White Matter Structures Associated with Emotional Intelligence: Evidence from Diffusion Tensor Imaging

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Abstract: Previous studies of brain lesions, functional activity, and gray matter structures have suggested that emotional intelligence (EI) is associated with regions involved in the network of social cognition (SCN) and in somatic marker circuitry (SMC). Our new study is the first to investigate the association between white matter (WM) integrity and EI. We examined this relationship in the brain of healthy young adult men [$n = 74$, mean age = 21.5 years, standard deviation (SD) = 1.6] and women ($n = 44$, mean age = 21.9 years, SD = 1.4). We performed a voxel-based analysis of fractional anisotropy, which is an indicator of WM integrity, using diffusion tensor imaging and used a questionnaire (EI Scale) for measuring EI to identify the correlation of WM integrity with individual EI factor (intrapersonal, interpersonal, and situation management factors). Our results showed that (a) the intrapersonal factor of EI was positively correlated with WM integrity in the right anterior insula, and (b) the interpersonal factor of EI was associated with WM integrity in a part of the right inferior longitudinal fasciculus (ILF). The right anterior insula is one of the important nodes of the SMC, whereas the ILF connects the visual cortex and areas related to SCN, and thus, is a part of the SCN. Our findings further support the notion that the brain regions involved in the SCN and in the SMC are associated with EI. *Hum Brain Mapp 34:1025–1034, 2013.*

Key words: facial perception; emotional processing; gray matter; intrapersonal factor; interpersonal factor; situation management factor; fractional anisotropy

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INTRODUCTION

Emotional intelligence (EI) is 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]. Measurements of EI can act as valuable predictors of competence and success with regards to important lifestyle choices [Van Rooy and Viswesvaran, 2004].

According to neuroimaging studies, EI is associated with somatic marker circuitry (SMC) and neural network involved in social cognition (SCN) [Takeuchi et al., in 2011c]. The somatic marker hypothesis [Damasio et al., 1991] proposes that emotion-based biasing signals arising from the body are integrated in higher brain regions, in particular the ventromedial prefrontal cortex (VMPFC), to regulate decision-making in situations of complexity. Several regions, including the VMPFC, insula, and amygdala, belong to the SMC [Damasio, 1998]. On the other hand, EI is related to SCN, such as the network related to the theory of mind which involves the medial prefrontal cortex and the superior temporal sulcus (STS) and so on (for a summary of the neural circuitry involved in SCN, see Pelphrey and Carter [2008]). It has been illustrated that (a) the SMC's brain activity during the perception of fearful faces [Killgore and Yurgelun-Todd, 2007], (b) lesions to the SMC [Bar-On et al., 2003; Krueger et al., 2009], and (c) the SMC's regional gray matter density (rGMD) [Takeuchi et al., in 2011c] are associated with EI. SCN's brain activity during social reasoning [Stone et al., 2002] and its rGMD [Takeuchi et al., in 2011c] are also associated with EI.

However, despite several studies on it, the details of the relationship of EI with regard to white matter (WM) integrity remains unclear. The purpose of this study is to investigate the association between EI and WM integrity. We hypothesize that fractional anisotropy (FA), an indicator of WM integrity, in the SMC and SCN regions of the brain is associated with EI.

Understanding the underlying WM structural integrity with EI is important for gathering new insights into brain function, specifically how the SMC and SCN regions can interact and lead to decision-making processes that are important in the achievement of a successful social life. WM integrity is possibly associated with EI in nonclinical samples for several reasons. WM integrity, found in nonclinical samples is associated with cognitive function with reference to nonsocial and nonemotional thought processes [Jung et al., 2010a; Olesen et al., 2003; Schmithorst et al., 2005; Takeuchi et al., 2010d]. Furthermore, in Autism patients, reduced WM integrity is seen in WM regions adjacent to several regions in the SCN [Barnea-Goraly et al., 2004]. Dysfunctions of these brain region are believed to contribute to the EI-related social deficits in autism [Frith, 2001].

We performed a voxel-based analysis of FA using diffusion tensor imaging (DTI) [Le Bihan, 2003] to assess WM integrity. For EI assessment, we used the Japanese version of the EI Scale [Uchiyama et al., 2001], which has three factors: intrapersonal, interpersonal, and situation management factors; these factors evaluate the ability to understand and adapt emotions with regards to oneself, others, and specific situations, respectively [Uchiyama et al., 2001].

MATERIAL AND METHODS

Subjects

This study, which is a part of an ongoing project to investigate the association between brain imaging, cognitive function, and aging [Takeuchi et al., in 2011c; Takeuchi et al., 2010c; Takeuchi et al., 2010d; Takeuchi et al., 2011a; Taki et al., in press; Taki et al., 2010], included 118 healthy, right-handed individuals (74 men and 44 women). In our previous study, data from 55 subjects were used to investigate the association between EI and rGMD [Takeuchi et al., in 2011c]. All subjects enrolled in this study also became subjects of our intervention studies [Takeuchi et al., in 2011b; Takeuchi et al., in 2011d]. In these intervention studies, psychological tests and MRI not described in this study were performed concomitantly with experiments described in this study (data from psychological tests and MRI performed before the intervention was used in this study). The mean age of the subjects was 21.6 years (standard deviation, SD = 1.57). All subjects were university students or postgraduate students, with normal vision, no history of neurological or psychiatric illness, and no recent report of usage of psychoactive or antipsychotic drugs. We provided questionnaires to all potential experimental subjects for the assessment of psychiatric illnesses and recent drug use history. In the questionnaire, subjects were asked to provide a detailed list of all drugs that they had recently used. Handedness was evaluated using the Edinburgh Handedness Inventory [Oldfield, 1971]. Written informed consent was obtained from each subject for his/her participation in the study experiment. All study procedures were approved by the Ethics Committee of Tohoku University.

Emotional Intelligence Scale

The Japanese version of the EI scale [Fukunishi et al., 2001b; Uchiyama et al., 2001] was used to assess EI as it was in our previous study [Takeuchi et al., in 2011c]. The EI Scale is a self-reported measurement that provides an estimate of underlying emotional and social intelligence. The scale was developed and standardized for use with Japanese subjects. A detailed discussion and history of the development of the psychometric properties of this questionnaire is included in the EI Scale's technical manual [Uchiyama et al., 2001]. The EI Scale comprises of 65 items and a five-point Likert scale with a response format ranging from "not true of me" to "very often true of me." The subjects' responses were categorized into the following three composite scale scores (factors): (a) intrapersonal factor (comprised of self-insight, self-motivation, and self-control), (b) interpersonal factor (comprised of empathy, altruism, and interpersonal control), and (c) situation management factor (comprised of insight into and control over a situation). Each composite scale score is comprised of three subscale scores.

The intrapersonal factor evaluates (1) self-awareness, (2) the ability to sustain one's behavior, and (3) the ability to act appropriately. The interpersonal factor evaluates the ability to maintain appropriate personal relationships based on the understanding and empathy toward another person's emotions. The situation management factor evaluates (1) the ability of an individual to endure and adapt to a change, (2) provide leadership, and (3) exhibit flexibility in the control and use of their abilities in dynamic situations. Some examples of items on the EI Scale are included in our previous article [Takeuchi et al., in 2011c]. As summarized in our previous work [Takeuchi et al., in 2011c], in addition to this three-component model of EI, a four-component model of EI [Salovey and Mayer, 1990] and a five-component model of EI [Bar-On, 1997] also exist. The Bar-On model of EI [Bar-On, 1997] consists of two major factors, an intrapersonal and an interpersonal factor, in addition to several miscellaneous factors, such as stress coping, adaptability, and general mood. On the contrary, Otake et al. [2001] proposed a third major factor (situation management), which is equal to the minor factors of the Bar-On model.

The EI Scale is an established test based on normative data with a large sample size ($n = 703$) [Uchiyama et al., 2001]. The scoring of each factor is based on a test manual. Confirmatory factor analyses validate 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, interpersonal, and situation management factors) are 0.894, 0.915, and 0.915, respectively (Cronbach's coefficient α).

Scores on the EI Scale are associated with EI related measurements such as the Toronto Alexithymia Scale [Fukunishi et al., 2001a]. This indicates the external validity of the EI Scale.

All three factors of the EI Scale are associated with improved mental health as determined by a general health questionnaire as well as increased optimism as determined by the LOT Optimism Scale [Uchiyama et al., 2001]. Specifically, the situation management factor was strongly associated with better mental health [Uchiyama et al., 2001]. These results are consistent with the idea that higher EI leads to better mental health [Salovey et al., 2000].

Assessment of Psychometric Measures of General Intelligence

Raven's Advanced Progressive Matrix [Raven, 1998], is a measurement that is most correlated with general intelligence and is considered to be the best measurement of general intelligence [Raven, 1998]. Raven's Advanced Progressive Matrix was used to assess intelligence and adjust for the effect of general intelligence on WM structures [Schmithorst et al., 2005]. More detailed information about how this test was performed in our study is described in previous studies [Takeuchi et al., 2010c; Takeuchi et al., 2010d].

Image Acquisition

All MRI data acquisition was conducted with a 3-T Philips Achieva scanner. As in our previous study [Takeuchi et al., 2010d], diffusion-weighted data were acquired using a spin-echo echo-planar imaging (EPI) sequence (repetition time (TR) = 10293 ms, echo time (TE) = 55 ms, big delta (Δ) = 26.3 ms, little delta (δ) = 12.2 ms, field of view (FOV) = 22.4 cm, $2 \times 2 \times 2$ mm^3 voxels, slice thickness = 2 mm, 60 slices, sensitivity encoding (SENSE) reduction factor = 2, number of acquisitions = 1). Diffusion weighting was isotropically distributed along 32 directions (b value = 1,000 s/mm^2). In addition, a data set with no diffusion weighting (b value = 0 s/mm^2) ($b = 0$ image) was acquired. The total scan time was 7 min and 17 s. FA values were calculated from the collected images.

Preprocessing of Diffusion Imaging Data

In DTI, FA in each voxel was used as a measurement for the degree of diffusion anisotropy, with FA reflecting the angle (degree of directionality) of cellular structures within the fiber tracts, and therefore, reflecting the fiber structural integrity [Chua et al., 2008]. FA varies between 0, representing isotropic diffusion, and 1 representing diffusion taking place along one plane or direction.

Preprocessing and data analyses were performed using statistical parametric mapping software (SPM5; Wellcome Department of Cognitive Neurology, London, UK) and implemented in Matlab (Mathworks, Natick, MA). A normalization procedure was performed as described in our previous study [Takeuchi et al., 2010d]. Briefly, using the affine and nonlinear spatial normalization algorithm, the skull-stripped $b = 0$ images of each participant were normalized to the original skull-stripped $b = 0$ image template made in our previous study [for the details of this procedure, see Takeuchi et al., 2010d]. By applying the parameters derived from the normalization of the skull-stripped $b = 0$ image of each participant, the FA map image of each participant was spatially normalized to give an image with $2 \times 2 \times 2$ mm^3 voxels. Finally, the normalized FA map image was spatially smoothed using a Gaussian kernel of 6-mm full width at half-maximum. The resulting maps representing FA were then forwarded to the group regression analysis described below.

The Statistical Analysis Using Data From Both Sexes

In the statistical analysis, we tested for a relationship between individual EI and regional FA. In the whole brain

TABLE I. The mean, range, and SD of scores of age, Raven's Advanced Progressive Matrix, and of each factor of EI for males and females

Measures	Males			Females		
	Mean	Range	SD	Mean	Range	SD
Age	21.5	18–27	1.6	21.9	19–27	1.4
Raven's advanced progressive matrix	27.9	18–35	3.5	27.2	18–35	4.0
Intrapersonal factor	48.7	23–80	10.5	47.8	26–78	11.8
Interpersonal factor	44.8	8–67	11.2	47.8	13–84	14.4
Situation management factor	42.7	14–73	12.5	41.6	13–73	14.5

analysis, we used multiple linear regression to search for areas where FA was significantly related to the individual three EI Scale scores (intrapersonal, interpersonal, and situation management factors).

In addition to the individual three EI Scale scores, sex, age, and the Raven's Advanced Progressive Matrix score were also utilized as additional covariates, resulting in six covariates. In this analysis, we confined the search to voxels with FA > 0.20 [Albrecht et al., 2007] for each participant because FA is more susceptible to error arising from partial volumes [Pfefferbaum and Sullivan, 2003]. With this FA cutoff value, we can dissociate WM structures from other tissues [Salat et al., 2005].

The Statistical Analysis Using Data From Each Sex Separately

Covarying sex may mask any findings unique to males or females. Thus, in the whole brain analysis using only data from males or females, we performed a multiple linear regression analysis to find areas where FA was significantly related to individual scores on the three factors of the EI Scale (intrapersonal, interpersonal, and situation management factors). The analysis was performed with age and the Raven's Advanced Progressive Matrix score as additional covariates.

Statistical Threshold

Regions of significance were inferred using cluster-level statistics [Friston et al., 1996]. Only clusters with a $P < 0.05$ after correcting for multiple comparisons (controlling for familywise error) at the cluster size with a voxel-level cluster-determining threshold of $P < 0.005$, uncorrected, were considered statistically significant in this analysis.

For areas with a strong *a priori* hypothesis, the level of statistical significance was set at 100 voxels, with an underlying voxel level of $P < 0.005$. Liberal thresholds on areas with a strong *a priori* hypothesis were previously utilized [e.g., Pochon et al., 2002]. In this study, such an approach was also the more appropriate because areas with a strong *a priori* hypothesis in this case did not fit the anatomical label. The standard region of interest (ROI) approach was inappropriate and we were not able to set functional ROIs in this study. Furthermore, it was difficult to perform small volume corrections using certain sized spheres in this study, because based on previous functional activation or gray matter structural studies, the centers of the spheres had to be in the gray matter areas. There were no equivalent WM studies. Any small volume corrections would consequently result in the inclusion of huge WM areas unrelated to the areas with a strong *a priori* hypothesis. Areas with a strong *a priori* hypothesis in this study were the WM regions adjacent to the VMPFC, the right anterior insula, the right STS, and the precuneus. These regions are key nodes of the SCN and the SMC. RGMD in these regions significantly correlated with individual scores on the factors of the EI Scale [Takeuchi et al., in 2011c].

RESULTS

Behavioral Data

For both sexes, the average score, the SD and range of age, the Raven's Advanced Progressive Matrix score and the scores for each factor of the EI Scale are presented in Table I. Average scores of the three EI Scale factors (intrapersonal, interpersonal, and situation management factors) for males correspond to the 72th, 68th, and 70th percentile [Uchiyama et al., 2001] among adults (Fig. 1). Average scores on the three factors for females correspond to the 71th, 77th, and 66th percentile [Uchiyama et al., 2001] among adults. However, the average EI Scale factor scores did not significantly differ between males and females (*t*-test, two-tailed, $P > 0.1$).

Correlation of FA and the Intrapersonal Factor of EI in the Analysis Using Data From Both Sexes

A multiple regression analysis utilizing age, sex Raven's Advanced Progressive Matrix score as well as the three factor scores of EI as covariates revealed that intrapersonal factor scores were significantly and positively correlated with FA in a WM region in the right anterior insula (Fig. 2a,b; x, y, z = 34, 6, 18, t = 4.45, 113 voxels with an underlying voxel level of $P < 0.005$, uncorrected for areas with a strong *a priori* hypothesis. This statistical level corresponds

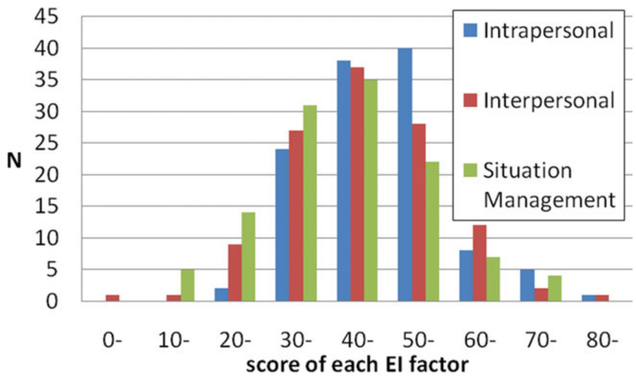

Figure 1.
Distribution of the scores of each factor of EI in our sample.

to $P = 0.106$, corrected for multiple comparisons at the cluster size at the whole brain level). No regions showed significant negative correlations in this analysis.

Correlation of FA and the Interpersonal Factor of EI in the Analysis Using Data From Both Sexes

A multiple regression analysis utilizing age, sex Raven's Advanced Progressive Matrix score as well as the three factor scores of EI as covariates revealed that interpersonal factor scores were significantly and positively correlated with FA in a WM region that extends from the right middle occipital lobe to the regions adjacent to the fusiform gyrus and the parahippocampus [Fig. 3a,b; x, y, $z = 32$, -60, 0, $t = 3.96$, $P = 0.010$ corrected for multiple comparisons at the cluster size at the whole brain level (194 voxels) with an underlying voxel level of $P < 0.005$, uncorrected]. No regions showed significant negative correlations in this analysis.

Correlation of FA and the Situation Management Factor of EI in the Analysis Using Data From Both Sexes

A multiple regression analysis utilizing age, sex Raven's Advanced Progressive Matrix score as well as the three factor scores of EI as covariates revealed that the factor score of the situation management did not significantly correlate with FA in any regions.

Correlation of FA and Each Factor of EI in the Analysis Using Data From Each Sex Separately

Data from males or females alone did not exhibit significant correlation between FA and EI factor scores in the multiple regression analysis utilizing age, Raven's Advanced Progressive Matrix score as well as the three factor scores of EI as covariates. The analysis of each sex alone did not result in a significant correlation in

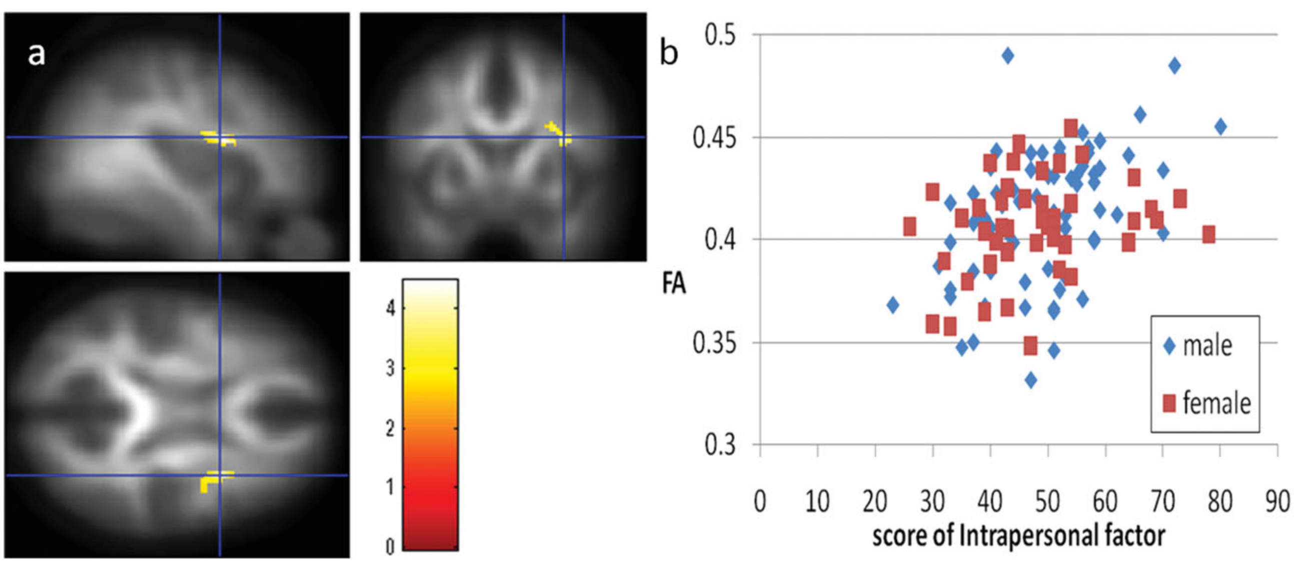

Figure 2.
(**a**) Regions of significant positive correlation between FA and intrapersonal factor scores of the Emotional Intelligence Scale. Results were shown with an extent threshold of 100 voxels, with an underlying voxel level of $P < 0.005$, uncorrected. Regions of significant correlation are overlaid on the mean, smoothed FA images from all participants. Regions with significant positive correlation can be seen in a WM region in the right anterior insula. (**b**) A scatter plot of the relationship between the intrapersonal factor scores of the Emotional Intelligence Scale and mean FA values in the significant cluster of the WM region in the right anterior insula.

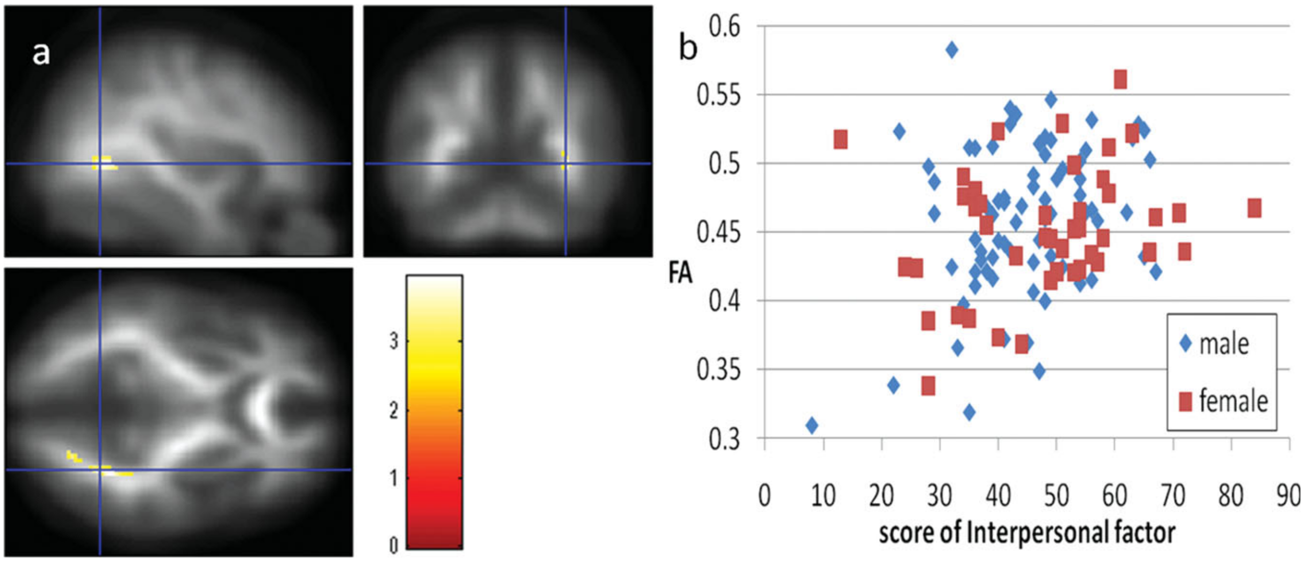

Figure 3.

(**a**) Regions of significant positive correlation between FA and the **i**nterpersonal factor scores of the Emotional Intelligence Scale. Results were shown with $P < 0.05$ after a correction for multiple comparisons at cluster size, with a voxel-level cluster-determining threshold of $P < 0.005$, uncorrected. Regions of significant correlation are overlaid on the mean, smoothed FA images from all participants. The regions with significant positive correlation are seen in a WM region that extends from the right middle occipital lobe to the regions adjacent to the fusiform gyrus and the parahippocampus (a part of the ILF). (**b**) A scatter plot of the relationship between the interpersonal factor scores of the Emotional Intelligence Scale and mean FA values in the significant cluster in the ILF.

relationship to EI in the areas identified by the analysis of data from both sexes. This may suggest that data from both sexes show similar tendencies in these areas and that both the data from males and from females contribute to form significant correlations between these areas in the analysis using data from both sexes.

DISCUSSION

To our knowledge, this is the first study to investigate the association between EI and WM integrity using FA. The result of the analysis using data from both sexes showed that EI intrapersonal factor was positively correlated with WM integrity in the right anterior insula. This result also showed EI interpersonal factor was positively correlated with WM integrity in a WM region that extends from the right middle occipital lobe to the regions adjacent to the fusiform gyrus and the parahippocampus. The right anterior insula is an important node in the SMC [Damasio, 1998]. Furthermore, the WM region extending from the right middle occipital lobe to the regions adjacent to the fusiform gyrus and the parahippocampus is related to facial perception and the processing of emotional information (as discussed below), both of which play key roles in social interactions. The results of our study are partly consistent with our hypothesis and are in line with the notion that brain areas in the SMC and in the SCN support EI [Takeuchi et al., in 2011c].

The significant positive correlation observed between the EI intrapersonal factor and the right anterior insula is in accordance with the idea that brain regions in the SMC are related to EI. Among the regions conforming to the somatic marker hypothesis [Damasio et al., 1991], studies show that the insula, which has abundant connections to other associations and primary sensory areas, is involved in vestibular and pain perception. In addition, this region is important for monitoring ongoing somatic and visceral states and for integrating multimodal information [Dunckley et al., 2005; Nagai et al., 2007; Reiman, 1997; Reiman et al., 1997]. The structural integrity of the WM pathways adjacent to the right anterior insula may make the somatic states more accessible and increase the brain's ability to integrate information, leading to higher intrapersonal EI. Studies show the insula cortex is involved in various neuropsychiatric diseases, such as mood disorders, panic disorders, posttraumatic stress disorder (PTSD), obsessive-compulsive disorders, eating disorders, and schizophrenia [Nagai et al., 2007]. Improved structural WM integrity adjacent to the insula may play a role in increased EI Scale scores and intrapersonal EI levels, ultimately leading to improved mental health [Schutte et al., 2007; Uchiyama et al., 2001].

Increased WM integrity in the posterior WM region, which extends from the right middle occipital lobe to the regions adjacent to the fusiform gyrus and the parahippocampus, may be associated with higher interpersonal EI through its role in facial perception and the processing of emotional information. This WM region corresponds to parts of the inferior longitudinal fasciculus (ILF) [Catani et al., 2003], which consists of fiber connections between the occipital and anterior temporal cortex. The ILF originates in the extrastriate areas of the occipital lobe and the regions around the fusiform gyrus. The ILF terminates in the lateral temporal cortex and medial temporal cortex in the region of the amygdala and parahippocampal gyrus [Catani et al., 2003]. Among these regions, the fusiform gyrus plays a key role in facial perception, [for a review, see Kanwisher and Yovel, 2006], whereas the amygdala plays a key role in fear perception and aversive conditioning [e.g., LeDoux, 2000]. Note that this region is also an important node of the SMC as was discussed in the Introduction section. The right parahippocampal gyrus also was recently proposed to have a role in the processing of paralinguistic information in social contexts [Rankin et al., 2009]. The functions of these three brain regions are essential for interpersonal communication. The fusiform gyrus processes information related to facial perception [Kanwisher and Yovel, 2006], which conveys essential information during interpersonal communication. On the other hand, the amygdala serves as a protective "brake" in social situations [Amaral, 2002]. Lesions of the amygdala cause a lack of fear and lead to a kind of "socially uninhibited" pattern of behavior, which can be seen in people without fear who cannot avoid persons bearing them potential harm. Furthermore, amygdala lesions also have deleterious consequences on primate social behavior [Amaral, 2002]. Consistent with the fact that the ILF connects the visual cortex with the fusiform gyrus and the amygdala, symptoms caused by lesions of the ILF include prosopagnosia (a disorder of facial perception), and visual hypoemotionality (a deficit of emotions evoked visually with preserved emotional responses to nonvisual stimuli) [Bauer, 1982; Benson et al., 1974; Catani et al., 2003]. In summary, the highly integrated ILF is suggested to play a key role in interpersonal EI by causing to an increase in brain function related to the processing of facial, emotional, and paralinguistic information.

The association between high interpersonal EI and increased WM integrity in the ILF may be comparable to the results of an anatomical study of autistic patients [Cheung et al., 2009]. Children with autism have deficits in facial perception [Boucher and Lewis, 1992], and they are unable to recognize paralinguistic information in a social context [e.g., Martin and McDonald, 2004]. The ILF and the regions related to the ILF play a key role in the perception of faces and in the recognition of paralinguistic information in a social context. The fact that autistic subjects have lower WM integrity in the WM regions around the ILF [Cheung et al., 2009] is consistent with these two facts. Taken together, it is a tempting speculation that decreased WM integrity in the right ILF is one of the common neural indicators of an inferior interpersonal EI and an indicator of autistic traits, both of which could be underlain by problems with facial perception and proper recognition of paralinguistic information in social contexts.

Significant findings for the intrapersonal and the interpersonal factors were identified in the right hemisphere. Although these findings were significant compared with the null hypothesis, it is unclear whether the correlations are truly right hemisphere specific or right hemisphere dominant. The lack of clarity originates from the data analysis from both sexes in which a positive, although insignificant, correlative trend between intrapersonal factor scores and FA was found in the left hemisphere area. This trend was close to the peak voxel of the significant correlations observed in the right hemisphere (x, y, z = −30, 0, 12, t = 2.78, P = 0.003, uncorrected). A similar correlative trend was also identified for interpersonal factor scores and FA in the left hemisphere area close to the peak voxel of the significant correlations observed in the right hemisphere (x, y, z = −28, −70, 2, t = 2.45, P = 0.008, uncorrected). These trends may be congruent with (1) the finding of a substantial correlation between the interpersonal factors score and rGMD in the left anterior insula, in addition to the significant correlation in the right anterior insula [see figure of Takeuchi et al., in 2011c], and (2) the finding that the ability to perceive faces, which may be relevant to interpersonal EI as described above, seems to be associated with bilateral ILF [Thomas et al., 2008]. Bilateral WM structures may be associated with EI, but whether the involvement of WM structures in the right hemisphere with EI is stronger than those in the left hemisphere remains to be investigated with more statistical power.

As was discussed in our previous studies [Takeuchi et al., 2010a], increased FA, which is presumably secondary to increased myelination [Beaulieu, 2002] or increased axonal caliber [Mori and Zhang, 2006], may be associated with greater effectiveness in neural circuit communication. This in turn may lead to enhanced EI caused by an increased conduction velocity of an action potential through (a) axon myelination [Bloom et al., 1988], and (b) thicker neuron fibers [Arbuthnott et al., 1980; Waxman, 1980]. Faster action potential conduction velocity can facilitate and increase information flow as well as allow precise temporal coding of high-frequency bursts of neuronal activity [McDonald and Sears, 1970; Shrager, 1993; Swadlow, 1985]. Furthermore, integrity in the precise timing of sequential events in neuronal circuits can lead to a more effective cognitive performance [Peters, 2002].

No regions of the brain exhibited a significant correlation with WM integrity and the situation management factor of EI, despite the correlation between this factor and rGMD [Takeuchi et al., in 2011c]. The lack of a significant correlation could be because of a number of reasons, including a possibility that the situation management factor is related to gray matter structures but not to WM structures. A lack of statistical power, high statistical deviations, and other factors may also be responsible.

Although a whole brain analysis in neuroimaging studies is apparently not suitable for proving negative findings, future studies using different samples or different methods may be needed to investigate whether the situation management factor of EI is truly not related to WM integrity.

The present findings, together with our previous studies and other published reports, conforms with the notion that EI is psychometrically distinct from general cognitive intelligence [e.g., Mayer et al., 1999; Mayer et al., 2001; Takeuchi et al., in 2011c]. Previous neuroimaging studies have also revealed the distinct neural basis of EI and general cognitive intelligence. For example, as described in the introduction, EI is associated with brain activity and gray matter structure in the regions of the SMC and the SCN; however, general intelligence, or the closely associated working memory system, is associated with neural activities and gray matter structures of regions such as the lateral prefrontal cortex and the anterior cingulate cortex [Frangou et al., 2004; Gong et al., 2005; Haier et al., 2004; Jung and Haier, 2007; Narr et al., 2007; Takeuchi et al., 2010b; Toga and Thompson, 2005; Wilke et al., 2003]. On the other hand, our present results showed WM integrity in regions related to the SMC and the SCN. Furthermore, results from previous studies showed that WM integrity in regions related to the lateral frontal and parietal cortices are associated with working memory performance [Olesen et al., 2003] and WM integrity in regions related to the lateral frontal and occipitoparietal areas is related to general intelligence [Schmithorst et al., 2005]. These regions did not show significant correlations between FA and EI in our study, even with the threshold used in our ROIs.

At least one limitation exists in this study, which was also a limitation observed with our previous studies and in other studies that use college cohorts [Jung et al., 2010b; Song et al., 2008; Takeuchi et al., 2011a; Takeuchi et al., 2010c; Takeuchi et al., 2010d]. 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 [Jung et al., 2010b]. In our study, the average scores of the three factors of EI were slightly higher than those of average 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.

CONCLUSIONS

This is the first study to investigate the association between WM integrity and EI. Our results support previous neuroscientific studies, indicating that the SMC and the SCN are associated with EI. Our study showed that (a) intrapersonal EI was associated with WM integrity in the right anterior insula, which is one of the important nodes of the SMC, and that (b) interpersonal EI was associated with WM integrity in a part of the ILF, which connects the visual cortex and areas related to SCN, and hence, a part of the SCN, such as the amygdala, the fusiform gyrus, and the parahippocampal gyrus.

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