

# Contents

---

List of Contributors  
Acknowledgement

xxi  
xxvii

3. The Ventrolateral Frontal Region  
MICHAEL PETRIDES

---

## SECTION A

---

### INTRODUCTION

1. The Neurobiology of Language  
STEVEN L. SMALL AND GREGORY HICKOK

1.1 History	3
1.2 Lesion Analysis	3
1.3 From Neuropsychology to Cognitive Neuroscience	4
1.4 The Neurobiology of Language	5
1.5 Some Common Fallacies	5
1.6 Humans in Particular	6
1.7 Cognition and the Neurobiology of Language	7
1.8 Brain Disease, Treatment, and the Neurobiology of Language	7
1.9 Summary	8
References	8

3.1 Cytoarchitectonic Areas of the Ventrolateral Prefrontal Cortex	27
3.2 Parietal and Temporal Cortico-Cortical Connection Patterns of the Language Production Areas in the Ventrolateral Frontal Region	28
3.3 Functional Implications	30
3.4 Non-Ventrolateral Prefrontal Areas and Their Possible Role in Language	31
Acknowledgments	32
References	32

4. On the Neuroanatomy and Functional Role of the Inferior Parietal Lobule and Intraparietal Sulcus

FERDINAND CHRISTOPH BINKOFSKI, JULIANE KLANN AND SVENJA CASPERS

4.1 Gross Anatomy of the IPL and IPS	35
4.2 Modern Parcellation of the IPL and IPS	35
4.3 Connectivity of the IPL and IPS	38
4.4 Anatomical Differences Between Humans and Monkeys	39
4.5 Functions and Functional Connectivity of the IPL and IPS	39
4.6 Summary	43
References	43

2. A Molecular Genetic Perspective on Speech and Language

SIMON E. FISHER

2.1 Introduction	13
2.2 The Discovery of <i>FOXP2</i>	14
2.3 <i>FOXP2</i> Mutations in Speech and Language Disorders	15
2.4 Functions of <i>FOXP2</i> : The View from the Bench	16
2.5 Insights from Animal Models	17
2.6 <i>FOXP2</i> in Human Evolution	20
2.7 Conclusions	20
References	21

5. Human Auditory Cortex

BRIAN BARTON AND ALYSSA A. BREWER

5.1 Introduction	49
5.2 Cortical Field Maps	49
5.3 Tonotopy: The First Dimension of AFMs	50
5.4 Cortical Organization of the Monkey Auditory System	50
5.5 Cortical Organization of the Human Auditory System	51
5.6 Periodotopy: The Second Dimension of AFMs	52
5.7 Similarities to AFM Organization in the Human Visual System	53
5.8 "Clover Leaf" Clusters Across Senses	55

5.9 Conclusion	55	9.6 Models of Thalamus and Language	109
References	56	9.7 Summary and Conclusions	110
		Acknowledgments	112
		References	112
6. Motor Cortex and Mirror System in Monkeys and Humans		10. The Insular Cortex	
GIACOMO RIZZOLATTI AND STEFANO ROZZI		JESSICA D. RICHARDSON AND JULIUS FRIDRIKSSON	
6.1 Introduction	59	10.1 Gross Anatomy	115
6.2 Anatomy of the Monkey Motor Cortex	59	10.2 Cytoarchitecture	115
6.3 The Human Motor Cortex	65	10.3 Vasculature	117
6.4 Motor System and Communication	67	10.4 Connectivity	118
6.5 Conclusion	68	10.5 Insular Cortex and Behavior	120
Acknowledgment	69	10.6 Association with Speech—Language Behavior	122
References	69	References	125
7. Cerebellar Contributions to Speech and Language		11. White Matter Pathways in the Human	
HERMANN ACKERMANN AND BETTINA BRENDEL		HUGUES DUFFAU	
7.1 Introduction	73	11.1 Introduction	129
7.2 Macroscopic and Microscopic Anatomy of the Human Cerebellum	73	11.2 Projection Pathways	130
7.3 Comparative Anatomic Perspectives on Size and Composition of the Cerebellum	76	11.3 Long-Distance Association Pathways	131
7.4 Cerebellar Support of Motor Control in Humans: Upper Limb Movements	76	11.4 Implication of a Hodotopical View of Brain Organization in Humans: Rethinking the Connectivity of Language and Its Relationships with Cognition	133
7.5 Contributions of the Cerebellum to Speech Motor Control	77	11.5 The Limiting Role of Axonal Connectivity in Brain Plasticity	134
7.6 Engagement of the Cerebellum in Nonmotor Functions	80	11.6 Conclusion	135
7.7 Conclusion	82	References	135
References	82		
8. The Anatomy of the Basal Ganglia		<b>SECTION C</b>	
KATE E. WATKINS AND NED JENKINSON		<b>BEHAVIORAL FOUNDATIONS</b>	
8.1 Introduction	85	12. Phonology	
8.2 Historical Background	85	WILLIAM J. IDSARDI AND PHILIP J. MONAHAN	
8.3 Overview of Basal Ganglia Anatomy	86	12.1 Introduction	141
8.4 The Role of the Basal Ganglia in Speech Motor Control	90	12.2 Speech Sounds and the MAP Loop	141
8.5 The Role of the Basal Ganglia in Language	91	12.3 Features or the Internal Composition of Sounds	145
8.6 Segregated Functional Loops for Speech and Language	92	12.4 Local Sound Combinations and Chunking	147
8.7 Summary	92	12.5 Nonlocal Sound Combinations	148
References	92	12.6 Summary	149
		References	149
9. The Thalamus and Language		13. Morphology	
DANIEL A. LLANO		ALEC MARANTZ	
9.1 Overview of Thalamic Organization	95	13.1 Introduction	153
9.2 Defining the Role of the Thalamus in Language	96	13.2 Why Morphology?	154
9.3 A Thalamic “Locus” for Language?	103	13.3 What Makes Morphology, Morphology	156
9.4 Imaging of the Thalamus in Language Tasks	105		
9.5 Thalamic Circuitry and Physiology	107		

13.4 Types of Morphemes, Types of Morphologies, Types of Morphological Theories	157	17.3 Adaptive Processing and Perceptual Learning	198
13.5 The View from Above	160	17.4 Empirical Evidence for Active Processing in Talker Normalization	200
13.6 Words and Rules: The Modern Consensus on Decomposition	161	17.5 Toward an Active Theory of Contextual Normalization	201
Acknowledgments	163	17.6 Neurobiological Theories of Speech Perception	202
References	163	17.7 Subcortical Structures and Adaptive Processing	204
14. Syntax and the Cognitive Neuroscience of Syntactic Structure Building		17.8 Conclusion	205
JON SPROUSE AND NORBERT HORNSTEIN		Acknowledgments	206
14.1 Introduction	165	References	206
14.2 A Brief History of Syntactic Theory	166	18. Successful Speaking: Cognitive Mechanisms of Adaptation in Language Production	
14.3 Two Concrete Examples of Syntactic Structure-Building Computations	168	GARY S. DELL AND CASSANDRA L. JACOBS	
14.4 Additional Properties of Syntactic Theories That One Would Expect from a Theory of Cognitive Computations	170	18.1 Language Production	209
14.5 The Collaboration Necessary to Engage in This Program	171	18.2 Long-Term Speaker Tuning: Implicit Learning	211
14.6 Challenges to This Research Program	172	18.3 Short-Term Speaker Tuning	214
14.7 Conclusion	173	18.4 Conclusion	218
References	173	Acknowledgments	218
15. Speech Perception as a Perceptuo-Motor Skill		References	218
CAROL A. FOWLER		19. Speech Motor Control from a Modern Control Theory Perspective	
15.1 Introduction	175	JOHN F. HOUDE AND SRIKANTAN S. NAGARAJAN	
15.2 Research Findings	177	19.1 Introduction	221
15.3 Conclusion	181	19.2 The Role of the CNS in Processing Sensory Feedback During Speaking	221
References	182	19.3 The CNS as a Feedforward Source of Speech Motor Commands	222
16. Speech Perception	185	19.4 Current Models of the Role of the CNS in Speech Motor Control	224
ANDREW J. LOTTO AND LORI L. HOLT		19.5 The Concept of Dynamical State	224
16.1 Introduction	185	19.6 A Model of Speech Motor Control Based on State Feedback	225
16.2 Effects of Auditory Distinctiveness on the Form of Speech	186	19.7 SFC Models Motor Actions as an Optimal Control Process	226
16.3 Effects of Auditory Interaction on the Form of Speech	187	19.8 Speaking Behaves Like an Optimal Control Process	227
16.4 Effects of Learnability on the Form of Speech	189	19.9 SFC Explains the Task-Specific Role of the CNS in Speech Feedback Processing	230
16.5 Moving Forward	191	19.10 Is SFC Neurally Plausible?	230
References	192	19.11 SFC Accounts for Efference Copy Phenomena	231
17. Understanding Speech in the Context of Variability		19.12 Neural Substrate of the SFC Model	232
SHANNON HEALD, SERENA KLOS AND HOWARD NUSBAUM		19.13 Conclusion	234
17.1 Speech and Speakers	195	References	234
17.2 The Lack of Invariance Problem	197		

## 20. Spoken Word Recognition: Historical Roots, Current Theoretical Issues, and Some New Directions

DAVID B. PISONI AND CONOR T. MCLENNAN

20.1 Introduction	239
20.2 Historical Roots and Precursors to SWR	239
20.3 Principle Theoretical Issues in SWR	240
20.4 SWR and the Mental Lexicon	246
20.5 Some New Directions and Future Challenges	248
20.6 Summary and Conclusions	249
Acknowledgments	249
References	249

## 21. Visual Word Recognition

KATHILEEN RASTLE

21.1 The Architecture of Visual Word Recognition	255
21.2 Orthographic Representation	256
21.3 Processing Dynamics and Mechanisms of Selection	258
21.4 Visual Word Recognition and the Reading System	260
21.5 Conclusion	262
Acknowledgment	262
References	262

## 22. Sentence Processing

FERNANDA FERREIRA AND DERYA ÇOKAL

22.1 Sources of Information for Sentence Processing	265
22.2 Theoretical Controversies	268
22.3 Classes of Models of Sentence Processing	270
22.4 Conclusion	272
References	272

## 23. Gesture's Role in Learning and Processing Language

ÖZLEM ECE DEMİR AND SUSAN GOLDIN-MEADOW

23.1 Gesture Not Only Reflects Thought, It Can Play a Role in Changing Thought	275
23.2 Role of Gesture in Language Learning	276
23.3 Role of Gesture in Language Processing	279
23.4 Implications for the Neurobiology of Language	281
References	281

# SECTION D

## LARGE-SCALE MODELS

### 24. Pathways and Streams in the Auditory Cortex

JOSEF P. RAUSCHECKER AND SOPHIE K. SCOTT

24.1 Human Speech Perception	287
24.2 Where Is "Wernicke's Area"?	287
24.3 Dual Processing Streams and Hierarchical Organization in the Auditory Cortex of the Monkey	288
24.4 Dual Processing Streams in the Auditory Cortex of Humans	290
24.5 Conclusions: A Common Computational Function for the Postero-Dorsal Stream?	293
Acknowledgments	294
References	294

### 25. Neural Basis of Speech Perception

GREGORY HICKOK AND DAVID POEPEL

25.1 Introduction	299
25.2 The Dual Route Model of Speech Processing	299
25.3 Clinical Correlates of the Dual Stream Model	307
25.4 Summary	307
References	308

### 26. Brain Language Mechanisms Built on Action and Perception

FRIEDEMANN PULVERMÜLLER AND LUCIANO FADIGA

26.1 Introduction	311
26.2 Phonemes	312
26.3 Signs	314
26.4 Meaning	314
26.5 Combinations and Constructions	317
26.6 Speech Acts and Social-Communicative Interaction	318
26.7 Outlook: Key Issues in Brain Language Research	319
Acknowledgments	321
References	321

### 27. The Dual Loop Model in Language

CORNELIUS WEILLER, TOBIAS BORMANN, DOROTHEE KUEMMERER, MARIACHRISTINA MUSSO AND MICHEL RIJNTJES

27.1 Patients	327
27.2 Neuropsychology	328

27.3 Functions of the Dual Loop Model	329
27.4 Anatomy, Hubs, Divisions	329
27.5 Development	333
References	334

## 28. MUC (Memory, Unification, Control): A Model on the Neurobiology of Language Beyond Single Word Processing

PETER HAGOORT

28.1 Introduction	339
28.2 Memory, Unification, and Control	339
28.3 The Network Topology of the Language Cortex	340
28.4 The Empirical Evidence for the MUC Model	342
28.5 A General Account of the Role of LIFC in Language Processing	343
28.6 The Dynamic Interplay Between Memory and Unification	344
28.7 Attentional Control	345
28.8 Beyond the Classical Model	345
Acknowledgments	346
References	346

## 29. The Neuroanatomical Pathway Model of Language: Syntactic and Semantic Networks

ANGELA D. FRIEDERICI

29.1 Introduction	349
29.2 From Dorsal and Ventral Streams to Fiber Tracts	349
29.3 The Neuroanatomical Pathway Model of Language	350
29.4 Conclusion	354
Acknowledgments	354
References	354

## 30. The Argument Dependency Model

INA BORNKESSEL-SCHLESEWSKY AND MATTHIAS SCHLESEWSKY

30.1 Introduction	357
30.2 A Brief History of the Development of eADM	357
30.3 Design Principles	358
30.4 The Model Architecture	360
30.5 Evidence for the Model	364
30.6 Consequences for Electrophysiology	366
30.7 Outlook	366
Acknowledgments	367
References	367

## SECTION E

### DEVELOPMENT, LEARNING, AND PLASTICITY

## 31. Language Development

FREDERIC DICK, SALONI KRISHNAN, ROBERT LEECH AND  
SUZANNE CURTIN

31.1 Precursors to Language	373
31.2 First Words	376
31.3 Individual Variability, Developmental Trajectories, and the Vocabulary "Burst"	377
31.4 Early Language and Its Relationship to Nonlinguistic Abilities	378
31.5 Relationship Between Early Development and Later Language Abilities	379
31.6 The Relationship Between Vocabulary and Grammar	379
31.7 The Nature of Children's Early Grammar	381
31.8 Language Development in Older Children	381
31.9 Neural Measures of Language Development	382
31.10 Conclusion	384
Acknowledgments	384
References	384

## 32. The Neurobiology of Gesture and Its Development

ANTHONY STEVEN DICK AND IRIS BROCE

32.1 Exploring Gesture and Its Development at the Behavioral Level	389
32.2 Gesture and Its Development in the Context of a Broader Neurobiology of Language	390
32.3 The Neurobiology of Gesture: Electrophysiology	390
32.4 The Neurobiology of Gesture: Functional Imaging	391
32.5 The Neurobiology of Gesture Development	395
32.6 Conclusion	395
References	395

## 33. Development of the Brain's Functional Network Architecture

DEANNA J. GREENE, CHRISTINA N. LESSOV-SCHLAGGAR  
AND BRADLEY L. SCHLAGGAR

33.1 What Is a Network and How Can We Study Brain Networks?	399
33.2 Organization of the Brain's Functional Network Architecture	401
33.3 Is There a Language Network?	401
33.4 Development of Brain Networks	403

33.5 Implications of Development of Brain Networks to Language-Related Brain Regions	404
33.6 Future Directions	405
Acknowledgment	405
References	405
34. Bilingual Development and Age of Acquisition	
ARTURO E. HERNANDEZ	
34.1 Introduction	407
34.2 Age of Acquisition	407
34.3 AoA in a Single Language	408
34.4 The Relationship Between AoA and Sensitive Periods	409
34.5 AoA and Second Language Learning	409
34.6 Phonology in a Second Language	410
34.7 AoA and the Bilingual Brain	411
34.8 Grammatical Processing and AoA	412
34.9 Isolating AoA	413
34.10 AoA Effects During Grammatical Processing	413
34.11 Comparing First and Second Languages	415
34.12 AoA and Development	415
References	416
35. Bilingualism: Switching	
ALBERT COSTA, FRANCESCA M. BRANZI AND CESAR ÁVILA	
35.1 Introduction	419
35.2 Language Switching: Instantiating the Paradigm	419
35.3 Evidence from Electrophysiology	421
35.4 The Neural Correlates of Language Control: A Frontal, Parietal, and Subcortical Network	424
35.5 Conclusion	428
References	428
36. Neurobiology of Sign Languages	
DAVID P. CORINA AND SHANE BLAU	
36.1 Introduction	431
36.2 Sign Language Aphasia	431
36.3 Right Hemisphere Damage	435
36.4 Neuroimaging	437
36.5 Sign Language and the Mirror Neuron System	439
36.6 Conclusion	440
Acknowledgments	441
References	441

## SECTION F

### PERCEPTUAL ANALYSIS OF THE SPEECH SIGNAL

#### 37. Phoneme Perception

JEFFREY R. BINDER

37.1 Neuropsychological Studies	450
37.2 Functional Imaging Studies	450
37.3 Direct Electrophysiological Recordings	454
37.4 The Role of Articulatory Representations in Phoneme Perception	455
37.5 Hemispheric Specialization in Phoneme Perception	457
References	458

#### 38. A Neurophysiological Perspective on Speech Processing in "The Neurobiology of Language"

LUC H. ARNAL, DAVID POEPEL AND ANNE-LISE GIRAUD

38.1 Overview	463
38.2 Cortical Processing of Continuous Sounds Streams	466
38.3 Broadening the Scope: Functional Models	472
References	475

#### 39. Direct Cortical Neurophysiology of Speech Perception

MATTHEW K. LEONARD AND EDWARD F. CHANG

39.1 Introduction	479
39.2 Invasive Neural Recording Methods	479
39.3 Intracranial Contributions to the Neurobiology of Language	482
39.4 The Future of Invasive Methods in Language Research	487
References	487

#### 40. Factors That Increase Processing Demands When Listening to Speech

INGRID S. JOHNSRUDE AND JENNIFER M. RODD

40.1 Types of Processing Demand	493
40.2 Summary	499
References	499

#### 41. Neural Mechanisms of Attention to Speech

LEE M. MILLER

41.1 Overview and History	503
41.2 Neural Networks for Attentional Control	504

41.3 Levels of Attentional Selection	505	45. A Common Neural Progression to Meaning in About a Third of a Second	
41.4 Speech Representations that Attention Selects	507	KARA D. FEDERMEIER, MARTA KUTAS AND DANIELLE S. DICKSON	
41.5 Neural Mechanisms and Top-Down/ Bottom-Up Interactions	508	45.1 Part 1: The Timecourse of Semantic Access Out of Context	558
41.6 Interactions Between Attention, Perception, and Prediction	509	45.2 Part 2: Context and the Timecourse of Semantic Access	562
41.7 Future Directions	510	45.3 Conclusions	565
Acknowledgments	511	Acknowledgments	565
References	511	References	565
<b>42. Audiovisual Speech Integration: Neural Substrates and Behavior</b>		<b>46. Left Ventrolateral Prefrontal Cortex in Processing of Words and Sentences</b>	
MICHAEL S. BEAUCHAMP		NAZBANOU NOZARI AND SHARON L. THOMPSON-SCHILL	
42.1 Neuroarchitecture of Audiovisual Speech Integration	515	46.1 Introduction	569
42.2 Behavioral Approaches for Studying Audiovisual Speech Integration	518	46.2 VLPFC in Single-Word Processing	570
42.3 Intersubject Variability	519	46.3 VLPFC in Sentence Processing	574
42.4 Neural Substrates of the McGurk Effect	521	46.4 Summary	576
Acknowledgments	524	46.5 Concluding Remarks and Future Avenues	579
References	524	Acknowledgments	580
		References	580
<b>43. Neurobiology of Statistical Information Processing in the Auditory Domain</b>		<b>SECTION H</b>	
URI HASSON AND PASCALE TREMBLAY		<b>SENTENCE PROCESSING</b>	
43.1 Introduction	527	<b>47. The Role of the Anterior Temporal Lobe in Sentence Processing</b>	
43.2 Brain Systems Involved in Statistical Information Processing	529	CORIANNE ROGALSKY	
43.3 Connectional Anatomy of the Statistical Network	533	47.1 What About Broca's Area?	587
43.4 Related Work and Further Afield	534	47.2 Where Is the ATL?	588
43.5 Conclusion and Future Work	535	47.3 Domain-General Semantics	588
References	535	47.4 The ATL Responds to Sentence Structure	589
		47.5 Syntax	590
<b>SECTION G</b>		47.6 Combinatorial Semantics	591
<b>WORD PROCESSING</b>		47.7 Prosody	591
<b>44. The Neurobiology of Lexical Access</b>		47.8 The ATL Is Part of a Large Language Network	592
MATTHEW H. DAVIS		47.9 Summary	592
44.1 Introduction	541	Acknowledgments	592
44.2 Three Challenges for Lexical Access in Speech	541	References	592
44.3 Mapping Lexical Computations onto Neurobiology	542	<b>48. Neural Systems Underlying the Processing of Complex Sentences</b>	
44.4 Functional Segregation and Convergence in Lexical Processing	549	LARS MEYER AND ANGELA D. FRIEDERICI	
44.5 Conclusion	550	48.1 Introduction	597
Acknowledgment	551	48.2 Why Are Word-Order Deviations Difficult to Process?	597
References	551	48.3 Why Are Embedded Sentences Difficult to Process?	598

48.4 Which Brain Regions Are Involved in Processing Complex Sentences?	599	51.5 An Alternative Framework for Viewing the Memory System for Parsing and Interpretation	638
48.5 What Do Word-Order Deviations and Embedding Have in Common?	603	51.6 A Comment on the Neural Basis of Procedural (LT-WM) Memory Mechanisms Underlying Sentence Comprehension	641
48.6 Summary	604	Acknowledgments	641
References	604	References	641
49. The Timecourse of Sentence Processing in the Brain		Further Reading	645
INA BORNKESSEL-SCHLESEWSKY, ADRIAN STAUB AND MATTHIAS SCHLESEWSKY			
49.1 Preliminaries: Challenges to a Neurobiological Perspective on the Timecourse of Sentence Processing	607	52. Grounding Sentence Processing in the Sensory-Motor System	
49.2 Neurobiological Considerations	608	MARTA GHIO AND MARCO TETTAMANTI	
49.3 Differing Perspectives on the Timecourse of Sentence Processing in the Brain	609	52.1 Introduction	647
49.4 Behavioral Insights	615	52.2 Grounding of Action-Related Sentence Processing in the Sensory-Motor System	648
49.5 Open Questions/Perspectives for Future Research	617	52.3 Flexible Modulations of Sensory-Motor Grounding by Grammatical and Syntactic Aspects	650
References	618	52.4 Figurative Language as an Abstract Sentential-Semantic Context for Action-Related Verbs	651
50. Composition of Complex Meaning: Interdisciplinary Perspectives on the Left Anterior Temporal Lobe		52.5 Emotion-Related Language: Abstract but Partially Grounded in the Sensory-Motor System	653
LIINA PYLKKÄNEN			
50.1 "Semantics" in the Brain Sciences Versus Linguistics	622	52.6 Abstract Sentence Processing Is Grounded in Experiential Neurocognitive Systems	654
50.2 The Sentence Versus List Paradigm	623	52.7 Concluding Remarks	655
50.3 An Empirical Question: Do Concepts Matter for Composition?	624	References	655
50.4 Methodological Starting Points for the Cognitive Neuroscience of Semantic Composition	624	<b>SECTION I</b>	
50.5 The LATL as a Combinatory Region: Evidence from MEG	625	<b>DISCOURSE PROCESSING AND PRAGMATICS</b>	
50.6 Delving Deeper: What Types of Representations Does the LATL Combine?	626	53. Discourse Comprehension	
50.7 Closing Remarks	628	JEFFREY M. ZACKS AND EVELYN C. FERSTL	
Acknowledgments	629	53.1 Cohesion	662
References	629	53.2 Coherence	664
51. Working Memory and Sentence Comprehension		53.3 Situation Model Construction	665
DAVID CAPLAN			
51.1 Early Studies of STM/WM and Its Relation to Comprehension	633	53.4 Shifting and Mapping	668
51.2 Changes in Models of STM/WM	634	53.5 Conclusion	669
51.3 Retrieval Mechanisms in Parsing	635	References	671
51.4 Capacity Limits in STM/WM and Sentence Comprehension	638	54. At the Core of Pragmatics	
		BRUNO G. BARA, IVAN ENRICI AND MAURO ADENZATO	
		54.1 Communicative Intention: The Core Feature of Pragmatic Phenomena	675



54.2 Neural Substrates of Communicative Intention: The Intention Processing Network	676
54.3 Communication Is More than Language	679
54.4 Communicative Exchange	681
54.5 Steps Toward an Ecology of Communication	683
Acknowledgments	684
References	684

## SECTION J

### SPEAKING

#### 55. Neurobiology of Speech Production: Perspective from Neuropsychology and Neurolinguistics

SHEILA E. BLUMSTEIN AND SHARI R. BAUM

55.1 Introduction	689
55.2 Historical Perspective: Speech Production Deficits in Aphasia	689
55.3 Phonological Processes in Speech Production	690
55.4 Phonetic Processes in Production	692
55.5 Summary	696
Acknowledgments	697
References	697

#### 56. Word Production from the Perspective of Speech Errors in Aphasia

MYRNA F. SCHWARTZ AND GARY S. DELL

56.1 Speech Errors in Aphasia: The Neurological Tradition	701
56.2 Two Stages of Lexical Access in Production	703
56.3 Model-Inspired Lesion Analysis of Semantic Errors	705
56.4 Summation Dual-Route Model of Repetition	707
56.5 Implications for Neurocognitive Models of Language	710
56.6 Conclusion	711
Acknowledgments	712
References	712

#### 57. Motor-Timing and Sequencing in Speech Production

SONJA A. KOTZ AND MICHAEL SCHWARTZE

57.1 Formal and Temporal Prediction: Fundamentals in Speech Processing	717
57.2 A Synchronized Speech Processing Mode	718
57.3 Timing Speech: Subcortico-Cortical Interactions	720
57.4 Conclusion	722
References	723

#### 58. Neural Models of Motor Speech Control

FRANK H. GUENTHER AND GREGORY HICKOK

58.1 Introduction	725
58.2 The Planning of Speech Movements	726
58.3 Brain Regions Involved in Speech Articulation	727
58.4 Neurocomputational Models of Speech Production	727
58.5 The DIVA Model	728
58.6 The GODIVA Model of Speech Sound Sequencing	733
58.7 The HSFC Model	733
58.8 Future Directions	736
Acknowledgments	737
References	737

#### 59. Neurobiology of Speech Production: A Motor Control Perspective

PASCALE TREMBLAY, ISABELLE DESCHAMPS AND  
VINCENT L. GRACCO

59.1 Introduction	741
59.2 Neurobiology of Speech Motor Control	741
59.3 Speech Movement Execution	744
59.4 Feedback Processing and Sensory-Motor Integration	745
59.5 Conclusion	746
Acknowledgments	746
References	747

#### 60. Sentence and Narrative Speech Production: Investigations with PET and fMRI

RICHARD J.S. WISE AND FATEMEH GERANMAYEH

60.1 Introduction	751
60.2 What Have We Learned from Meta-Analyses of Language Studies	754
60.3 Narrative Speech Production	756
60.4 Functional MRI Studies of Sentence Production	758
60.5 Conclusion	760
References	761

## SECTION K

### CONCEPTUAL SEMANTIC KNOWLEDGE

#### 61. The Hub-and-Spoke Hypothesis of Semantic Memory

KARALYN PATTERSON AND MATTHEW A. LAMBON RALPH

61.1 Introduction	765
-------------------	-----

61.2 The Importance of the Spokes and the Regions from Which They Emanate	766	64.5 Conclusions	813
61.3 The Insufficiency of the Spokes and Their Sources: Why We Need a Hub	767	References	813
61.4 Why Should the Hub Be Centered on the ATL?	769	65. Developmental Dyslexia	
61.5 Evidence for and Possible Reasons for a Bilateral ATL Hub	770	GUINEVERE F. EDEN, OLUMIDE A. OLULADE, TANYA M. EVANS, ANTHONY J. KRAFNICK AND DIANA R. ALKIRE	
61.6 The Graded Hub Hypothesis	772	65.1 Introduction	815
61.7 Concluding Comment	773	65.2 Functional Anatomy of Reading	816
References	773	65.3 Neuroanatomical Bases of Dyslexia	816
62. What Does It Mean? A Review of the Neuroscientific Evidence for Embodied Lexical Semantics		65.4 Neurofunctional Bases of Dyslexia	817
OLAF HAUKE		65.5 Genetic and Physiological Mechanisms in Dyslexia	819
62.1 Introduction	777	65.6 Neurobiology of Reading Interventions	820
62.2 Models of Embodied Semantics	777	65.7 Cause Versus Consequence?	821
62.3 Methods for Neuroscientific Research on Embodied Semantics	780	65.8 Important Variables in Studies of Dyslexia	821
62.4 Review of the Empirical Literature	780	65.9 Conclusion	822
62.5 The Influence of Task, Context, and Individual Experience	784	Acknowledgments	822
62.6 Conclusion	785	References	822
References	786		
<b>SECTION L</b>			
<b>WRITTEN LANGUAGE</b>			
63. Acquired Dyslexia		<b>SECTION M</b>	
H. BRANCH COSLETT AND PETER TURKELTAUB		<b>ANIMAL MODELS FOR LANGUAGE</b>	
63.1 Introduction	791	66. Rodent Models of Speech Sound Processing	
63.2 Peripheral Dyslexias	792	CRYSTAL T. ENGINEER, TRACY M. CENTANNI AND MICHAEL P. KILGARD	
63.3 Central Dyslexias	795	66.1 Rodent Models Are Important for Studying Neural Correlates of Speech Perception	829
63.4 Computational Models of Reading	798	66.2 Speech Sound Discrimination by Rodents	829
63.5 Assessment of Reading	800	66.3 Speech Sound Neural Coding	831
References	800	66.4 Speech Sound Processing Problems	833
64. Imaging Brain Networks for Language: Methodology and Examples from the Neurobiology of Reading		References	836
ANJALI RAJA BEHARELLE AND STEVEN L. SMALL		<b>SECTION N</b>	
64.1 Introduction	805	<b>MEMORY FOR LANGUAGE</b>	
64.2 Functional Connectivity Analyses: A Set of Exploratory Techniques	806	67. Introduction to Memory	
64.3 Effective Connectivity Analyses: A Set of Confirmatory Techniques	808	SHAUNA M. STARK AND CRAIG E.L. STARK	
64.4 Techniques Spanning Both Functional and Effective Domains	811	67.1 Introduction: Amnesia and Patient H.M.	841
		67.2 Medial Temporal Lobe Memory System	841
		67.3 Episodic Memory	843
		67.4 Semantic Memory	844
		67.5 Procedural Memory	845
		67.6 Memory Consolidation and Sleep	846
		67.7 Neurogenesis	847
		67.8 Aging and Memory	847
		67.9 Language Learning and the Medial Temporal Lobe	848
		References	849

68. Neural Basis of Phonological Short-Term Memory		71.2 Phenomenology, Assessment, and Course of Formal Thought and Language Disorder	888
JULIE A. FIEZ		71.3 Structural Brain Changes and FTD	889
68.1 Theoretical Perspectives on Phonological Short-Term Memory	855	71.4 Neural Correlates of FTD (Symptom Catching)	889
68.2 Neural Perspectives on Short-Term Phonological Memory	857	71.5 Semantics	890
68.3 Summary	860	71.6 Pragmatics	891
References	860	71.7 Auditory Sensory, Phonological, and Prosodic Processing	892
		71.8 Syntax	893
69. Working Memory and Language		71.9 Neurotransmitter Dysfunction	893
BRADLEY R. BUCHSBAUM		71.10 Genetic Influence on Speech and Language Dysfunctions in Schizophrenia	894
69.1 Introduction	863	71.11 Lateralization Asymmetry in Schizophrenia	894
69.2 The Emergence of the Concept of Short-Term Memory	863	71.12 Conclusions and Future Perspectives	894
69.3 Neurological Evidence for a Separation of Short-Term and Long-Term Memory	864	References	895
69.4 The Emergence of the Concept of Working Memory	865	72. Specific Language Impairment	
69.5 The Phonological Loop	866	JULIA L. EVANS AND TIMOTHY T. BROWN	
69.6 Neural Basis of Verbal Working Memory	867	72.1 Introduction	899
69.7 Neurological Studies of Language and Verbal Short-Term Memory	868	72.2 Neuropsychological Profile	899
69.8 Functional Neuroimaging Investigations of Verbal Working Memory	869	72.3 Structural Imaging of SLI	900
69.9 Event-Related fMRI Studies of Verbal and Auditory Working Memory	870	72.4 Functional Imaging of SLI	902
69.10 Reconciling Neuropsychological and Functional Neuroimaging Data	872	72.5 Conclusion	906
69.11 Summary and Conclusion	872	72.6 Towards a Neurobiology of SLI	907
References	873	References	908
		73. Vascular Aphasia Syndromes	
<b>SECTION O</b>		DONNA C. TIPPETT AND ARGYE E. HILLIS	
<b>LANGUAGE BREAKDOWN</b>		73.1 Introduction	913
70. Language Development in Autism		73.2 Classic Aphasia Categorization: Vascular Syndromes	913
MORTON ANN GERNSBACHER, EMILY M. MORSON AND ELIZABETH J. GRACE		73.3 Vascular Syndromes and Contemporary Paradigms	917
70.1 Delay in Autistic Language Development	879	73.4 Cognitive Processes Underlying Aphasia	917
70.2 Heterogeneity and Variability in Autistic Language Development	880	73.5 Potential Usefulness of Vascular Syndromes	918
70.3 Trajectories of Language Development	881	73.6 Conclusion	920
70.4 Language Delay Versus Language Deviance	883	Acknowledgments	920
References	884	References	920
		74. Psycholinguistic Approaches to the Study of Syndromes and Symptoms of Aphasia	
71. Symptoms and Neurobiological Models of Language in Schizophrenia		SHEILA E. BLUMSTEIN	
ARNE NAGELS AND TILO KIRCHER		74.1 Introduction	923
71.1 Introduction	887	74.2 The Aphasia Syndromes	923
		74.3 Some Caveats and Challenges	924
		74.4 Language Deficits Underlying Aphasia Syndromes	925

74.5 Lexical Impairments	927
74.6 Syntactic Impairments	929
74.7 Conclusion	930
Acknowledgments	930
References	930

75. Introduction to Primary Progressive Aphasia

MARIA LUISA GORNO-TEMPINI AND PETER PRESSMAN

75.1 Introduction and History of Primary Progressive Aphasia	935
75.2 The Nonfluent/Agrammatic Variant	937
75.3 The Semantic Variant	941
75.4 The Logopenic Variant (lvPPA)	944
75.5 Future Directions in PPA	947
References	948

76. The Declarative/Procedural Model: A Neurobiological Model of Language Learning, Knowledge, and Use

MICHAEL T. ULLMAN

76.1 The Memory Systems	954
76.2 Predictions for Language	958
76.3 Evidence	961
76.4 Summary and Conclusion	965
Acknowledgments	965
References	965

77. Perinatal Focal Brain Injury: Scope and Limits of Plasticity for Language Functions

SUSAN C. LEVINE, ANJALI RAJA BEHARELLE, ÖZLEM ECE DEMIR AND STEVEN L. SMALL

77.1 Perinatal Focal Brain Injury: Language Development and Neural Plasticity	969
77.2 Four Central Questions	970
77.3 How Do Focal Perinatal Lesions Affect Language Development?	970
77.4 How Do Biological Characteristics of Early Focal Lesions Relate to Language Functioning?	972
77.5 What Is the Role of Language Input on the Language Development of Children with Perinatal Lesions?	976
77.6 What Is the Mechanism of Language Plasticity After Early Lesions?	977
77.7 Summary and Future Directions	979
References	979

78. Motor Speech Impairments

WOLFRAM ZIEGLER AND ANJA STAIGER

78.1 Introduction	985
78.2 Motor Impairments Within a Neurological Framework	985

78.3 Motor Impairments for Spoken Language Production	988
78.4 Sensory-Motor Aspects of Speech Sound Production Impairment	990
78.5 Conclusion	993
Acknowledgment	993
References	993

79. The Neurobiology of Developmental Stuttering

KATE E. WATKINS, JENNIFER CHESTERS AND EMILY L. CONNALLY

79.1 Introduction	995
79.2 Developmental Stuttering	995
79.3 Enhancing Fluency in People Who Stutter	996
79.4 Genetic Studies of Developmental Stuttering	997
79.5 The Neural Basis of Developmental Stuttering	998
79.6 Conclusion	1002
References	1002

SECTION P

LANGUAGE TREATMENT

80. Neuroplasticity Associated with Treated Aphasia Recovery

JULIUS FRIDRIKSSON AND KIMBERLY SMITH

80.1 Neuroplasticity	1007
80.2 Acute and Chronic Considerations	1008
80.3 Structural Brain Changes and Aphasia Recovery	1009
80.4 Functional Brain Changes and Aphasia Recovery	1009
References	1011

81. Melodic Intonation Therapy

GOTTFRIED SCHLAUG

81.1 The Impact of Nonfluent Aphasia	1015
81.2 The Basis and Components of Intonation-Based Speech Therapy for Patients with Nonfluent Aphasia	1016
81.3 Experiences with the Application of MIT	1017
81.4 Examining Aspects of Rhythm and Melody in Cross-Sectional Studies	1018
81.5 Neural Correlates of MIT: Neuroimaging Findings	1018
81.6 Possible Mechanisms Explaining the Effects of an Intonation-Based Speech Therapy	1020
81.7 Conclusion	1021
Acknowledgment	1021
References	1021

## 82. Constraint-Induced Aphasia Therapy: A Neuroscience-Centered Translational Method

FRIEDEMANN PULVERMÜLLER, BETTINA MOHR AND EDWARD TAUB

82.1 Aphasia Therapy: Relevance and Classic Paradigms	1025
82.2 Neuroscience and Language Evidence	1025
82.3 CIAT: Methods and Efficacy	1028
82.4 Variants and Extensions of Original CIAT Methods	1031
82.5 Summary and Outlook	1032
References	1032

## 83. Noninvasive Brain Stimulation in Aphasia Therapy: Lessons from TMS and tDCS

H. BRANCH COSLETT

83.1 Introduction	1035
83.2 TMS as Treatment for Aphasia	1035
83.3 tDCS as Therapy for Aphasia	1042
83.4 tDCS as a Treatment for Aphasia	1043
83.5 General Discussion	1049
References	1050

## 84. Imitation-Based Aphasia Therapy

E. SUSAN DUNCAN AND STEVEN L. SMALL

84.1 Introduction: Repetition and Imitation in Aphasia	1055
84.2 Neurobiological Approaches to Language and Aphasia	1055
84.3 Mirror Neuron System	1055
84.4 Mirror Neuron System and Language	1057
84.5 Dual Streams for Speech	1059
84.6 Aphasia Therapy: Speech Imitation as Therapeutic Tool	1060
84.7 Mirror Neuron System and Rehabilitation	1061
84.8 Aphasia Therapy: Speech Imitation as Therapeutic Theory	1061
84.9 Aphasia Therapy: Nonspeech Motor Observation and Imitation	1062
84.10 Conclusion	1063
References	1063

## 85. Pharmacotherapy for Aphasia

DANIEL A. LLANO AND STEVEN L. SMALL

85.1 Introduction	1067
85.2 Major Challenges	1067
85.3 Mechanisms of Recovery and Pharmacotherapy	1068
85.4 Human Studies: Pharmacotherapy for Aphasia	1072

85.5 Conclusion	1078
Acknowledgments	1078
References	1078

## 86. Cell-Based Therapies for the Treatment of Aphasia

HAL X. NGUYEN AND STEVEN C. CRAMER

86.1 Introduction	1085
86.2 Stem Cell Therapies: Introduction	1085
86.3 Human Neural Stem Cells	1086
86.4 Adult/Fetal hNSCs	1086
86.5 Human Embryonic Stem Cells and Neural Derivatives	1086
86.6 Human-Induced Pluripotent Stem Cells and Neural Derivatives	1087
86.7 Mesenchymal Stem Cells	1088
86.8 Issues Related to Clinical Application of Stem Cell Therapies	1088
References	1089

# SECTION Q

## PROSODY, TONE, AND MUSIC

### 87. Processing Tone Languages

JACKSON T. GANDOUR AND ANANTHANARAYAN KRISHNAN

87.1 Introduction	1095
87.2 Tone Languages of East and Southeast Asia	1095
87.3 Lexical Versus Sublexical Units	1096
87.4 Tonal Versus Segmental Units	1100
87.5 Tonal Features	1101
87.6 Tonal Processing at the Level of the Auditory Brainstem	1101
87.7 Categorical Perception of Tone	1102
87.8 Tone Versus Other Suprasegmental Units	1103
87.9 Conclusion	1104
Acknowledgment	1104
References	1104

### 88. The Neurocognition of Prosody

SILKE PAULMANN

88.1 Introduction	1109
88.2 Brain Mapping of Prosody	1109
88.3 The Neural Basis of Linguistic Prosody Processing	1110
88.4 The Neural Basis of Emotional Prosody Processing	1114
88.5 Summary	1117
Acknowledgments	1117
References	1118

89. Environmental Sounds		89.4 Section Two: Neural Factors in Processing Environmental Sounds	1128
FREDERIC DICK, SALONI KRISHNAN, ROBERT LEECH AND AYŞE PINAR SAYGIN		89.5 Conclusion	1134
89.1 What Are Environmental Sounds?	1121	Acknowledgments	1135
89.2 Perceptual, Cognitive, and Neural Processing of Environmental Sounds	1123	References	1135
89.3 Section One: Perceptual and Cognitive Factors in Processing Environmental Sounds	1123	<b>Index</b>	<b>1139</b>