LANGUAGE IN OUR BRAIN

THE ORIGINS OF A UNIQUELY HUMAN CAPACITY

ANGELA D. FRIEDERICI

FOREWORD BY NOAM CHOMSKY

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LINGUISTICS/COGNITIVE NEUROSCIENCE

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Language makes us human. It is an intrinsic part of us, although we seldom think about it. Language is also an extremely complex entity with subcomponents responsible for its phonological, syntactic, and semantic aspects. In this landmark work, Angela Friederici offers a comprehensive account of these subcomponents and how they are integrated. Tracing the neurobiological basis of language across brain regions in humans and other primate species, she argues that species-specific brain differences may be at the root of the human capacity for language.

Friederici shows which brain regions support the different language processes and, more important, how these brain regions are connected structurally and functionally to make language processes that take place in milliseconds possible. She finds that one particular brain structure (a white matter dorsal tract), connecting syntax-relevant brain regions, is fully present only in the mature human brain and only weakly present in other primate brains. Is this the "missing link" that explains humans' capacity for language?

Friederici describes the basic language functions and their brain basis; the language networks connecting different language-related brain regions; the brain basis of language acquisition during early childhood and when learning a second language (and proposes a neurocognitive model of the ontogeny of language); and the evolution of language and underlying neural constraints. She finds that it is the information exchange between the relevant brain regions, supported by the white matter tract, that is the crucial factor in both language development and evolution.

ANGELA D. FRIEDERICI is Vice President of the Max Planck Society and Director of the Max Planck Institute for Human Cognitive and Brain Sciences, Leipzig.

"In this masterful summary of decades of work on the neurobiological foundations of language, Friederici develops a comprehensive account of how this most complex of human computational functions is organized, providing a detailed and lucid perspective on the neuroscience of language. This is essential reading for anyone interested in a theoretically motivated and biologically sophisticated perspective on how language is represented and processed in the brain."

—DAVID POEPPEL, Professor of Psychology and Neural Science, New York University; Scientific Member and Director, Neuroscience Department, Max Planck Institute of Empirical Aesthetics

"No stone has been left unturned in Angela Friederici's masterful all-encompassing scientific analysis of the brain systems that allow human beings to communicate with one another. It is a delightful and enriching read for linguists and neuroscientists alike."

—CATHY J. PRICE, Professor in Cognitive Neuroscience, University College London

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Language in Our Brain

Es ist recht unwahrscheinlich, daß die reine Psychologie zu einer wirklichen naturgemäßen Anschauung der Gliederung im Geistigen vordringen wird, solange sie der Anatomie des Seelenorgans grundsätzlich den Rücken kehrt.

It is rather unlikely that psychology, on its own, will arrive at the real, lawful characterization of the structure of the mind, as long as it neglects the anatomy of the organ of the mind.
—Paul Flechsig (1896), Leipzig

Foreword

Fifty years ago, Eric Lenneberg published his now-classic study that inaugurated the modern field of biology of language—by now a flourishing discipline, with remarkable richness of evidence and sophistication of experimentation, as revealed most impressively in Angela Friederici's careful and comprehensive review of the field, on its fiftieth anniversary.

Friederici's impressive study is indeed comprehensive, covering a rich range of experimental inquiries and theoretical analyses bearing on just about every significant aspect of the structure and use of language, while reaching as well to the ways language use is integrated with systems of belief about the world generally. Throughout, she adopts the general (and in my view highly reasonable if not unavoidable) conception that processing and perception access a common "knowledge base," core internal language, a computational system that yields an unbounded array of structured expressions. Her discussion of a variety of conceptions and approaches is judicious and thoughtful, bringing out clearly the significance and weaknesses of available evidence and experimental procedures. Her own proposals, developed with careful and cautious mustering and analysis of evidence, are challenging and far-reaching in their import.

Friederici's most striking conclusions concern specific regions of Broca's area (BA 44 and BA 45) and the white matter dorsal fiber tract that connects BA 44 to the posterior temporal cortex. Friederici suggests that "This fiber tract could be seen as the missing link which has to evolve in order to make the full language capacity possible." The conclusion is supported by evidence that this dorsal pathway is very weak in macaques and chimpanzees, and weak and poorly myelinated in newborns, but strong in adult humans with language mastery. Experiments reported here indicate further that the "Degree of myelination predicts behavior in processing syntactically complex non-canonical sentences" and that increasing strength of this pathway "correlates directly with the increasing ability to process complex syntactic structures." A variety of experimental results suggest that "This fiber tract may thus be one of the reasons for the difference in the language ability in human adults compared to the prelinguistic infant and the monkey." These structures, Friederici suggests, appear to "have evolved to subserve the human capacity to process syntax, which is at the core of the human language faculty."

BA 44, then, is responsible for generation of hierarchical syntactic structures, and accordingly has "particular characteristics at the neurophysiological level," differing from other brain regions at both functional and microstructural levels. More specifically, it is the ventral part of B44 in which basic syntactic computations—in the simplest case Merge—are localized, while adjacent areas are involved in combinatorial operations independent of syntactic structure. BA 45 is responsible for semantic processes. Within Broca's area neural networks are differentiated for language and action. These are bold proposals, with rich implications insofar as they can be sustained and developed further.

Friederici's extensive review covers a great deal of ground. To give only a sample of topics reviewed and proposed conclusions, the study deals with the dissociation of syntactic/semantic processing both structurally and developmentally. It reviews the evidence that right-hemisphere specialization for prosody may be more primitive in evolution, and that its contributions are integrated very rapidly (within a second) with core language areas for assignment and interpretation of prosodic structure of expressions. Experimentation reveals processes of production that precede externalization. The latter is typically articulatory, though since the pioneering work of Ursula Bellugi enriched by the illuminating work of Laura Ann Petitto and others, it is now known that sign is readily available for externalization and is so similar to speech in relevant dimensions that it is plausible, Friederici suggests, to conclude that there is "a universal neural language system largely independent of the input modality," modulated slightly by lifelong use of sign. Brain regions are specialized for semantic-syntactic information and syntactic processing of complex non-canonical sentences. Language mastery develops in regular and systematic ways that are revealed by mutually supportive behavioral and neurological investigations, with some definite semi-critical periods of sensitivity. By ages 2–3, children have attained substantial syntactic knowledge though full mastery of the language continues to early adolescence, as shown by behavioral studies and observation of neural domain-specificity for syntactic structures and processes.

The result of this wide-ranging exploration is a fascinating array of insights into what has been learned in this rapidly developing field and a picture of the exciting prospects that lie ahead.

Noam Chomsky
November 2016
Cambridge, Massachusetts

Preface

Language makes us human. It is an intrinsic part of us. We learn it, we use it, and we seldom think about it. But once we start thinking about it, language seems like a sheer wonder. Language is an extremely complex entity with several subcomponents responsible for the language sound, the word's meaning, and the grammatical rules governing the relation between words.

I first realized that there are indeed such subcomponents of language when I worked as a student in a clinic of language-impaired individuals. On one of my first days in the clinic I was confronted with a patient who was not able to speak in full sentences. He seemed quite intelligent, was able to communicate his needs, but did so in utterances in which basically all grammatical items were missing—similar to a telegram. It immediately occurred to me: if grammar can fail separately after a brain injury, it must be represented separately in the brain. This was in 1973. At this time structural brain imaging such as computer tomography was only about to develop and certainly not yet available in all clinics.

Years later in 1979, when I spent my postdoctoral year at the Massachusetts Institute of Technology (MIT) and at the Boston Veterans Hospital of the Boston University, the neurologist Norman Geschwind was one of the first to systematically relate sensory and cognitive impairments to particular brain sites in vivo by means of computer tomography. In his clinical seminars he examined a given patient behaviorally and from this predicted the site of the patient's brain lesion. Then the computer tomographic picture of the patient's brain lesion was presented. Norman Geschwind most of the time had made the correct prediction, thereby providing impressive evidence for a systematic relation between brain and behavior.

Today, more than 35 years later, our knowledge about the relationship between brain and cognitive behavior has dramatically increased due to the advent of new brain imaging techniques such as functional magnetic resonance tomography. This is in particular true for the domain of language thanks to studies that were guided and informed by linguistic theory.

Linguistics provides a systematic description of the three relevant language components: the sound of language, its semantics (dealing with the meaning of words and word combinations), and its syntax (dealing with the grammatical rules determining the combination

of words). All these different components have to work together in milliseconds in order to keep track of online language use. If we want to understand language we first have to disentangle this complex entity into its relevant pieces—its subcomponents—and then see how they work together to make language use possible. It is like a mosaic, in that once all the pieces are in place a coherent picture will evolve.

In *Language in Our Brain* I will provide a description of the relevant brain systems in support of language with its subcomponents, how they develop during the first years of life, and, moreover, how they possibly emerged during evolution.

For this book I drew primarily from empirical data on the language-brain relationship available in the literature. Parts of it come from articles I have written together with my students and colleagues. It is the work and discussions with them on which the view laid down here is built. My thanks go to all who have been working with me over the years.

Acknowledgments

Had I not met Noam Chomsky in fall 1979 at a workshop at the MIT Endicott House, I would not have written this book. His idea of language as a biological organ, and Jerry Fodor's postulate of the modularity of mind—hotly debated at the time—left their trace in my subsequent work. I set out for the search of the neurobiological basis of language. In *Language in Our Brain* I present what we know today about the neural language network and its ontogeny and phylogeny.

On my scientific path I received support from a number of excellent teachers and colleagues. During my post-doctoral year at MIT this was Merrill Garrett, and back in Europe it was Pim Levelt, who offered me the chance to conduct my research at the Max Planck Institute for Psycholinguistics.

In 1994 the dream of my scientific life became true. The Max Planck Society offered an opportunity to me and to my dear colleague, the neurologist Yves von Cramon, to build up a new Max Planck Institute for Cognitive Neuroscience in Leipzig. Now we only had to turn the dream into reality, which with the help of the Max Planck Society we did. I am most grateful for this.

My sincere thanks go to my colleagues from inside and outside the institute who have read and critiqued portions of *Language in Our Brain*, each with their special expertise. I am deeply thankful to Pim Levelt and Marco Tettamanti for their feedback on large parts of the book. Special thanks go to Wolfgang Prinz, who as a non-expert in neuroscience gave many helpful suggestions that have greatly improved its clarity.

Many thanks go to the colleagues in my department who together with me wrote major review articles upon which parts of the book are based, and who also gave critical feedback on various parts of the book. These are, in alphabetical order: Alfred Anwander, Jens Brauer, Tomás Goucha, Thomas C. Gunter, Gesa Hartwigsen, Claudia Männel, Lars Meyer, Michael A. Skeide, and Emiliano Zaccarella.

Special thanks go to Emiliano Zaccarella, who constructed the glossary of this book. I am indebted to Andrea Gast-Sandmann, who produced and adapted the figures for this book. Many thanks go to Elizabeth Kelly for editing the text in English. I am indebted to Christina Schröder for her support throughout all stages of the emergence of this book. Moreover, I express my gratitude to Margund Greiner for her tireless commitment to bring the complete manuscript into a presentable form.

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