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BOOK REVIEW

Neuroanatomy of Language Regions of the Human Brain

By Michael Petrides
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The ability to speak and understand language – albeit a consciously fast and effortless process – requires the recruitment of several brain regions, attesting to its computational complexity. That language relies on the integration of computations carried out in disparate brain regions underscores the functional importance of structural white matter connections between these regions. However, despite more than a century of research devoted to understanding the neural bases of language, the connectional architecture of language remains largely unknown. While recent advances in neuroimaging techniques such as diffusion tensor imaging (DTI) enable *in vivo* investigations of white matter connectivity in the human brain, these methods are limited in their ability to reliably reconstruct and isolate distinct fiber tracts (for a review, see Dick and Tremblay, 2012). Investigations of connectivity in the nonhuman primate brain provide increased anatomical specificity. However, significant discrepancies in the terminology of cytoarchitectonic areas in the monkey vs. human brain make this information largely unavailable to researchers interested in the connectional architecture of language. It is within this context that Michael Petrides' *Neuroanatomy of Language Regions of the Human Brain* (2014) informs the cognitive neuroscientist of nonhuman primate neuroanatomical findings potentially relevant for understanding the neural bases of language.

Petrides presents an atlas centered on making primate neuroanatomical findings accessible to investigators interested in the human brain. The book is divided into six sections that collectively describe the neuroanatomical characteristics (i.e., morphological, cytoarchitectural, and connectional properties) of regions thought to be crucial for language processes. The atlas also offers comparative analyses of human and macaque monkey neuroanatomy, describing both the similarities and differences between homologous regions in the respective species' brains. As discussed below, this book has potential as a pedagogical tool, but will likely serve best as a supplementary text – at least for courses at the undergraduate level.

Petrides begins the book by briefly summarizing the seminal research that led to the discovery of the 'core language regions' – or those regions that play a crucial role in language processing. This section places neurolinguistic research in a historical context, providing a succinct overview of the pioneering works of early language researchers such as Paul Broca, Carl Wernicke, and Joseph Jules Dejerine. Petrides motivates the investigation of white matter in language processes by informing the reader of both the early interpretations of lesion-symptom mapping in aphasia and modern interpretations of those findings (e.g., Broca's two now famous patients Leborgne and Lelong) from studies using imaging techniques to quantify both cortical gray matter and subcortical white matter damage (see Dronkers et al., 2007). In addition, this section reviews pertinent findings from studies using electrical stimulation during neurosurgery. Thus, this section is not meant to be an exhaustive account of previous explorations on the neural bases of language. Yet, it informs the reader of two complementary methodological approaches that provide converging evidence of the peri-Sylvian region's critical role in language processes.

The section entitled '[magnetic resonance imaging] MRI Sections' is an excellent resource for learning how to identify core language regions based on MRI slices. Several figures depict the location of language regions with respect to one another on slices of an individual MRI structural scan transformed into Montreal Neurological Institute (MNI) standard stereotaxic space. These figures display the same region(s) across sagittal, axial, and coronal MRI slices. Below each MRI slice is a rendered schematic of the brain with a black line indicating the relative location of the corresponding MR image. The abbreviations used to label each language region are listed in the immediately preceding section entitled 'Abbreviations.' These two sections alone are extremely informative to both students and researchers in the field of neuroscience, as they provide concrete examples of how to identify language regions as commonly viewed in MNI space on MRI neuroimages.

This atlas devotes two sections to describing in great detail the morphological and cytoarchitectural characteristics of core language regions. The section on morphology serves to introduce the reader to the similarities between regions important for language in the human brain with those presumably not subserving language in the macaque brain. Petrides relates the sulcal and gyral patterns of the human peri-Sylvian area with that of the homologous area in the macaque. Similarly, the section on cytoarchitecture bridges the gap between the terminologies used in the nonhuman primate literature with those used in the human literature. Together, these sections serve to motivate the neuroanatomical study of species without language to understand the functional neuroanatomy of language in the human brain.

It is worth noting, however, that the sections on morphological and cytoarchitectural characteristics of core language regions are quite dense. Petrides acknowledges that the atlas is not meant to review neuroanatomy with respect to cognitive processes such as language, but rather it serves to inform the cognitive researcher of anatomical distinctions potentially critical to understanding functional neuroanatomy. To that end, the text provided in these sections is better suited for the seasoned neuroscientist/neuroanatomist.

Lastly, and most importantly, Petrides concludes the book by reviewing evidence elucidating the connectional architecture of language processes – as inferred from neuroanatomical studies of human and nonhuman primates. Due to its infancy, the investigation of white matter pathways in the human brain has yet to establish a concise framework with which the functional relevance of fiber tracts can be systematically integrated with neurolinguistic research (see Dick and Tremblay, 2012). This is evidenced by vast differences in the nomenclature used to label individual white matter pathways both within and across species. While the atlas is conscientious of this issue regarding macaque vs. human delineations of the so-called dorsal language pathways (i.e., the arcuate and superior longitudinal fasciculi [SLF I, II, and III]), it largely ignores issues with ventral language pathway nomenclature. For example, Petrides argues that the ventral language pathways consist of the extreme capsule (EmC). However, Catani and Mesulam (2008) claim that ventral language pathways include the inferior longitudinal fasciculus (ILF), uncinate fasciculus (UF), and the inferior fronto-occipital fasciculus (IFOF). Indeed, evidence elsewhere suggests that these ventral language pathways play an important role in language processes, where the UF, connecting frontal with temporal regions, is critical for controlling the activation of semantic knowledge (Harvey et al., 2013) and the ILF, connecting posterior with anterior temporal lobe regions, is important for word-to-meaning mapping (Saur et al., 2008, 2010; Wong et al., 2011). Thus, although this atlas offers a complete discussion of dorsal language pathway nomenclature issues, it fails to recognize these same issues with ventral language pathways.

Can language researchers draw conclusions about the neural bases of language from species whose evolution did not result in the development of language? Although Petrides acknowledges the inherent differences between human and macaque language capacities, one still wonders whether it is appropriate to use the macaque brain as a neuroanatomical model for language processes. Petrides argues that the structural properties of homologous regions should be the same regardless of whether or not their functional properties differ. While this explanation seems reasonable, others doubt its validity (see Catani, 2009). Nevertheless, the methods currently available for researching human neuroanatomy do not offer the anatomical specificity achievable with those used in nonhuman primate brain research. Improvements in DTI methods will increase our ability to reliably reconstruct and isolate human white matter pathways. Until then, we are left with the next best approach – the structurally similar primate brain.

In conclusion, *Neuroanatomy of Language Regions of the Human Brain* (2014) serves as an excellent resource for understanding neuroanatomical characteristics of the human brain as it relates to nonhuman primate neuroanatomy. This atlas features exceptional figures illustrating where core language regions are located in the brain and the neuroanatomical characteristics of these regions. While the atlas is not meant to be a complete discussion of language processes from a cognitive perspective, it provides enough background information to place the topic in context. Further, despite the incomplete discussion of issues regarding ventral language pathway nomenclature, the atlas does provide useful information regarding the issues with dorsal language pathway nomenclature. However, because some of the neuroanatomical discussion requires an advanced understanding of functional neuroanatomical relationships, it is recommended that the atlas serve as a supplementary text in advanced undergraduate courses with a focus on neuroanatomy.

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