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Morphometric variations of superior temporal sulcus

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Abstract

Aim: This study focuses on the Superior Temporal Sulcus (STS), a crucial structure in the brain that delineates the anatomical boundary between the superior and medial temporal gyri. The STS is significant in social cognition, particularly in tasks involving cognitive empathy and perspective- taking. Understanding its anatomical relationship with superficial skull landmarks is vital for cranial surgery and surgical planning.

Materials and Methods: The study involved an in-depth examination of the STS in sixteen adult human brains, totaling 32 hemispheres. The research included detailed measurements of sulcal lengths, assessments of sulcal depths, and observations of segment and branch variations within the STS.

Results: The continuous pattern was observed in 28.6% (4 cases) of the left hemisphere and 71.4% (10 cases) in the right hemisphere. The interrupted pattern was identified in 55.6% (5 cases) of the left hemisphere and 44.4% (4 cases) in the right hemisphere. The temporal pole pattern was present in 77.8% (7 cases) of the left hemisphere and 22.2% (2 cases) in the right hemisphere. The number of segments in STS showed significant variation across these pattern types, with a p- value of 0.0001, indicating statistical significance.

Conclusion: A comprehensive understanding of the STS's anatomy is essential for neurosurgeons as it serves as a critical guide in navigating cerebral pathologies.The anatomical and cadaveric studies substantially deepen our comprehension of the STS's structural variations, thereby enriching the field's knowledge base and potentially facilitating the refinement of neurosurgical planning processes.This research highlights the critical significance of the STS within clinical and neuroscientific frameworks, particularly its vital contribution to neurosurgical procedures.

Introduction

Superior temporal sulcus (STS) divides the superior and medial temporal gyrus, often accompanied by the temporoparietal junction, plays a pivotal role in various aspects of social cognition and get activated during tasks involving cognitive empathy and perspective-taking [1]. Moreover, this sulcus is instrumental in discerning social cues, facial expressions, encompassing prosody, trustworthiness, and intention [2,3,4].

The use of superficial skull landmarks becomes crucial in cranial surgery, as their consistent relationships with underlying cortical regions can be considered during the planning of surgical procedures [5]. Detailed knowledge of the anatomy of the STS holds immense significance for neurosurgeons, serving as a crucial roadmap for navigating various cerebral pathologies. The STS is a complex and convoluted structure within the brain, and its thorough understanding is monumental.

Materials and Methods

Sulcal lengths, depth assessments and segment and branch variations of 32 hemispheres from sixteen adult human brains were investigated. The brains employed in this study were sourced from adult individuals devoid of reported psychiatric or neurological disorders, and they showed no notable pathological alterations, such as intracerebral hematomas or cerebral infarcts. Inclusion criteria did not factor in age or gender, and all specimens underwent fixation in 10% buffered formalin before being archived in the Department of Pathology and Laboratory Medicine at the University of Wisconsin, Madison.

The average brain weight was 1,189 grams, with a range of 1,022–1,754 grams. Brains weighing less than 1,000 grams and those displaying gross evidence of atrophy were excluded from the study. After fixation, the specimens

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were transferred to 50% ethanol to facilitate handling and evaluation. Following this, the cerebellum and brainstem were extracted, and a median cut through the corpus callosum was made to separate the cerebral hemispheres. This was followed by the meticulous removal of the arachnoid and cerebral blood vessels from the cortical surface. Photographs capturing the undersides of each hemisphere were acquired at a 50 cm distance using a high-resolution Nikon D5000 digital camera (Nikon Co., Tokyo, Japan). The Microsoft Paint program was utilized for the delineation and annotation of major sulci on digital images representing the inferior temporal lobe surface, each identified with a distinct color. To ensure precision in assessment, the length and depth of each sulcus were measured using a soft vinyl measuring tape, specifically inserted into each sulcus. Sulcal depth measurements excluded sections shallower than 0.2 cm, reserving portions surpassing this threshold as the designated actual sulcus. Sulcal lengths in the anteroposterior direction were gauged using a caliper (Mitutoyo Corporation, Kawasaki, Japan) at each terminus. Depth assessments were conducted on both the principal stem and lateral branches of the sulci, taking into account the longest segment for sulci composed of multiple segments. We categorized the sulci as short (less than 2 cm length) and long (more than 2 cm length) sulci based on their lengths.

In our study, the phrase "Sulcus continuation in the parietal lobe" was employed to describe instances where the STS extended into the parietal lobe, surpassing the boundary demarcated by the Sylvian fissure. Similarly, the designation "Sulcus continuation in the occipital lobe" was applied to describe scenarios wherein the STS transcended an imaginary line drawn between the parieto-occipital sulcus and the preoccipital notch which is the border of the occipital lobe for the lateral surface.

Statistical analysis

The analytical outcomes of this study were quantitatively articulated, with categorical variables being delineated through frequencies and proportions, while discrete variables were summarized using medians and interquartile ranges (IQRs). To evaluate the association between categorical variables, the chi-square test was employed. Given the adherence of the variables to a Poisson distribution, the Kruskal-Wallis and Mann-Whitney U tests were utilized to scrutinize differences across the variables under investigation. Significance was adjudged at a p-value threshold of 0.05, underscoring the statistical rigor applied in discerning meaningful disparities. All statistical computations were facilitated by the SPSS software (IBM SPSS Statistics for Windows, Version 26.0, Armonk, NY: IBM Corp), underscoring the application of established statistical methodologies in the analysis of the data.

The Institutional Review Board of the University of Wisconsin, Madison (IRB-University of Wisconsin, Madison) granted ethical approval for the study.

Results

We categorized the sulcus patterns into three main categories to simplify the classification.

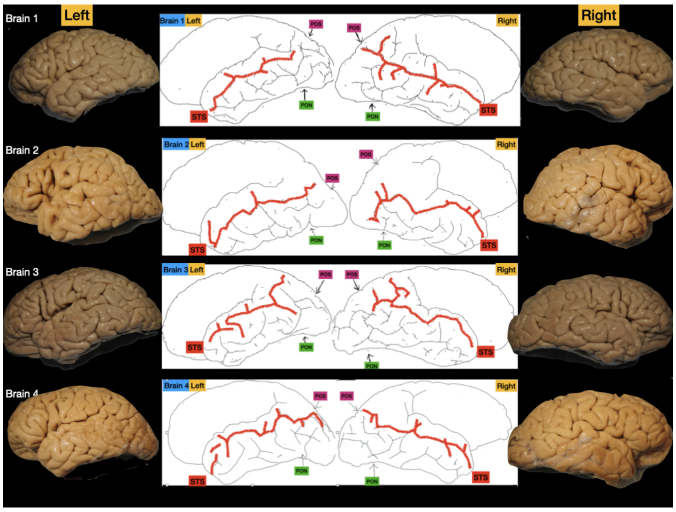

Figure 1. A juxtaposition of cadaveric photographs and corresponding tracing images show the mapping of the temporal sulci of brain hemispheres 1-2-3-4. Superior temporal sulcus is highlighted in red. In the anatomical imaging, the parieto-occipital sulcus (POS) and the preoccipital notch (PON) are delineated, each marked by corresponding arrows to facilitate the visualization of the demarcation between the temporal and occipital lobes.

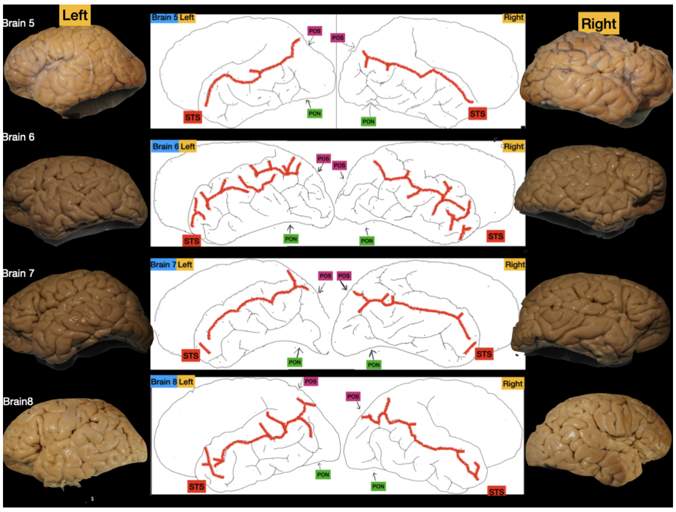

Figure 2. Cadaveric photographs and corresponding digital images, when placed side by side, demonstrate the mapping of the temporal sulci in brain hemispheres labeled 5-6-7-8. Both the parieto-occipital sulcus (POS) and the preoccipital notch (PON) are clearly delineated, with each being marked by corresponding arrows.

The Continuous Sulcus Pattern refers to a consistent and uninterrupted configuration of STS . In this pattern, the sulci on the temporal lobe, form a continuous and unbroken course without significant interruptions or deviations. The examination of neuroanatomical pattern distributions across cerebral hemispheres disclosed notable variations in the frequency of occurrence among different pattern types. The analysis meticulously quantified the prevalence of the

Table 1. Detailed analysis of superior temporal sulcus patterns, including segments and branches.

	Sulcus Pattern	Number of segments	Number of Short branches	Number of Long branches	Sulcus continuation in occipital lobe	Sulcus continuation in parietal lobe
Left Hemisphere						
Brain 1	Continious Pattern	1	3	1	0	0
Brain 2	Continious Pattern	1	0	2	0	0
Brain 3	Interrupted Pattern	2	2	1	0	0
Brain 4	Temporal Pole Pattern	3	3	3	1	0
Brain 5	Continious Pattern	1	0	1	0	0
Brain 6	Interrupted Pattern	4	10	2	0	0
Brain 7	Temporal Pole Pattern	2	0	1	0	1
Brain 8	Temporal Pole Pattern	2	4	4	1	0
Brain 9	Continious Pattern	1	3	2	0	0
Brain 10	Temporal Pole Pattern	2	3	2	0	1
Brain 11	Temporal Pole Pattern	2	3	2	0	0
Brain 12	Temporal Pole Pattern	2	4	3	1	0
Brain 13	Interrupted Pattern	3	3	4	1	0
Brain 14	Interrupted Pattern	5	4	7	0	1
Brain 15	Temporal Pole Pattern	2	5	4	1	1
Brain 16	Interrupted Pattern	3	3	3	1	0
Right Hemisphere						
Brain 1	Continious Pattern	1	1	5	0	0
Brain 2	Continious Pattern	1	3	3	1	0
Brain 3	Continious Pattern	1	1	3	0	0
Brain 4	Continious Pattern	1	4	2	0	0
Brain 5	Continious Pattern	1	2	1	0	0
Brain 6	Interrupted Pattern	3	2	4	0	0
Brain 7	Temporal Pole Pattern	2	3	2	0	0
Brain 8	Continious Pattern	1	2	2	0	0
Brain 9	Continious Pattern	1	4	5	0	0
Brain 10	Interrupted Pattern	3	2	5	1	0
Brain 11	Interrupted Pattern	2	2	2	0	0
Brain 12	Continious Pattern	1	3	1	1	0
Brain 13	Continious Pattern	2	4	5	1	0
Brain 14	Temporal Pole Pattern	2	5	2	0	1
Brain 15	Interrupted Pattern	4	5	3	0	0
Brain 16	Continious Pattern	1	3	1	0	0

Table 2. Comparative distribution of sulcus pattern types across hemispheres.

Pattern types n(%)	Left hemisphere (n=16)	Right hemisphere (n=16)	X^2	p
Continious Pattern	4(%25)	10(%62.5)		
Interrupted Pattern	5(%31.25)	4(%25.0)	5.46	0.065
Temporal Pole Pattern	7(%43.75)	2(%12.5)		

*Chi-square.

continuous, interrupted, and temporal pole pattern types, thereby elucidating their respective lateralization tendencies.

The distribution of pattern types across hemispheres was investigated, revealing variability in occurrence rates. Specifically, the continuous pattern type was identified in 4 cases (25.0%) within the left hemispheres, compared to 10 cases (62.5%) within the right hemisphere.

Conversely, the interrupted pattern type exhibited a different distribution, being observed in 5 cases (31.25%) in the left hemisphere and 4 cases (25.0%) in the right hemisphere. Additionally, the temporal pole pattern type showed a pronounced lateralization, appearing in 7 instances (43.75%) in the left hemisphere and only 2 instances (12.5%) in the right hemisphere. Despite these disparities in pattern type distribution between the left and right hemispheres, statistical analysis revealed that these differences were not significant (Table 1) (Figure 1-5).

Table 3. Hemispheric comparison of segment numbers and branch lengths.

	Side	N	Median (IQR)	Mean rank	p
Short branches	Left	16	3(1.75)	17	0.756
	Right	16	3(2)	16	
Long branches	Left	16	2(2.5)	15.53	0.549
	Right	16	2.5(2.75)	17.47	
Segment numbers	Left	16	2(1.75)	19.03	0.105
	Right	16	1(1)	13.97	

*Mann Whitney-U test.

Table 4. Impact of pattern types on variability in segment numbers and branch lengths.

	Pattern types	N	Median (IQR)	Mean rank	p
Short branches	Continious Pattern	14	3(2.25)	13.68[a]	0.245
	Interrupted Pattern	9	3(2.5)	17.28[a]	
	Temporal Pole Pattern	9	3(1.5)	20.11[a]	
Long branches	Continious Pattern	14	2(2.5)	14.25[a]	0.302
	Interrupted Pattern	9	3(2.5)	20.28[a]	
	Temporal Pole Pattern	9	2(1.5)	16.22[a]	
Segment numbers	Continious Pattern	14	1(0.0)	7.86[a]	0.0001
	Interrupted Pattern	9	3(1.5)	26.56[b]	
	Temporal Pole Pattern	9	2(0.0)	19.89[c]	

*Kruskal Wallis test.

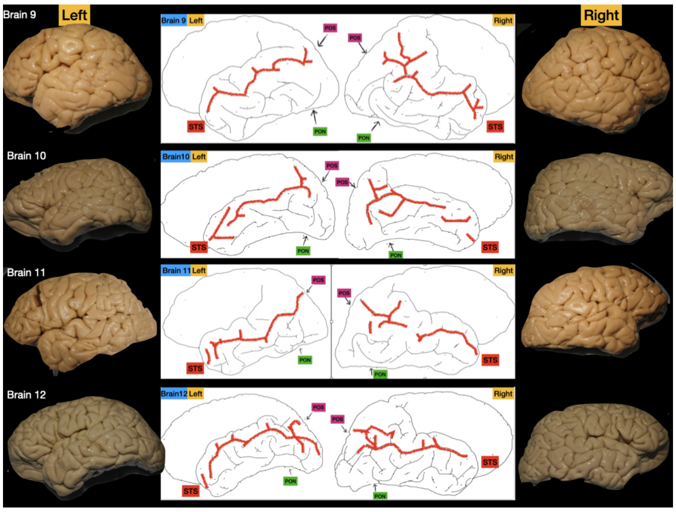

Figure 3. Cadaveric photographs and corresponding digital images, when placed side by side, demonstrate the mapping of the temporal sulci in brain hemispheres labeled 9-10-11-12.The parieto-occipital sulcus (POS) and the preoccipital notch (PON) are precisely outlined, with each feature indicated by respective arrows.

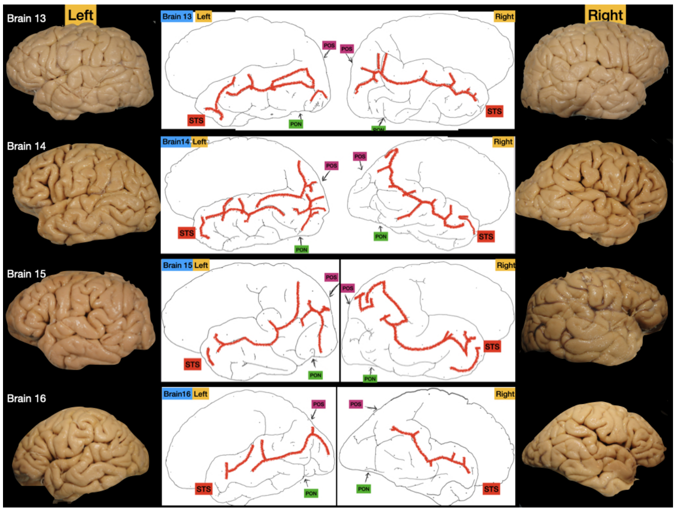

Figure 4. Cadaveric photographs and corresponding digital images, when placed side by side, demonstrate the mapping of the temporal sulci in brain hemispheres labeled 13-14-15-16.The parieto-occipital sulcus (POS), the preoccipital notch (PON).

Continuous sulcus pattern

For the continuous pattern type, an asymmetric distribution was observed, with a total of 4 instances (25.0%) being documented within the left hemispheres of the study cohort. In contrast, this pattern type was more prevalent in the right hemispheres, manifesting in 10 cases (62.5%) (Figure 1-2-3). A chi-square test resulted in a value of X^2=5.46 with a p-value of 0.065, suggesting a trend toward the right hemisphere but not reaching conventional levels of statistical significance (Table 2).

Within the left hemispheres featuring the continuous sulcus pattern, a notable trend emerged with more upward sulcus branches. In left hemispheres with continuous pattern total of 9 upward sulcus branches and 3 downward branches were observed.

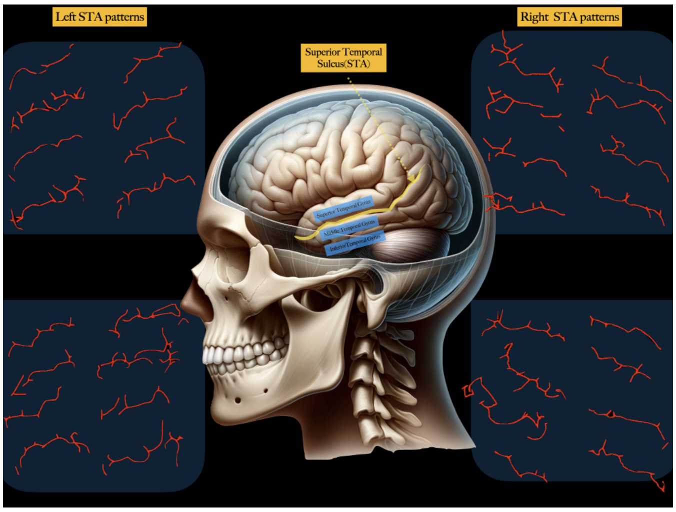

Figure 5. The illustration provides a detailed visualization of the variety of sulcus pattern types identified in our research. Superior temporal sulcus patterns across both the right (on right side) and left cerebral hemispheres (on left side), including a representation of the superior temporal sulcus itself (middle image).

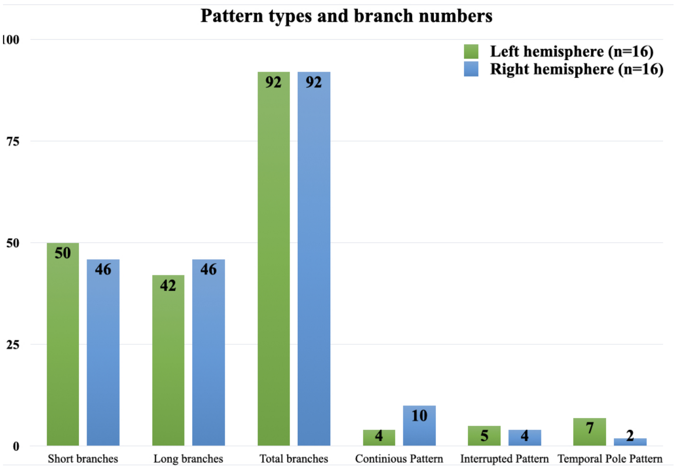

Figure 6. Chart reveals the categorization and quantification of branching patterns observed within the cerebral hemispheres, detailing both the type of pattern and the number of branches associated with each.

Upon scientific analysis of right hemispheres characterized by a continuous sulcal pattern, a total of 31 ascending sulcal branches were identified, yielding an average of approximately 3.1 ascending branches per hemisphere. In contrast, descending sulcal branches were comparatively infrequent; each left hemisphere exhibiting a continuous sulcal pattern presented with an average of 1 descending branch.

Interrupted pattern

In this pattern, certain sulci do not follow a continuous path and instead exhibit interruptions, irregularities, or deviations in their trajectory. These interruptions can take various forms, such as breaks in the main stem of a sulcus or the presence of irregularly shaped segments within a sulcus.

In the case of the interrupted pattern type, the distribution exhibited a contrasting pattern to that of the continuous type. It was identified in 5 cases (31.25%) within the left hemispheres, compared to a slightly lower occurrence of 4 cases (25.0%) within the right hemispheres. This distribution underscores a more balanced presence across hemispheres, potentially reflecting a different set of functional associations or developmental mechanisms compared to the continuous pattern.

Temporal pole pattern

Temporal pole pattern is characterized by the presence of one long main sulcus stem and one or two perpendicular sulci branches at the temporal pole. In simpler terms, when observing the sulcal pattern near the temporal pole, one would notice a main sulcus extending in a particular direction with one or two additional sulci branching off mostly perpendicularly.

Moreover, the temporal pole pattern type demonstrated a significant lateralization towards the left hemisphere, with 7 instances (43.75%) recorded, in stark contrast to a minimal occurrence in the right hemisphere, noted in only 2 instances (12.5%). This pronounced lateralization highlights the left hemisphere's dominant role in harboring the temporal pole pattern, suggesting a potential link to specialized cognitive or neural processes localized predominantly within the left cerebral hemisphere.

Despite these observed disparities in the distribution of pattern types between the left and right hemispheres, subsequent statistical analyses indicated that the differences in pattern type prevalence did not reach statistical significance.

Segments, short and long branches

For 'Short branches', in both sides, medians are 3 with slightly different IQRs (1.75 on the left and 2 on the right), but the mean ranks are nearly equal (17 on the left and 16 on the right), and the p-value of 0.756 suggests no significant difference between sides. (Figure 6).

For 'Long branches', the median and IQR are slightly higher on the right (2.5 and 2.75, respectively) compared to the left (2 and 2.5). The mean ranks are 15.53 on the left and 17.47 on the right. The p-value of 0.549 indicates no significant difference between sides.

For 'Segment numbers', the median on the left being 2 (IQR 1.75) and on the right being 1 (IQR 1). The mean ranks differ more here, with 19.03 on the left and 13.97 on the right, suggesting a potential difference between sides. However, the p-value of 0.105 is above the common threshold for significance, suggesting that any observed difference could be due to chance (Table 3).

Overall, none of the comparisons between the left and right sides across the three categories shows statistical significance, as all p-values are above 0.05.

For Continuous Pattern, the median is 1 with an IQR of 0.0, and the mean rank is 7.86. Interrupted Pattern has a median of 3 with an IQR of 1.5, and a much higher mean rank of 26.56. Temporal Pole Pattern has a median of 2 with an IQR of 0.0, and a mean rank of 19.89. The p- value for Continuous Pattern is highly significant at 0.0001, indicating a statistically significant difference in segment numbers for the Continuous Pattern compared to the others. The different letters (a, b, c) next to the mean ranks suggest that post hoc analysis was performed and showed significant differences between the groups. The data suggest that there is a statistically significant difference in segment numbers across different pattern types, particularly noting the Continuous Pattern's lower mean rank and significant p-value. There is no significant difference in the short and long branches across different pattern types based on the provided p-values (Table 4).

Discussion

The temporal lobe, where the STS is located, is a common site for surgical interventions, including the resection of tumors, treatment of epilepsy, and the management of vascular abnormalities. The STS serves as an important landmark for orienting the surgeon and planning the safest and most effective route to the target area, minimizing disruption to critical brain functions. Given microneurosurgeon should aim to use the natural corridors instead of a transcortical approaches, STS anatomy is very important to know for a safe surgery for the superior and middle temporal gyrus lesions [5, 6, 7]. The safety of resecting the anterior portion of the STS warrants careful consideration, as it is associated with functional implications.

Preoperative imaging techniques such as functional MRI and diffusion tensor imaging can help in visualizing the STS and assessing its relationship to the surgical target. These technologies enable surgeons to tailor their approach to the individual patient's brain anatomy, maximizing therapeutic outcomes while minimizing risks. We posit that an enriched understanding of the STS will augment the neurosurgeon's proficiency in preoperative planning and decision-making, thereby facilitating improved surgical outcomes.

Neuroanatomical studies have highlighted the role of the STS in various cognitive processes, including audiovisual integration and social perception [8, 9]. Furthermore, data indicate that damage to the STS may be linked to deficits in facial emotion recognition and language processing, anxiety and depressive symptoms on sleep quality [10,11,12]. Dole et al. observed functional anomalies within the right STS in adults with dyslexia during tasks involving word processing. This asymmetry within the mid-portion of the right STS may be indicative of the region's specialized role in the processing of vocal information in humans [13]. Furthermore, the study by Horn et al. revealed that the gray matter volume around the STS is crucial for language processing, particularly in the storage of lexical information. Structural irregularities in this area could impair the retrieval of lexical information, potentially playing a role in the development of formal thought disorder, a primary symptom of schizophrenia [14]. Along the same line, Boddaert et al. observed significant bilateral decreases in grey matter concentration in the STS by comparing voxel-based morphometry of cerebral MRI between 21 autistic children and 12 neurotypical children [15].

Detailed sulci and gyri anatomy is monumental for neurosurgeons given it provide important roadmap to reach various cerebral pathologies [7, 16 17, 18]. Ochiai et al. conducted a study examining the sulcal pattern and morphology of the STS in 29 normal adult volunteers through magnetic resonance imaging. They found a notable asymmetry between the right and left STS, with the left STS complex being consistently situated more posteriorly than its right counterpart, as well as significant fluctuations in depth within STS offer valuable insights. The observed variations serve as discriminative features, facilitating the identification of prospective anatomical landmarks integral to the meticulous segmentation of the sulcus. Our own results align with Ochiai et al.'s observations, supporting and corroborating the documented significant asymmetry in the STS in between right and left hemisphere. This consistency in outcomes underscores the robustness of the observed anatomical asymmetry and contributes to the growing body of evidence regarding the distinct morphological characteristics of the left and right STS in the general adult population [19]. A similar asymmetry between two hemispheres was found in a autopsy study by Gonul et al. In their study, utilizing specimens, the research team observed a distinct asymmetry between the left and right hemispheres concerning the structural configuration of the STS. Their methodological approach involved categorizing the STS based on its morphological continuity, specifically delineating it as either 'continuous' or 'interrupted.' This classification was executed without accounting for the diverse branching patterns that the STS may exhibit. Such an omission underscores a focused yet limited perspective on the anatomical variability of the STS, potentially overlooking intricate details that could contribute to a more comprehensive understanding of its functional implications and variability across individuals [20]. In our study we categorized the STS patterns with three patterns which include the temporal pole pattern. It is extensively shown that the temporal pole is a multifaceted anatomical area, comprising various unique zones, each characterized by specific cellular structures and patterns of connectivity. Consequently, it is linked to a wide range of functions, including visual, language, semantic, and socio-emotional roles, as evidenced by studies on lesions and functional imaging [21]. Furthermore, several PET studies conducted on healthy volunteers have demonstrated the activation of both temporal poles during linguistic tasks, such as story recall, word list recall, story reading, and comprehension tasks, showing a left-sided dominance for language functions. Additionally, numerous studies in the realm of neurodegenerative diseases have corroborated the significance of the temporal pole in language processing [21, 22, 23].

Cadaveric studies are crucial for learning about brain anatomy, providing detailed insights into the surface features like sulci and gyri, as well as deeper structures within the brain. On the other hand, radiological studies using MRI and CT scans are valuable tools that complement cadaveric studies. They provide a non-invasive way to visualize the brain's structures in living individuals, offering insights into both the anatomy and functioning of the brain, which is crucial for medical research and practice. Sulci and gyri examination of human brains is essential for understanding both normal brain anatomy and the physical impacts of neurological diseases [24,25].

Conclusion

A thorough comprehension of the STS anatomy is pivotal not only for precise surgical navigation but also plays a crucial role in the evolution of neurosurgical methodologies, facilitating procedures that are both safer and more efficacious for patients presenting with diverse brain pathologies.

The undertaking of additional cadaveric studies centered on the STS is anticipated to greatly enhance the expertise and knowledge base of neurosurgeons. The analysis of sulci and gyri is fundamental for elucidating the normative anatomical configuration of the brain as well as delineating the morphological alterations associated with neuropathological conditions.

Ethical approval

The Institutional Review Board of the University of Wisconsin, Madison (IRB-University of Wisconsin, Madison) granted ethical approval for the study (Date: 7/19/202, Number: HRP-312) .

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