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ORIGINAL ARTICLE

Comparative analysis of auditory cortex volumes in schizophrenia patients via magnetic resonance imaging

Rumeysa Nur Çakır[1], Filiz Özsoy[2], Fatma Kökcü[3], Hilal Irmak Sapmaz[1]

[1]*Department of Anatomy, Tokat Gaziosmanpaşa University Faculty of Medicine, Tokat, Türkiye*
[2]*Department of Mental Health and Illnesses, Tokat Gaziosmanpaşa University Faculty of Medicine, Tokat, Türkiye*
[3]*Department of Radiology, Tokat Gaziosmanpaşa University Faculty of Medicine, Tokat, Türkiye*

ABSTRACT

Objectives: This study aims to investigate whether Heschl's gyrus (HG) is structurally affected in terms of volume and cortical thickness in schizophrenia patients compared with healthy individuals.

Patients and Methods: Between January 2017 and December 2024, a total of 80 individuals were enrolled, consisting of a schizophrenia group (n = 39) and a healthy control group (n = 41). The study group was further categorized into two clinical subgroups based on the presence of auditory verbal hallucinations (AVH): AVH(+) (11 males, 5 females; mean age: 31.9±9.8 years; range, 19 to 49) and AVH(–) (12 males, 11 females; mean age: 29.6±11.2 years; range 18 to 54). DICOM (Digital Imaging and Communications in Medicine) images were converted to NIfTI (Neuroimaging Informatics Technology Initiative) and analyzed with the online automated segmentation tool vol2Brain. The total cortical volume, right cortical volume, left cortical volume, total cortical thickness, right cortical thickness, and left cortical thickness values of HG obtained from the reports were statistically compared between the groups.

Results: No statistically significant differences were observed between groups in HG-related volume and cortical thickness parameters. The total cortical thickness of HG value was lower in the schizophrenia group compared to healthy controls (p = 0.040; p (B) = 0.120). The right cortical thickness of HG value in male patients was significantly lower than in healthy males (p = 0.038; p (B) = 0.114). Within the patient group, the right cortical volume of HG value was significantly higher in the group with AVH than in the group without AVH (p = 0.041, p (B) = 0.123).

Conclusion: The HG is a region worth studying in schizophrenia patients, but morphometric changes in this region can be elucidated with a larger sample and more detailed clinical information.

Keywords: Auditory cortex, auditory verbal hallucination, cortical thickness, Heschl's gyrus, magnetic resonance imaging, schizophrenia, volume.

Structural brain imaging studies conducted over many years have revealed significant changes in gray matter volume and cortical thickness in various neuropsychiatric disorders.[1] The volume and cortical thickness of various regions of the brain are morphometric parameters frequently examined in brain imaging studies.[2,3] The volume loss observed on magnetic resonance imaging (MRI) suggests atrophy in the affected area, and it has been reported that this may be associated with microstructural changes such as a decrease in neuron number or cell volume, loss of dendritic branching and synaptic density, and remodeling in glial cells and neuropil.[4-6] In the pathophysiology of schizophrenia, one of

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Correspondence: Rumeysa Nur Çakır, MD.
E-mail: nurtr78@gmail.com

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the cortical regions where neuroanatomical changes and structural abnormalities are concentrated is the temporal lobe.[7] Structural MRI studies consistently reveal volume and cortical thickness losses, particularly at the level of the hippocampus, amygdala, insula, medial temporal gyrus, and superior temporal gyrus (STG).[8,9] Literature reports indicate a strong correlation between morphological abnormalities, particularly in the STG region, and auditory hallucinations and auditory memory deficits, which are among the core clinical symptoms of schizophrenia.[7,10] The Heschl's gyrus (HG) is located in the STG and houses the primary auditory cortex (Brodmann 41 and 42). Due to its central role in auditory perception, it is an important region in the neurobiological origin of auditory hallucinations and sensory processing deficits observed in schizophrenia.[11,12] In addition to widespread cortical gray matter loss in schizophrenia, structural deterioration has been shown to be more pronounced in specific brain regions (mostly prefrontal, temporal, and limbic). Among the brain cortex regions, a decrease in gray matter volume and cortex thickness has been reported in schizophrenia.[13-15]

The aim of this study was to investigate whether HG is structurally affected in terms of volume and cortical thickness in patients with schizophrenia compared to healthy controls. Furthermore, we aimed to determine whether these morphometric parameters differ between clinical subgroups based on the presence of auditory verbal hallucinations (AVH(+) and AVH(–)).

PATIENTS AND METHODS

Study design and participants

This retrospective study was conducted at Tokat Gaziosmanpaşa University, Faculty of Medicine, Department of Radiology between January 2017 and December 2024. A total of 80 individuals were enrolled, consisting of a schizophrenia group (n = 39) and a healthy control group (n = 41). The study group was further categorized into two clinical subgroups based on the presence of AVH(+) (11 males, 5 females; mean age: 31.9±9.8 years; range, 19 to 49) and AVH(–) (12 males, 11 females; mean age: 29.6±11.2 years; range 18 to 54). Participants were selected based on specific inclusion criteria. These criteria were defined as follows: having been diagnosed with schizophrenia or non-organic psychosis at the time of admission to hospital; having undergone a cranial MRI scan for any reason following the date of diagnosis; and the availability of images of sufficient quality for radiological assessment. For both groups, mental retardation, multiple sclerosis, epilepsy, alcohol/substance dependence, head trauma, and the presence of intracranial space-occupying lesions were considered exclusion criteria. One suitable candidate in the patient group was excluded from the study due to artifacts in their images. Ethical approval for this study was obtained from the Tokat Gaziosmanpaşa University Faculty of Medicine Local Ethics Committee (Date: 30.09.2025, Decision No. 25-MOBAEK-340). The study was conducted in accordance with the ethical principles for medical research involving human subjects as outlined in the Declaration of Helsinki.

The healthy control group was created by matching the patient group in terms of age and sex distribution. Imaging data was obtained from the hospital archive system (Sectra), using a 1.5-T MRI scanner (SIGNA Explorer, GE HealthCare, Milwaukee, WI, USA) by selecting T1-weighted images with a 1 mm slice thickness from the A by 3D Bravo sequence. The raw images were first converted to DICOM (Digital Imaging and Communications in Medicine) format using RadiAnt DICOM Viewer 2024.2 software, and then to NIfTI (Neuroimaging Informatics Technology Initiative) format using the dcm2niigui tool integrated into MRIcron software (v1.0.20190902). Data in NIfTI format were uploaded to the vol2Brain online analysis platform (version 1.0 release 23-11-2021) for automated segmentation. Outputs are provided in PDF and CSV formats; when the user provides age and sex information, normal ranges based on a large, reliable reference dataset are added to the report and made available for download. The reference ranges provided here vary by age and sex; a common reference range covering all ages and sexes is not provided.[16]

The parameters of total HG volume, right HG volume, left HG volume, total HG thickness, right HG thickness, and left HG thickness obtained from the analysis reports were recorded. Using plotted color images on the individual-specific MRI obtained from vol2Brain outputs, a colored three-dimensional image of HG was created in ITK-SNAP [17] software (version 4.4.0), as shown in Figures 1 and 2.

The cortical thickness estimate presented in Vol2Brain reports is calculated internally using the DiReCT method. For each cortical area, the thickness values of the right and left hemispheres are recorded as independent parameters. In the official presentation report, the total cortical thickness measurement was accepted as a bilateral average and defined according

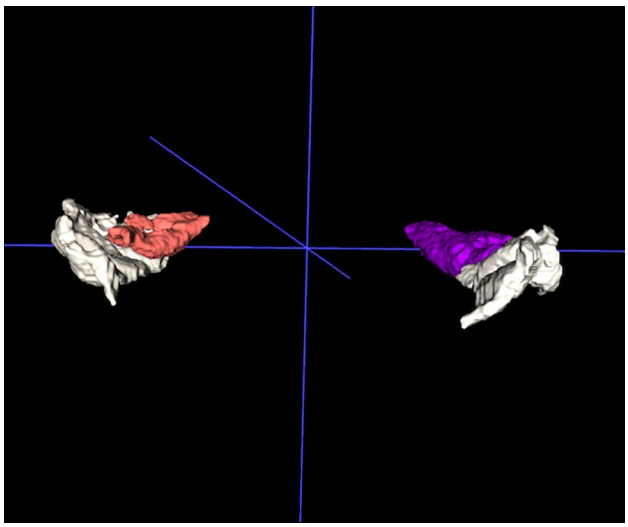

Figure 1. Bilateral color-coded three-dimensional image of Heschl's gyrus located on the superior temporal gyrus.

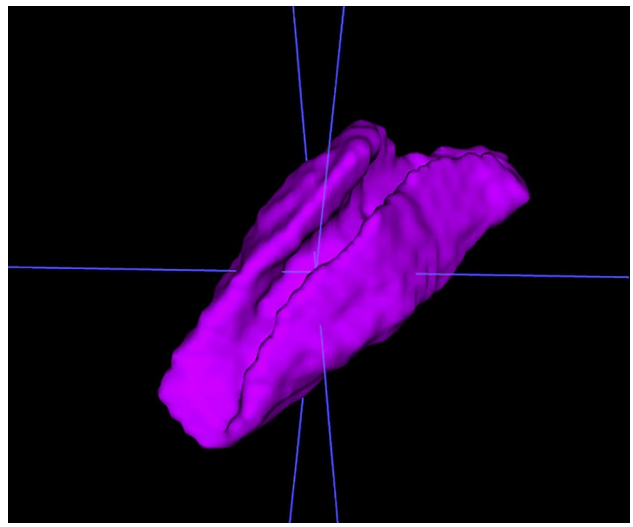

Figure 2. Colored three-dimensional image of the left Heschl's gyrus.

to the formula 'total = (right + left) / 2'.[16] In our study, cortical thickness values related to HG were evaluated in mm according to this reporting approach of vol2Brain.

In vol2Brain reports, volume measurements are recorded separately for the right and left hemispheres. The total volume value is defined as the sum of the volumes of both sides, as "total = right + left". The resulting volume parameter is presented in the report as absolute volume in mm^3. In our study, to compensate for inter-individual intracranial volume differences, relative volumes expressed as percentages (%) obtained by dividing absolute volume values by intracranial volume were used.

Statistical analysis

Statistical analysis was performed using IBM SPSS version 30.0 software (IBM Corp., Armonk, NY, USA). Before analysis, the Kolmogorov-Smirnov test was used to examine the normality of the dataset distribution and the sample size ($n > 50$). Depending on the distribution characteristics of the variables, the independent samples t-test was applied for intergroup comparisons of normally distributed data, while the Mann-Whitney U test was applied for non-normally distributed data. These tests were used to evaluate general differences between diagnosis (healthy/sick) and sex groups, as well as sub-divisions within groups (within-group sex and within-sex diagnosis differences). In all statistical evaluations, a confidence interval of 95% and a significance level of $p < 0.05$ were accepted. Within the patient group, subgroups were formed based on the presence of AVH: those with hallucinations (AVH(+)) and those without (AVH(–)), and comparisons were made across six selected parameters. In all hypothesis tests, the significance level was set at $\alpha = 0.05$. To control for the possibility of type 1 errors arising from multiple comparisons, Bonferroni correction was applied to the relevant analyses, and corrected p-values were calculated and reported; the significance threshold after Bonferroni correction was determined as α/m ($\alpha = 0.05/3 = 0.0167$ for $m = 3$). The demographic and clinical characteristics between the AVH(+) and AVH(–) groups were evaluated as two independent groups. To compare group means in continuous variables, Welch's adjusted independent samples t-test was used to reduce sensitivity to the assumption of variance homogeneity. Where variables were anticipated to have a skewed distribution or exhibit ordinal/numerical characteristics, intergroup differences were examined using the Mann-Whitney U test, and median (min-max) values were reported where appropriate. Group proportions for categorical variables were compared using the chi-square test; when expected cell frequencies were low (< 5), Fisher's exact test was preferred. In all analyses, the level of statistical significance was assessed bilaterally, and results were reported as p-values alongside the relevant test statistic.

RESULTS

In the schizophrenia group, volume parameters were higher and cortical thickness parameters were lower compared to the healthy control group. Only the difference in total HG thickness was statistically

Table 1. Comparison of variables according to schizophrenia/healthy control groups

Variables	Mean±SD	Median	t/U	*p*	d	*p* (B)
Total HG volume (%)						
Schizophrenia	0.2124±0.0394	0.217	1.273	0.207	0.285	0.621
Healthy control	0.2018±0.0355	0.199				
Right HG volume (%)						
Schizophrenia	0.0982±0.0240	0.100	1.566	0.121	0.350	0.363
Healthy control	0.0906±0.0192	0.087				
Left HG volume (%)						
Schizophrenia	0.1142±0.0203	0.113	0.614	0.541	0.137	1.0
Healthy control	0.1113±0.0213	0.112				
Total HG thickness (mm)						
Schizophrenia	0.0158±0.0038	0.016	587.500*	**0.040**	–0.443	0.120
Healthy control	0.0174±0.0034	0.018				
Right HG thickness (mm)						
Schizophrenia	0.0152±0.0041	0.015	605.000*	0.060	–0.374	0.180
Healthy control	0.0166±0.0030	0.016				
Left HG thickness (mm)						
Schizophrenia	0.0161±0.0042	0.016	–1.966	0.053	–0.440	0.159
Healthy control	0.0179±0.0040	0.018				

SD, standard deviation; HG: Heschl's Gyrus; t/U: Independent Samples t-test; *p*: Probability value indicating statistical significance; d: Cohen's d effect size; * Mann-Whitney U test, *p* (B): Bonferroni-corrected *p*-value (m = 3 comparisons; adjusted α = 0.05/3 = 0.0167).

significant among these parameters (U = 587.500, *p* = 0.040, d = –0.443, *p* (B) = 0,120), as shown in Table 1, Figures 3 and 4.

In comparisons within sex groups, the schizophrenia group had higher volume parameters and lower cortical thickness parameters compared to the healthy control group, as shown in Tables 2 and 3, Figures 5-8. In males in the schizophrenia group, only the right HG thickness value was found to be significantly lower compared to males in the healthy group (U = 179.500, *p* = 0.038, d = –0.600, *p* (B) = 0.114) (Table 2, Figures 5 and 6).

Of the 39 patients, 16 were identified as AVH(+) and 23 as AVH(–). When AVH(+) and AVH(–) patients were compared, right HG volume, a parameter related to HG, was found to be significantly higher in AVH(+) individuals (*p* = 0.041). Although most HG parameters were not statistically significant, they were found to be higher in the AVH(+) group than in the AVH(–) group, as shown in Table 4, Figures 9 and 10. Patients' educational status, occupation, marital status, family history, antipsychotic use, duration of illness, and number of hospital admissions

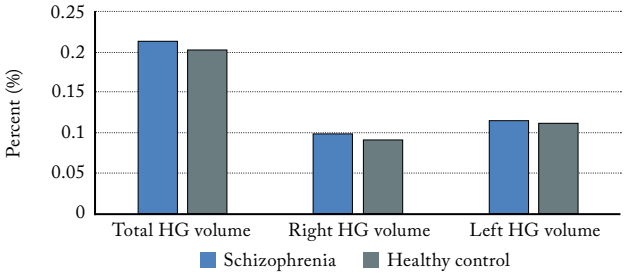

Figure 3. Comparison of volume variable according to schizophrenia/healthy control groups.
HG: Heschl's gyrus.

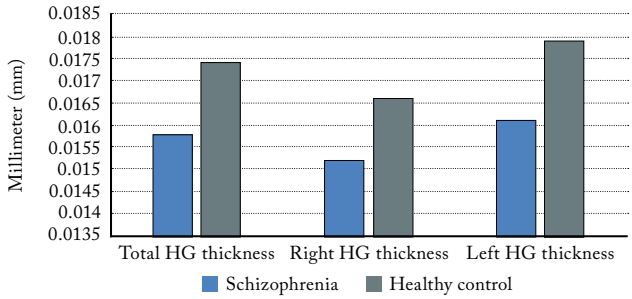

Figure 4. Comparison of thickness variables according to schizophrenia/healthy control groups.
HG: Heschl's gyrus.

Table 2. Intergroup comparison of variables in males

Variables	Mean±SD	Median	t/U	*p*	d	*p* (B)
Total HG volume (%)						
Schizophrenia	0.2147±0.0405	0.217	0.893	0.376	0.261	1.0
Healthy control	0.2046±0.0364	0.203				
Right HG volume (%)						
Schizophrenia	0.0983±0.0248	0.100	1.001	0.322	0.292	0.966
Healthy control	0.0918±0.0199	0.091				
Left HG volume (%)						
Schizophrenia	0.1163±0.0196	0.113	0.546	0.588	0.159	1.0
Healthy control	0.1131±0.0203	0.112				
Total HG thickness (mm)						
Schizophrenia	0.0157±0.0035	0.016	187.500*	0.057	–0.509	0.171
Healthy control	0.0173±0.0026	0.018				
Right HG thickness (mm)						
Schizophrenia	0.0151±0.0034	0.015	179.500*	**0.038**	–0.600	0.114
Healthy control	0.0168±0.0023	0.017				
Left HG thickness (mm)						
Schizophrenia	0.0161±0.0042	0.016	–1.302	0.199	–0.380	0.597
Healthy control	0.0175±0.0032	0.018				

SD, standard deviation; HG: Heschl's Gyrus; t/U: Independent Samples t-test; *p*: Probability value indicating statistical significance; d: Cohen's d effect size; * Mann-Whitney U test. *p* (B): Bonferroni-corrected *p*-value (m = 3 comparisons; adjusted α = 0.05/3 = 0.0167).

Table 3. Intergroup comparison of variables in females

Variables	Mean±SD	Median	t/U	*p*	d	*p* (B)
Total HG volume (%)						
Schizophrenia	0.2093±0.0388	0.218	0.898	0.376	0.313	1.0
Healthy control	0.1978±0.0347	0.194				
Right HG volume (%)						
Schizophrenia	0.0979±0.0237	0.103	1.228	0.229	0.428	0.687
Healthy control	0.0889±0.0185	0.086				
Left HG volume (%)						
Schizophrenia	0.1112±0.0216	0.113	0.303	0.764	0.106	1.0
Healthy control	0.1088±0.0232	0.112				
Total HG thickness (mm)						
Schizophrenia	0.0158±0.0043	0.016	113.500*	0.423	-0.379	1.0
Healthy control	0.0175±0.0044	0.017				
Right HG thickness (mm)						
Schizophrenia	0.0154±0.0049	0.015	124.500*	0.683	-0.168	1.0
Healthy control	0.0162±0.0039	0.015				
Left HG thickness (mm)						
Schizophrenia	0.0161±0.0043	0.017	-1.442	0.159	-0.502	0.477
Healthy control	0.0185±0.0050	0.018				

SD, standard deviation; HG: Heschl's Gyrus; t/U: Independent Samples t-test; *p*: Probability value indicating statistical significance; d: Cohen's d effect size; * Mann-Whitney U test, *p* (B): Bonferroni-corrected *p*-value (m = 3 comparisons; adjusted α = 0.05/3 = 0.0167).

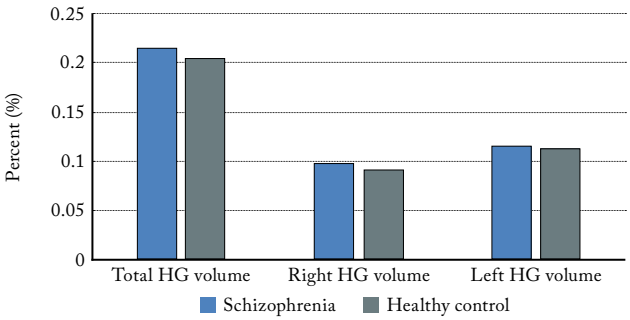

Figure 5. Intergroup comparison of volume variables in men.
HG: Heschl's gyrus.

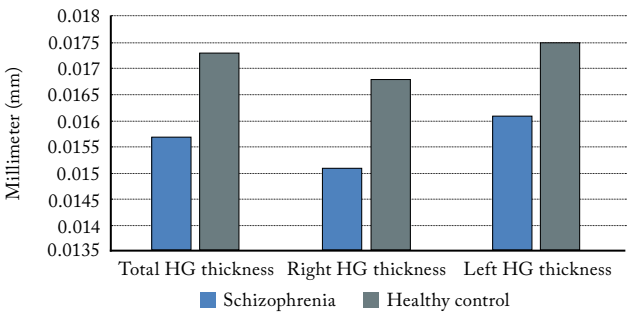

Figure 6. Intergroup comparison of cortical thickness variables in men.
HG: Heschl's gyrus.

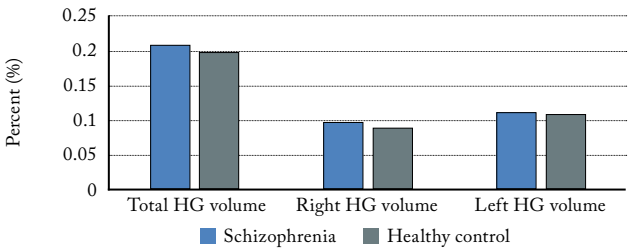

Figure 7. Intergroup comparison of volume variables in women.
HG: Heschl's gyrus.

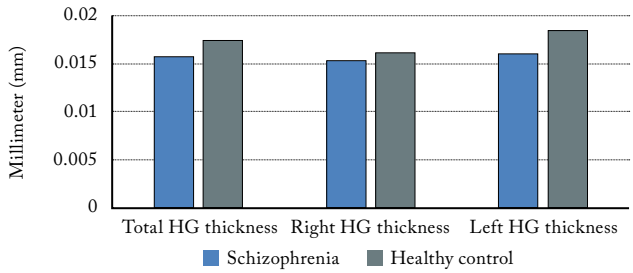

Figure 8. Intergroup comparison of cortical thickness variables in women.
HG: Heschl's gyrus.

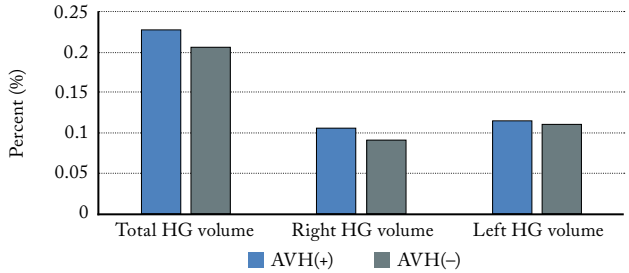

Figure 9. Comparison of volume variables according to AVH(+)/AVH (-) groups.
AVH: auditory verbal hallucination.

are provided in Table 5. Looking at the most commonly used drugs, olanzapine ranked first (n = 14, 35.9%), followed by aripiprazole (n = 11, 28.2%) and risperidone (n = 9, 23.1%). The drug groups used consisted of antipsychotics (all atypical except haloperidol), antidepressants, and mood stabilizers. Since the Positive and Negative Syndrome Scale (PANSS) score, was only available for four individuals, it was not included in the variables. The treatment status was mentioned in the history, but as the single or multiple use of the medication and its duration were unknown, only the medications mentioned in the history were referred to.

Table 4. Comparison of variables according to AVH(+)/AVH(–) groups

Variables	AVH(+) Mean±SD	AVH(–) Mean±SD	t/U	*p*	d	*p* (B)
Total HG volume (%)	0.225±0.041	0.204±0.036	-1.870	0.061	0.555	0.183
Right HG volume (%)	0.107±0.025	0.092±0.021	-2.042	0.041	0.684	0.123
Left HG volume (%)	0.117±0.018	0.112±0.022	-1.114	0.265	0.265	0.795
Total HG thickness (mm)	0.016±0.003	0.016±0.004	-0.488	0.626	0.130	1.0
Right HG thickness (mm)	0.016±0.004	0.015±0.004	-0.803	0.422	0.189	1.0
Left HG thickness (mm)	0.016±0.003	0.016±0.005	-0.388	0.698	0.074	1.0

AVH: Auditory verbal hallucination; SD, standard deviation; HG: Heschl's gyrus; t/U: Independent Samples t-test; *p*: Probability value indicating statistical significance; d: Cohen's d effect size; * Mann-Whitney U test, *p* (B): Bonferroni-corrected *p*-value (m = 3 comparisons; adjusted α = 0.05/3 = 0.0167).

Table 5. Subject characteristics for schizophrenia patients with and without auditory verbal hallucinations

	AVH(+) (n = 16)					AVH(–) (n = 23)					
Variables	n	%	Mean±SD	Median	Range	n	%	Mean±SD	Median	Range	*p*
Age (year)			31.9±9.8					29.6±11.2			0.486*
Sex											0.301†
Male	11	68.8				12	52.2				
Female	5	31.2				11	47.8				
Marital status: married	8	50.0				4	17.4				0.041‡
Family history: present	4	28.6				4	19.0				0.685‡
Education											0.421†
Literate (no formal education)	1	6.2				0	0.0				
Primary school	8	50.0				8	36.4				
High school	5	31.2				8	36.4				
University/College	2	12.5				6	27.3				
Occupation											0.217†
Retired	0	0.0				1	4.3				
Homemaker	3	18.8				4	17.4				
Worker	3	18.8				0	0.0				
Civil servant	1	6.2				4	17.4				
Farmer	2	12.5				1	4.3				
Unemployed	7	43.8				13	56.5				
Number of hospitalizations				1	0-6				1	0-4	0.267¶
Illness duration (year)				7	1-16				8	1-25	0.655¶

AVH: Auditory verbal hallucinations; SD, standard deviation; * Welch's t-test; † Chi-square; ‡ Fisher exact test; ¶ Mann-Whitney U test.

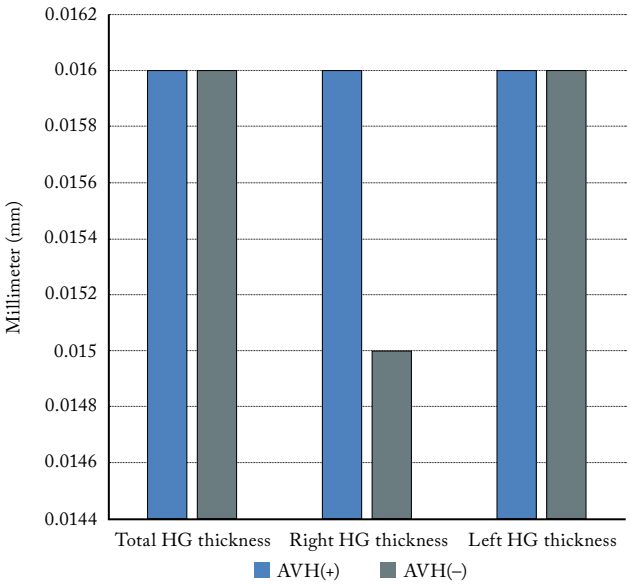

Figure 10. Comparison of cortical thickness variables according to AVH(+)/AVH(–) groups.
AVH: auditory verbal hallucination.

DISCUSSION

In the literature, morphometric studies evaluating HG, particularly in auditory processing and psychiatric disorders, have generally reported decreases in parameters such as volume, cortical thickness, and cortical surface area.[18-20] A meta-analysis by Sun et al.[8] examining surface-based morphometry studies in schizophrenia patients reported a decrease in cortical thickness in the bilateral STG. Mørch-Johnsen et al.,[21] in their study comparing schizophrenia patients with and without auditory hallucinations, found a decrease in cortical thickness in HG, especially on the left side. In our study, however, no significant difference in HG cortical thickness was found in either hemisphere between the images of patients and healthy individuals.

In a study by Chen et al.[11] it was reported that HG impairment in schizophrenic patients with auditory hallucinations was more pronounced in the right hemisphere compared to the left hemisphere. In our study, the total HG thickness value was also found to be significantly lower in schizophrenia. Regarding the auditory cortex, the right HG volume parameter was found to be higher in those with AVH(+). In a study conducted by Rojas et al.[22] using MRI images of schizophrenia patients, it was reported that the effect on HG volume and surface area was more pronounced in males than in females. Due to the small sample size in our study, no sex-based interpretations were made.

In a study by Shen et al.,[23] patients were evaluated by dividing them into subgroups based on the duration of their illness: 5, 15, and 25 years. Particularly in the five-year subgroup, no significant difference was found in gray matter density in any region of the brain between patients and healthy controls, while more pronounced structural differences emerged in groups with longer disease duration. In our study, we formed groups based on disease duration, similar to Shen et al.,[23] but we were unable to make comparisons, particularly in the group with 10 years or more, due to the significantly low sample size.

The decrease in cortical thickness indicates thinning of the gray matter layer in the affected area and may be associated with microstructural processes such as decreased dendritic arborization of pyramidal neurons, decreased synaptic density, and disruption of the neuropil content (consisting of dendrites, axons, and glial extensions) and the stratified organization of the cerebral cortex.[24,25] In brain morphometry, volume loss primarily reflects macro-level structural changes, while a decrease in cortical thickness is considered a more sensitive indicator of microstructural processes. Furthermore, since cortical volume is a measure derived from a combination of cortical thickness and cortical surface area, a decrease in one parameter does not necessarily imply a simultaneous or proportional change in the others.[25-28]

The main limitations of this study are the relatively small sample size and the inability to assess hemispheric asymmetry because information on participants' handedness was unavailable. The limited sample size may have decreased the statistical power of the analyses, particularly for detecting subtle differences between groups. Moreover, the lack of handedness data constrained the interpretation of structural variations associated with cerebral lateralization. Further studies with larger cohorts and available handedness data are needed to confirm and expand upon these findings.

In conclusion, in our study, although no changes were observed in the volume and cortical thickness of the HG in schizophrenia, we believe that the HG is a region worthy of study and that detailed results can be obtained when examined in a larger number of schizophrenia patients with detailed clinical information.

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Data Sharing Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

AI Disclosure: The authors declare that artificial intelligence (AI) tools were not used, or were used solely for language editing, and had no role in data analysis, interpretation, or the formulation of conclusions. All scientific content, data interpretation, and conclusions are the sole responsibility of the authors. The authors further confirm that AI tools were not used to generate, fabricate, or 'hallucinate' references, and that all references have been carefully verified for accuracy.

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