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Structural alterations of the superior temporal gyrus in schizophrenia: Detailed subregional differences

K. Ohi [a,*], Y. Matsuda [a,b,*], T. Shimada [a], T. Yasuyama [a], K. Oshima [a], K. Sawai [a], H. Kihara [a], Y. Nitta [a], H. Okubo [a], T. Uehara [a], Y. Kawasaki [a]

[a] Department of Neuropsychiatry, Kanazawa Medical University, Ishikawa, Japan
[b] Project Research Center, Kanazawa Medical University, Ishikawa, Japan

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ABSTRACT

Background: Reduced gray matter volumes in the superior temporal gyrus (STG) have been reported in patients with schizophrenia. Such volumetric abnormalities might denote alterations in cortical thickness, surface area, local gyrification or all of these factors. The STG can be anatomically divided into five subregions using automatic parcellation in FreeSurfer: lateral aspect of the STG, anterior transverse temporal gyrus of Heschl gyrus (HG), planum polare (PP) of the STG, planum temporale (PT) of the STG and transverse temporal sulcus.
Methods: We acquired magnetic resonance imaging (MRI) 3T scans from 40 age- and sex-matched patients with schizophrenia and 40 healthy subjects, and the scans were automatically processed using FreeSurfer. General linear models were used to assess group differences in regional volumes and detailed thickness, surface area and local gyrification.
Results: As expected, patients with schizophrenia had significantly smaller bilateral STG volumes than healthy subjects. Of the five subregions in the STG, patients with schizophrenia showed significantly and marginally reduced volumes in the lateral aspect of the STG and PT of the STG bilaterally compared with healthy subjects. The volumetric alteration in bilateral lateral STG was derived from both the cortical thickness and surface area but not local gyrification. There was no significant laterality of the alteration in the lateral STG between patients and controls and no correlation among the structures and clinical characteristics.
Conclusions: These findings suggest that of five anatomical subregions in the STG, the lateral STG is one of the most meaningful regions for brain pathophysiology in schizophrenia.

1. Introduction

Schizophrenia is a common and complex psychiatric disease with cerebral alterations. Reduced brain volumes in multiple regions have been demonstrated by imaging studies using computed tomography (CT) and magnetic resonance imaging (MRI) in the last several decades [1,2]. Patients with schizophrenia show decreased whole brain volume, particularly gray matter (GM) volume, compared with healthy individuals. Although reduced regions in schizophrenia were inconsistent among imaging studies, meta-analyses have shown that patients with schizophrenia tend to exhibit a reduction in GM volume in the anterior cingulate, thalamus, frontal lobe, hippocampus, amygdale and superior and medial temporal gyri [3,4].

There has been an increasing body of literature supporting brain morphological alterations in the superior temporal gyrus (STG) in schizophrenia patients [4–10]. Patients with schizophrenia have smaller STG volumes compared with healthy subjects. Antipsychotic-naive individuals as well as individuals taking antipsychotics at ultra-high risk of psychosis also show significantly smaller STG volumes bilaterally compared with controls [11,12]. In addition, the volumetric reductions of the STG were more highly progressive in ultra-high risk individuals for psychosis as well as childhood onset and first-episode patients with schizophrenia compared with controls over time [9,10,13,14]. These previous studies have focused on brain volumes, but advances in neuroimaging data processing have made it possible to separate local gyrification (cortical folding patterns) as well as

Abbreviations: MRI, magnetic resonance imaging; ROI, region of interest; SE, standard error; STG, superior temporal gyrus; PT, planum temporale; HG, Heschl's gyrus; PP, planum polare.

* Corresponding authors. Department of Neuropsychiatry, Kanazawa Medical University, 1-1 Daigaku, Uchinada, Ishikawa, 920-0293, Japan.
Tel.: +81 76 286 2211; fax: +81 76 286 3341.
E-mail addresses: ohi@kanazawa-med.ac.jp (K. Ohi), yukiy2001@hotmail.com (Y. Matsuda).

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cortical thickness and surface area. To date, widespread reductions in cortical thickness, including in temporal regions, have been demonstrated in schizophrenia patients [15,16]. In addition, decreased cortical gyrification has been identified in schizophrenia patients compared with healthy individuals [17,18]. However, although a few studies have investigated the changes in the cortical area in schizophrenia patients [16,19], these findings were inconsistent among studies.

The STG is one of three gyri in the temporal lobe and is a long region located along the Sylvian fissure dorsally and superior temporal sulcus ventrally. The STG is divided into several regions both structurally and functionally [8]. The most anterior portion of the STG is the temporal polar cortex (Brodman's areas [BA] 38) [20]. The dorsal surface of the STG is located within the Sylvian fissure and is divided into Heschl's gyrus (HG), the planum polare (PP) and the planum temporale (PT) [21]. The STG contains several important structures of the brain, including the primary auditory cortex (BA 41/42) in the HG and the auditory association cortical areas (BA 22) in the anterior portion of the PT, which surrounds the HG [20,22]. Abnormalities in temporal lobe structures play a role in dysfunction of auditory and language processing, i.e., auditory hallucinations and thought disorders, in patients with schizophrenia [7,23,24]. Several researchers have tried to identify detailed regional differences of the STG in schizophrenia, and they found that patients with first-episode psychosis as well as schizophrenia and schizotypal patients had smaller volumes of the PT, HG or the posterior part of the STG compared to controls [5,9,13,25]. Kasai et al. found that patients with schizophrenia had a significant progressive decrease in STG, and this change was more prominent in the posterior portion of the STG compared with controls [6]. Furthermore, the long duration of untreated psychosis (DUP) was significantly associated with smaller GM volumes of the STG, particularly the PT, in schizophrenia patients [26,27].

The STG can be anatomically divided into five regions:

- lateral aspect of the STG;
- anterior transverse temporal gyrus (of HG);
- PP of the STG;
- PT of the STG;
- transverse temporal sulcus [28].

However, which regions contribute to the volume reduction of the STG in schizophrenia patients remains unclear. In addition, it is unclear whether these volumetric alterations occur due to differences in cortical thickness, surface area, local gyrification (cortical folding patterns) or all of the above factors. To the best of our knowledge, there have been no studies that identified brain structural alterations in cortical thickness, cortical area or local gyrification or that examined volumes in the specific subregions of the STG in schizophrenia patients.

In the current study, to extract five anatomical subregions of the STG, we used a standardized method [28] to measure the GM volume and detailed cortical thickness, surface area and local gyrification index (LGI) in three-dimensional (3D) surface reconstructions. We investigated the morphological differences, lateralization of the alterations and effects of clinical characteristics in the five subregions of the STG between patients with schizophrenia and healthy subjects.

2. Methods

2.1. Subjects

Subjects for this study consisted of 40 age- and sex-matched patients with schizophrenia (45.0% males, 18 males/22 females, mean age ± SD: 36.3 ± 9.8 years) and 40 healthy subjects (45.0% males, 18 males/22 females, mean age ± SD: 36.1 ± 9.9 years). All subjects were of Japanese descent. Patients were recruited from both outpatients and inpatients at Kanazawa Medical University Hospital. Each patient with schizophrenia had been diagnosed by at least two trained psychiatrists based on an unstructured clinical interview and medical recodes; diagnosis was made based on the criteria of the fifth edition of the *Diagnostic and Statistical Manual of Mental Disorders* (DSM-5). Healthy subjects were recruited through local advertisements or from hospital staffs at Kanazawa Medical University. Psychiatrically healthy subjects were evaluated using an unstructured interview to exclude individuals who had current or past contact with psychiatric services or had received psychiatric medication. Subjects were excluded from this analysis if they had neurological or medical conditions that could potentially affect the central nervous system, such as atypical headache, head trauma with loss of consciousness, chronic lung disease, kidney disease, chronic hepatic disease, cancer with active stage, cerebrovascular disease, epilepsy, seizures, substance-related disorders or mental retardation. Demographic information is shown in Table 1. In the patients with schizophrenia, 38 patients received antipsychotic medication (2 typical, 28 atypical, and 8 a combination of typical and atypical), while two patients received no antipsychotics at the time of investigation. The mean age and gender ratio did not differ significantly between patients and controls ($P > 0.05$), while years of education, estimated premorbid intelligence quotient (IQ) and total GM volumes were significantly lower in patients than controls ($P < 0.05$). Written informed consent was obtained from all subjects after the procedures had been fully explained. This study was performed according to the World Medical Association's Declaration of Helsinki and approved by the Research Ethical Committee of Kanazawa Medical University.

2.2. MRI

All subjects underwent brain MRI scans using a Siemens 3T Magnetom Trio a Tim System (Siemens, Erlangen, Germany).

Table 1
Demographic information for patients with schizophrenia and healthy controls included in this study.

Variables	Schizophrenia ($N = 40$)	Control ($N = 40$)	P-values (z)
Age (years)	36.3 ± 9.8	36.1 ± 9.9	0.76 (0.31)
Gender (male/female)	18/22	18/22	> 0.99 (< 0.01)[a]
Education (years)	12.7 ± 1.6	17.0 ± 1.8	< **0.001 (−7.04)**
Estimated premorbid IQ	100.1 ± 10.9	110.0 ± 6.1	< **0.001 (−4.10)**
Handedness (rt./lt./bil.)	36/1/3	38/1/1	0.59 (1.05)[a]
Gray matter volume (ml)	616.8 ± 644.2	635.5 ± 110.2	**0.023 (−2.28)**
CPZeq (mg/day)			
Total antipsychotics	447.3 ± 390.8	–	–
Typical antipsychotics	50.9 ± 111.1	–	–
Atypical antipsychotics	396.4 ± 345.8	–	–
Age at onset (years)	25.9 ± 6.7	–	–
Duration of illness (months)			
Total patients ($N = 40$)	124.9 ± 118.4	–	–
First-episode patients ($N = 8$)	8.0 ± 4.4	–	–
Chronic patients ($N = 32$)	154.1 ± 115.0	–	–
PANSS positive symptoms	14.4 ± 5.6	–	–
PANSS negative symptoms	16.7 ± 6.6	–	–
PANSS general psychopathology	31.0 ± 8.5	–	–

CPZeq: chlorpromazine equivalents of total antipsychotics; PANSS: Positive and Negative Syndrome Scale. First-episode patients were defined as patients with a duration of illness less than 12 months, while chronic patients were defined as patients with a duration of illness more than 12 months. The current symptoms of schizophrenia were evaluated using the PANSS. Means ± SD are shown. Complete demographic information was not obtained for all subjects (estimated premorbid IQ in patients, $N = 37$; in controls, $N = 38$).

[a] χ^2 test. Significant P-values are shown in boldface and underlined.

High-resolution T1-weighted images were acquired with a 3D Magnetization Prepared-RApid Gradient Echo (MP-RAGE TR = 1420 ms, inversion time = 800 ms, echo time = 2.08 ms, flip angle = 9°, resolution = 1 × 1 × 1 mm^3, matrix size = 256 × 256), yielding 192 contiguous slices of 1.0 mm thickness in the sagittal plane, which were used for surface-based analysis. This sequence provided high-resolution T1-weighted images with good contrast between GM and white matter (WM) using this scanner in our scanning environment. We screened all scans and found no gross abnormalities, such as infarcts, hemorrhages or brain tumors, in any of the subjects.

Surface-based analysis was performed using FreeSurfer version 5.3.0 (Massachusetts General Hospital, Harvard Medical School; http://surfer.nmr.mgh.harvard.edu). This processing package included motion correction and averaging of multiple volumetric T1-weighted images, removal of nonbrain tissue using a hybrid watershed/surface deformation procedure [29], automated Talairach transformation, segmentation of the subcortical WM and deep GM volumetric structures [30,31], intensity normalization [32], tessellation of the GM/WM boundary, automated topology correction [33,34], and surface deformation following intensity gradients to optimally place the gray/white and gray/cerebrospinal fluid borders at the location where the greater shift in intensity defined the transition to the other tissue class [35–37]. All steps of the FreeSurfer processing stream are further described in previous studies [30–38]. The output was manually reviewed by the coauthors, confirming the accuracy of the pial surface and potential errors with regard to the WM surface.

The surface of the STG was parcellated into five subregions:

- lateral aspect of the STG;
- anterior transverse temporal gyrus (of HG);
- PP of the STG;
- PT of the STG;
- transverse temporal sulcus (Fig. 1) using Destrieux's sulcogyral atlas, which follows anatomical conventions and allows separation of the sulcal from gyral regions based on anatomical constraints of consistently occurring cortical folds [28].

Briefly, the anatomical features of five subregions according to Destrieux et al. [28] were as follows. The lateral aspect of the STG running parallel to the lateral sulcus was a part of the STG visible from lateral view. The anterior transverse temporal gyrus (of HG) was a small swelling containing primary auditory cortex [39]. The PP of the STG was the part of the superior aspect of the STG located anterior to the transverse temporal gyrus. The PT of the STG was the part of the superior aspect of the STG, posterior to the transverse temporal sulcus. The transverse temporal sulcus was posterior and parallel to the transverse temporal gyrus (of HG), which divided the PT from the transverse temporal gyrus (of HG). The average volume, cortical thickness and LGI of all vertices that were included in a parcellated region were assigned as the measurement values for each corresponding brain region. Surface area was calculated by estimating the relative areal expansion or compression at each vertex on the tessellated surface of the pial matter. GM volume, cortical thickness and surface area were estimated for the cortical areas. Total GM volume was also measured.

After initial cortical surface reconstruction, the folding patterns for each of the several thousands of vertices across the entire cortical surface were measured. To obtain the LGI, the method advocated by Schare et al. [40] based on an index originally proposed by Zilles et al. [41] was used. Briefly, the pial cortical surface ("buried" surface) was reconstructed in 3D space. An outer surface ("visible" surface) that tightly wraps the pial cortical surface was created. Next, the ratio of two surface areas within a 25 mm radius spherical region of interest (ROI) was calculated. The outer surface area was the denominator, and the pial cortical surface area was the numerator. This ratio LGI was assigned to each correspondent vertex of the reconstructed cortical sheet. These processes yielded a continuous gyrification surface map for each subject with each vertex on the reconstructed pial surface representing the LGI.

2.3. Statistical analyses

Statistical analyses of demographic variables and ROI analysis were performed using IBM SPSS Statistics 19.0 software (IBM Japan, Tokyo, Japan). Based on the assumption that most demographic variables, such as age and years of education, and brain structures were not fitted to a normality distribution using the Kolmogorov-Smirnov test ($P < 0.05$), the differences in continuous variables, such as age and years of education, were analyzed using the nonparametric Mann-Whitney *U*-test; the differences in categorical variables, such as gender or handedness, were analyzed using the Pearson's χ^2. To assess structural alterations in the five subregions of the STG in patients compared to controls, we performed multiple linear regression analyses with each structural phenotype as a dependent variable and diagnosis status as an independent variable. Age, gender and total GM volumes were included as the covariates to control for confounding factors. When we examined LGI, total GM volumes were not included as the covariates. Standardized effect sizes were calculated using Cohen's *d* method (http://www.uccs.edu/faculty/lbecker). The correlations among brain phenotypes or between the brain structures and clinical characteristics were

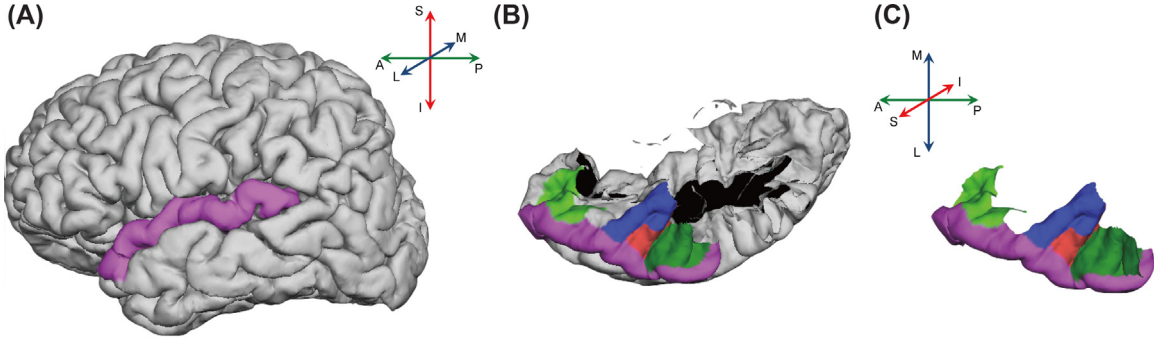

Fig. 1. Anatomical parcellations of the superior temporal gyrus (STG) using standard anatomical nomenclature. S: superior; I: inferior; A: anterior; P: posterior; L: lateral; M: medial. (A) The STG (magenta) is shown on the surface-rendered view of the brain region. (B, C) Five anatomical parcellations of the STG; lateral aspect of the STG (magenta), anterior transverse temporal gyrus of Heschl gyrus (HG) (blue), planum polare (PP) of the STG (light green), planum temporale (PT) of the STG (dark green) and transverse temporal sulcus (red), are shown.

assessed using nonparametric Spearman's correlation coefficient. The significance level for all statistical tests was set at two-tailed $P < 0.05$.

3. Results

3.1. Volumetric alterations in the five anatomical subregions of the bilateral STG in schizophrenia patients

As expected, patients with schizophrenia had significantly smaller bilateral STG volumes than healthy subjects ($\beta \pm SE = -1184.4 \pm 492.3$, $P = 0.019$). We first investigated volumetric alterations in five anatomical subregions of the bilateral STG between patients with schizophrenia and healthy subjects. Of the five subregions of the STG (Fig. 1.), patients with schizophrenia had significantly smaller volumes in the bilateral lateral aspect (magenta in Fig. 1 and Fig. 2, $\beta \pm SE = -770.4 \pm 278.3$, $P = 0.0071$) and marginally smaller volumes in the bilateral PT (dark green in Fig. 1, $\beta \pm SE = -292.2 \pm 130.3$, $P = 0.028$) compared with healthy subjects (Table 2). The difference in the bilateral lateral aspect of the STG was still significant after Bonferroni correction ($\alpha = 0.05/5$) to control multiple testing ($_{corrected}P = 0.036$), while the difference in the bilateral PT was not significant after applying the correction ($_{corrected}P = 0.14$). There was no significant difference in any of the other three subregions between patients and controls ($_{uncorrected}P > 0.05$) although patients tended to have smaller volumes in these subregions than controls (Table 2).

3.2. Alterations in thickness, surface area and local gyrification in the bilateral lateral STG in schizophrenia patients

To identify more detailed volumetric alterations in the lateral STG, we further examined morphological differences in cortical thickness, surface area and LGI in bilateral lateral STG between patients with schizophrenia and healthy subjects (Table 3). The cortical thickness and surface area of the bilateral lateral STG were significantly thinner and smaller in patients with schizophrenia than healthy subjects (cortical thickness; $\beta \pm SE = -0.14 \pm 0.07$, $P = 0.046$ and surface area; $\beta \pm SE = -131.3 \pm 60.6$, $P = 0.034$). There was no difference in LGI in the bilateral lateral STG between patients and controls ($P > 0.05$). As shown in Fig. 3, we examined correlations among structural phenotypes of the bilateral lateral STG and between the phenotypes and clinical characteristics in patients with schizophrenia and in healthy subjects. The volume of the bilateral lateral STG was significantly positively correlated with the cortical thickness (schizophrenia; $P = 4.71 \times 10^{-5}$, control; $P = 4.35 \times 10^{-3}$) and surface area (schizophrenia; $P = 2.84 \times 10^{-7}$, control; $P = 1.00 \times 10^{-13}$) and nominally positively correlated with the LGI (schizophrenia; $P = 0.024$, control; $P = 0.022$) in both patients and controls. However, there were no significant correlations between the cortical thickness

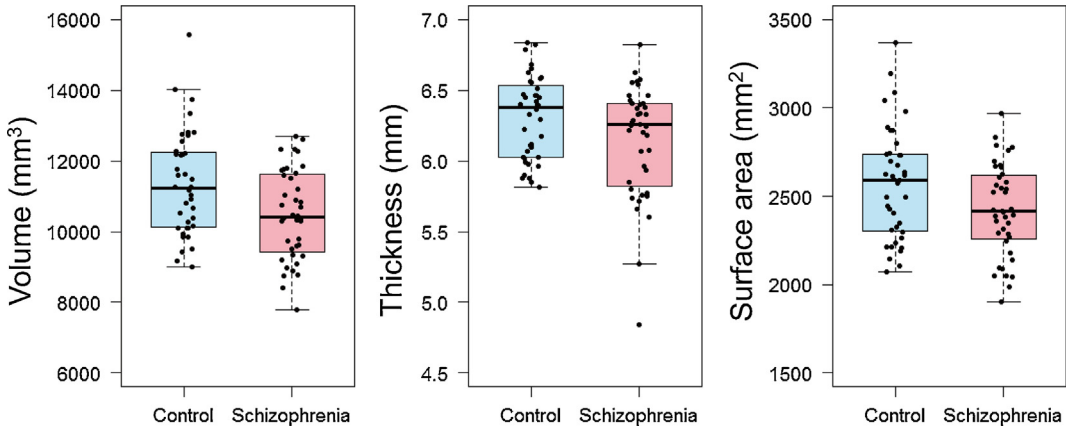

Fig. 2. Reductions in volume, thickness and surface area in the bilateral lateral aspect of the STG in schizophrenia patients. Closed circles represent each individual.

Table 2
Volumetric differences in five anatomical subregions of the STG between patients with schizophrenia and healthy subjects.

Anatomical subregions of the STG	Schizophrenia ($N = 40$)	Control ($N = 40$)	Cohen's d	β (SE)	P-values
Bil. lateral aspect of the STG (mm^3)	10470.0 ± 1276.6	11362.2 ± 1452.3	−0.65	−770.4 (278.3)	**0.0071**
Bil. anterior transverse temporal gyrus (of HG) (mm^3)	1991.0 ± 421.1	2021.6 ± 426.5	−0.07	−5.5 (92.0)	0.95
Bil. PP of the STG (mm^3)	3396.8 ± 703.8	3565.1 ± 620.0	−0.25	−104.6 (128.9)	0.42
Bil. PT of the STG (mm^3)	3262.7 ± 572.0	3581.4 ± 628.4	−0.53	−292.2 (130.3)	**0.028**
Bil. transverse temporal sulcus (mm^3)	943.7 ± 151.1	961.2 ± 162.5	−0.11	−11.7 (34.7)	0.74

STG: superior temporal gyrus; HG: Heschl gyrus; PP: planum polare; PT: planum temporale; SE: standard error of β; Bil: bilateral. Significant P-values are shown in boldface and underlined.

Table 3
Differences in thickness, surface area and local gyrification index (LGI) of the bilateral lateral STG between patients with schizophrenia and healthy subjects.

	Schizophrenia ($N = 40$)	Control ($N = 40$)	Cohen's d	β (SE)	P-values
Thickness (mm)	6.1 ± 0.4	6.3 ± 0.3	−0.47	−0.14 (0.07)	**0.046**
Surface area (mm^2)	2420.8 ± 260.1	2571.7 ± 315.3	−0.52	−131.3 (60.6)	**0.034**
Gyrification index	5.5 ± 0.6	5.6 ± 0.4	−0.20	−0.09 (0.12)	0.47

Significant P-values are shown in boldface and underlined.

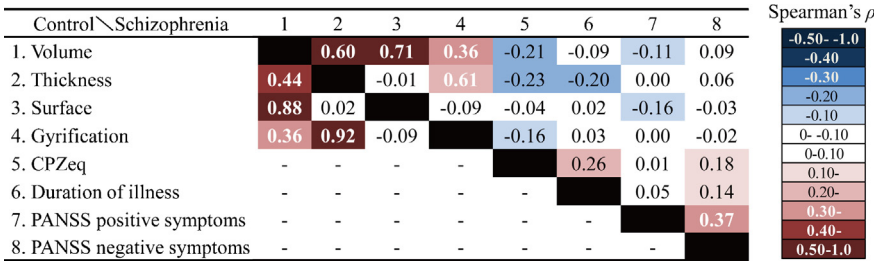

Fig. 3. Correlations among structural phenotypes in the lateral STG or between the structural phenotypes and clinical characteristics in patients with schizophrenia (upper) and in controls (lower). The correlations among structural phenotypes or between the structural phenotypes and clinical variables are indicated according to Spearman's ρ scores shown with the colored bars. Significant Spearman's ρ scores are shown as white numbers.

and surface area, the surface area and LGI or these brain phenotypes and clinical characteristics ($P > 0.05$).

3.3. Laterality of the alterations in lateral STG in schizophrenia patients

We further investigated the lateralization of differences in the lateral STG between patients with schizophrenia and healthy subjects. Patients with schizophrenia had significantly smaller volumes in both the right and left lateral STG compared with healthy subjects (right; $\beta \pm \mathrm{SE} = -370.8 \pm 149.8$, $P = 0.016$, left; $\beta \pm \mathrm{SE} = -399.6 \pm 168.3$, $P = 0.020$). Furthermore, patients showed marginally thinner cortical thickness and smaller surface area in both the right and left lateral STG compared with healthy subjects (thickness, right; $\beta \pm \mathrm{SE} = -0.07 \pm 0.04$, $P = 0.079$, left; $\beta \pm \mathrm{SE} = -0.08 \pm 0.05$, $P = 0.086$, surface area, right; $\beta \pm \mathrm{SE} = -63.1 \pm 33.6$, $P = 0.064$, left; $\beta \pm \mathrm{SE} = -68.2 \pm 34.8$, $P = 0.054$). There was no significant laterality of differences in the lateral STG between patients with schizophrenia and healthy subjects (laterality index = (left – right)/(left + right): volume, cortical thickness or surface area, all $P > 0.05$).

4. Discussion

To the best of our knowledge, this is the first study to investigate the subregional differences in volume, cortical thickness, surface area and gyrification of the STG in schizophrenia patients. Of the specific subregions of the STG, the lateral STG had a significantly smaller GM volume bilaterally in patients with schizophrenia than controls. The volumetric alterations were derived from differences in both decreased cortical thickness (Cohen's $d = -0.47$) and surface area (Cohen's $d = -0.52$) but not gyrification. We could identify subregional specificity of the STG in schizophrenia patients. Our findings suggest that decreased GM volume of the STG in schizophrenia patients might be primarily caused by a volumetric loss of both cortical thickness and surface area in the lateral STG.

Consistent with previous studies, our findings support the hypothesis that GM volumes in the STG were decreased in patients with schizophrenia. Morphological abnormalities in the STG have been consistently reported in schizophrenia patients, and several researchers have investigated the timing of their occurrence [5–7,9,42,43]. They suggest that the morphological abnormalities of the STG appear to already be present before illness onset or at onset and that the abnormalities are progressive regardless of the effects of antipsychotics after onset, particularly during the earliest phases of schizophrenia. In addition, offspring of patients with schizophrenia have significantly smaller volumes of the bilateral STG than controls [44], indicating that morphological abnormality of the STG might be a premorbid vulnerability to schizophrenia. However, it has also been recently reported that a progressive volumetric loss of the STG is mediated by genetic factors [45]. These findings suggest that genetic factors contribute to reduced STG volumes in schizophrenia patients both before and after onset. Because the patients with schizophrenia who participated in this study were relatively chronic (duration of illness was 10.4 ± 9.9 years), our findings might reflect both premorbid morphological changes and the changes after such a progressive pathological process.

Some studies have found that volumetric alterations in the STG were affected by psychotic symptoms [21,46,47] and the duration of illness [46]. However, in our subjects, although there were positive correlations among volume, cortical thickness and surface area, these structures were not correlated with any clinical characteristics, such as duration of illness, daily dosage of total antipsychotics, or the positive and negative syndrome scale. The correlations among the STG and clinical variables were inconsistent among studies [8,48]. These findings suggest that these clinical correlations may be secondarily caused by morphological changes of the STG. On the other hand, clinical heterogeneity, MRI acquisition parameters and anatomical landmarks for ROI are likely to lead to inconsistent results, while small sample sizes might be one of the main factors resulting in heterogeneous results. Further studies, such as a meta-analysis for the correlations, are required to increase the statistical power. The other explanation may be that changes in brain structure or functions in schizophrenia may occur in a relatively limited period around illness onset rather than continuously progressing over the course of the illness [49,50]. Because our patients were relatively chronic, we might not detect the correlation.

We could not detect lateralization of the morphological differences in lateral STG between patients and controls. Abnormalities in cerebral asymmetries in schizophrenia patients have been reported but inconsistently reported [51,52]. Several studies have demonstrated a significant hemispheric effect on STG volumes in schizophrenia patients [10,51]. In particular, GM volume reductions in the anterior portion, HG and PT of the STG were prominent in the left hemisphere but not the right hemisphere. We found marginal volumetric differences in the bilateral PT of the STG between patients and controls, although this relationship was not significant after applying the Bonferroni correction. Because the laterality of the PT has been reported, we further investigated lateralization in our subjects. Consistent with previous studies, we found that the GM volume reduction of the PT was prominent in the left hemisphere ($\beta \pm \mathrm{SE} = -168.7 \pm 84.3$, $P = 0.049$) but not the right hemisphere ($\beta \pm \mathrm{SE} = -123.5 \pm 72.2$, $P = 0.09$). These findings support the hypothesis that there could be laterality in specific subregions of the STG in schizophrenia patients, although the present study may be limited by a small sample size.

There were several limitations to this study. This study focused on the STG and the detailed analyses were performed. However,

other brain regions, such as the frontal cortex and the hippocampus, are also important regions for brain pathophysiology in schizophrenia. Further studies for these brain regions are required. To match age and gender between patients with schizophrenia and healthy subjects, we selected 40 age- and gender-matched patients and 40 healthy subjects in this study. Thus, our results were not based on a community-based sample of patients with schizophrenia and healthy subjects. We evaluated both patients with schizophrenia and controls using an unstructured clinical interview. Because we did not use the Structured Clinical Interview for DSM-IV or -5 (SCID) to evaluate these subjects, our study might not be representative of the typical patients with schizophrenia and healthy subjects, despite confirmations of the diagnosis by at least two trained psychiatrists. We could not completely exclude the influences of duration of illness and antipsychotics on brain morphology, although there was no correlation among these clinical factors and brain structures in our patients. Particularly, the effects of medication on the brain have been frequently reported. Duration of antipsychotic treatment [53,54] and different types of antipsychotics [55] have been shown to have different effects on the brain. Our results might be affected by these factors.

In conclusion, we examined age- and sex-matched patients with schizophrenia and healthy subjects to identify morphological changes in subregions of the STG in schizophrenia patients. GM volumes of the lateral STG were reduced in schizophrenia patients, and the volumetric alterations were derived from both decreased cortical thickness and surface area.

Disclosure of interest

The authors declare that they have no competing interest.

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