EDITORIAL

Probing the tract organization of language: Heschl's gyrus fiber intersection area

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IN 1878, Richard Ladislas Heschl was the first author to describe the anterior transverse temporal gyrus, in *Über die vordere quere Schläfenwindung des menschlichen Grosshirns*.⁷ This gyrus, known today as Heschl's gyrus, is understood to contain the primary auditory cortex, as it reliably exhibits tonotopic maps³ (i.e., how sound frequencies map to different locations) presumably originating from the tonotopic maps encoded by the cochleae. Myriad investigations of Heschl's gyrus have been carried out related to many aspects of auditory processing, including developmental maturation,¹⁵ normal auditory processing,¹⁰ disorders of auditory processing such as autism,¹⁸ pitch processing in musicians,²⁰ and auditory hallucinations in schizophrenia,² among many others. A number of techniques have been used to examine the auditory cortex, including transcranial direct current stimulation,¹¹ PET,¹³ magnetoencephalography,⁹ and functional MRI (fMRI).¹⁶ Techniques used to analyze white matter within and in contact with the auditory cortex, such as volumetric morphometry,¹⁷ electron microscopy,¹ and diffusion MRI,⁶ often reveal an asymmetry between the 2 hemispheres, which is hypothesized to be related to language lateralization.

In this article, Fernández, Velásquez, García Porrero, Marco de Lucas, and Martino present converging evidence from cadaveric fiber dissections, in vivo diffusion MRI tractography, and intraoperative subcortical stimulation to describe the complex white matter architecture in the posterior region of the superior temporal lobe around Heschl's gyrus and the acoustic radiations.⁵ The authors performed detailed dissections in 8 cadaveric hemispheres (4 left and 4 right). They also acquired and analyzed data from diffusion MRI probabilistic tractography in 8 control hemispheres from 4 healthy subjects and intraoperative electrical stimulation mapping in 6 patients with left temporal lobe gliomas who underwent awake resections. Based on these data, the authors propose that 5 fiber tracts

pass through a high-density tract area, which they term the "Heschl's gyrus fiber intersection area (HGFIA)." These tracts are the anterior arcuate fasciculus, the middle longitudinal fasciculus, the acoustic radiation and U fibers connecting Heschl's gyrus with the middle temporal gyrus and, beneath this, the inferior fronto-occipital fasciculus and the optic radiation. The article contains high-quality cerebral hemisphere dissection panels which show these tracts.

The authors relate their anatomical findings of fiber relationships to language theory. Specifically, they note that their work supports the hypothesis that the primary auditory area directly contacts the anterior arcuate fasciculus posteriorly. This contact between the primary auditory area and the anterior arcuate fasciculus could be viewed as support for the existence of the external and internal loops of auditory feedback and the articulatory loop essential for speech articulation. Hickok and Poeppel proposed a framework of dorsal and ventral streams involved in language production,⁸ which itself rests on Liberman's motor theory of speech perception.¹⁴ Inspired by emerging understanding of visual processing via distinct ventral and dorsal streams, Hickok and Poeppel proposed 2 processing streams for language: a ventral stream, which they postulated is involved in mapping sound onto meaning (semantic processing), and a dorsal stream, involved in mapping sound onto articulatory-based representations (phonemic processing). In the present article, Fernández et al. offer the conjecture that the HGFIA is related to these 2 streams of language; superficially, to the dorsal phonological stream via the long and anterior segments of the arcuate fasciculus, and deeply, to the ventral stream via the inferior fronto-occipital fasciculus. Additionally, the authors note that the U fibers connecting the superior and middle temporal gyri may represent a direct connection between the primary auditory area and arcuate fasciculus, which could explain auditory information propagation to

the middle temporal gyrus and from there via the long segment of the arcuate fasciculus to the ventral premotor cortex and the inferior frontal gyrus.

The work presented in this article raises additional questions regarding the role of Heschl's gyrus in language function. The demonstration that stimulation of the HGFA at cortical and subcortical areas results in anomia and semantic paraphasias, in addition to the detailed anatomical descriptions of these tracts, prepares the ground for investigations regarding the neural architecture of language supported by these 5 tracts. The authors note previous work in which stimulating the long segment of the arcuate fasciculus caused phonemic paraphasias.^{4,12,19} With this work established, it would be interesting to see investigations into the specific language disturbances that result from stimulation of each of these 5 tracts individually. For example, future studies could investigate whether stimulation of the anterior segment of the arcuate fasciculus results in speech comprehension and articulation deficits associated with auditory feedback, as the authors describe. Is it possible to separately stimulate each of these 5 tracts? And would such stimulation result in phonological, morphological, syntactic, semantic, or pragmatic language comprehension and production deficits? In future awake surgeries attempts could be made to use neuronavigation and intraoperative imaging to locate and stimulate each tract as precisely and separately as possible while asking patients to perform strategic tasks designed to elicit associated language deficits.

The authors acknowledge that the sample sizes in the present work (8 cadaver hemispheres, 8 healthy control hemispheres, and 6 left temporal glioma patients who underwent intraoperative stimulation testing) were limited. As a result, the reported fiber tract findings are not broken down by sex or language proficiency, including effects on specific languages spoken by multilingual patients undergoing awake surgery. While the authors clearly state the handedness of the surgical tumor patients, handedness of healthy subjects in the study is not specified; in fact, cerebral hemisphere is a between-subject variable only among the 8 dissected human cadaver specimens, preventing comparisons of tract size or connections by hemisphere or handedness. Notably, no formal between-hemisphere analysis was conducted in the healthy control subjects who underwent DTI. Future work could establish the locations of the functional language cortex in the healthy subjects and patients by using fMRI and show how these locations relate to the fiber tracts. Correlating fMRI and language lateralization with tract findings—particularly the question of whether the HGFA differs when language is co-dominant compared to when it is lateralized—would be an interesting future investigation, as would comparing the tracts across a wider age range (the age of cadaver specimens is expectedly narrow, 63–82 years; no age range is specified for the healthy controls or brain tumor patients).

Taken together, the article presents detailed white matter fiber descriptions based on anatomic dissections, diffusion MRI tractography, and functional subcortical mapping. Understanding of the numerous tracts in this region could contribute an interesting perspective on the language function of a specialized area of the posterior-

superior temporal lobe, the HGFA as described by the authors. In showing that resection of the superior temporal gyrus anterior to Heschl's gyrus did not result in language deficits despite resection of a considerable portion of middle longitudinal fasciculus, the work supports the hypothesis that the middle longitudinal fasciculus is not essential for language processing. Thus, the work has important practical implications for approaches to tumor resections in the dominant temporal lobe. Future work remains to further elucidate the exact function of each of the 5 tracts that comprise the area, including differences in dominant and nondominant hemispheres. For example, diffusion imaging with high spatial and angular resolution, perhaps in cadaveric specimens in which extended image acquisitions can be obtained, could build on the proposed fiber organization. We eagerly look forward to seeing what future work this article inspires.

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Disclosures

The authors report no conflict of interest.

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