

Full Contents

Preface	xv
About the Editors	xvii
List of Contributors	xix

I

NEUROSCIENCE

1. Fundamentals of Neuroscience

FLOYD E. BLOOM

A Brief History of Neuroscience	3
The Terminology of Nervous Systems Is Hierarchical, Distributed, Descriptive, and Historically Based	3
Neurons and Glia Are Cellular Building Blocks of the Nervous System	4
The Operative Processes of Nervous Systems Are also Hierarchical	5
Cellular Organization of the Brain	6
Organization of this Text	7
This Book Is Intended for a Broad Range of Scholars of the Neurosciences	8
Clinical Issues in the Neurosciences	8
The Spirit of Exploration Continues	9
The Genomic Inventory Is a Giant Step Forward	9
Neuroscience Today: A Communal Endeavor	10
The Creation of Knowledge	10
Responsible Conduct	11
Summary	13
References	13

2. Basic Plan of the Nervous System

LARRY W. SWANSON

Introduction	15
Evolution Highlights: General Organizing Principles	15

Development Reveals Basic Vertebrate Parts	22
The Basic Plan of Nervous System Connectivity	27
Overview of the Adult Mammalian Nervous System	31
References	37
Suggested Readings	38

II

CELLULAR AND MOLECULAR NEUROSCIENCE

3. Cellular Components of Nervous Tissue

PATRICK R. HOF, JEAN DE VELLIS, ESTHER A. NIMCHINSKY,
GRAHAME KIDD, LUZ CLAUDIO, AND BRUCE D. TRAPP

Neurons	41
Specific Examples of Different Neuronal Types	45
Neuroglia	47
Cerebral Vasculature	54
References	57
Suggested Readings	58

4. Subcellular Organization of the Nervous System: Organelles and Their Functions

SCOTT T. BRADY, DAVID R. COLMAN, AND PETER J. BROPHY

Axons and Dendrites: Unique Structural Components of Neurons	59
Protein Synthesis in Nervous Tissue	63
Cytoskeletons of Neurons and Glial Cells	70
Molecular Motors in the Nervous System	77
Building and Maintaining Nervous System Cells	80
References	85

5. Electrotonic Properties of Axons and Dendrites

GORDON M. SHEPHERD

- Toward a Theory of Neuronal Information Processing 87
- Basic Tools: Cable Theory and Compartmental Models 88
- Spread of Steady-State Signals 88
- Spread of Transient Signals 93
- Electrotonic Properties Underlying Propagation in Axons 95
- Electrotonic Spread in Dendrites 98
- Dynamic Properties of Passive Electrotonic Structure 101
- Relating Passive to Active Potentials 106
- References 108

6. Membrane Potential and Action Potential

DAVID A. MCCORMICK

- Membrane Potential 112
- Action Potential 117
- References 131
- Suggested Readings 132

7. Neurotransmitters

ARIEL Y. DEUTCH AND ROBERT H. ROTH

- Several Modes of Neuronal Communication Exist 133
- Chemical Transmission 134
- Classical Neurotransmitters 136
- Nonclassical Neurotransmitters 147
- Peptide Transmitters 148
- Unconventional Transmitters 149
- Synaptic Transmission in Perspective 154
- References 154

8. Release of Neurotransmitters

THOMAS L. SCHWARZ

- Transmitter Release Is Quantal 157
- Excitation-Secretion Coupling 160
- Molecular Mechanisms of the Nerve Terminal 163
- Quantal Analysis: Probing Synaptic Physiology 173
- Short-Term Synaptic Plasticity 176
- References 180
- Suggested Readings 180

9. Neurotransmitter Receptors

M. NEAL WAXHAM

- Ionotropic Receptors 181
- G-Protein Coupled Receptors 193
- References 203

10. Intracellular Signaling

HOWARD SCHULMAN AND JAMES L. ROBERTS

- Signaling Through G-Protein-Linked Receptors 205
- Modulation of Neuronal Function by Protein Kinases and Phosphatases 214
- Intracellular Signaling Affects Nuclear Gene Expression 222
- References 226
- Suggested Readings 226

11. Postsynaptic Potentials and Synaptic Integration

JOHN H. BYRNE

- Ionotropic Receptors: Mediators of Fast Excitatory and Inhibitory Synaptic Potentials 227
- Metabotropic Receptors: Mediators of Slow Synaptic Potentials 239
- Integration of Synaptic Potentials 242
- References 245
- Suggested Readings 245

12. Complex Information Processing in Dendrites

GORDON M. SHEPHERD

- Strategies for Studying Complex Dendrites 247
- Building Principles Step by Step 248
- An Axon Places Constraints on Dendritic Processing 249
- Dendrodendritic Interactions between Axonal Cells 250
- Passive Dendritic Trees Can Perform Complex Computations 251
- Separation of Dendritic Fields Enhances Complex Information Processing 252
- Distal Dendrites Can be Closely Linked to Axonal Output 253
- Depolarizing and Hyperpolarizing Dendritic Conductances Interact Dynamically 255
- The Axon Hillock-Initial Segment Encodes Global Output 256
- Multiple Impulse Initiation Sites Are under Dynamic Control 256
- Retrograde Impulse Spread into Dendrites Can have Many Functions 258

- Examples of How Voltage-gated Channels Enhance
Dendritic Information Processing 261
- Dendritic Spines Are Multifunctional Microintegrative
Units 263
- Summary: The Dendritic Tree as a Complex Information
Processing System 266
- References 268

13. Brain Energy Metabolism

PIERRE J. MAGISTRETTI

- Energy Metabolism of the Brain as a Whole Organ 271
- Tight Coupling of Neuronal Activity, Blood Flow, and
Energy Metabolism 274
- Energy-Producing and Energy-Consuming Processes in the
Brain 277
- Brain Energy Metabolism at the Cellular Level 282
- Glutamate and Nitrogen Metabolism: a Coordinated
Shuttle Between Astrocytes and Neurons 289
- The Astrocyte-Neuron Metabolic Unit 292
- References 292

III

NERVOUS SYSTEM DEVELOPMENT

14. Neural Induction and Pattern Formation

ANDREW LUMSDEN AND CHRIS KINTNER

- Neural Induction 297
- Early Neural Patterning 303
- Regionalization of the Central Nervous System 307
- Conclusions 318
- References 319

15. Cellular Determination

WILLIAM A. HARRIS AND VOLKER HARTENSTEIN

- Origins and Generation of Neuronal Progenitors 321
- Spatial and Temporal Coordinates of Neuronal
Specification 323
- The Proneural and Neurogenic Genes 326
- Asymmetric Cell Division and Cell Fate 328
- Central Neurons and Glia 330
- Sensory Neurons of the Peripheral Nervous System 330
- The Retina: a Collaboration of Intrinsic and Extrinsic
Cues 336
- Combinatorial Coding in Motor Neurons
Determination 342
- Cells of the Cerebral Cortex 344
- Conclusions 348
- References 348

16. Neurogenesis and Migration

MARIANNE BRONNER-FRASER AND MARY E. HATTEN

- Introduction 351
- Development of the Peripheral Nervous System 352
- Cell Migration in the CNS 361
- References 372
- Suggested Readings 375

17. Growth Cones and Axon Pathfinding

ALEX L. KOLODKIN AND MARC TESSIER-LAVIGNE

- Growth Cones Are Actively Guided 377
- Guidance Cues for Developing Axons 380
- Guidance Cues and the Control of Cytoskeletal
Dynamics 391
- Guidance at the Midline: Changing Responses to
Multiple Cues 395
- References 399

18. Target Selection, Topographic Maps, and Synapse Formation

STEVEN J. BURDEN, DENNIS D.M. O'LEARY, AND
PETER SCHEIFFELE

- Target Selection 401
- Development of the Neuromuscular Synapse 416
- Synapse Formation in the Central Nervous System 426
- References 434
- Suggested Readings 435

19. Programmed Cell Death and Neurotrophic Factors

RONALD W. OPPENHEIM AND
CHRISTOPHER S. VON BARTHELD

- Cell Death and the Neurotrophic Hypothesis 438
- The Origins of Programmed Cell Death and its
Widespread Occurrence in the Developing Nervous
System 438
- Functions of Neuronal Programmed Cell Death 444
- Modes of Cell Death in Developing Neurons 445
- The Mode of Neuronal Cell Death Reflects the
Activation of Distinct Biochemical and Molecular
Mechanisms 447
- Nerve Growth Factor: The Prototype Target-Derived
Neuronal Survival Factor 450
- The Neurotrophin Family 452
- Neurotrophin Receptors 453
- Secretion and Axonal Transport of Neurotrophins and
Pro-Neurotrophins 455
- Signal Transduction Through TRK Receptors 457
- Cytokines and Growth Factors have Multiple
Activities 458

- Programmed Cell Death Is Regulated by Interactions with Targets, Afferents, and Nonneuronal Cells 463
 The Role of Programmed Cell Death in Neuropathology 464
 References 466
 Suggested Readings 467

20. Synapse Elimination

JUAN C. TAPIA AND JEFF W. LIGHTMAN

- Overview 469
 The Purpose of Synapse Elimination 472
 A Structural Analysis of Synapse Elimination at The Neuromuscular Junction 475
 A Role for Interaxonal Competition and Activity 478
 Is Synapse Elimination Strictly A Developmental Phenomenon? 488
 Summary 488
 References 489

21. Dendritic Development

HOLLIS CLINE, ANIRVAN GHOSH, AND YUH-NUNG JAN

- Dynamics of Dendritic Arbor Development 491
 Genetic Control of Dendrite Development in *Drosophila* 492
 Extracellular Regulation of Dendritic Development in The Mammalian Brain 496
 Effect of Experience on Dendritic Development 504
 Mechanisms that Mediate Activity-Dependent Dendritic Growth 507
 Convergence and Divergence 508
 Conclusion 510
 References 510

22. Early Experience and Sensitive Periods

ERIC I. KNUDSEN

- Birdsong: Learned by Experience 517
 Sound Localization: Calibrated by Early Experience in the Owl 520
 Principles of Developmental Learning 529
 References 532

IV

SENSORY SYSTEMS

23. Fundamentals of Sensory Systems

STEWART H. HENDRY, STEVEN S. HSIAO, AND M. CHRISTIAN BROWN

- Sensation and Perception 535
 Receptors 537

- Peripheral Organization and Processing 540
 Central Pathways and Processing 542
 Sensory Cortex 544
 Summary 548
 References 548
 Suggested Readings 548

24. Chemical Senses: Taste and Olfaction

KRISTIN SCOTT

- Taste 549
 Olfaction 560
 Pheromone Detection 576
 References 578
 Suggested Readings 579

25. Somatosensory System

STEWART HENDRY AND STEVEN HSIAO

- Peripheral Mechanisms of Somatic Sensation 581
 Nociception, Thermoreception, and Itch 589
 Cns Components of Somatic Sensation 592
 Thalamic Mechanisms of Somatic Sensation 598
 The Path From Nociception to Pain 598
 The Trigeminal System 602
 Cortical Representation of Touch 604
 References 607
 Suggested Readings 608

26. Audition

M. CHRISTIAN BROWN AND JOSEPH SANTOS-SACCHI

- External and Middle Ear 609
 The Cochlea 610
 The Auditory Nerve 618
 Central Nervous System 624
 References 635
 Suggested Readings 636

27. Vision

R. CLAY REID AND W. MARTIN USREY

- Overview 637
 The Eye and the Retina 639
 The Retinogeniculocortical Pathway 649
 References 658
 Suggested Readings 659

V

MOTOR SYSTEMS

28. Fundamentals of Motor Systems

STEN GRILLNER

- Basic Components of the Motor System 665
- Motor Programs Coordinate Basic Motor Patterns 667
- Roles of Different Parts of the Nervous System in the Control of Movement 668
- Conclusion 676
- References 676

29. The Spinal and Peripheral Motor System

MARY KAY FLOETER AND GEORGE Z. MENTIS

- Locomotion is a Cycle 677
- Connecting the Spinal Cord to the Periphery 680
- Spinal Interneuron Networks 686
- Descending Control of Spinal Circuits 693
- Sensory Modulation 693
- References 697
- Suggested Readings 697

30. Descending Control of Movement

MARC H. SCHIEBER AND JAMES F. BAKER

- The Medial Postural System 699
- The Lateral Voluntary System 710
- Summary 723
- References 724

31. The Basal Ganglia

JONATHAN W. MINK

- Basal Ganglia Anatomy 725
- Signaling in Basal Ganglia 734
- The Effect of Basal Ganglia Damage on Movement 737
- Fundamental Principles of Basal Ganglia Operation for Motor Control 742
- Basal Ganglia Participation in Nonmotor Functions 744
- References 749
- Suggested Readings 750

32. Cerebellum

MICHAEL D. MAUK AND W. THOMAS THACH

- Anatomy and Phylogenetic Development of the Cerebellum 751
- Assessing Cerebellar Function 758
- References 770

33. Eye Movements

RICHARD J. KRAUZLIS

- Eye Movements are Used to Stabilize Gaze or to Shift Gaze 775
- The Mechanics of Moving the Eyes 778
- The Fundamental Circuits for Stabilizing Gaze 780
- The Commands for Shifting Gaze are Formed in the Brain Stem 782
- Gaze Shifts are Controlled by the Midbrain and Forebrain 785
- The Control of Gaze Shifts Involves Higher-Order Processes 788
- The Control of Eye Movements Changes Over Time 790
- Conclusions 791
- References 792
- Suggested Readings 792

VI

REGULATORY SYSTEMS

34. The Hypothalamus: An Overview of Regulatory Systems

J. PATRICK CARD, LARRY W. SWANSON, AND
ROBERT Y. MOORE

- Historical Perspective 795
- Hypothalamic Cytoarchitecture 796
- Functional Organization of the Hypothalamus 797
- Effector Systems of the Hypothalamus are Hormonal and Synaptic 800
- References 805
- Suggested Readings 806

35. Central Control of Autonomic Functions: Organization of the Autonomic Nervous System

TERRY L. POWLEY

- Sympathetic Division: Organized to Mobilize the Body for Activity 809
- Parasympathetic Division: Organized for Energy Conservation 812
- The Enteric Division of the ANS: The Nerve Net Found in the Walls of Visceral Organs 816
- Ans Pharmacology: Transmitter and Receptor Coding 816
- Autonomic Coordination of Homeostasis 819
- Hierarchically Organized ANS Circuits in the CNS 823
- Perspective: Future of the Autonomic Nervous System 825
- Summary and General Conclusions 827

References 827
Suggested Readings 828

36. Neural Regulation of the Cardiovascular System

JOHN LONGHURST

An Anatomical Framework 829
Anatomy and Chemical Properties of Autonomic Pathways 834
Network Generators 837
Short-Term Control Mechanisms 838
Reflex Control of the Cardiovascular System 838
Arterial Baroreceptors 838
Peripheral Arterial Chemoreceptors 844
Cardiac Receptors 847
Abdominal Visceral Reflexes 849
References 852

37. Neural Control of Breathing

JACK L. FELDMAN AND DONALD R. MCCRIMMON

Early Neuroscience and the Brain Stem 855
Central Nervous System and Breathing 856
Where are the Neurons Generating Respiratory Pattern? 857
Discharge Patterns of Respiratory Neurons 859
Where are the Neurons that Generate the Breathing Rhythm? 862
Sensory Inputs and Altered Breathing 865
Mechanoreceptors in the Lungs Adjust Breathing Pattern and Initiate Protective Reflexes 867
Modulation and Plasticity of Respiratory Motor Output 868
Suprapontine Structures and Breathing 870
References 872

38. Food Intake and Metabolism

STEPHEN C. WOODS AND EDWARD M. STRICKER

Caloric Homeostasis 873
Role of Caloric Homeostasis in Control of Food Intake 875
Central Control of Food Intake 882
Neuropeptides and the Control of Food Intake 884
References 888
Suggested Readings 888

39. Water Intake and Body Fluids

EDWARD M. STRICKER AND JOSEPH G. VERBALIS

Body Fluid Physiology 889
Osmotic Homeostasis 890
Volume Homeostasis 898

References 902
Suggested Readings 903

40. Neuroendocrine Systems

ANDREA C. GORE

The Hypothalamus Is a Neuroendocrine Organ 905
Hypothalamic Releasing/Inhibiting Hormones and their Targets 906
The Hypothalamic-Adenohypophyseal Neuroendocrine Systems 909
The Hypothalamic-Neurohypophyseal Systems 925
Hormones and the Brain 926
References 929

41. Circadian Timekeeping

DAVID R. WEAVER AND STEVEN M. REPERT

Overview of the Mammalian Circadian Timing System 931
The Suprachiasmatic Nuclei Are the Site of the Primary Circadian Pacemaker in Mammals 933
A Hierarchy of Cell-Autonomous Circadian Oscillators 934
The Molecular Basis for Circadian Oscillation Is a Transcriptional Feedback Loop 936
Circadian Photoreception 943
Circadian Output Mechanisms 949
Diversity of Output Pathways Leading to Physiological Rhythms 950
General Summary 955
References 956
Suggested Readings 957

42. Sleep, Dreaming, and Wakefulness

EDWARD F. PACE-SCHOTT, J. ALLAN HOBSON AND ROBERT STICKGOLD

The Two States of Sleep: Rapid Eye Movement and Nonrapid Eye Movement 959
Sleep in the Modern Era of Neuroscience 962
Anatomy and Physiology of Brain Stem Regulatory Systems 965
Modeling the Control of Behavioral State 975
Sleep has Multiple Functions 980
References 982
Suggested Readings 985

43. Reward, Motivation, and Addiction

GEORGE F. KOOB, BARRY J. EVERITT, AND TREVOR W. ROBBINS

Reward and Motivation 987
Addiction 999
References 1014

VII

BEHAVIORAL and COGNITIVE
NEUROSCIENCE

44. Human Brain Evolution

JON H. KAAS AND TODD M. PREUSS

- Evolutionary and Comparative Principles 1019
- Evolution of Primate Brains 1027
- Why Brain Size Is Important 1034
- Conclusions 1036
- References 1037
- Suggested Readings 1037

45. Cognitive Development and Aging

PETER R. RAPP AND JOCELYNE BACHEVALIER

- Brain Development 1039
- Cognitive Development and Aging: A Life Span Perspective 1043
- Pathological Processes In Cognitive Development and Aging 1055
- References 1065
- Suggested Readings 1066

46. Visual Perception of Objects

LUIZ PESSOA, ROGER B. H. TOOTELL, AND
LESLIE G. UNGERLEIDER

- The Problem of Object Recognition 1067
- Substrates for Object Perception and Recognition: Early Evidence from Brain Damage 1068
- Visual Pathways for Object Processing in Nonhuman Primates 1071
- Neuronal Properties Within the Object Recognition Pathway 1074
- Functional Neuroimaging and Electrophysiology of Object Recognition in Humans 1080
- Perception and Recognition of Specific Classes of Objects 1083
- Overall Summary 1088
- References 1088
- Suggested Readings 1089

47. Spatial Cognition

CAROL L. COLBY AND CARL R. OLSON

- Neural Systems for Spatial Cognition 1091
- Parietal Cortex 1092
- Frontal Cortex 1102
- Hippocampus and Adjacent Cortex 1107
- Spatial Cognition and Spatial Action 1109

References 1110

Suggested Readings 1111

48. Attention

JOHN H. REYNOLDS, JACQUELINE P. GOTTLIEB,
AND SABINE KASTNER

- Introduction 1113
- Varieties of Attention 1113
- Neglect Syndrome: A Deficit of Spatial Attention 1114
- Single Unit Recording Studies in Nonhuman Primates Provide Convergent Evidence for A Fronto-Parietal Attentional Control System 1116
- Attention Affects Neural Activity in the Human Visual Cortex in the Presence and Absence of Visual Stimulation 1121
- Attention Increases Sensitivity and Boosts the Clarity of Signals Generated by Neurons in Parts of the Visual System Devoted to Processing Information about Objects 1122
- Attention Modulates Neural Responses in the Human Lateral Geniculate Nucleus 1123
- The Visual Search Paradigm has been Used to Study the Role of Attention in Selecting Relevant Stimuli from Within a Cluttered Visual Environment 1124
- Where Is the Computational Bottleneck as Revealed by Search Tasks? 1126
- Neuronal Receptive Fields Are a Possible Neural Correlate of Limited Capacity 1126
- Competition Can Be Biased by Nonspatial Feedback 1127
- Filtering of Unwanted Information in Humans 1129
- Conclusions 1130
- References 1131
- Suggested Readings 1131

49. Learning and Memory: Basic Mechanisms

JOHN H. BYRNE

- Paradigms have been Developed to Study Associative and Nonassociative Learning 1133
- Invertebrate Studies: Key Insights From *Aplysia* Into Basic Mechanisms of Learning 1134
- Vertebrate Studies: Long-Term Potentiation 1140
- Long-Term Depression 1148
- How Does a Change in Synaptic Strength Store a Complex Memory? 1149
- References 1151
- Suggested Readings 1152

50. Learning and Memory: Brain Systems

JOSEPH R. MANNS AND HOWARD EICHENBAUM

- Introduction 1153
- History of Memory Systems 1153

Major Memory Systems of the Mammalian Brain	1156
Behavior Supported by Multiple Memory Systems	1174
Conclusion	1175
References	1175
Suggested Readings	1177

51. Language and Communication

DAVID N. CAPLAN AND JAMES L. GOULD

Animal Communication	1179
Human Language	1184
Conclusions	1196
References	1197
Suggested Readings	1198

52. The Prefrontal Cortex and Executive Brain Functions

EARL MILLER AND JONATHAN WALLIS

Introduction	1199
Controlled Processing	1199
Anatomy and Organization of the Prefrontal Cortex	1201
Effects of Damage to the Prefrontal Cortex in Humans	1203
Neuroimaging Studies and PFC	1207

Effects of Damage to the Prefrontal Cortex in Monkeys	1208
Neurophysiology of the Prefrontal Cortex	1211
Theories of Prefrontal Cortex Function	1217
Further Readings	1221
References	1221
Suggested Readings	1221

53. Consciousness

CHRISTOF KOCH

What Phenomena Does Consciousness Encompass?	1224
The Neurobiology of Free Will	1224
Consciousness in Other Species	1225
Arousal and States of Consciousness	1225
The Neuronal Correlates of Consciousness	1228
The Neuronal Basis of Perceptual Illusions	1229
Other Perceptual Puzzles of Contemporary Interest	1231
Forward versus Feedback Projections	1232
An Information-Theoretical Theory of Consciousness	1233
Conclusion	1234
References	1234

Index 1237