# Contents

# Preface xiii

- 1. A Framework for Mind and Brain
- Introduction to the Study of Mind and Brain 1
   Where Do We Begin? 2
- Consciousness, Cortical Core, Connectivity, and Consistency 4
- 3. Consciousness 4
  - 3.1 A Useful Framework for Investigating Conscious and Unconscious Brain Processing 4
  - 3.2 Conscious and Unconscious Processes Together Form the Bases of Our Mental Processes 6
  - 3.3 Global States: Waking, Sleeping, and Dreaming 6
  - 3.4 The Theater of the Mind and Its Stage 7
- 4. The Cortical Core 10
- 5. Connectivity 11
- 6. Consistency 12
- 7. Summary 12

#### 2. The Brain

- 1. Introduction 17
- 2. Brain Structure-Neuroanatomy 19
  - 2.1 The Cortex 19
    - 2.1.1 Planes of the Brain 20
    - 2.1.2 Cortical Anatomy 21
  - 2.2 The Subcortex 23
  - 2.3 The Cerebellum 27
  - 2.4 The Brainstem 27
- 3. Brain Cells—Neurophysiology 28
  - 3.1 The Structure of an Idealized Neuron 29
  - 3.2 Action Potentials 30
  - 3.3 Connectivity Basics 30
  - 3.4 Brodmann Areas 32

- 4. Brain Function—Functional Neuroanatomy 34
  - 4.1 Right Brain—Left Brain 34
  - 4.2 The "Front-Back" Division 34
    - 4.2.1 Sensory and Motor Functions 34
  - 4.3 The Cerebral Lobes 36
    - 4.3.1 The Frontal Lobe 37
    - 4.3.2 The Parietal Lobe 39
    - 4.3.3 The Temporal Lobe 39
    - 4.3.4 The Medial Temporal Lobe 40
    - 4.3.5 The Occipital Lobe 41
- 5. Brain Pathways: Neuroconnectivity 41
  - 5.1 The Arcuate Fasciculus 46
  - 5.2 The Corpus Callosum 46
  - 5.3 The Internal Capsule/Corona Radiate 46
- 6. Brain Dynamics—Brain Rhythms and Oscillations 48
- 7. Putting It All Together 50
- 8. Study Questions 52
  - 3. Observing the Brain
- 1. Introduction 53
  - 1.1 Basics 55
  - 1.2 Accuracy in Space and Time 55
  - 1.3 A Brain in a Shoebox: Coordinates 56
- 2. Observing Brain Structure: Neuroanatomy 57
- 3. Observing Brain Cells: Neurophysiology 62
  - 3.1 Recording Neuron Activity From Inside the Brain 62
    - 3.1.1 Recording From Single and Clusters of Neurons 63
  - 3.2 Recording From Single and Clusters of Neurons in Humans 63
- Observing Brain Function: Functional Neuroanatomy 65
  - 4.1 Functional Neuroimaging Using Functional Magnetic Resonance Imaging: A Blood Oxygen Level–Dependent New World 65
  - 4.2 Measuring Metabolic Brain Activity: Positron Emission Tomography 73

- 4.3 Measuring Electrical and Magnetic Fields: Electroencephalography and Magnetoencephalography Recording 76
  - 4.3.1 Electroencephalography: The Electrical Fields of the Brain 77
  - 4.3.2 Magnetoencephalography: Magnetic Fields of the Brain 83
- 4.4 Zapping the Brain: Transcranial Magnetic Stimulation 85
- 5. Observing Brain Pathways: Neuroconnectivity 88
- Observing Brain Dynamics: Brain Rhythms and Oscillations 89
- 7. Summary 97
- 8. Study Questions 97

## 4. The Art of Seeing

- 1. Introduction 99
- Functional Organization of the Visual System 103
  - 2.1 The Retina 103
  - 2.2 Lateral Geniculate Nucleus 106
  - 2.3 Primary—or Striate—Visual Cortex 107
     2.3.1 A Subcortical Route to Visual Cortex 109
  - 2.4 Extrastriate Visual Areas—Outside V1 110
  - 2.5 Area Middle Temporal 112
  - 2.6 Connectivity Patterns in Visual Cortex: Feedforward, Feedback, and Parallel Flows 113
  - 2.7 The Ventral and Dorsal Pathways: Knowing What and Where 114
  - 2.8 Areas Involved in Object Recognition 114
    - 2.8.1 The Lateral Occipital Complex 115
      - 2.8.2 The Fusiform Face Area 115
      - 2.8.3 The Parahippocampal Place Area 115
- 3. Constructive Perception 115
  - 3.1 Perceptual Filling-In: The Blind Spot 117
  - 3.2 Apparent Motion 118
  - 3.3 Illusory Contours 119
  - 3.4 Gestalt Principles 120
  - 3.5 2-D to 3-D Mapping 121
  - 3.6 Color Perception 122
  - 3.7 Color Constancy 123
  - 3.8 Crowding 124
  - 3.9 Multistable Perception 125
  - 3.10 Perceived Motion 127

- 4. Object (and Face) Recognition 127
  - 4.1 A Two-Step Process for Object Recognition 127
  - 4.2 Faces and Places 128
- 5. How the Visual System Creates Your Perception 129
- 6. Visual Consciousness 130
  - 6.1 Brain Areas Necessary for Visual Awareness: Lesion Studies 132
    - 6.1.1 Consequences of Damage to Early Visual Areas 132
    - 6.1.2 Extrastriate Lesions—Damage Outside Area V1 134
  - 6.2 Brain Areas Necessary for Visual Awareness: Experimental Studies 137
    - 6.2.1 Binocular Rivalry Experiments 137
    - 6.2.2 Attentional Blindness Experiments-Or Did You See the Gorilla? 138
- 7. Summary 141
- 8. Study Questions 141
  - 5. Sound, Speech, and Music Perception
- 1. Introduction 143
  - 1.1 A Model for Sound Processing 144
    - 1.1.1 A Working Framework for Sound Perception 144
    - 1.1.2 Limited and Large Capacity 144
    - 1.1.3 Orders of Magnitude and Levels of Analysis 145
    - 1.1.4 Time 146
  - 1.2 Sound and Hearing Basics 147
    - 1.2.1 Physical Features of Sounds 148
    - 1.2.2 A Scale for Sound Intensity 149
    - 1.2.3 Psychological Aspects of Sounds 150
    - 1.2.4 Auditory Processing Begins—and Ends—at the Ear 150
- 2. Pathways to Auditory Cortex 152
- 2.1 Auditory Pathways 152
  - 2.1.1 Ascending Pathways 153
  - 2.1.2 Descending Pathways 155
  - 2.2 Auditory Cortex 155
    - 2.2.1 Auditory Cortical Anatomy 155
    - 2.2.2 Neurophysiology 158
- 3. Cortical Auditory Functions and Pathways: What and Where 161
  - 3.1 Auditory Object Learning and Recognition 161
  - 3.2 Auditory Scene Analysis 162

### vi

- 3.3 "What" and "Where" Processing Streams 164
  - 3.3.1 Dual Streams for Processing What and Where Information 164
- 4. Speech Perception 165
  - 4.1 Dual Processing Streams: Dorsal and Ventral 167
- 5. Music Perception 172
  - 5.1 Stages of Music Processing 172
  - 5.2 A Separate System for Music Perception? 174
- 6. Auditory Awareness and Imagery 179
  - 6.1 Auditory Awareness During Sleep and Sedation 179
  - 6.2 Auditory Imagery 180
- 7. Summary 181
- 8. Study Questions and Drawing Exercises 182
  - 8.1 Study Questions 182
  - 8.2 Drawing Exercises 182

6. Language and Thought

- 1. Introduction 185
- 2. Language...Spoken and Heard 187
  - 2.1 The Sounds of Language—Phonology and Word Identification 187
  - 2.2 Words and Meaning-Semantics 189
  - 2.3 Rules and More Rules—Syntax and Grammar 189
  - 2.4 The Melody of Language—Intonation and Stress 191
  - 2.5 The Goals of Language—Propositions and Discourse 191
  - 2.6 The Learning of Language—Language Acquisition 192
  - 2.7 The Cortical Orgnization of Language 192
     2.7.1 Classical Theories: Broca's and Wernicke's Area 193
    - 2.7.2 Current Models 193
  - 2.8 Thoughts About Language and Thought 196
- 3. Thoughts 196
  - 3.1 Thinking and Problem-Solving 196
    - 3.1.1 Conscious and Unconscious Processes 199
    - 3.1.2 Explicit Thinking and Problem-Solving 199
    - 3.1.3 Executive Function, Attention, Working Memory, and Problem-Solving 199

- 3.1.4 Using Inner Speech to Solve Problems 200
- 3.1.5 Expert Thinking and Cognitive Load 200
- 3.1.6 Fixedness and Mental Flexibility 202
- 3.1.7 Mental Effort 203
- 3.2 Implicit Thinking 203
  - 3.2.1 Implicit Problem-Solving 204
  - 3.2.2 Implicit Problem-Solving: The Aha! Moment 204
- 3.3 Cortical Organization for Thinking and Problem-Solving 207
- 4. Summary 212
- 5. Study Questions 213
  - 7. Learning and Remembering
- 1. Introduction 216
  - 1.1 Memory Is Not a Single Thing: A Useful Classification 216
  - 1.2 Episodic and Semantic Memory 217
- Episodic Learning and Memory 219
   2.1 An Example of Episodic Learning 220
- 3. Semantic Memory Is Different 222
  - 3.1 Episodic and Semantic Networks 222
  - 3.2 The Hippocampus in Remember/Know Experiments 223
  - 3.3 Schemas and Memory 223
- 4. Memory Trace Formation and Consolidation 224
  - 4.1 "Excitatory" and "Inhibitory" Memory Traces 224
  - 4.2 Rapid Consolidation: Synaptic Mechanisms, Gene Transcription, and Protein Synthesis 225
  - 4.3 System Consolidation: Interaction Between the Medial Temporal Lobes and the Cortex 225
- 5. Memory Traces and Models 226
  - 5.1 Episodic Memory Traces and Consciousness 226
  - 5.2 A Multiple Trace Theory Is Proposed 227
  - 5.3 Challenges to the Multiple Trace Theory 228
  - 5.4 Some Current Views About Memory Processes 228
    - 5.4.1 A New View About the Classic Long-Term/Short-Term Memory Distinction 228

- 5.4.2 A Debate: Is Consciousness Needed for Episodic Learning? 228
- 5.4.3 The Role of Schemas in Memory Encoding and Retrieval 229
- 5.4.4 Strengthening Memories: The Relative Effectiveness of Restudy Versus Retrieval 231
- 5.5 A Continual Process 233
- 6. Control of Memory 233
  - 6.1 Working With Memory: The Frontal Lobe Works Purposefully With Memory 233
  - 6.2 Prefrontal Cortex in Explicit (Conscious) and Implicit (Unconscious) Learning and Memory 233
  - 6.3 Prefrontal Cortex and Working Memory— Storage or Executive Control? 234
    - 6.3.1 The Prefrontal Cortex and Animal Studies of Working Memory 234
    - 6.3.2 The Prefrontal Cortex and Delayed-Response Tasks 234
    - 6.3.3 The Prefrontal Cortex and Human Studies 237
    - 6.3.4 The Prefrontal Cortex in Patients With Brain Damage 238
    - 6.3.5 The Prefrontal Cortex and Working With Memory 238
  - 6.4 Real Memories Are Dynamic 238
- 7. When Memories Are Lost 239
  - 7.1 Hippocampal Versus Cortical Damage 239
  - 7.2 Defining Amnesia 241
  - 7.3 Amnesia Can Impair Working Memory 244
  - 7.4 Habits and Implicit Memory Tend to Survive Amnesia 244
- 8. Summary 245
- 9. Study Questions 246
  - 8. Attention and Consciousness
- 1. Introduction 247
  - 1.1 Three Global Brain States 248
- 2. Waking: Purposeful Thoughts and Actions 250
  - 2.1 The Stadium Analogy: Chattering, Cheering, and Chanting 2522.1.1 Chattering in the Waking Brain 253

- 2.1.2 Cheering in the Waking Brain 253
- 2.1.3 Chanting in the Unconscious Brain 253
- 3. Consciousness 255
  - 3.1 Waking Has Conscious and Unconscious Threads 255
  - 3.2 What We Expect From Conscious People 256
  - 3.3 The Scientific Rediscovery of Consciousness: A Global Workspace Theory 257
  - 3.4 Components of Consciousness and Unconsciousness: Awareness and Wakefulness 258
- 4. Attention 260
  - 4.1 Attention Selects Conscious Events 261
  - 4.2 Voluntary and Automatic Attention: "Top-Down" Control and "Bottom-Up" Capture 261
  - 4.3 The "Spotlight of Voluntary Attention": Global Workspace Theory Revisited 262
  - 4.4 Neural Bases of Voluntary Attention: Alerting, Orienting, and Executive Control 263
  - 4.5 Neural Oscillations Underlying Sustained Attention 265
- 5. Attention and Consciousness: Separable
  - but Closely Intertwined Processes 270
  - 5.1 Disentangling Attention and Conscious Perception: The No-Report Paradigm 270
  - 5.2 Neural "Switches" for Consciousness Versus Unconsciousness 271
- 6. Exceptional States of Mind 273
  - 6.1 Epilepsy, Drugs, and Psychoses 273
  - 6.2 Out-of-Body Experiences 273
  - 6.3 Neurofeedback 274
  - 6.4 Sensorimotor Rhythm Feedback 274
  - 6.5 Rhythmic Entrainment 274
  - 6.6 Hypnosis and Conversion 275
  - 6.7 Meditation and Yoga 275
- 7. Summary 276
- 8. Study Questions 276

- 9. Decisions, Goals, and Actions
- 1. Introduction 279
  - 1.1 The Many and Complex Frontal Lobe Functions 280
  - From the Silent Lobes to the Organ of Civilization 287
  - 1.3 "Memory of the Future" 288
  - 1.4 Self-awareness and Executive Function 289
  - 1.5 Frontal Lobe Development 290
- 2. Structure of the Frontal Lobes 291
  - 2.1 Neuroanatomy and Neurophysiology of the Frontal Lobes 291
  - 2.2 How Prefrontal Cortex Is Defined 291
  - 2.3 The Vast Connective Highways of the Frontal Lobes 291
- A Closer Look at Frontal Lobe Functions 293
  - 3.1 Executive Functions 293
  - 3.2 Social Maturity and Moral Development 295
    - 3.2.1 Early Life Experience and Orbitofrontal Cortex Development 295
    - 3.2.2 Moral Development and the Frontal Cortex 296
    - 3.2.3 Age of Maturity and Frontal Lobe Development 297
- 4. Neuroimaging the Executive Brain 297
  - 4.1 Attention and Perception 298
  - 4.2 Working Memory 299
  - 4.3 Executive Function and Motor Control 301
  - 4.4 Decision-Making 306
  - 4.5 Rule Adoption 310
- 5. Damage to the Executive Brain 310
  - 5.1 The Fragile Frontal Lobes 311
  - 5.2 Frontal Lobe Syndromes 312
    - 5.2.1 Dorsolateral Prefrontal Syndromes 313
    - 5.2.2 Orbitofrontal Prefrontal Syndromes and Self-control 314
    - 5.2.3 Reticulofrontal Disconnection Syndrome 314
  - 5.3 Frontal Lobe Damage and Asocial Behavior 315

- 5.4 Other Clinical Conditions Associated With Frontal Lobe Damage 315
  5.4.1 Attention Deficit (Hyperactivity) Disorder 315
- 6. A Current View of Organizing Principles of the Frontal Lobes 316
- 7. Toward a Unified Theory of Frontal Lobe Function 316
- 8. Study Questions 319
  - 10. Humans Are Social Beings
- 1. Introduction 322
  - 1.1 Terms That Are Used to Refer to Social Cognition 322
- 2. Four Central Aspects of Social Cognition 326
  - 2.1 Brain Areas Subserving the Four Central Aspects of Social Cognition 327
- 3. Theory of Mind Model: An Organizing Framework for Social Cognition 328
  - 3.1 Intention 330
  - 3.2 Eye Detection 330
  - 3.3 Shared Attention Mechanism 330
  - 3.4 Higher-Order Theory of Mind 331
  - 3.5 Brain Areas for Theory of Mind Processes 333
    - 3.5.1 Intention 334
    - 3.5.2 Eye Detection and Gaze Perception 334
    - 3.5.3 Shared Attention 336
    - 3.5.4 Higher-Order Theory of Mind Abilities': Attribution of Mental States to Ourselves and Others 337
- 4. Empathy 343
- 5. Social Perception 344
  - 5.1 Face Perception 344
  - 5.2 Biological Motion Perception 346
- 6. Social Behavior 349
  - 6.1 The Ventromedial Prefrontal Cortex 349
  - 6.2 The Orbitofrontal Cortex 350
- 7. An Integrated Model for Social Cognition 351
- 8. Disorders of Social Cognition 353
- 9. Summary 355
- 10. Study Questions and Drawing Exercises 35610.1 Study Questions 35610.2 Drawing Exercises 356

#### 11. Feelings

- 1. Introduction 357
  - 1.1 Emotions—Categories and Dimensions 358
  - 1.2 Emotions: Continuous or Discrete? 358
- 2. The Emotional Brain Circuitry 361
- Emotional Regulation and Cognitive Reappraisal 365
  - 3.1 Generation and Regulation of Emotions 365
  - 3.2 Valuation: Is This Bad for Me or Good for Me? 365
  - 3.3 Cognitive Reappraisal 365
  - 3.4 Brain Regions Are Involved in Emotion Regulation 366
- 4. Emotional Perception 366
  - 4.1 Specific Pathways and Activation Patterns for Basic Emotions 369
  - 4.2 Emotional Facial Expression Processing 370
- 5. Emotional Contagion and Empathy 371
- 6. Emotional Memories 374
- 7. Rewards and Motivation 375
- 8. Moods and Personality 377
- 9. Conflict and Conflict Resolution 380
- 10. Stress 382
- 11. Emotional Impairments and Disorders 383
  - 11.1 Posttraumatic Stress Disorder 383
  - 11.2 Addiction 383
  - 11.3 Mood Disorders 389
    - 11.3.1 Depression 389
    - 11.3.2 Bipolar Disorder 389
- 12. Summary 391
- 13. Study Guide 391
  - 12. Sleep and Levels of Consciousness
- 1. Introduction 394
  - 1.1 Sleep Is Crucial to Healthy Cognition 394
  - 1.2 Three Global Brain States: Awake, Asleep, and Dreaming 394
  - Levels of Consciousness: Awareness and Wakefulness 396
- From Wakeful to Sleepy...and Back Again: Daily Rhythms for Sleep 399
  - 2.1 The Two-Process Model of Sleep–Wake Regulation: Circadian Rhythms and Homeostasis 399
  - 2.2 Brain Bases of Process S and Process C 400

- 3. The Architecture of Sleep 401
  - 3.1 How Sleep Is Studied 405
  - 3.2 Sleep Stages: Nonrapid and Rapid Eye Movement Sleep 407
  - 3.3 Measuring Sleep Stages: Polysomnography 408
  - 3.4 Neurophysiology of Sleep Stages: Slow Wave Sleep and Rapid Eye Movement Sleep 408
    - 3.4.1 The Neural Symphony of Brain Oscillations During Slow Wave Sleep 410
    - 3.4.2 The Lively Brain During Rapid Eye Movement Sleep 411
  - 3.5 The Ups and Downs of Sleep Stages: Neuromodulators 411
  - 3.6 Brain Activation and Deactivation During Rapid Eye Movement Sleep 414
- 4. Memory and Sleep 416
  - 4.1 The Interaction of Sleep and Memory Processes 416
  - 4.2 Selective Memory Consolidation 416
  - 4.3 Encoding and Consolidation: Temporary and Long-Term Memory Stores 418
  - 4.4 Brain Bases of Two-Stage Model of Memory Consolidation 419
  - 4.5 Memory Consolidation Mechanisms During Rapid Eye Movement Sleep 421
- 5. Dreaming 422
  - 5.1 How Is Dreaming Studied? 423
  - 5.2 When Do We Dream? 424
  - 5.3 Dreaming in the Brain 425
  - 5.4 Nightmares Versus Night Terrors 425
- 6. Sleep Disorders 427
  - 6.1 Diagnosing a Sleep Disorder 427
  - 6.2 Insomnia 427
  - 6.3 Sleep Apnea 429
  - 6.4 Restless Legs Syndrome 430
  - 6.5 Narcolepsy 430
  - 6.6 Parasomnias: Nonrapid Eye Movement Sleep Disturbances 432
    - 6.6.1 Confusional Arousals 432
    - 6.6.2 Night Terrors 433
    - 6.6.3 Sleepwalking 433
  - 6.7 Parasomnias: Rapid Eye Movement Sleep Disturbances 433
    - 6.7.1 Sleep Paralysis 433
    - 6.7.2 Rapid Eye Movement Sleep Behavior Disorder 434

х

- 7. Summary 434
- 8. Study Questions 435

### 13. Disorders of Consciousness

- 1. Introduction 437
- 2. Reversible Unconsciousness 438
  - 2.1 Reversible Unconsciousness Slow Wave Sleep 438
  - 2.2 Reversible Unconsciousness Anesthesia 439
- 3. Disorders of Consciousness 440
  - 3.1 Coma 442
  - 3.2 Vegetative State 442
  - 3.3 Minimally Conscious State 443
  - 3.4 Posttraumatic Confusional State 443
  - 3.5 Locked-In Syndrome 444
- 4. Neuroimaging Disorders of Consciousness 444
  - 4.1 Metabolic Brain Activity Reflects Conscious State 444
  - 4.2 Hemodynamic Brain Activity Reflects Conscious State 445
- 5. Summary 451
- 6. Study Questions 451

## 14. Growing Up

- 1. Introduction 453
  - 1.1 New Techniques for Investigating the Developing Brain 454
  - 1.2 The Mystery of the Developing Brain: Old Questions and New 454
- Prenatal Development: From Blastocyst to Baby 454
  - 2.1 Epigenesis 456
  - 2.2 The Anatomy of Brain Development 457
  - 2.3 Neural Migration 459
  - 2.4 The Unborn Baby: Prenatal Experience Causes Lifelong Effects 461

- 2.4.1 Prenatal Hearing Experience: Voice and Music Perception Before Birth 461
- 2.4.2 Teratogens and Their Lasting Effects: Alcohol 462
- 2.4.3 Teratogens and Their Lasting Effects: Marijuana and Cigarette Smoke Exposure 463
- 3. The Developing Brain: A Lifetime of Change 467
  - 3.1 The Rise and Fall of Postnatal Brain Development 467
  - 3.2 Regional Differences in Brain Development 469
- 4. Developing Mind and Brain 471
  - 4.1 The First Year of Life: An Explosion of Growth and Development 471
    - 4.1.1 Developing the Language Brain: Infant Language Capabilities 472
    - 4.1.2 Developing the Executive Brain: What do Babies Know? 475
    - 4.1.3 Developing the Social Brain: Faces and Places 480
  - 4.2 Childhood and Adolescence: Dynamic and Staged Growth 483
    - 4.2.1 The Linguistic Brain: Language Acquisition 483
    - 4.2.2 The Executive Brain: Taking Cognitive Control 484
    - 4.2.3 The Social Brain: Face Perception in Childhood 486
- 5. Early Brain Damage and Developmental Plasticity 489
- 6. Summary 492
- 7. Study Questions 493

Glossary 495 References 511 Index 529