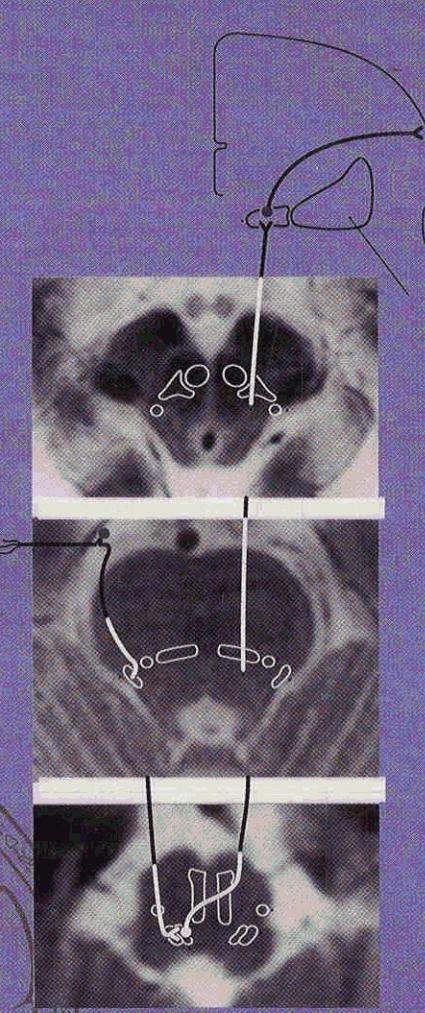
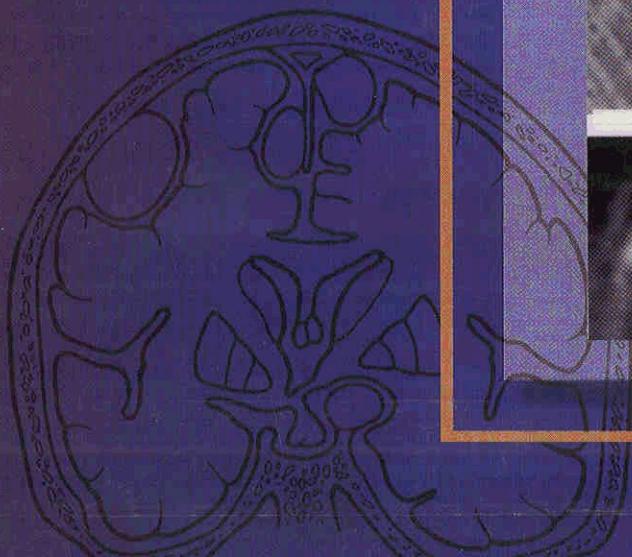
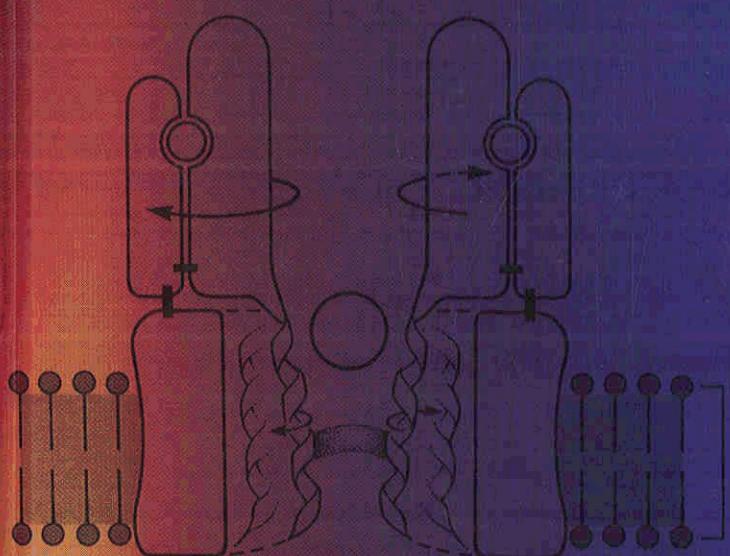


THIRD EDITION

DUANE E. HAINES

online access  
+  
interactive  
extras  
[studentconsult.com](http://studentconsult.com)

# Fundamental Neuroscience for Basic and Clinical Applications



CHURCHILL  
LIVINGSTONE



# Contents

## SECTION 1

### Essential Concepts

1	Orientation to Structure and Imaging of the Central Nervous System	2
	<i>D. E. Haines, F. A. Raila, and A. C. Terrell</i>	
	Overview, 3	
	Central, Peripheral, and Visceromotor Nervous Systems, 3	
	Neurons, 3	
	Reflexes and Pathways, 3	
	Regions of the Central Nervous System, 5	
	Spinal Cord, 5	
	Medulla Oblongata, 5	
	Pons and Cerebellum, 5	
	Midbrain, 6	
	Thalamus, 6	
	Cerebral Hemispheres, 6	
	Functional Systems and Regions, 6	
	Localizing Signs and Localization, 6	
	The Concept of Afferent and Efferent, 7	
	Posterior (Dorsal), Anterior (Ventral), and Other Directions in the Central Nervous System, 7	
	Symptom or Sign? 8	
	Clinical Images of the Brain and Skull, 9	
	Computed Tomography, 9	
	Magnetic Resonance Imaging, 9	
	Imaging of the Brain and Skull, 12	
2	The Cell Biology of Neurons and Glia	14
	<i>J. P. Naftel, M. D. Ard, J. D. Fratkin, and J. B. Hutchins</i>	
	Overview, 15	
	The Structure of Neurons, 15	
	Dendrites, 15	
	Cell Body, 15	
	Axons and Axon Terminals, 17	
	Axonal Transport, 19	
	Axonal Transport as a Research Tool, 20	
	Classification of Neurons and Groups of Neurons, 21	
	Electrical Properties of Neurons, 21	
	Neurons as Information Receivers, 22	
	Sensory Neural Information, 22	
	Other Neural Information, 22	
	Neurons as Information Transmitters, 22	
	Synapses, 22	
	Chemical Synapses, 22	
	Neurotransmitters, 24	
	Disorders of Neurotransmitter Metabolism, 24	
	Glia, 25	
	Astrocytes, 26	
	Structural Support and Response to Injury, 26	
	Growth Factors and Cytokines, 26	
	Environmental Modulation, 26	
	Metabolism, 26	
	Regional Heterogeneity, 26	
	Astrocytes at the Blood-Brain Barrier, 26	
	CNS Tumors	
	Oligodendrocytes, 26	
	Microglia, 28	
	Tumors of the Central Nervous System, 29	
	<i>Glia-derived Tumors, 29</i>	
	<i>Tumors in Children, 29</i>	
	<i>Benign Primary Tumors, 29</i>	
	<i>Metastatic Tumors, 29</i>	
	Supporting Cells of the Peripheral Nervous System, 30	
	Degeneration and Regeneration, 32	
3	The Electrochemical Basis of Nerve Function	35
	<i>T. M. Dwyer</i>	
	The Combined Forces of Chemical Gradients and Electrical Potentials, 36	
	<i>Forces Due to Concentration Gradients, 36</i>	
	<i>Electrical Forces, 36</i>	
	<i>The Membrane Potential, 37</i>	
	<i>Fluid Transport by Epithelia, 38</i>	
	<i>Ohm's Law, 38</i>	
	<i>Pain and a Syndrome of Periodic Paralysis, 39</i>	
	<i>Attack by the Immune System: Membrane Attack Complexes and Porins, 39</i>	
	<i>Microbial Attacks: Antibiotics, 40</i>	
	Graded Potentials, 40	
	<i>Generator Potentials, 40</i>	
	<i>Synaptic Potentials, 40</i>	
	<i>Synaptic Structure and Function: The Neuromuscular Junction, 41</i>	
	<i>Receptor Binding and Channel Gating, 43</i>	
	<i>Specific Responses via Increases in Ionic Permeability, 43</i>	
	<i>Muscle Weakness: Failure of Transmission at the NMJ, 44</i>	
	Action Potentials in the Nerve and in the Neuron, 45	
	<i>Compound Action Potentials, 46</i>	
	<i>Cable Properties of Neuronal Processes, 46</i>	
	<i>Nerve Conduction Velocity, 47</i>	
	Regenerative Potentials with a Single Active Current, 47	
	<i>A Sodium Channel Activated by Depolarization, 47</i>	
	<i>Regeneration, 49</i>	
	<i>Repolarization, 49</i>	
	<i>Threshold Voltage, 49</i>	
	<i>Refractory Period, 49</i>	
	<i>Unidirectional Propagation, 50</i>	
	<i>Saltatory Conduction, 50</i>	
	<i>Gating, Selectivity, and the Structure of the Sodium Channel, 50</i>	
	Modifiers of Excitability, 51	
	<i>Accommodation, 51</i>	
	<i>Anode Break, 51</i>	

Tetany, 51		
<i>Use-Dependent Block and the Treatment of Epilepsy, 52</i>		
Genetic Defects, Toxins and Venoms, 52		
Demyelinating Disease, 52		
Potassium and the Variety of Neuronal Activity, 52		
<i>Repolarizing the Neuron, 52</i>		
<i>Controlling Excitability, 52</i>		
<i>Pacing AP's, 53</i>		
Neuronal Activity as Information, 53		
<b>4 The Chemical Basis for Neuronal Communication</b>	<b>56</b>	
<i>R. W. Rockhold</i>		
Overview, 57		
Fundamentals of Chemical Neurotransmission, 57		
<i>Neurotransmitters, 57</i>		
<i>Fast and Slow Synaptic Transmission, 58</i>		
<i>Information Flow Across Chemical Synapses, 58</i>		
Synthesis, Storage, and Release of Chemical Messengers, 59		
<i>Composition of Vesicle Membranes, 59</i>		
<i>Biosynthesis, 59</i>		
<i>Localization, 60</i>		
<i>Release, 61</i>		
Signal Transduction, 61		
<i>Receptors and Receptor Subtypes, 61</i>		
<i>Structure and Function, 61</i>		
<i>Ligand-Gated Ion Channels, 61</i>		
<i>G Protein-Coupled Receptors, 63</i>		
<i>Effector Proteins, 64</i>		
<i>Receptor Regulation, 64</i>		
Regulation of Neuronal Excitability, 64		
Maintenance of the Synaptic Environment, 65		
Drug-Induced Parkinson Disease, 65		
Pharmacologic Modification of Synaptic Transmission, 65		
<i>The Noradrenergic Synapse, 66</i>		
<b>5 Development of the Nervous System</b>	<b>69</b>	
<i>O. B. Evans and J. B. Hutchins</i>		
Overview, 70		
Development of the Neural Tube, 70		
Brain Development, 71		
<i>Induction, 72</i>		
<i>Primary Neurulation, 72</i>		
<i>Congenital Nervous System Defects of Primary Neurulation, 72</i>		
<i>Secondary Neurulation, 73</i>		
<i>Congenital Nervous System Defects of Secondary Neurulation, 74</i>		
<i>Primary Brain Vesicles, 74</i>		
<i>Secondary Brain Vesicles, 74</i>		
<i>Diencephalon and Cerebral Hemispheres, 74</i>		
<i>Defects of Prosencephalization, 74</i>		
<i>Infectious Diseases Causing Congenital Nervous System Defects, 76</i>		
<i>Ventricular System, 76</i>		
Peripheral Nervous System, 77		
<i>Neural Crest, 77</i>		
<i>Placodes, 77</i>		
<i>Cranial Nerve Ganglia, 77</i>		
<i>Posterior Root Ganglia, 78</i>		
<i>Visceral Motor System, 78</i>		
<i>Schwann Cells, 78</i>		
Central Nervous System, 79		
<i>Basic Features, 79</i>		
<i>Spinal Cord, 80</i>		
<i>Relationship of Spinal Cord to Vertebral Column, 81</i>		
<i>Brainstem, 81</i>		
<i>Cerebellum, 82</i>		
Thalamus, 82		
Cerebral Cortex, 83		
Abnormalities of Cortical Development, 84		
Cellular Events in Brain Development, 85		
<i>Overproduction of Neurons and Apoptosis, 85</i>		
<i>Axonal Outgrowth, 85</i>		
<i>Synaptogenesis, 86</i>		
<i>Plasticity and Competition, 86</i>		
<i>Myelination, 87</i>		
<b>SECTION 2</b>		
<b>Regional Neurobiology</b>		
<b>6 The Ventricle, Choroid Plexus, and Cerebrospinal Fluid</b>	<b>90</b>	
<i>J. J. Corbett, D. E. Haines, M. D. Ard, and J. A. Lancon</i>		
Overview, 91		
Development, 91		
<i>Foramina of the Fourth Ventricle, 92</i>		
<i>Formation of the Choroid Plexus, 92</i>		
Ventricles, 93		
<i>Lateral Ventricle, 93</i>		
<i>Third Ventricle, 95</i>		
<i>Cerebral Aqueduct, 95</i>		
<i>Fourth Ventricle, 96</i>		
<i>Hemorrhage into the Ventricle, 96</i>		
Ependyma, Choroid Plexus, and Cerebrospinal Fluid, 97		
<i>Ependyma, 97</i>		
<i>Ependymomas, 98</i>		
<i>Choroid Plexus, 98</i>		
<i>Tumors of the Choroid Plexus, 99</i>		
<i>Cerebrospinal Fluid in Health and Disease, 100</i>		
<i>Cerebrospinal Fluid Production and Circulation, 100</i>		
Hydrocephalus and Related Conditions, 101		
<i>Obstructive Hydrocephalus, 101</i>		
<i>Aqueductal Stenosis, 103</i>		
<i>Communicating Hydrocephalus, 103</i>		
<i>Hydrocephalus ex Vacuo, 104</i>		
<i>Idiopathic Intracranial Hypertension, 104</i>		
<i>Normal Pressure Hydrocephalus, 105</i>		
<b>7 The Meninges</b>	<b>106</b>	
<i>D. E. Haines</i>		
Overview, 107		
Development of the Meninges, 107		
Overview of the Meninges, 108		
Dura Mater, 108		
<i>Periosteal and Meningeal Dura, 108</i>		
<i>Dural Border Cell Layer, 109</i>		
<i>Blood Supply, 109</i>		
<i>Nerve Supply, 109</i>		
<i>Dural Infoldings and Sinuses, 110</i>		
<i>Compartments and Herniation Syndromes, 111</i>		
<i>Cranial versus Spinal Dura, 112</i>		
Arachnoid Mater, 112		
<i>Arachnoid Barrier Cell Layer, 112</i>		
<i>Arachnoid Trabeculae and the Subarachnoid Space, 112</i>		
<i>Arachnoid Villi, 113</i>		
Meningioma, 114		
<i>Origins and Locations, 114</i>		
<i>General Histologic Features, 115</i>		
<i>Symptoms and Treatment, 115</i>		
Meningeal Hemorrhages, 116		
<i>Extradural and "Subdural" Hemorrhages, 116</i>		
<i>Hygroma, 118</i>		
<i>Pia Mater, 118</i>		

<i>Cisterns, Subarachnoid Hemorrhages, and Meningitis</i> , 118	
<i>Cisterns</i> , 118	
<i>Subarachnoid Hemorrhage</i> , 119	
<i>Meningitis</i> , 121	
<b>8 A Survey of the Cerebrovascular System</b>	123
<i>D. E. Haines and J. A. Lancon</i>	
Overview, 124	
Causes of Vascular Compromise, 124	
<i>Aneurysm</i> , 124	
<i>Cerebral Embolism</i> , 124	
<i>Arteriovenous Malformation</i> , 125	
Internal Carotid System, 126	
<i>Internal Carotid Artery</i> , 126	
<i>Anterior Cerebral Artery</i> , 127	
<i>Middle Cerebral Artery</i> , 128	
Vertebobasilar System, 128	
<i>Vertebral Artery</i> , 129	
<i>Basilar Artery</i> , 130	
<i>Posterior Cerebral Artery</i> , 131	
Cerebral Arteries and Watershed Infarcts, 132	
Circle of Willis, 132	
<i>Central Branches</i> , 132	
Veins and Venous Sinuses of the Brain, 134	
<i>Cerebral Hemispheres</i> , 134	
<i>Basal Aspect of the Brain</i> , 136	
<i>Internal Veins of the Hemisphere</i> , 136	
<i>Brainstem and Cerebellum</i> , 137	
<i>Cerebral Venous Thrombosis</i> , 137	
Arteries of the Spinal Cord, 137	
Veins of the Spinal Cord, 139	
<i>Spinal Arteriovenous Malformations</i> , 139	
Blood–Brain Barrier, 140	
<b>9 The Spinal Cord</b>	142
<i>D. E. Haines, G. A. Mihailoff, and R. P. Yezierski</i>	
Overview, 143	
Development, 143	
<i>Neural Plate</i> , 143	
<i>Neural Tube</i> , 144	
<i>Neural Tube Defects</i> , 144	
Spinal Cord Structure, 144	
<i>Surface Features</i> , 144	
<i>Spinal Meninges</i> , 145	
<i>White Matter</i> , 145	
<i>Gray Matter</i> , 145	
<i>Blood Supply</i> , 145	
Regional Characteristics, 147	
<i>Cervical Levels</i> , 147	
<i>Thoracic Levels</i> , 147	
<i>Lumbar Levels</i> , 147	
<i>Sacral Levels</i> , 147	
Spinal Nerves, 147	
<i>Sensory Components of the Spinal Nerve</i> , 149	
<i>Neurotransmitters of Primary Sensory Neurons</i> , 149	
<i>Deafferentation Pain and the Posterior Root Entry Zone Procedure</i> , 150	
<i>Motor Components of the Spinal Nerve</i> , 150	
<i>Neurotransmitters of Spinal Motor Neurons and Myasthenia Gravis</i> , 151	
Spinal Reflexes, 151	
<i>Muscle Stretch Reflex</i> , 151	
<i>Flexor Reflex</i> , 152	
<i>Crossed Extension Reflex</i> , 153	
Peripheral Nerve Lesions, 153	
<i>Radiculopathy</i> , 153	
<i>Mononeuropathy</i> , 153	
<b>10 An Overview of the Brainstem</b>	158
<i>D. E. Haines and G. A. Mihailoff</i>	
Basic Divisions of the Brainstem, 159	
<i>Medulla Oblongata</i> , 159	
<i>Pons</i> , 159	
<i>Midbrain</i> , 159	
<i>Tegmental and Basilar Areas</i> , 160	
Ventricular Spaces of the Brainstem, 160	
<i>Rhomboid Fossa</i> , 160	
Cranial Nerve Nuclei and Their Functional Components, 161	
Herniation Syndromes Related to the Brainstem, 165	
<i>Central Herniation</i> , 165	
<i>Uncal Herniation</i> , 165	
<i>Upward Cerebellar Herniation</i> , 165	
<i>Tonsillar Herniation</i> , 165	
<b>11 The Medulla Oblongata</b>	167
<i>D. E. Haines and G. A. Mihailoff</i>	
Development, 168	
<i>Basal and Alar Plates</i> , 168	
External Features, 169	
<i>Anterior Medulla</i> , 169	
<i>Lateral Medulla</i> , 169	
<i>Posterior Medulla</i> , 169	
<i>Vascularity</i> , 169	
Internal Anatomy of the Medulla, 170	
<i>Summary of Ascending Pathways</i> , 170	
<i>Summary of Descending Pathways</i> , 171	
<i>Spinal Cord–Medulla Transition</i> , 171	
<i>Caudal Medulla: Level of the Motor Decussation</i> , 171	
<i>Caudal Medulla: Level of the Sensory Decussation</i> , 171	
<i>Midmedullary Level</i> , 173	
<i>Rostral Medulla and Pons–Medulla Junction</i> , 173	
<i>Reticular and Raphe Nuclei</i> , 175	
Internal Vasculature of the Medulla and Medullary Syndromes, 175	
Tonsillar Herniation, 178	
<b>12 The Pons and Cerebellum</b>	181
<i>G. A. Mihailoff and D. E. Haines</i>	
Development, 182	
<i>Basal and Alar Plates</i> , 182	
<i>Cerebellum</i> , 183	
External Features, 183	
<i>Basilar Pons</i> , 183	
<i>Rhomboid Fossa of the Pons</i> , 183	
<i>Cerebellum</i> , 183	
<i>Vascularity of the Pons and Cerebellum</i> , 184	
Internal Anatomy of the Pons, 185	
<i>Summary of Ascending Pathways</i> , 185	
<i>Summary of Descending Pathways</i> , 185	
<i>Caudal Pontine Level</i> , 185	
<i>Mid–Pontine Level</i> , 186	
<i>Rostral Pontine Level</i> , 187	
<i>Reticular and Raphe Nuclei</i> , 190	
<i>Internal Vasculature of the Pons</i> , 190	
Vascular Syndromes of the Pons, 190	

	Internal Anatomy of the Cerebellum, 192 Cerebellar Cortex, 192 Cerebellar Nuclei, 193 Vasculature of the Cerebellum, 193		Medial Hypothalamic Zone, 238 Afferent Fiber Systems, 239 Efferent Fibers, 239 Ventral Thalamus (Subthalamus), 239 Epithalamus, 239 Vasculature of the Diencephalon, 241	
13	The Midbrain <i>G. A. Mihailoff, D. E. Haines, and P. J. May</i> Development, 196 Basal and Alar Plates, 196 External Features, 196 Anterior (Ventral) Midbrain, 196 Posterior (Dorsal) Midbrain, 197 Vasculature of the Midbrain, 197 Internal Anatomy of the Midbrain, 198 General Regions: Tectum, Tegmentum, and Basis Pedunculi, 198 Summary of Ascending Pathways, 198 Summary of Descending Pathways, 199 Caudal Midbrain Levels, 199 Rostral Midbrain Levels, 199 Midbrain-Diencephalon Junction, 204 Reticular and Raphe Nuclei, 204 Internal Vasculature of the Midbrain, 204 Vascular Syndromes of the Midbrain, 205 Herniation Syndromes Related to the Midbrain, 205	195	16 The Telencephalon <i>D. E. Haines and G. A. Mihailoff</i> Overview, 245 Development, 245 Developmental Defects, 246 Lobes of the Cerebral Cortex, 246 Frontal Lobe, 247 Parietal Lobe, 248 Temporal Lobe, 248 Insular Lobe, 250 Occipital Lobe, 251 Limbic Lobe, 251 Vasculature of the Cerebral Cortex, 251 White Matter of the Cerebral Hemisphere, 252 Association Fibers, 252 Commissural Fibers: The Corpus Callosum, 253 Projection Fibers: The Internal Capsule, 253 Vasculature of the Internal Capsule, 255 Basal Nuclei (Ganglia), 255 Caudate and Lenticular Nuclei, 255 Nucleus Accumbens and Substantia Innominata, 258 Subthalamic Nucleus and Substantia Nigra, 258 Major Connections of the Basal Nuclei, 258 Vasculature of the Basal Nuclei and Related Structures, 259 Hippocampus and Amygdala, 259 Temporal Lobe Lesions, 259 Vasculature of the Hippocampus and Amygdala, 259	244
14	A Synopsis of Cranial Nerves of the Brainstem <i>D. E. Haines and G. A. Mihailoff</i> Overview, 210 Motor Cell Columns and Nuclei, 210 Sensory Cell Columns and Nuclei, 210 Cranial Nerves of the Medulla Oblongata, 211 Hypoglossal Nerve, 213 Accessory Nerve, 214 Vagus Nerve, 214 Glossopharyngeal Nerve, 216 Jugular Foramen, 217 Syndromes of the Jugular Foramen, 218 Cranial Nerves of the Pons-Medulla Junction, 218 Vestibulocochlear Nerve, 218 Lesions in the Cerebellopontine Angle, 220 Facial Nerve, 220 Abducens Nerve, 222 Cranial Nerve of the Pons, 223 Trigeminal Nerve, 223 Cranial Nerves of the Midbrain, 225 Trochlear Nerve, 225 Oculomotor Nerve, 226	209		
15	The Diencephalon <i>G. A. Mihailoff and D. E. Haines</i> Overview, 230 Development of the Diencephalon, 230 Basic Organization, 231 Dorsal Thalamus (Thalamus), 233 Anterior Thalamic Nuclei, 233 Medial Thalamic Nuclei, 233 Lateral Thalamic Nuclei, 233 Intralaminar Nuclei, 237 Midline Nuclei, 237 Thalamic Reticular Nucleus, 237 Summary of Thalamic Organization, 237 Internal Capsule, 238 Hypothalamus, 238 Lateral Hypothalamic Zone, 238	229	17 The Somatosensory System I: Tactile Discrimination and Position Sense <i>S. Warren, N. F. Capra, and R. P. Yezierski</i> Overview, 263 Posterior Column-Medial Lemniscal System (PCMLS), 263 Peripheral Mechanoreceptors, 263 Primary Afferent Fibers, 265 Spinal Cord and Brainstem, 265 Ventral Posteriorlateral Nuclei, 270 Primary Somatosensory (SI) Cortex, 271 Additional Cortical Somatosensory Regions, 272 Trigeminal System, 272 Trigeminal Nerve, 272 Anterior and Posterior Trigeminotthalamic Tracts, 272 Peripheral Receptors, 272 Receptive Field Properties of Cortical Neurons, 274 Neuroimaging and Functional Localization, 275 Plasticity and Reorganization in the Primary Somatosensory Cortex, 275 Nonconscious Proprioception: Spinocerebellar Pathways, 275 Posterior Spinocerebellar Tract, 275 Cuneocerebellar Tract, 276 Anterior Spinocerebellar Tract, 276 Rostral Spinocerebellar Tract, 276 Trigeminocerebellar Connections, 277	262

## SECTION 3

# Systems Neurobiology

---

18	The Somatosensory System II: Touch, Thermal Sense, and Pain <i>S. Warren, R. P. Yezierski, and N. F. Capra</i> Overview, 281 Anterolateral System, 281 <i>Receptors and Primary Neurons, 281</i> <i>Peripheral Sensitization and Primary Hyperalgesia, 282</i> <i>Central Sensitization and Secondary Hyperalgesia, 282</i> <i>Pain Receptors in Muscles, Joints, and Viscera, 283</i> <i>Central Pathways, 285</i> Spinal Trigeminal Pathway: Anterior Trigeminothalamic Tract, 290 <i>Primary Neurons, 290</i> <i>Central Pathways, 290</i> Imaging Studies of Pain in the Somatosensory Pathway, 296 Pain Perception, 296 Pain Perception in the Somatosensory Thalamus, 297 Pain Transmission and Control, 299	280	Primary Visual Cortex, 324 <i>Functional Organization of Visual Cortex, 324</i> <i>Receptive Field Properties of Cortical Neurons, 324</i> <i>Orientation Columns, 324</i> <i>Ocular dominance Columns, 324</i> Abnormal Development of Visual Cortex, 330 Other Visual Cortical Areas, 331	
19	Viscerosensory Pathways <i>S. G. Hardy and J. P. Naftel</i> Viscerosensory Receptors, 303 Viscerosensory Fibers, 303 Ascending Pathway for Sympathetic Afferents, 304 <i>Projections to Thalamus, 304</i> <i>Projections to Reticular Formation, 304</i> <i>Referred Pain, 305</i> <i>Angina, 305</i> Pathways for Parasympathetic Afferents, 307 <i>Sacral Parasympathetic Afferents, 307</i> <i>Cranial Parasympathetic Afferents, 307</i> <i>Baroreceptor Reflex, 309</i> Visceral Input to the Reticular Activating System, 310	302	21 The Auditory System <i>C. K. Henkel</i> Overview, 335 Properties of Sound Waves and Hearing, 335 Processing of Sound: The Ear, 335 <i>External (Outer) Ear, 335</i> <i>Middle Ear, 335</i> <i>Conduction Deafness, 336</i> <i>Inner Ear: Structure of the Cochlea, 336</i> <i>Mechanoelectrical Transduction, 337</i> <i>Tuning of the Cochlea, 338</i> <i>Primary Afferent Innervation and Function, 339</i> <i>Sensorineural/Nerve Deafness, 339</i> The Weber and Rinne Tests, 339 An Overview of Central Auditory Pathways, 340 <i>Vascular Supply of the Auditory Brainstem and Cortex, 340</i> Brainstem Auditory Nuclei and Pathways, 341 <i>Cochlear Nuclei, 341</i> <i>Superior Olivary Complex, 343</i> <i>Lateral Lemniscus and Its Nuclei, 344</i> <i>Inferior Colliculus, 345</i> <i>Medial Geniculate Nucleus, 345</i> <i>Central Deafness, 345</i> Auditory and Related Association Cortices, 346 Descending Auditory Pathways, 347 <i>The Olivocochlear Bundle, 347</i> Middle Ear Reflex, 347 Acoustic Startle Reflex, Orientation, and Attention, 348	334
20	The Visual System <i>J. C. Lynch, J. J. Corbett, and J. B. Hutchins</i> Overview, 312 Anatomy of the Eye, 312 <i>Cornea, 312</i> <i>Chambers of the Eye, 312</i> <i>Iris, 313</i> <i>Lens, 313</i> <i>Cataract, 313</i> <i>Uvea, 313</i> The Neural Retina and Pigment Epithelium, 313 Photoreceptor Cells, 314 <i>Rods, 314</i> <i>Cones, 315</i> <i>Macula and Fovea, 316</i> Receptive Fields, 317 Processing of Visual Input in the Retina, 317 <i>Outer and Inner Plexiform Layers, 318</i> <i>Horizontal Cells, 318</i> <i>Bipolar Cells, 318</i> <i>Amacrine Cells, 319</i> <i>Ganglion Cells, 319</i> Retinal Projections, 319 <i>Retinogeniculate Projections, 319</i> <i>Optic Nerve, Chiasm, and Tract, 320</i> Visual Fields Correlated With Visual Structures as Seen in Magnetic Resonance Imaging, 321 Lateral Geniculate Nucleus, 322 <i>Magnocellular and Parvocellular Layers, 322</i> <i>Ipsilateral and Contralateral Layers, 323</i> Optic Radiations, 323	311	22 The Vestibular System <i>J. D. Dickman</i> Overview, 351 Peripheral Vestibular Labyrinth, 351 <i>Vestibular Receptor Organs, 352</i> <i>Membranous Labyrinth, 352</i> <i>Ménière Disease, 352</i> <i>Semicircular Canal Dehiscence, 353</i> Vestibular Sensory Receptors, 353 <i>Hair Cell Morphology, 353</i> <i>Hair Cell Transduction, 354</i> <i>Morphologic Polarization of Hair Cells, 355</i> Semicircular Canals and Otolith Organs, 355 <i>Function of Semicircular Canals, 356</i> <i>Function of Otolith Organs, 357</i> Vestibular Nuclei, 357 <i>Vestibular Afferent Inputs, 357</i> <i>Cerebellar Connections, 358</i> <i>Commissural Connections, 360</i> <i>Other Afferent Connections, 360</i> <i>Other Efferent Connections, 360</i> Vestibulo-ocular Network, 360 <i>Rotational Vestibulo-ocular Reflex, 360</i> <i>Linear Vestibulo-ocular Reflex, 361</i> <i>Nystagmus, 361</i> Vestibulospinal Network, 362 <i>Lateral Vestibulospinal Tract, 362</i> <i>Medial Vestibulospinal Tract, 363</i>	350

Vestibulo-Thalamo-Cortical Network, 363		
<i>Vestibular Thalamus</i> , 363		
<i>Vestibular Cortex</i> , 364		
Dizziness and Vertigo, 364		
<i>Benign Paroxysmal Positional Vertigo</i> , 364		
<i>Vestibular Neuritis</i> , 364		
<b>23 Olfaction and Taste</b>	<b>366</b>	
<i>K. L. Simpson and R. D. Sweazey</i>		
Overview, 367		
Olfactory Receptors, 367		
Olfactory Transduction, 369		
Central Olfactory Pathways, 369		
<i>Olfactory Bulb</i> , 369		
<i>Olfactory Bulb Projections</i> , 371		
<i>Olfactory Cortex Projections</i> , 372		
<i>Disorders of the Olfactory System</i> , 372		
Taste Receptors, 373		
Distribution of Taste Receptors, 373		
<i>Lingual Taste Buds</i> , 373		
<i>Extralingual Taste Buds</i> , 375		
Taste Transduction, 375		
Peripheral Taste Pathways, 376		
Central Taste Pathways, 376		
Disorders of the Gustatory System, 377		
<b>24 Motor System I: Peripheral Sensory, Brainstem, and Spinal Influence on Anterior Horn Neurons</b>	<b>379</b>	
<i>G. A. Mihailoff and D. E. Haines</i>		
Overview, 380		
Anterior Horn Motor Neurons, 380		
<i>Types and Distribution</i> , 380		
<i>Neuromuscular Function</i> , 380		
<i>Motor Units</i> , 381		
<i>Size Principle</i> , 382		
Peripheral Sensory Input to the Anterior (Ventral) Horn, 382		
<i>Muscle Spindles</i> , 382		
<i>Gamma Loop</i> , 383		
<i>Golgi Tendon Organ</i> , 384		
<i>Reflex Circuits</i> , 385		
Brainstem-Spinal Systems: Anatomy and Function, 385		
<i>Vestibulospinal Tracts</i> , 385		
<i>Reticulospinal Tracts</i> , 386		
<i>Rubrospinal Tract</i> , 387		
Functional Role of Brainstem-Spinal Interactions, 387		
<i>Decerebration</i> , 387		
<i>Posterior (Dorsal) Root Section</i> , 388		
<i>Cerebellar Anterior Lobe Section</i> , 389		
<i>Decortication</i> , 391		
<b>25 Motor System II: Corticofugal Systems and the Control of Movement</b>	<b>394</b>	
<i>G. A. Mihailoff and D. E. Haines</i>		
Overview, 395		
General Features of Motor Deficits, 395		
<i>Lower Motor Neuron Signs</i> , 395		
<i>Upper Motor Neuron Signs</i> , 395		
<i>Spasticity</i> , 395		
Corticospinal System, 395		
<i>Origin</i> , 395		
<i>Course</i> , 396		
<i>Termination</i> , 401		
Corticounuclear (Corticobulbar) System, 403		
<i>Origin</i> , 403		
<i>Course</i> , 404		
<i>Termination</i> , 404		
Other Corticofugal Systems, 408		
<i>Corticorubral System</i> , 408		
<i>Corticoreticular System</i> , 408		
<i>Corticopontine System</i> , 408		
Motor Cortex and the Control of Movement, 408		
<i>Primary Motor Cortex</i> , 408		
<i>Supplementary Motor Cortex</i> , 409		
<i>Premotor Cortex</i> , 409		
<i>Posterior Parietal Cortex</i> , 410		
<i>Cingulate Motor Cortex</i> , 410		
<i>Cerebellar and Pallidal Influences</i> , 410		
Hierarchical Organization Versus Parallel Distributed Processing in the Motor System, 410		
<b>26 The Basal Nuclei</b>	<b>413</b>	
<i>T. P. Ma</i>		
Overview, 414		
Components of the Basal Nuclei, 414		
<i>Striatal Complex</i> , 415		
<i>Pallidal Complex</i> , 416		
<i>Subthalamic Nucleus</i> , 416		
<i>Nigral Complex</i> , 417		
<i>Parabrachial Pontine Reticular Formation</i> , 419		
<i>Ventral Basal Nuclei</i> , 419		
Direct and Indirect Pathways of Basal Nuclear Activity, 419		
<i>Disinhibition as the Primary Mode of Basal Nuclear Function</i> , 421		
Parallel Circuits of Information Flow Through the Basal Nuclei, 421		
<i>The Motor Loop</i> , 421		
Behavioral Functions of the Basal Nuclei, 423		
<i>Hypokinetic Disturbances</i> , 423		
<i>Hyperkinetic Disturbances</i> , 423		
<i>Integrated Function of the Basal Nuclei</i> , 423		
Etiology of Basal Nuclear Related Disorders, 425		
<i>Huntington Disease</i> , 425		
<i>Parkinson Disease</i> , 427		
<i>Wilson Disease</i> , 428		
<i>Sydenham Chorea</i> , 428		
<i>Tardive Dyskinesia</i> , 429		
<b>27 The Cerebellum</b>	<b>431</b>	
<i>D. E. Haines, G. A. Mihailoff, and J.R. Bloedel</i>		
Overview, 432		
Basic Structural Features, 432		
<i>Cerebellar Peduncles</i> , 432		
<i>Cerebellar Lobes, Lobules, and Zones</i> , 433		
<i>Cerebellar Nuclei</i> , 433		
<i>Blood Supply to Cerebellar Structures</i> , 435		
Cerebellar Cortex, 436		
<i>Purkinje Cell Layer</i> , 436		
<i>Granule Cell Layer</i> , 436		
<i>Molecular Layer</i> , 438		
<i>Cerebellar Afferent Fibers</i> , 439		
<i>Topographic Localization</i> , 440		
<i>Synaptic Interactions in the Cerebellar Cortex</i> , 441		
Functional Cerebellar Modules, 443		
<i>Vestibulocerebellar Module</i> , 443		
<i>Vestibulocerebellar Dysfunction</i> , 444		
<i>Vestibular Connections of the Vermis</i> , 444		
<i>Spinocerebellar Module</i> , 445		
<i>Pontocerebellar Module</i> , 447		
<i>Pontocerebellar Dysfunction</i> , 447		
Cerebellar Influence on Visceromotor Functions, 449		
The Cerebellum and Motor Learning, 449		

28	<b>Visual Motor Systems</b> <i>P. J. May and J. J. Corbett</i> Overview, 454 Peripheral Structures, 454 <i>Extraocular Muscles, 454</i> <i>Intraocular Eye Muscles, 454</i> <i>Eyelid, 454</i> Central Structures, 456 <i>Oculomotor Nucleus, 456</i> <i>Edinger-Westphal Nucleus, 456</i> <i>Trochlear Nucleus, 456</i> <i>Abducens Nucleus, 456</i> <i>Abducens Internuclear Neurons, 458</i> <i>Sympathetic Supply to the Orbit, 460</i> Targeting Movements, 461 <i>Saccades, 461</i> <i>Extraocular Muscle Motor Neurons, 461</i> <i>Horizontal and Vertical Gaze Centers, 461</i> <i>Supranuclear Control, 462</i> <i>Smooth Pursuit, 463</i> <i>Vergence Movements and the Near Triad, 466</i> Reflex Movements, 466 <i>Optokinetic Eye Movements, 466</i> <i>Pupillary Light Reflex, 467</i> <i>Blinking and Other Lid Movements, 469</i>	453	Fornix, 492 Medial Forebrain Bundle, 492 Amygdalohypothalamic Fibers, 492 Other Afferent Fibers, 492 Hypothalamic Efferent Fibers, 493 <i>Ascending Projections, 493</i> <i>Descending Projections, 493</i> Intrinsic Hypothalamic Connections, 495 <i>Supraopticohypophysial Tract, 495</i> <i>Tuberoinfundibular Tract, 496</i> Pituitary Tumors, 496 <i>Secretting Tumors, 496</i> <i>Cushing Disease, 497</i> <i>Prolactin-Secreting Tumors, 497</i> <i>Gonadotrope Tumors, 498</i> Regional Functions of the Hypothalamus, 498 <i>Caudolateral Hypothalamus, 498</i> <i>Rostromedial Hypothalamus, 498</i> Hypothalamic Reflexes, 498 <i>Baroreceptor Reflex, 498</i> <i>Temperature Regulation Reflex, 499</i> <i>Water Balance Reflex, 499</i>	
29	<b>Visceral Motor Pathways</b> <i>J. P. Naftel and S. G. P. Hardy</i> Overview, 473 Organization of the Visceral Motor System, 473 <i>Targets of Visceral Motor Outflow, 473</i> <i>General Features of Peripheral Visceral Motor Outflow, 473</i> Development, 474 <i>Preganglionic Visceral Motor Neurons, 474</i> <i>Postganglionic Visceral Motor Neurons, 474</i> Sympathetic Division, 476 <i>Sympathetic Preganglionic Neurons, 476</i> <i>Sympathetic Ganglia, 476</i> <i>Internal Organization of Sympathetic Ganglia, 477</i> <i>Functional and Chemical Coding, 478</i> <i>Receptor Types in Sympathetic Targets, 479</i> <i>Causalgia, 479</i> Parasympathetic Division, 480 <i>Preganglionic and Postganglionic Neurons, 480</i> <i>Parasympathetic Outflow Pathways, 480</i> <i>Functional and Chemical Coding, 480</i> <i>Receptor Types in Parasympathetic Targets, 481</i> Enteric Nervous System, 481 Regulation of Visceral Motor Outflow, 483 <i>Major Central Nervous System Components, 483</i> <i>Cardiovascular System, 483</i> Urinary Bladder and Micturition, 484	472	31 <b>The Limbic System</b> <i>R. B. Chronister and S. G. P. Hardy</i> Overview, 502 Cytoarchitectural Definitions of the Limbic Cortex, 502 Early Functional Concepts, 502 Blood Supply to the Limbic System, 503 Hippocampal Formation, 503 <i>Structure, 503</i> <i>Afferent Fibers, 505</i> <i>Efferent Fibers, 505</i> <i>Complete Circuit of Papez, 505</i> <i>Dysfunctions and Korsakoff Syndrome, 506</i> Long-Term Potentiation and Memory, 506 Amygdaloid Complex, 506 <i>Structure, 506</i> <i>Afferent Fibers, 506</i> <i>Efferent Fibers, 508</i> <i>Klüver-Bucy Syndrome, 509</i> Tempora Lobe Seizures, 509 Septal Region, 509 Nucleus Accumbens, 509 Limbic System and Emotions, 509 Limbic System and Cognitive Function, 510	500
30	<b>The Hypothalamus</b> <i>S. G. P. Hardy, R. B. Chronister, and A. D. Parent</i> Overview, 487 Boundaries of the Hypothalamus, 487 Hypothalamus and Pituitary, 487 Divisions of the Hypothalamus, 487 <i>Preoptic Area, 487</i> <i>Lateral Zone, 487</i> <i>Medial Zone, 489</i> <i>Periventricular Zone, 491</i> Feeding Motivation, 491 Blood Supply of the Hypothalamus, 492 Hypothalamic Afferent Fibers, 492	486	32 <b>The Cerebral Cortex</b> <i>J. C. Lynch</i> Overview, 512 Histology of the Cerebral Cortex, 512 Layers of the Cerebral Cortex, 513 Neurotransmitters of the Cerebral Cortex, 513 Neuron Types in the Cerebral Cortex, 514 <i>Pyramidal Cells, 514</i> <i>Local Circuit Neurons, 514</i> Laminar Organization, 514 <i>Intrinsic Circuitry of the Cerebral Cortex, 514</i> <i>Cytoarchitecture, 516</i> Columnar Organization, 516 Synopsis of Thalamocortical Relationships, 517 Blood Supply to the Cerebral Cortex, 519 Higher Cortical Functions, 520 <i>Dominant Hemisphere and Language, 521</i> <i>Wernicke and Broca Aphasia, 521</i> <i>Conduction and Global Aphasia, 522</i>	511

<i>Parietal Association Cortex: Space and Attention</i> , 522	
<i>Contralateral Neglect and Related Symptoms</i> , 523	
<i>Apraxia and Agnosia</i> , 524	
<i>Prefrontal Cortex and "Plans for Future Operation"</i> , 524	
<b>33 The Neurologic Examination</b>	<b>527</b>
<i>M. E. Santiago and J. J. Corbett</i>	
<i>Overview</i> , 528	
<i>Evaluation versus Examination</i> , 528	
<i>The Mental Status Examination</i> , 529	
<i>Cranial Nerve Function Testing</i> , 529	
<i>Cranial Nerve I</i> , 529	
<i>Cranial Nerve II</i> , 529	
<i>Cranial Nerves III, IV, and VI</i> , 532	
<i>Cranial Nerve V</i> , 533	
<i>Cranial Nerve VII</i> , 534	
<i>Cranial Nerve VIII</i> , 535	
<i>Cranial Nerves IX and X</i> , 536	
<i>Cranial Nerve XI</i> , 536	
<i>Cranial Nerve XII</i> , 536	
<i>The Motor Examination</i> , 536	
<i>Muscle Stretch Reflexes</i> , 538	
<i>Cerebellar Testing</i> , 539	
<i>The Sensory Examination</i> , 539	
<b>Figure Acknowledgments</b>	<b>545</b>
<b>Index</b>	<b>547</b>