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Uncoupled relationship in the brain between regional homogeneity and attention function in first-episode, drug-naïve schizophrenia

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ABSTRACT

The relationship between the cognitive impairment and the structural and functional abnormalities in the brains of patients with schizophrenia (SZ) is not yet clear. This study aims to investigate the relationship, thereby exploring the neuromechanism underlying SZ. We collected multimodal MRI data from 68 first-episode, drug-naïve patients with SZ, and 64 well-matched healthy controls, and used regional homogeneity (ReHo) and gray matter volume (GMV) to assess the functional and structural integrity of the brains, respectively. We then evaluated in the entire brain the correlations between ReHo/GMV and the participants' neuropsychological assessment scores for each group using a partial correlation analysis controlling for age and sex. We found significant uncoupling between attention performance and mean ReHo in the left middle frontal gyrus, right superior/inferior parietal lobe (IPL), right angular gyrus (AG) and right middle/inferior temporal lobe (ITG) in SZ compared with healthy controls. Moreover, we found that the SZ group showed decreased GMV in the right IPL and AG, and a significant coupling between ReHo and GMV in the right ITG. Our findings suggest that the attention dysfunction found in SZ may be associated with the structural and functional abnormalities as well as the structure-function interrelation in several SZ-related brain regions.

1. Introduction

Schizophrenia (SZ) is a psychiatric disease originating from abnormal neurodevelopmental processes due to genetic or environmental factors or both (Insel, 2010), and is often characterized by complex and heterogeneous behaviors and cognitions (Owen et al., 2016). SZ is one of the top 10 causes of health burden in the world and affects about 1% of the population (Salomon et al., 2012). It has the highest mortality rate compared to other psychiatric diseases (Khan et al., 2013). Clinical presentations of patients with SZ can be summarized as positive and/or negative psychiatric symptoms (Howes and Murray, 2014). Moreover, SZ patients also show abnormal cognition functions, including attention, executive function, and memory dysfunctions (Arican et al., 2018; Knowles et al., 2015). For example, early-onset SZ patients showed significant decreases in neurocognitive functioning tests of attention, verbal memory, and processing speed compared with healthy controls (HCs) (Oie et al., 2010). Patients with SZ deficit syndrome may suffer from a more severe degree of impairment in the general executive function than those without such deficit (Polgar et al., 2010). Patients with SZ spectrum disorders also show significant damage in measures of sustained attention, verbal memory and executive function (Groom et al., 2008). Additionally, a three-factor model of executive function, vigilance/speed of process and memory appear to be effective to discriminate SZ cases from healthy ones (Lam et al., 2014). Although these studies consistently found cognitive dysfunctions in patients with SZ, the neural mechanism underlying the cognition impairments is still

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Resting-state functional magnetic resonance imaging (rs-fMRI) is a noninvasive and attractive technique for evaluating neuronal function, which primarily detects low-frequency (0.01–0.08 Hz) fluctuations (which are considered to reflect spontaneous brain activities) in blood oxygenation level-dependent (BOLD) signals at rest (Du et al., 2018; Mueller et al., 2015), whereas the BOLD signals are a representation or index of brain activities. As a classical and highly efficient test-retest metric in rs-fMRI, regional homogeneity (ReHo) is used typically to measure the similarity of the time series at a given voxel to that at the voxel's nearest neighbors in a voxel-wise way. ReHo basically describes local synchronization of low-frequency oscillations in the BOLD signals (Zang et al., 2004). This metric has been used to identify the changes in neural activity in specific regions in SZ patients. Following this approach, SZ participants showed a decreased ReHo in the left superior temporal gyrus compared with control subjects and major depressive disorder patients, and an increased ReHo in the right superior frontal gyrus compared with control subjects (Chen et al., 2013). Compared to HCs, another study on SZ patients with delusions revealed increased ReHo in the right anterior cingulate gyrus and left medial superior frontal gyrus, and decreased ReHo in the left superior occipital gyrus (Wang et al., 2015a). In addition, Yu et al. reported that SZ patients showed frequency-specific changes of ReHo in fusiform gyrus, superior frontal gyrus, basal ganglia, parahippocampus, and dorsal middle prefrontal gyrus (Yu et al., 2013). Generally, the functional alterations are frequently found to be a consequence of structural impairments in human brains (Bucker et al., 2017; Ernst et al., 2017). On the other hand, gray matter volume (GMV) is an index that frequently used for examining the structural variability in the entire brain using voxel-based morphometry (VBM) method (Di et al., 2013; Liu et al., 2015). Zhang et al. demonstrated that adolescent-onset SZ patients showed decreased GMV in the right superior/middle temporal gyrus (Zhang et al., 2015). Frisoni et al. found that elderly SZ patients exhibited a lower total GMV, and decreased regional GMV in the cingulate gyrus and orbitofrontal cortex than the controls (Frisoni et al., 2009). Similarly, Honea et al. reported that SZ patients showed GMV decreases in the frontal, temporal and parietal cortices compared with healthy volunteers (Honea et al., 2008). On the relationship between ReHo and GMV, previous studies have revealed whether and how brain structure affects the inter-regional coupling of neural activities (de Kwaasteniet et al., 2013; Greicius et al., 2009; Honey et al., 2009; Wang et al., 2015b). Qing et al. highlighted a substantial impact of brain volume/size on brain functional activity across healthy individuals (Qing and Gong, 2016). Lei et al.'s research suggested that the non-synchronous activity measured by ReHo in specific areas might be due to the altered GMV in borderline personality disorder (Lei et al., 2017). As evidenced by ReHo, fractional amplitude of low-frequency fluctuation and VBM results, Cao et al. revealed the functional change could be resulted from GMV change in several brain areas among postherpetic neuralgia patients (Cao et al., 2018). However, the relationship between ReHo, GMV and cognitive functions in SZ patients has never been investigated in depth, although the cognitive deficits and the alterations in ReHo or GMV have been independently reported in SZ patients.

Based on multi-modal MRI data, this study aimed to explore the group difference in the relationship between the whole-brain structure, function and cognitive performances when comparing SZ with HCs by combining both ReHo and GMV with neuropsychological assessments. We hypothesized that the relationships between ReHo, GMV and cognitive functions in SZ would have been altered in several regions known to be related to SZ, and such alterations might be associated with the abnormalities found in ReHo or GMV or the ReHo-GMV relationship in these regions.

2. Method

2.1. Participants

Sixty-eight (68) SZ patients were recruited from the First Affiliated Hospital of Zhejiang University, who fulfilled the diagnostic criteria for SZ in the Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition (DSM-IV). The Structured Clinical Interview for DSM Disorders (SCID), routine laboratory tests, and physical and neurological examinations were administered for each participant by two clinicians. Inclusion and exclusion criterion for all participants were identical to that reported in our previous study (Zhao et al., 2018a). In brief, SZ patients in this study were first-episode onset, drug-naïve and their age ranged from 13 to 45 years. In addition, patients with a brain tumor, cerebral trauma, seizure disorder, mental retardation, or structural brain abnormalities, and those who were pregnant, lactating or planning to be pregnant within the following 6 months, and those with any contraindications or incompatibility for MRI were excluded from the present study. Moreover, sixty-four (64) age-, sex-, and handedness-matched healthy participants were identified to compose a control group. All participants provided written informed consent. The study was approved by the local Ethics Committee at the First Affiliated Hospital, College of Medicine, Zhejiang University, China.

2.2. Neuropsychological assessments

Two neuropsychological assessments including the modified version of Wisconsin card sorting test (WCST) and the Continuous performance test CPT were used in assessing these participants.

2.2.1. Wisconsin card sorting test (modified version)

The WCST is a cognitive task that predominantly assesses executive function because of its reported sensitivity to frontal lobe dysfunction. The task requires a participant to sort 48 cards on the basis of three possible categories (color, number, and shape). After six consecutive correct responses, the participant needs to change the sorting principle to another category. The test is ended when the participant completes sorting all the six categories correctly or has used 48 cards. The total trials (TT), correct trials (CT), total number of errors (TE), perseverative errors (PE), random errors (RE), and number of completed categories (CC) are recorded.

2.2.2. Continuous performance test

The CPT measures participants' sustained and selective attention. It is divided into three parts: (1) different numbers appear on the screen one by one, and the mouse is expected to be clicked when "4" appears; (2) eight numbers appear on the screen at the same time, and the mouse is expected to be clicked when "4" appears; and (3) eight numbers appear on the screen at the same time, and the mouse is expected to be clicked when "7" appears. In our experiment, each number remained on the screen for 150 ms, and the interval time was 550 ms. The participants needed to finish all the three parts. The correct trials of three parts (CT 1, CT 2, and CT 3) were recorded.

2.3. MRI data acquisition

All MRI scans were performed on a Philips Achieva 3.0T TX MRI system (Philips Healthcare, Netherlands), which was equipped with an eight-channel head coil array. We used foam pads to fixate the head of each participant to restrict head movement and reduce noise from the scanner. Rs-fMRI data were acquired along the axial direction in a sequential mode using a fast field echo-echo planar imaging (FFE-EPI) sequence with the following scan parameters: 24 slices, TR/TE = 2000/35 ms, flip angle (FA) = 80°, slice thickness/gap = 5.0/1.0 mm, voxel size = 2.4 × 2.4 × 5.0 mm^3, matrix = 100 × 100, FOV = 240 × 240 mm^2. The rs-fMRI scan lasted 6 min and 48 s, and

we collected a total of 200 image volumes. In addition, individual three-dimensional high-resolution T1-weighted images were also acquired using a fast field echo sequence: 150 slices, TR/TE = 7.5/3.7 ms, matrix = 240 × 240, slice thickness = 1 mm, FOV = 240 × 240 mm^2, voxel size = 1 × 1 × 1 mm^3, FA = 8°.

2.4. Functional MRI image processing

Consistent with the routine reported in our previous publications (Zhao et al., 2017, Zhao et al., 2018b), rs-fMRI data were preprocessed using the advanced DPARSF (http://www.restfmri.net) and SPM8 (http://www.fil.ion.ucl.ac.uk/spm) toolkits. The pre-processing included slice time, motion correction (There was no significant difference in head motion between groups [a two-sample t-test: $p = 0.23$ for translation, $p = 0.43$ for rotation, $p = 0.52$ for mean frame-wise displacement (FD) of Jenkinson]), spatial normalization (EPI template), filtering (0.01–0.1 Hz) and detrend. Additionally, white matter, cerebrospinal fluid, and head motion based on Friston 24-parameter model (Friston et al., 1996) were removed as the nuisance variables. Then we used Resting-State fMRI Data Analysis Toolkit V1.7 (REST) (http://www.restfmri.net) and performed the ReHo analysis. The technical details of ReHo calculation were provided in our previous report (Zhao et al., 2018b). Finally, the ReHo maps for each participant were smoothed using an isotropic Gaussian kernel at a full width and at a half maximum (FWHM) of 6 mm to reduce spatial noise.

2.5. Voxel-based Morphometry Analysis

The structural images (T1-weighted images) were processed with the VBM8 toolbox (http://dbm.neuro.unijena.de/vbm8) based on Statistical Parametric Mapping (SPM8, http://www.fil.ion.ucl.ac.uk/spm). In particular, the raw MRI data were first checked visually to ensure no obvious artifacts. Second, individual structural images were segmented into gray matter (GM), white matter and cerebrospinal fluid using an adaptive Maximum A Posteriori technique, and the resultant GM maps were spatially normalized to the Montreal Neurological Institute (MNI) space using a "Diffeomorphic Anatomical Registration Through Exponential Lie Algebra" approach (Ashburner, 2007). Third, a non-linear modulation was applied to compensate for spatial normalization effects, and it essentially corrected for individual variability in brain size. Finally, the images were smoothed with a 10-mm FWHM Gaussian kernel.

2.6. Statistical analysis

We referred to an Anatomical Automatic Labeling (AAL) atlas with cerebellum (116 regions) (Tzourio-Mazoyer et al., 2002) and performed a region of interest (ROI) based analysis for each participant. To extract ReHo and GMV values, we first generated binary masks for each ROI within the atlas. Second, the binary masks were applied to the ReHo and GMV maps of each participant, respectively. Finally, mean ReHo and GMV values of each ROI for all the participants were obtained by averaging all voxel values within each mask. Next, we performed a two-step analysis as follows: (1) We calculated the correlations between mean ReHo, GMV and neuropsychological assessments for each ROI in the AAL atlas (which were repeated 116 times) for each group separately using a partial correlation analysis controlling for age and sex as covariates (FDR corrected, $p < 0.05$). Then, we compared the correlation between the variables for the two groups. We deemed the correlation between the groups for each ROI as different when the correlation of the variables was significant in one group but did not survive in the other group. (2) We used a two-sample t-test to compare the differences between the groups in ReHo and GMV, and tested the alteration of the relationship between ReHo and GMV across all the ROIs with AAL atlas in SZ by using a partial correlation with age and sex as covariates (FDR corrected, $p < 0.05$).

Table 1
Demographic and clinical characteristics of SZ ($n = 68$), and HCs ($n = 64$).

Measure	SZ (Mean ± SD)	HCs	*p*-value
Age (year)[a]	22.64 ± 7.74	23.22 ± 7.81	0.67
Sex (male/female)[b]	29/39	22/42	0.33
Handedness	R	R	
Course of illness (months)	12.72 ± 16.58	-	
Age of first onset (years)	21.22 ± 7.12	-	
PANSS total scores	85.06 ± 15.47	-	
PANSS P scores	22.35 ± 6.38	-	
PANSS N scores	18.68 ± 7.78	-	
PANSS G scores	39.85 ± 8.47	-	
PANSS S scores	4.18 ± 1.98	-	
FD[a]	0.09 ± 0.04	0.09 ± 0.04	0.52

PANSS: Positive and Negative Syndrome Scale; FD: frame-wise Displacement.
[a] t-test;
[b] χ^2 test.

3. Result

3.1. Demographic information and neuropsychological performance

The demographic and clinical data of the patients and HCs showed no significant differences between groups in age, sex, handedness and FD (Table 1). Except for TT during WCST, the neuropsychological performance all showed a significant group difference. This suggests that SZ patients suffer from abnormal executive and attention functions (Table 2).

3.2. MRI results

We found significant positive correlations between CT 1 during CPT and mean ReHo in the left middle frontal gyrus (MFG), right superior/inferior parietal lobe (SPL/IPL), right angular gyrus (AG) and right middle/inferior temporal gyrus (MTG/ITG) in the HCs group. However, these correlations were invisible in the SZ group (FDR corrected, $p < 0.05$) (Fig. 1 and Table 3). The correlations between CPT and GMV in the whole brain did not differ significantly between the two groups. Additionally, to explore the possible reasons why the correlations altered between the two groups, we also tested the difference of GMV and ReHo and their relationship between the two groups (uncorrected, $p < 0.05$) in whole brain, and there was no significant finding when FDR correction ($p < 0.05$) was used. Because the present study primarily focused on the regions that showed a significant difference across the groups regarding the GMV/ReHo-CPT correlation, we here only reported the differences in those regions. We found that the patient group showed decreased GMV in the right IPL ($p = 0.01$) and AG

Table 2
Comparison of neuropsychological assessments between groups.

Measure	SZ (Mean ± SD)	HCs	*p*-value
Wisconsin Card Sorting Test			
TT	47.53 ± 1.57	46.94 ± 2.29	0.08
CT	26.29 ± 9.25	33.50 ± 7.49	<0.001
TE	21.00 ± 9.72	13.39 ± 8.30	<0.001
PE	13.41 ± 6.58	8.14 ± 5.79	<0.001
RE	7.63 ± 4.85	5.44 ± 3.87	0.005
Categories	2.97 ± 2.02	4.70 ± 1.67	<0.001
Continuous Performance Test			
CT 1	10.04 ± 2.12	10.70 ± 0.94	0.02
CT 2	8.43 ± 3.32	9.95 ± 2.28	0.003
CT 3	10.53 ± 2.06	11.39 ± 2.04	0.02

TT: total trials; CT: correct trials; TE: total number of errors; PE: perseverative errors; RE: random errors; CC: number of completed categories. CT 1, CT 2, and CT 3 represent the correct trials of three parts in Continuous Performance Test, respectively.

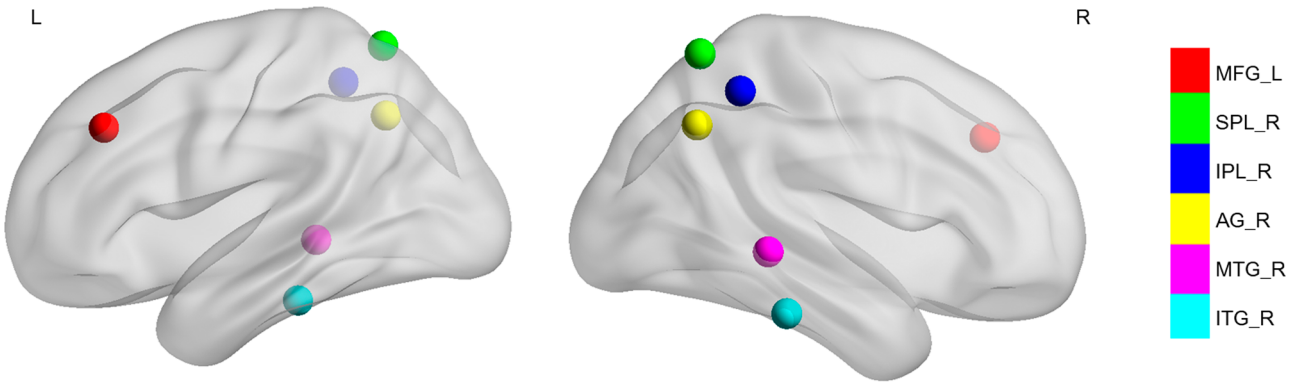

Fig. 1. Differences of correlations between CT1 during CPT and ReHo in the two groups. MFG: middle frontal gyrus; SPL: superior parietal lobe; IPL: inferior parietal lobe; AG: angular gyrus; MTG: middle temporal lobe; ITG: inferior temporal gyrus; L: left; R: right. CT1 represents the correct trials of the first part in Continuous Performance Test.

Table 3
The correlations between ReHo and CT1 during CPT in two groups.

Regions	HCs (r/*p*)	Patients (r/*p*)
Left middle frontal gyrus	0.381/0.002	−0.021/0.866
Right superior parietal lobe	0.508/< 0.001	−0.027/0.830
Right inferior parietal lobe	0.401/0.001	−0.017/0.890
Right angular gyrus	0.498/< 0.001	−0.002/0.988
Right middle temporal gyrus	0.425/0.001	−0.218/0.078
Right inferior temporal gyrus	0.399/0.001	−0.025/0.841

r: correlation coefficient; *p*: *p* value.

($p = 0.02$) compared with HCs group (Fig. 2A), and there was no significant difference in ReHo between the groups in the six brain regions. We also found a significant negative correlation between ReHo and GMV in the right ITG in the patient group ($p = 0.01$, $r = -0.31$) but not in the HCs ($p = 0.38$, $r = -0.11$) (Fig. 2B).

4. Discussion

To the best of our knowledge, this is the first MRI study that explores the relationships between ReHo, GMV in the entire brain and cognitive performances in patients with SZ. We found the relationships between attention function detected by CPT and mean ReHo in the left MFG, right SPL, right IPL, right AG, right MTG, and right ITG were different between HCs and the SZ patients. Furthermore, we found that the uncoupling of ReHo-attention in the right IPL and AG might be associated with decreased GMV in SZ and that the uncoupling in the right ITG might be related to the coupling between ReHo and GMV. Our findings suggest that attention function impairment in SZ may be associated with the uncoupling between attention function and ReHo in several disease-related brain regions.

Previous studies have demonstrated that disturbances in attention may represent the core characteristics of SZ (Park et al., 2002; Sponheim et al., 2006). MFG can be theorized to instantiate premotor representations based on external contextual cues accompanying stimuli (Koechlin et al., 2003), indicating that hypo-activation in this region may result in a cognitive control impairment. By using continuous arterial spin labeling perfusion fMRI, a number of studies revealed that MFG showed increased regional cerebral blood flow during a visual sustained attention task in SZ (Kim et al., 2006), and this region was sensitive to demands for attention effort and control (Demeter et al., 2011). Poppe et al. observed a lower activity in the executive/attention network including MFG in SZ compared with HCs (Poppe et al., 2016). An event-related fMRI study reported that MFG showed an aberrant activation during a modified continuous performance task in SZ (MacDonald et al., 2005). Using a similar method, another study revealed that siblings of those individuals with SZ

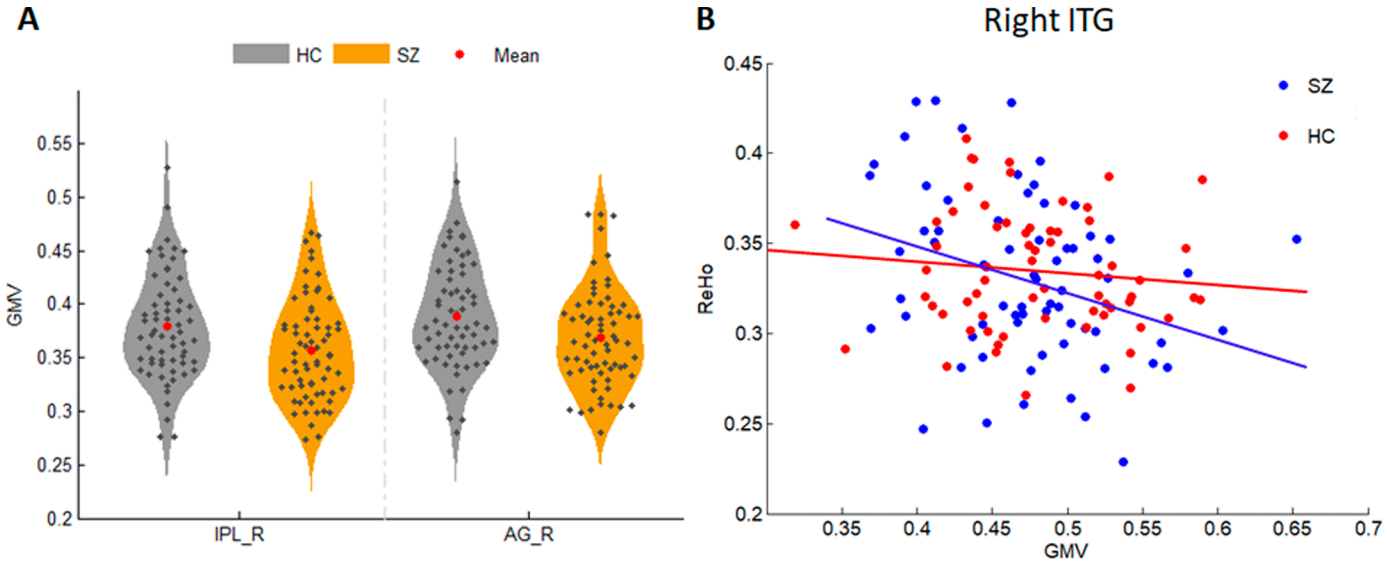

Fig. 2. Between-group difference in GMV in the right IPL and AG (A) and relationship between ReHo and GMV in the right ITG (B). GMV: Gray matter volume; IPL: inferior parietal lobe; AG: angular gyrus; ITG: inferior temporal lobe. The digits on the bar chart (A) represent the mean GMV. * represents $p < 0.05$.

showed greater deactivation in left MFG than HCs during the task (Delawalla et al., 2008). Additionally, volumetric measurements studies demonstrated an association between reduced GM density in frontal regions and deficits in sustained attention in SZ (Salgado-Pineda et al., 2003), and MFG volume was reduced in relatives with worse attention of SZ patients compared to controls (Bhojraj et al., 2011). Collectively, these reports imply that attention impairment in SZ may be associated with functional and/or structural abnormalities in the MFG. The present study revealed a positive correlation between CT1 and mean ReHo in the left MFG in HCs but not in SZ. This may be attributed to the functional and structural alterations of MFG.

The AG and IPL are involved in the middle longitudinal fascicle (MdLF), which is a prominent association cortico-cortical fiber pathway (Makris et al., 2013). A prior study based on diffusion tensor imaging data demonstrated that SZ patients showed significant fractional anisotropy reductions in the bilateral MdLF relative to control subjects, and a significant negative relationship between the fractional anisotropy in the right MdLF and poor attention (Asami et al., 2013). It is well known that parietal cortical disorder may give rise to attention dysfunction in patients with SZ (Danckert et al., 2004). In addition, poorer sustained attention was found to be positively associated with weaker fractional amplitude of low-frequency fluctuations of BOLD signals in parietal regions in SZ patients (Fryer et al., 2015). Furthermore, decreased ReHo in IPL was also found in first-degree relatives of persons with SZ (Liao et al., 2012). These findings demonstrate that the disrupted brain activities and destructed structure in parietal lobule may be a pathological mechanism underlying attention dysfunctions in the SZ. Enhancing the aforementioned viewpoints, this present study further found that SZ patients showed an uncoupling effect between ReHo (in the right SPL/IPL, right AG) and attention performance. One possible reason, as shown in Fig. 2A, could be that the GMV in SZ patients was significantly decreased than that in the HCs. Our findings are consistent with those published in previous studies. For example, Zhou et al. reported that GMV in all the parietal sub-regions reduced in patients with SZ compared with HCs (Zhou et al., 2007). Bhojraj et al. also observed decreased GMV in SPL and AG in the first and second-degree relatives of SZ patients compared to HCs (Bhojraj et al., 2011).

ITG is connected to the inferior occipital gyrus, which is a part of sensorimotor networks including the auditory and language regions (Alderson-Day et al., 2016). Neuropsychological studies have reported that individuals with SZ suffer from deficits in attention (Braff, 1993; Strauss, 1993). First-episode, drug-naïve SZ patients exhibited lower network homogeneity than controls in the right MTG (Guo et al., 2014). First-degree relatives of patients with SZ showed decreased ReHo in the MTG (Liao et al., 2012). Effective connectivity between ITG and default mode network in SZ patients with auditory verbal hallucinations (AVHs) decreased compared with non-AVHs patients (Zhao et al., 2018a). In contrast to functional findings, structural studies indicated that SZ was associated with regional volume alterations in the temporal lobe. For instance, previous studies revealed reduced GMV of bilateral posterior ITG in first-episode SZ (Kuroki et al., 2006) and in chronic SZ (Onitsuka et al., 2004). In addition, the GMV in the left posterior ITG was negatively correlated with mood disorders, indicating that the reduction in GMV of ITG may be related to the common pathology of SZ and affective psychosis (Kuroki et al., 2006), which may be due to the main inability of SZ to attenuate accuracy at sensory-associated cortical levels (Adams et al., 2013). Moreover, GMV deficits in the MTG also were reported during a very early stage of SZ (Lui et al., 2009) and in first-episode, drug-naïve SZ (Hu et al., 2013). SZ patients reportedly showed a reduction of brain tissue in the temporal lobes, compared to HCs (Rossi et al., 1990). In addition, previous structure-cognition studies in SZ also demonstrated several associations between regional brain volume and cognitive performance (Antonova et al., 2005; Salgado-Pineda et al., 2003). And, decreased GM density in the right MTG was thought to be associated with worse performance of SZ patients during divided attention (Wolf et al., 2008). Along the same direction, we found in this study significant positive correlations between attention performance and ReHo in the right MTG/ITG in the HCs. However, such correlations disappeared in the SZ group. In addition, we found a significant ReHo-GMV coupling effect in the right ITG in the SZ group. A previous study using dynamic functional connectivity and GM densities found that stronger structures were linked to dynamic states that were more strongly modularized in the temporal lobe regions in healthy brains (Plis et al., 2018). We speculate that the reinforced function-structure relationship in the right ITG may be a compensatory effect for patients' attention deficits. Undoubtedly, this insight helps further understanding of cognitive impairment of SZ at the structural and functional level.

Several limitations in the present study should be noted. First, sample size was relatively small because of the relatively strict recruitment criteria, including the inclusion requirements on patients being drug-naïve and first-episode. This may be one of the reasons why some of our statistical results did not survive FDR correction. A larger sample size will be necessary to confirm our findings. Second, the design of this current study was cross-sectional, and we therefore were unable to capture dynamically the pattern in the areas with abnormal relationships between ReHo and attention function during the clinical course of SZ. A longitudinal study in the future may be necessary to capture such dynamics. Third, using correlation analysis, our research is not capable of identifying whether ReHo or GMV is the initial factor that was affected by the disease and the causality of the two metrics. In the future, we shall use more advanced methods such as the Granger causality analysis to explore the causality of ReHo and GMV in SZ patients. Finally, this study was an exploratory work. Although we have identified that several brain regions were related to attention function in SZ, whether these could be interpreted more meaningfully in relation to more specific cognition functions or as a biomarker of cognitive dysfunctions in SZ remains challenging. We plan to further address these thoughts by recruiting SZ patients with or without deficient in attention function in the future.

5. Conclusions

In summary, this study investigated the relationship between attention function and ReHo and found difference between the patient and healthy groups in several SZ-related brain regions, including the left MFG, right SPL, right IPL, right AG, right MTG, and right ITG. Moreover, the findings suggest that the uncoupling in the right IPL and right AG might be associated with decreased GMV and that in the right ITG might be related to the coupling between ReHo and GMV. Altogether, these findings could provide complementary evidence suggesting that attention impairments in SZ may be associated with uncoupled relationships between attention function and local synchronization of spontaneous brain activities in several regions, and may promote our understanding of the neural substrates of attention dysfunction in SZ.

Declaration of Competing Interests

All authors declare that there is no conflict of interest.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.pscychresns.2019.110990.

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