Emotional Intelligence Scale is a self-report measure of emotionally and socially intelligent behavior, which provides an estimate of one's underlying emotional and social intelligence. The scale was developed and standardized for use with Japanese subjects. A more detailed discussion of the psychometric properties of this instrument and how it was developed is found in the Emotional Intelligence Scale technical manual [Uchiyama et al., 2001]. The Emotional Intelligence Scale comprises 65 items and employs a five-point Likert scale with a response format ranging from "not true of me" to "very often true of me". The subject's responses render the following three composite scale scores (factors). Each composite scale score comprise three subscale scores.

- (a) Intrapersonal factor (comprising self-insight, self-motivation and self-control).
- (b) Interpersonal factor (comprising empathy, altruism and interpersonal control).
- (c) Situation Management factor (comprising insight to and control toward a situation).

The Intrapersonal factor evaluates (1) the ability to know oneself, (2) the ability to sustain one's behavior, and (3) the ability to act appropriately. Interpersonal factor evaluates the ability to maintain appropriate personal relationships based on the cognition of, as well as empathy toward, another person's emotions. Situation Management factor evaluates (1) the ability of an individual to endure changes in the situations surrounding oneself, (2) leadership, and (3) the ability to control and use one's abilities and skills flexibly, based on dynamic situations.

The following are examples of items on the Emotional Intelligence Scale

"I know when my emotions change" (self-insight subscale in the Intrapersonal factor).

"I do not want to say something that offends someone else" (altruism subscale in the Interpersonal factor).

"I can respond to situational changes effectively" (control toward situation subscale in the Situation Management factor).

This is an established test based on normative data with a large sample size ($N = 703$; Uchiyama et al., 2001] and scoring of each factor is based on the test manual. Confirmatory factor analyses validated the model of this test [Otake et al., 2001; Uchiyama et al., 2001]. According to the test manual [Uchiyama et al., 2001], the internal consistencies of the three factors (Intrapersonal Factor, Interpersonal Factor, and Situation Management Factor) are 0.894, 0.915, 0.915 (Cronbach's coefficient of α).

Scores on the Emotional Intelligence Scale have been shown to be associated with other measures associated with some aspects of EI, such as the Toronto Alexithymia Scale [Fukunishi et al., 2001], (suggesting that the Emotional Intelligence Scale successfully assess some aspects of EI and showing the external validity of the Emotional Intelligence Scale).

All of three factors of the Emotional Intelligence Scale have been shown to be associated with better mental health measured by a General Health Questionnaire and higher optimism measured by the LOT Optimism scale [Uchiyama et al., 2001]. Specifically, the Situation Management factor has been shown to be strongly associated with better mental health [Uchiyama et al., 2001]. These results suggest that higher EI leads to better mental health [Salovey et al., 2000].

Assessment of General Intelligence

General intelligence refers to the g factor [Spearman, 1904] which contributes to success on diverse forms of cognitive tests, regardless of whether they are verbal or non-verbal. Raven's Advanced Progressive Matrix (RAPM)

[Raven, 1998], which is the measure often shown to be the most correlated with g , thus the best measure of general intelligence [Raven et al., 1998], was used to assess general intelligence. This test was used in our study to adjust for the effect of individual psychometric measures of intelligence on brain structure. It was also performed because we had to exclude the possibility that any significant correlation between brain structure and EI was caused by an indirect association between brain structure and general intelligence [e.g., Shaw et al., 2006]. It contains 36 nonverbal items requiring fluid reasoning ability. Each item consists of a 3×3 matrix with a missing piece to be completed by selecting the best of eight alternatives. The score on this test (number of correct answers in 30 min) was used as an index of individual psychometric measure of intelligence.

Image Acquisition and Analysis

All MRI data acquisition was conducted with a 3-T Philips Intera Achieva scanner. Using a MRPAGE sequence, high-resolution T1-weighted structural images (240×240 matrix, TR = 6.5 ms, TE = 3 ms, FOV = 24 cm, 162 slices, 1.0 mm slice thickness) were collected.

VBM Analysis

Data preprocessing of the morphological data was performed with VBM2 software [Gaser, 2006], an extension of SPM2. Default parameter settings were used [Gaser, 2006]. We applied an optimized method of VBM [Good et al., 2001], which is summarized below, to produce maps of the gray matter density of each subject.

Creation of the Custom Template (the First Normalization Step)

Spatial normalization to the standard anatomical space was performed in a two-stage process. In the first step, to reduce the scanner-specific bias, we created a customized GM anatomical template from the preintervention data of all participants in this study. To create the customized template, each T1-weighted structural image was first segmented into gray and white matter partitions and the gray matter segment was normalized to the standard SPM gray matter template (standard Montreal Neurological Institute (MNI) MRI template). The normalization parameters determined from this initial step were then applied to the native T1 image. This generated a normalized T1 image, which was then segmented into gray and white matter images. The normalized T1, gray and white matter segments were then resampled to $1 \times 1 \times 1 \text{ mm}^3$ resolution, giving a T1 template, and prior probability maps. This process was repeated for each participant, and an average of all the 55 scans was produced. The T1 template and

prior probability maps were then smoothed with an 8-mm Gaussian kernel.

The Second Normalization and Smoothing Step

Next, each initially native T1-weighted structural image was segmented into gray and white matter partitions using the new gray and white matter prior probability maps. The resulting images included extracted gray and white matter partitions in the native space. The gray matter partition was then normalized to the new gray matter probability map. The normalization parameters determined from this initial step were then applied to the native T1 weighted structural image. These normalized T1-weighted structural data were then segmented into gray and white matter partitions. Finally, the normalized, segmented, gray and white matter images were smoothed with a 10-mm Gaussian kernel.

Reasons for Using rGMD and VBM2

In this study, we used gray matter density instead of gray matter volume as the gray matter index. When we use rGMD, VBM can be thought of as a comparison between the relative concentrations of gray or white matter structures in the spatially normalized images. When we use regional gray matter volume, VBM can be thought of as comparing the absolute volume of gray or white matter structures. The results of rGMD and regional gray matter volume are usually similar [Good et al., 2001]. To our knowledge, the implication of the (subtle and probably statistically meaningless) difference between these two analyses is not known. Each of these methods has been frequently used in structural studies [Metcheli et al., 2005]. In this study, we used rGMD for two reasons. First, in a recent study with a similar research subject to our own [Herold et al., 2009; Yamada et al., 2007] rGMD across the brain was reported to be positively correlated with schizophrenic patients' theory of mind performances and emotional-attribution abilities which may be associated with emotional intelligence as described in the Introduction. Second, in our study, developmental cortical thinning is relevant to our interest as described in the Introduction. Most of the prestigious developmental studies of regional gray matter have been done using rGMD [e.g., Sowell et al., 1999, 2001, 2003]. Furthermore, in our studies, VBM2 instead of VBM5 has been used for preprocessing of the morphological data. This measure has been performed because our T1-weighted images taken by the MRPAGE sequence were not compatible with VBM5's preprocessing and the use of VBM5, unlike the use of VBM2's optimized protocol, resulted in a large number of apparent segmentation errors. These measures were taken in previous studies [Ilg et al., 2008; Takeuchi et al., 2010a,b].

The Group Level Analysis Using Data From Both Sexes

A group analysis of the morphological data was performed with VBM5 software [Gaser, 2007], an extension of SPM5. In the group analysis, we included only voxels that showed a GM value >0.05 to avoid possible partial volume effects around the borders between GM and WM as well as between GM and CSF. At the group level analysis, we tested for the relationship between individual EI and rGMD. In the whole brain analysis, we used a multiple linear regression analysis to look for areas where rGMD was significantly related to individual scores on the three factors of the Emotional Intelligence Scale (Intrapersonal, Interpersonal, and Situation Management). The analysis was performed with sex, age and score of RAPM as additional covariates, resulting in six covariates as a whole. The effect of total gray matter volume (total brain volume or total intracranial volume) was not adjusted. We did not correct for any kind of global differences because we are not interested in the proportional difference between regional gray matter density and other brain regions [Mechelli et al., 2005].

The Group Level Analysis Using Data From Males

Covarying sex may mask any findings unique to males or to females. In our study, only the males had a sufficient sample size, but it was worth knowing whether removing the females changes or voids the regional findings. Thus, in the whole brain analysis, using only data from males, we used a multiple linear regression analysis to look for areas where rGMD was significantly related to individual scores on the three factors of the Emotional Intelligence Scale (Intrapersonal, Interpersonal, and Situation Management). The analysis was performed with age and score of RAPM as additional covariates.

Statistic

The level of statistical significance was set at $P < 0.05$, corrected at the nonisotropic adjusted cluster level [Hayasaka et al., 2004] with an underlying voxel level of $P < 0.005$. Nonisotropic adjusted cluster-size tests can and should be applied when cluster size tests are applied to data known to be nonstationary (in another words, not uniformly smooth), such as VBM data [Hayasaka et al., 2004]. In this nonstationary cluster-size test of random field theory, a lower cluster determining threshold resulted in a more conservative test [Hayasaka et al., 2004].

Statistic in Areas With a Strong a Priori Hypothesis

For areas with a strong a priori hypothesis, the level of statistical significance was set at $P < 0.05$, uncorrected at the

TABLE I. Average, SD and range of each factor of EI and RAPM score

	Average	SD	Range
Intrapersonal factor of EI score	48.2	10.2	30–80
Interpersonal factor of EI score	44.9	12.0	8–71
Situation Management factor of EI score	40.9	12.1	14–73
Raven's advanced progressive matrices score	28	3.42	23–34

non-isotropic adjusted cluster level [Hayasaka et al., 2004] with an underlying voxel level of $P < 0.005$. Using liberal thresholds on areas with a strong a priori hypothesis has been performed elsewhere [e.g., Pochon et al., 2002]. In this study, such an approach is all the more appropriate, because areas with a strong a priori hypothesis in this study, as described below, do not fit the anatomical label. Thus, the standard region of interest (ROI) approach is inappropriate and we are not able to set functional ROIs in this study. Areas with a strong a priori hypothesis in this study were the lateral fronto-polar to anterior rostral medial prefrontal cortex (arMPFC), VMPFC and the right STS. These regions are key nodes of the social cognition network and the somatic marker circuitry, and most of these regions' functional activities were correlated with EI as described in the Introduction.

RESULTS

Behavioral Data

Table I shows the average score, SD and range of each factor of the Emotional Intelligence Scale and the score of RAPM. Average scores of the three factors (Intrapersonal, Interpersonal, and Situation Management) correspond to the 72nd, 70th, and 65th percentile [Uchiyama et al., 2001] among adults. Three factors of EI followed normal distribution according to the Kolmogorov-Smirnov test ($P > 0.05$), while the score of RAPM and age did not ($P < 0.05$). Note the distribution of the RAPM scores is not normal for most of the populations which have been studied [Raven, 1998].

The Intrapersonal factor of the EI score significantly correlated with the Situation Management factor of the EI score ($P < 0.001$. $r = 0.501$). The Interpersonal factor of the EI score significantly correlated with the Situation Management factor of the EI score ($P = 0.027$. $r = 0.298$). The Intrapersonal factor of the EI score did not significantly correlate with the Interpersonal factor of the EI score ($P > 0.05$). Correlations among factors are consistent with the nature of this test [Uchiyama et al., 2001] as well as other EI measures [for example, see Saklofske et al., 2003]. None of the epidemiological measures (RAPM score, age or sex) correlated significantly with any of the EI factors ($P > 0.05$). Few or low correlations between EI and the psychometric measure

Figure 1.

Distribution of the scores of each factor of EI in our sample.

of intelligence are consistent with previous studies [Goleman, 2001]. For complete data of the distribution of the scores of each factor of EI, see Figure 1.

Correlation of Regional Gray Matter Density and the Intrapersonal Factor of EI in the Analysis Using Data From Both Sexes

After controlling for the age, sex, score of RAPM, the Intrapersonal factor of the Emotional Intelligence Scale,

and the Situation Management factor of the Emotional Intelligence Scale, multiple regression analysis revealed that scores on the Intrapersonal factor of the Emotional Intelligence Scale significantly and negatively correlated with rGMD in an anatomical cluster that includes the right anterior insula and right claustrum, in the right cerebellum, in an anatomical cluster that extends from the cuneus to the precuneus (Fig. 2A,B,C, respectively; $P < 0.05$ corrected for multiple comparisons at the nonisotropic adjusted cluster level, with an underlying voxel level of $P < 0.005$ uncorrected), in an anatomical cluster that extends from the left arMPFC to the left lateral fronto-polar cortex (Fig. 2A,D, respectively; $P < 0.05$ uncorrected for multiple comparisons at the nonisotropic adjusted cluster level, with an underlying voxel level of $P < 0.005$ uncorrected for the a priori hypothesis, see Methods). These results are shown in Table 2.

Correlation of Regional Gray Matter Density and the Interpersonal Factor of EI in the Analysis Using Data From Both Sexes

After controlling for the age, sex, score of RAPM, the Intrapersonal factor of the Emotional Intelligence Scale, and the Situation Management factor of the Emotional Intelligence Scale, multiple regression analysis revealed

Figure 2.

Regions of significant negative correlation between rGMD and the scores of Intrapersonal factor in the Emotional Intelligence Scale. Results were shown with $P < 0.05$ uncorrected for multiple comparisons at the nonisotropic adjusted cluster level, with an underlying voxel level of $P < 0.005$ uncorrected. Regions of significant correlation are overlaid on single subject T1 image of SPM5 in sagittal and axial views. **A:** The regions with significant negative correlation are seen in

the right anterior insula together with other regions. **B:** A region with significant negative correlations is shown in the right cerebellum. **C:** An anatomical cluster with significant negative correlations is shown in regions of the precuneus extending from the cuneus. **D:** An anatomical cluster with significant negative correlations is shown in regions of the left medial prefrontal cortex extending into the left lateral fronto-polar cortex.

TABLE II. Brain regions with significant correlations between rGMD and the scores of each factor in the Emotional Intelligence Scale

Area		Brodmann's area	x	y	z	T score	Corrected P value (cluster)	Uncorrected P value (cluster)
Negative correlation between rGMD and Intrapersonal factor of EI								
Medial prefrontal cortex, lateral fronto-polar cortex	L	10	-19	64	-2	4.37	0.237	0.004*
Clastrum, Anterior insula	R	13	32	5	-4	4.29	0.019**	<0.001
Cerebellum	R		31	-44	-56	4.12	0.011**	<0.001
Cuneus, Precuneus	R	18/19/31	20	-79	27	4.07	0.021**	<0.001
Positive correlation between rGMD and Interpersonal factor of EI								
Superior temporal sulcus	R	21	42	-26	0	3.69	0.048**	0.001
Positive correlation between rGMD and Situation Management factor of EI								
Middle occipital lobe	R	19	43	-88	9	4.44	0.021**	<0.001
Posterior parietal cortex (caudal)	R	7	10	-74	45	3.85	0.003**	<0.001
Negative correlation between rGMD and Situation Management factor of EI								
Ventromedial prefrontal cortex		11	-17	48	-25	5.5	<0.001**	<0.001

** $P < 0.05$ corrected for multiple comparisons at the cluster level.

* $P < 0.05$ uncorrected for multiple comparisons at the cluster level for areas with a strong a priori hypothesis.

No regions showed significant positive correlations between rGMD and Intrapersonal factor of EI. No regions showed significant negative correlations between rGMD and Interpersonal factor of EI.

that scores on the Interpersonal factor of the Emotional Intelligence Scale significantly and positively correlated with rGMD in the rSTS (Fig. 3; $P < 0.05$ corrected for multiple comparisons at the nonisotropic adjusted cluster level, with an underlying voxel level of $P < 0.005$ uncorrected). These results are shown in Table II.

Correlation of Regional Gray Matter Density and the Situation Management Factor of EI in the Analysis Using Data From Both Sexes

After controlling for the age, sex, score of RAPM, the Intrapersonal factor of the Emotional Intelligence Scale, and the Interpersonal factor of the Emotional Intelligence Scale, multiple regression analysis revealed that scores on the Situation Management factor of the Emotional Intelligence Scale significantly and negatively correlated with rGMD in an anatomical cluster that included the VMPFC, bilaterally (Fig. 4A; $P < 0.05$ corrected for multiple comparisons at the nonisotropic adjusted cluster level, with an underlying voxel level of $P < 0.005$ uncorrected), and significantly and positively correlated with rGMD in the caudal part of the right posterior parietal cortex and the right middle occipital lobe (Fig. 4B; $P < 0.05$ corrected for multiple comparisons at the nonisotropic adjusted cluster level, with an underlying voxel level of $P < 0.005$ uncorrected). These results are shown in Table II.

Correlation of Regional Gray Matter Density and Each Factor of EI in the Analysis Using Data From Males

When only the data from males are used, the only significant results were that the right superior temporal sulcus in the analysis of the Interpersonal factor, and the posterior parietal cortex and the VMPFC in the analysis of the Situation Management factor remained significant. However, substantial tendencies of correlations remained in other regions. These data may suggest that data from both sexes show similar tendencies in most of the areas that showed significant correlations with EI in the analysis using both sexes. These results are shown in Table III.

DISCUSSION

To our knowledge, this is the first study to investigate the association between EI and rGMD. As a whole, consistent with our hypothesis, our findings showed that rGMD in regions in the social cognition network and the somatic marker circuitry is associated with each factor of EI which supports the idea that these structures support EI. Specifically, the Intrapersonal factor of EI was associated with the structure of regions that are thought to play a key role in self-related recognition within the system of social cognition and the system of somatic markers. The Interpersonal factor of EI was associated with the structure

TABLE III. Brain regions with significant correlations between rGMD and the scores of each factor on the Emotional Intelligence Scale when the data from only males were used

Area		Brodmann's area	x	y	z	T score	Corrected P value (cluster)	Uncorrected P value (cluster)
Negative correlation between rGMD and Intrapersonal factor of EI								
Medial prefrontal cortex, lateral fronto-polar cortex	L	10	-19	64	-2	3.59	1.000	0.189
Clastrum, Anterior insula	R	13	32	5	-4	3.81	0.419	0.008
Cerebellum	R		31	-43	-56	3.76	0.089	0.001
Cuneus, Precuneus	R	31	22	-61	24	3.98	0.991	0.071
Positive correlation between rGMD and Interpersonal factor of EI								
Superior temporal sulcus	R	21	35	-41	-8	3.85	0.347	0.006*
Positive correlation between rGMD and Situation Management factor of EI								
Middle occipital lobe	R	19	45	-89	6	4.36	0.066	0.001
Posterior parietal cortex (caudal)		7	-3	-72	56	4.16	0.041**	0.001
Negative correlation between rGMD and Situation Management factor of EI								
ventromedial prefrontal cortex	L	11	-17	59	-21	5.05	0.014**	<0.001

** $P < 0.05$ corrected for multiple comparisons at the cluster level.

* $P < 0.05$ uncorrected for multiple comparisons at the cluster level for areas with a strong a priori hypothesis.

Results of all regions are presented in the same order as the results in Table II regardless of whether the results were significant.

No regions showed significant positive correlations between rGMD and the Intrapersonal factor of EI. No regions showed significant negative correlations between rGMD and the Interpersonal factor of EI.

of rSTS which played a key role in perception during social cognition. And the Situation Management factor of EI was associated with the structure of VMPFC, which is the key node of the somatic marker circuitry and plays a pivotal role in decision making by using somatic markers as described below.

This study showed that EI, or the success of social interaction, depends on the anatomical development of the social cognition network and somatic marker circuitry. Growing evidence supports EI as being psychometrically distinct from general cognitive intelligence [Mayer et al., 1999, 2001]. The present findings may support this notion. Regions with significant correlation to EI in this study are neural substrates of social cognition and self-related recognition [Uddin et al., 2007] and parts of the somatic marker circuitry as described below; and they are rather distinct from the neural substrates of general intelligence or working memory, which are closely associated with general intelligence [Conway et al., 2003], such as the lateral prefrontal cortex and the anterior cingulate cortex (ACC) [Haier et al., 2004; Frangou et al., 2004; Gong et al., 2005; Narr et al., 2007; Toga and Thompson, 2005; Wilke et al., 2003; also for a recent review see Jung and Haier, 2007]. But the interesting point is that many of the identified regions in this study showed negative correlation with EI.

The negative correlation between rGMD in some of the ROIs and higher EI might be underlain by the fact that reduced rGMD is associated with increased and superior cortical development in the medial prefrontal region. Normal cortical development after adolescence is characterized by cortical thinning and the frontal lobe thins the most during late adolescence and early adulthood [Sowell et al., 1999]. Furthermore, developmental studies of intelligence have shown that children with the highest level of intelligence show the most vigorous cortical thinning in the medial prefrontal regions during adolescence [Shaw et al., 2006]. Another previous study showed cortical thinning was associated with functional activation change in a cohort of older children [Lu et al., 2009]. Taken together, these phenomena may point to an association between superior cognitive ability and reduced rGMD in relevant regions of the brain in early adulthood. Consistent with this, higher cognitive functions are sometimes associated with reduced cortical gray matter among young adults [Jung et al., 2010]. This kind of association may underlie the observed negative correlation between rGMD and higher EI. Nevertheless, this is a speculation and we don't know the details or the extent of this phenomenon. Among regions of the social cognition network and the somatic marker circuitry, the correlation between the rGMD

Figure 3.

A region of significant positive correlation between rGMD and the scores of Interpersonal factor in the Emotional Intelligence Scale. The result was shown with $P < 0.05$ corrected for multiple comparisons at the nonisotropic adjusted cluster level, with an underlying voxel level of $P < 0.005$ uncorrected. The region of significant correlation is overlaid on a single subject T1 image of SPM5 in sagittal, axial, and coronal views. The region with significant positive correlation is shown in the right superior temporal sulcus.

of the right STS and Interpersonal EI was positive, unlike other correlations. Although, the cause of this phenomenon is not clear, one possible cause may be the differences between developmental trajectories among brain regions. Unlike other regions, the lateral aspects of the brain and the posterior temporal and inferior parietal lobes bilaterally show different patterns of the developmental trajectory of rGMD [Sowell et al., 2003]. In these regions, there was a subtle increase in rGMD until age 30, which means there is no developmental decrease in rGMD when children grow up in to young adults in these regions. These specific characteristics of developmental change in the temporal region might lead to differential patterns of associations between EI and rGMD.

Specifically among negative correlations, the observed negative association between the Intrapersonal factor of EI and the structure of the right anterior insula (Fig. 5A) is in accordance with the somatic marker hypothesis. Among the regions conforming to the somatic marker hypothesis [Damasio et al., 1991], which posits that emotion-based biasing signals arising from the body are integrated in higher brain regions (namely, VMPFC) to regulate complex decision making in the personal and social realms, a number of studies have shown that the Insula is important for monitoring ongoing somatic and visceral states [e.g.,

Dunckley et al., 2005; Reiman, 1997a,b]. Perhaps, the highly developed anterior insula makes our somatic states more accessible, leading to higher Intrapersonal EI.

In addition, the Intrapersonal factor of EI was negatively correlated with rGMD of the left arMPFC extending into the left lateral fronto-polar cortex (Fig. 5B), the region around the precuneus and the cuneus, and the right cerebellum, all of which have been implicated to play a key role in several types of self-related recognitions by previous neuroimaging studies. Functional imaging studies showed that the arMPFC is activated by tasks involving self knowledge [for a review, see Amodio and Frith, 2006]. Lateral fronto-polar cortex activity has been observed in 13 out of 15 studies involving episodic memory tasks that require the “evaluation of self-generated material” [Christoff and Gabrieli, 2000], making one view of the arMPFC’s role the evaluation of internally generated information [for a review, see Christoff and Gabrieli, 2000]. On the other hand, the activity of the precuneus seems to correlate with self-reflection processes, possibly involving mental imagery and episodic/autobiographical memory retrieval [for a review, see Cavanna, 2007]. Finally, the cerebellum has been implicated in self-related recognition through an internal model [Ito, 2008]. The internal model is a

Figure 4.

Regions of significant correlation between rGMD and the scores of Situation Management factor in the Emotional Intelligence Scale. Results were shown with $P < 0.05$ corrected for multiple comparisons at the nonisotropic adjusted cluster level, with an underlying voxel level of $P < 0.005$ uncorrected. Regions of significant correlation are overlaid on single subject T1 image of SPM5 in sagittal and axial views. **A:** The region with significant negative correlation is shown in the VMPFC. **B:** The region with significant positive correlation is shown in the right caudal posterior parietal cortex together with the right middle occipital lobe.

Figure 5.

Scatter plot of relationships between rGMD and scores of each factor of EI. **A:** Relationship between the score of Intrapersonal Factor and the rGMD in the right anterior insula (32, 5, -4). **B:** Relationship between the score of Intrapersonal Factor and the rGMD in

the frontopolar cortex (-19, 64, 2). **C:** Relationship between the score of Interpersonal Factor and the rGMD in the right STS (42, -26, 0). **D:** Relationship between the score of Situation Management Factor and the rGMD in the VMPFC (-17, 48, 25).

functional dummy of a body part or of a mental representation in the cerebral cortex. Internal models are encoded in the neural circuitry of the cerebellum and mimic the essential properties of a body part or mental representation [Ito, 2008]. Thus one proposed explanation for the negative correlation between the Intrapersonal Factor and rGMD of these regions is that pruning of ineffective synapses during early development results in less regional gray matter in this region and improved cognition of self-referential processes, both of which contribute to higher Intrapersonal EI.

Increased rGMD of rSTS may be associated with higher Interpersonal EI (Fig. 5C) through its role in social and biological perception, and may be comparable with the results of an anatomical study of autistic patients. Neuroimaging studies in normal subjects and single-cell recordings in monkeys have emphasized the role of the STS in the processing of biological movements, including movements of the eyes, mouth, hands, and body, and in social perception [Allison et al., 2000; Blakemore and Decety, 2001; Hietanen and Perrett, 1996] as well as human voice perception [Belin et al., 2001], all of which are essential for interpersonal communication. Children with autism have deficits in the perception of eye gaze, poor eye contact during communication, and difficulties accessing informa-

tion to infer the mental state of others [Howard et al., 2000]. Consistent with STS's role in biological and social perception and the deficits of autistic patients in biological and social perception, autistic patients show hypoperfusion during rest [Ohnishi et al., 2000; Zilbovicius et al., 2000] as well as decreased rGMD [Boddaert et al., 2004] in this area. Putting these together, we might conclude that increased rGMD in the right STS underlies superior biological and social perception and that decreased rGMD in the rSTS is one of the common neural correlates of inferior intrapersonal EI and autistic traits, both of which could be underlain by problems in biological and social perception. Perhaps people with higher Interpersonal EI can obtain useful information through social perception and thus demonstrate high interpersonal EI.

Observed negative association between the Situation Management factor of EI and the structure of the VMPFC (Fig. 5D) is consistent with the somatic marker hypothesis. Among the regions corresponding to the somatic marker hypothesis, the VMPFC has been shown to be particularly important for its ability to use somatic markers to influence decision making toward advantageous outcomes [Bechara et al., 1999, 2000]. Pruning of ineffective synapses during early development may result in less regional gray matter in this region, aiding the effective uses of somatic

markers for decision making in social and personal life and helping properly manage the situations of social life.

The Situation Management factor of EI might be positively correlated with rGMD in the right caudal PPC and the middle occipital lobe through these regions' role in the short-term and working memory systems. These regions are thought to be the subsystems of working memory and are thought to be involved in the rehearsal and storage of visual information [Baddeley, 2003]. The magnitude of activation in the caudal PPC has been reported to be positively correlated with the amount of stored information in visual short-term memory and is suggested to be a key locus of our impoverished mental representation of the visual world [Todd and Marois, 2004]. Thus, these regions may contribute to a higher Situation Management EI by aiding the successful storage of visual information in social life and the recognition of proper solutions to problems.

Discrepancies between our VBM findings and previous clinical VBM studies that report associations between some of the cognitive functions that may relate to emotional or social intelligence and reduced amounts of rGMD could be caused by different physiological bases in clinical and nonclinical young adult samples. Our VBM finding is not congruent with clinical VBM studies that report a negative association between emotional or social competence and the amount of regional gray matter in the nodes of the social cognition network or somatic marker circuitry among patients [for example, see Yamada et al., 2007 for studies about the gray matter correlates of emotional-attribution abilities among patients with schizophrenia; mPFC]. However, potential correlates of the amount of regional gray matter may include the number and size of neurons and glia and the level of synaptic bulk; neurites [May and Gaser, 2006; Draganski et al., 2004] and VBM cannot differentiate those. Furthermore, it is widely assumed that, in neurodegeneration, less gray matter in VBM corresponds to neural loss [Baron et al., 2001; Thieben et al., 2002]. The incongruence between clinical VBM studies and our study described above might be due to the following mechanisms. On the one hand, among certain clinical samples, neuronal degeneration including neuron loss leads to reduced social or emotional competencies and reduced gray matter signaling in VBM. On the other, among nonclinical young adults, adaptive development underlain by increased synaptic pruning leads to better EI and reduced rGMV signaling.

VBM has been criticized because of a few methodological limitations. First, spatial normalization in VBM cannot perfectly register individuals [Nieto-Castanon et al., 2003] and VBM cannot comprehensively differentiate changes in tissue content from local misregistration of images [Bookstein, 2001]. Second, VBM as it is currently implemented also assumes simple linear relationships that are qualitatively similar throughout the brain and thus it may be insensitive to other types of relationships [Davatzikos, 2004]. Although the theory behind these criticisms is correct, it has been pointed out that these caveats appear to have limited applic-

ability to real imaging data [Ashburner and Friston, 2001]. Furthermore, direct comparisons have shown that VBM produces data that is comparable with that of the ROI analyses [Good et al., 2002; Testa et al., 2004].

Other than the limitation discussed above, a few other limitations exist in this study. One is that we used young healthy subjects with high educational backgrounds. Limited sampling of the full range of intellectual abilities is a common hazard when sampling from college cohorts. In our study, the average scores of the three factors of EI were all a bit higher than that of adults. Whether our findings would also hold across the full range of population samples and a normal distribution must be determined with larger and more representative samples. A second limitation is that the study population is unbalanced towards males and we did not, and could not, investigate the sex-specific relationship between brain structure and EI. Previous VBM studies have shown the differences both in brain structures between males and females [Cahill, 2006], and in the relationship between brain structures and cognitive functions [Haier et al., 2005]. It is possible that the relationship between brain structures and EI differ between females and males.

Finally, in our discussion we implied a simple rendering of functions to structures. This was because each factor of EI correlated with certain nodes of the networks and not with the whole network (for example, the Intrapersonal factor correlated to one of the nodes of the somatic marker; the anterior insula, while the Situation Management factor correlated to another key node of the somatic marker circuitry; the VMPFC). However, EI is apparently a highly complex phenomenon with complex brain network functioning, and when one can recruit the whole network efficiently, he or she may be able to contend with oneself, others and situations and exert a higher total EI. One interesting future topic is how individual differences in EI are associated with individual differences in functional connectivity within the somatic marker circuitry and social cognition network.

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