



# The Mind's Machine SECOND EDITION

## COMPANION WEBSITE



2e.mindsmachine.com

The Mind's Machine  
Foundations of Brain and Behavior  
Neil V. Watson • S. Marc Breedlove

CHAPTER 5  
Menu  
HOME / CHAPTERS / OUTLINE

### Chapter 5: The Sensorimotor System

Introduction  
Study questions: 1

#### PART I: SENSORY PROCESSING AND THE SOMATOSENSORY SYSTEM

Study questions: 2 | 3

#### Receptor Cells Convert Sensory Signals into Electrical Activity

Study questions: 4 | 5 | 6 | 7 | 8

#### Sensory Information Processing Is Selective and Analytical

- Sensory events are encoded as streams of action potentials
- Sensory neurons respond to stimuli falling in their receptive fields
- Receptors may show adaptation to unchanging stimuli
- Sometimes we need receptors to be quiet.

Study questions: 9 | 10 | 11

#### Successive Levels of the CNS Process Sensory Information

**The Mind's Machine** Companion Website is a free companion to the textbook that will help you learn the material presented in the book through a variety of study tools and multimedia resources. The website is tightly integrated with the text, with content corresponding to every section of each chapter and QR codes and direct Web addresses that link you directly to specific online resources. (See more at right.) Complex concepts and systems are made more accessible through the use of animations, videos, and activities, and key terms and concepts are reinforced through interactive study questions. The site also offers online quizzes that your instructor may assign. (Note that instructor registration is required in order for students to access the online quizzes.)

### Chapter 6 Study Questions

[Previous Question](#) | [Next Question](#)

#### Question 3.

The middle ear starts at the eardrum, which is formally known as the **tympenic** membrane. This is connected to the inner ear by a series of minuscule bones, the **malleus**, the **incus**, and the **stapes**, which are known collectively as the **ossicles**.

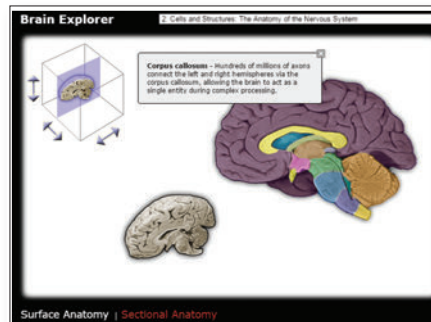
#### Correct Answer:

The middle ear starts at the eardrum, which is formally known as the **tympenic** membrane. This is connected to the inner ear by a series of minuscule bones, the **malleus**, the **incus**, and the **stapes**, which are known collectively as the **ossicles**.

**Textbook Reference:** Each Part of the Ear Performs a Specific Function in Hearing, pp.143–148

[Previous Question](#) | [Next Question](#)

**Study questions** reinforce your knowledge of all the important facts and concepts covered in each chapter through interactive fill-in-the-blank questions that check your answers immediately.



The **Brain Explorer** offers an interactive way to explore the brain anatomy discussed in each chapter, in both surface and sectional views.

Chapter 5 Visual Summary

Muscles around a joint work in pairs. **Antagonists** work in opposition; **synergists** work together. Action potentials travel over motor nerve fibers (axons from **motoneurons**) and reach muscle fibers at the **neuromuscular junction**, releasing **acetylcholine (ACh)** to trigger muscle contraction. Review **Figures 5.18** and **5.19**

Previous 8 of 11 Next

Online versions of the **visual summaries** provide a thorough review of each chapter and include links to figures, animations, videos, and activities.

Animation 13.3: AMPA and NMDA Receptors

Axon terminal

Na<sup>+</sup> Ca<sup>2+</sup> Na<sup>+</sup>

Na<sup>+</sup> Ca<sup>2+</sup> Na<sup>+</sup>

Signaling cascades

Dendritic spine (postsynaptic neuron)

**Textbook Reference:** Synaptic Plasticity Can Be Measured in Simple Hippocampal Circuits, p. 377  
[View all the text for this animation](#)

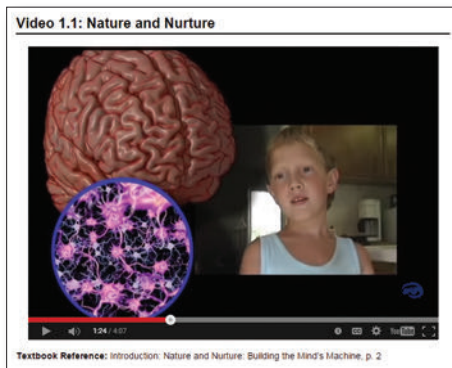
**Animations** present complex concepts in a clear, easy-to-follow narrative, using a visual style that closely matches the textbook's figures.

## Additional Features

- **Activities**, which help you learn and review key structures and important processes.
- **"A Step Further"** topics, which expand on the material covered in the textbook.
- **Flashcards** for each chapter offer a convenient way to learn and review the many new terms introduced in the textbook.
- A complete **glossary** for quick access to definitions.

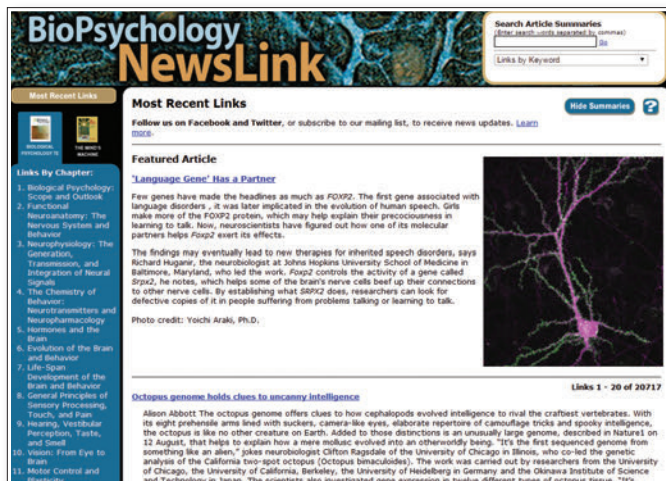
## QR Codes


Using your smartphone or tablet, scan the QR codes that appear throughout the textbook (or type in the Web address shown) to instantly access animations, videos, and visual summaries on the Companion Website. (QR code reader app required. These are available for free from your device's app store.)



## Videos

Videos present real-world examples of some of the key concepts and conditions discussed in the textbook.





chapter  
**1**


# An Introduction to Brain and Behavior

## Nature and Nurture: Building the Mind's Machine

We humans have a long history of using contemporary technology as a metaphor for the mysterious workings of the brain. Scholars of old, influenced by inventions such as aqueducts, plumbing, and ornamental fountains, proposed that behavior was the result of liquid "animal spirits" jettisoned around within the body. Later thinkers emphasized the possible importance of wires, switches, and relays: the technology of their day. Today it is commonplace to see the brain described as a computer, with "hardware" and "software." Perhaps tomorrow's neuroscientists will describe the brain in terms of holograms, quantum devices, or a technology that has yet to be imagined.

Modern research aims to describe the complicated machine within each of our heads, but we also want to know how the operation of the brain produces the *mind*—the perceptions, emotions, thoughts, self-awareness, and other cognitive processes that inform our behavior. During the twentieth century, a lot of ink was spilled over the "nature-nurture" controversy, with scholars arguing passionately about the extent to which mental characteristics and abilities are the result of learning experiences versus innate, "hardwired" genetic programs.

The two perspectives have often been presented as mutually incompatible alternatives, but thanks to more-powerful techniques, we have come to realize that there is nothing controversial about nature versus nurture: they are two sides of the same coin. Consider the case of rat pups who have inattentive mothers. As adults, the formerly neglected pups show elevated stress hormone responses to stressors that have little effect on rats that were not neglected as pups (T. Y. Zhang and Meany, 2010). How does this lasting reactivity develop—through experience or as a result of innate biological factors? Both, it turns out. As we'll see later in this chapter, and throughout the book, the mind and its machine are shaped by a precise combination of genes and experience, inextricably tied together.

To see the video Nature and Nurture, go to  
  
2e.mindsmachine.com/1.1

## BIOLOGICAL PSYCHOLOGY NewsLink 2e.mindsmachine.com/news

This invaluable online resource helps you make connections between the science of biological psychology and your daily life, and keeps you apprised of the latest developments in the field. The site is updated 3–4 times per week, and contains thousands of news stories organized both by keyword and by textbook chapter.

Find us on Facebook (Biopsychology).

# COMPANION WEBSITE Resources (2e.mindsmachine.com)

The **Mind's Machine** Companion Website includes animations, videos, and activities for each chapter (listed below) as well as an interactive version of each chapter's visual summary. Animations and Videos are referenced throughout the book with QR codes and direct Web addresses. Activities are referenced in each chapter's summary.

## Animations & Videos

<b>1.1</b> Nature and Nurture, p. 2	<b>8.6</b> Organizational Effects of Testosterone, p. 241	<b>2.4</b> Concept Matching: Sympathetic vs. Parasympathetic
<b>1.2</b> Brain Explorer, p. 4	<b>9.1</b> Anorexia, p. 254	<b>2.5</b> Gross Anatomy of the Human Brain: Lateral View
<b>2.1</b> Inside the Brain, p. 20	<b>9.2</b> Brain Explorer, p. 256	<b>2.6</b> The Developing Brain
<b>2.2</b> Brain Explorer, p. 22	<b>9.3</b> Negative Feedback, p. 257	<b>2.7</b> The Basal Ganglia
<b>2.3</b> Brain Development, p. 36	<b>9.4</b> Thermoregulation in Humans, p. 258	<b>2.8</b> The Limbic System
<b>2.4</b> Visualizing the Living Human Brain, p. 45	<b>10.1</b> Narcolepsy, p. 278	<b>2.9</b> Gross Anatomy of the Human Brain: Midsagittal View
<b>3.1</b> Electrical Stimulation of the Brain, p. 50	<b>10.2</b> Brain Explorer, p. 280	<b>2.10</b> Gross Anatomy of the Human Brain: Basal View
<b>3.2</b> Brain Explorer, p. 52	<b>10.3</b> Biological Rhythms, p. 281	<b>2.11</b> The Cerebral Ventricles
<b>3.3</b> The Resting Membrane Potential, p. 55	<b>10.4</b> A Molecular Clock, p. 286	<b>3.1</b> Distribution of Ions
<b>3.4</b> The Action Potential, p. 55	<b>10.5</b> Animal Sleep Activity, p. 301	<b>4.1</b> Families of Transmitters
<b>3.5</b> Action Potential Propagation, p. 59	<b>10.6</b> Narcoleptic Dachshund, p. 302	<b>5.1</b> Receptors in Skin
<b>3.6</b> Spatial Summation, p. 64	<b>10.7</b> REM Behavior Disorder, p. 304	<b>5.2</b> Ascending Pain Pathways in the CNS
<b>3.7</b> Synaptic Transmission, p. 65	<b>11.1</b> Stress, p. 310	<b>5.3</b> Subcortical Systems Involved in Movement
<b>4.1</b> Synaptic Transmission, p. 78	<b>11.2</b> Brain Explorer, p. 312	<b>6.1</b> Organ of Corti
<b>4.2</b> Brain Explorer, p. 81	<b>12.1</b> Lobotomy, p. 338	<b>6.2</b> Taste
<b>4.3</b> Neurotransmitter Pathways, p. 85	<b>12.2</b> Brain Explorer, p. 340	<b>7.1</b> The Structure of the Eye
<b>4.4</b> Agonists and Antagonists, p. 88	<b>12.3</b> Tardive Dyskinesia, p. 349	<b>8.1</b> Major Endocrine Glands
<b>5.1</b> Sensory Systems, p. 110	<b>13.1</b> Memory, p. 368	<b>9.1</b> An Appetite Controller in the Hypothalamus
<b>5.2</b> Brain Explorer, p. 112	<b>13.2</b> Brain Explorer, p. 370	<b>10.1</b> Stages of Sleep
<b>5.3</b> Somatosensory Receptive Fields, p. 116	<b>13.3</b> AMPA and NMDA Receptors, p. 391	<b>10.2</b> Sleep Mechanisms
<b>5.4</b> The Stretch Reflex Circuit, p. 133	<b>13.4</b> Morris Water Maze, p. 393	<b>11.1</b> Conditioned Fear Response
<b>6.1</b> Inside the Ear, p. 144	<b>13.5</b> Stages of Neuronal Development, p. 394	<b>11.2</b> The Stress Response and Pathological Consequences of Prolonged Stress
<b>6.2</b> Brain Explorer, p. 146	<b>13.6</b> Migration of a Neuron along a Radial Glial Cell, p. 395	<b>12.1</b> Concept Matching
<b>6.3</b> Sound Transduction, p. 150	<b>14.1</b> Attention and Perception, p. 408	<b>13.1</b> Learning and Memory
<b>6.4</b> Mapping Auditory Frequencies, p. 154	<b>14.2</b> Brain Explorer, p. 410	<b>13.2</b> The "Tower of Hanoi" Problem
<b>6.5</b> The Vestibular System, p. 163	<b>14.3</b> Inattentional Blindness, p. 411	<b>13.3</b> Development of the Nervous System
<b>6.6</b> The Human Olfactory System, p. 168	<b>14.4</b> From Input to Output, p. 414	<b>14.1</b> Subcortical Sites Implicated in Visual Attention
<b>7.1</b> Object Recognition, p. 174	<b>14.5</b> Reconstructing Brain Activity, p. 429	<b>14.2</b> Cortical Regions Implicated in the Top-Level Control of Attention
<b>7.2</b> Brain Explorer, p. 176	<b>15.1</b> Face Blindness, p. 438	<b>15.1</b> Speech and Language Areas
<b>7.3</b> Visual Pathways in the Human Brain, p. 183	<b>15.2</b> Brain Explorer, p. 440	<b>15.2</b> The Connectionist Model of Aphasia
<b>7.4</b> Receptive Fields in the Retina, p. 188	<b>15.3</b> Split-Brain Research, p. 441	<b>15.3</b> Song Control Nuclei of the Songbird Brain
<b>7.5</b> Spatial Frequencies, p. 192	<b>A.1</b> Gel Electrophoresis, p. A-4	
<b>8.1</b> Gender, p. 208		
<b>8.2</b> Brain Explorer, p. 210		
<b>8.3</b> Chemical Communication Systems, p. 212	<b>Activities</b>	
<b>8.4</b> Mechanisms of Hormone Action, p. 214	<b>2.1</b> Major Components and Classification of Neurons	
<b>8.5</b> The Hypothalamus and Endocrine Function, p. 220	<b>2.2</b> The Cranial Nerves	
	<b>2.3</b> Gross Anatomy of the Spinal Cord	

# The Mind's Machine

Foundations of Brain and Behavior

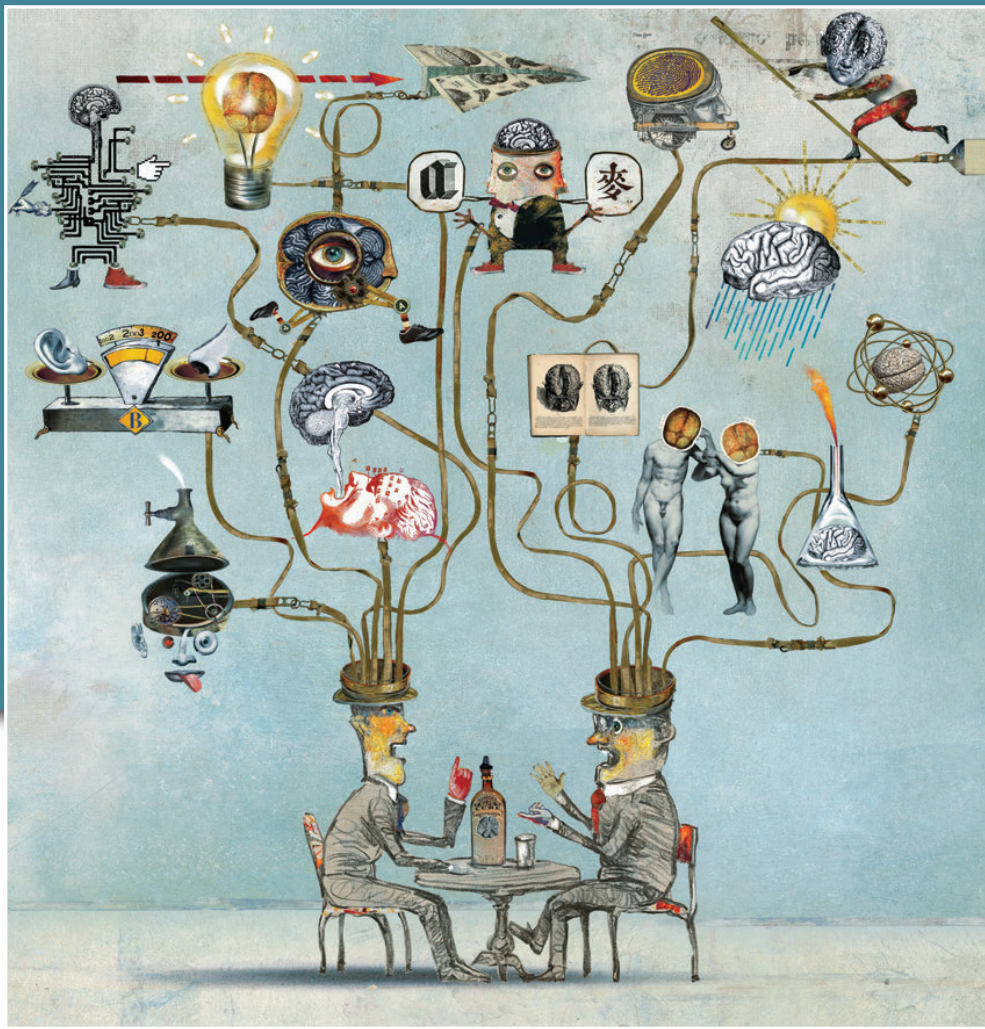
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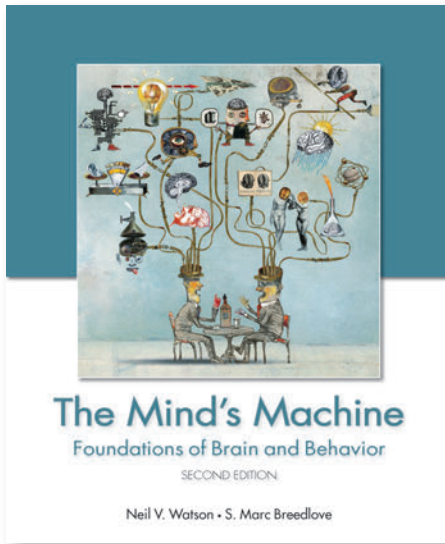
## Foundations of Brain and Behavior

SECOND EDITION



Neil V. Watson • S. Marc Breedlove  
*Simon Fraser University*     *Michigan State University*

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## About the Cover and Chapter Opener Images

Bruno Mallart is one of the most talented European artists, his work having appeared in some of the world's premier publications: *The New York Times*, *The Wall Street Journal*, and *The New Scientist*, to name a few. A freelance illustrator since 1986, Mallart first worked for several children's book publishers and advertising agencies, using a classical realistic watercolor and ink style. Some years later he began working in a more imaginative way, inventing a mix of drawing, painting, and collage. His work speaks of a surrealistic and absurd world and engages the viewer's imagination and sense of fun. Despite the recurring use of the brain in his art, Mallart's background is not scientific—though his parents were both neurobiologists. He uses the brain as a symbol for abstract concepts such as intelligence, thinking, feeling, ideas, and knowledge. Attracted to all that is mechanical, Mallart's art frequently includes machine parts such as gears and wheels that imply movement and rhythm. These features together, in their abstract representation, beautifully illustrate the topics discussed in *The Mind's Machine*, Second Edition. To see more of Bruno Mallart's art, please go to his website: [www.brunomallart.com](http://www.brunomallart.com).

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N. V. W.  
*For my little brother, Pete*

S. M. B.  
*For Sage William*

# Brief Contents

- CHAPTER 1 An Introduction to Brain and Behavior 2
- CHAPTER 2 Cells and Structures:  
The Anatomy of the Nervous System 20
- CHAPTER 3 Neurophysiology: The Generation, Transmission,  
and Integration of Neural Signals 50
- CHAPTER 4 The Chemistry of Behavior:  
Neurotransmitters and Neuropharmacology 78
- CHAPTER 5 The Sensorimotor System 110
- CHAPTER 6 Hearing, Balance, Taste, and Smell 144
- CHAPTER 7 Vision: From Eye to Brain 174
- CHAPTER 8 Hormones and Sex 208
- CHAPTER 9 Homeostasis 254
- CHAPTER 10 Biological Rhythms and Sleep 278
- CHAPTER 11 Emotions, Aggression, and Stress 310
- CHAPTER 12 Psychopathology: The Biology of Behavioral Disorders 338
- CHAPTER 13 Memory, Learning, and Development 368
- CHAPTER 14 Attention and Consciousness 408
- CHAPTER 15 Brain Asymmetry, Spatial Cognition,  
and Language 438

# Table of Contents

Preface XVIII



## CHAPTER 1 An Introduction to Brain and Behavior 2

### What's in a Name? 4

### The Science of Brain and Behavior Spans Past, Present, and Future 5

The behavioral role of the brain was uncertain to early scholars 5

Advances in experimental methodology propel modern biological psychology 8

#### **BOX 1.1** *We Are All Alike, and We Are All Different* 9

The future of biological psychology is in interdisciplinary discovery and knowledge translation 10

### Careful Research Design Is Crucial for Brain Research 14

Three kinds of studies probe brain-behavior relationships 14

Biological psychologists use several levels of analysis 15

Animal research is an essential part of life sciences research, including biological psychology 16

### Looking Forward: A Glimpse inside the Mind's Machine 17

**CHAPTER 1 VISUAL SUMMARY** 19



## CHAPTER 2 Cells and Structures: The Anatomy of the Nervous System 20

### The Nervous System Is Composed of Cells 22

The neuron has four principal divisions 22

Information is received through synapses 25

#### **BOX 2.1** *Visualizing the Cellular Structure of the Brain* 26

The axon integrates and then transmits information 28

Glial cells protect and assist neurons 28

### The Nervous System Extends throughout the Body 30

The peripheral nervous system has two divisions 30

The central nervous system consists of the brain and spinal cord 34

#### **BOX 2.2** *Three Customary Orientations for Viewing the Brain and Body* 35

### The Brain Is Described in Terms of Both Structure and Function 38

The cerebral cortex performs complex cognitive processing 38

Important nuclei are hidden beneath the cerebral cortex 39

The midbrain has sensory and motor systems 40

The brainstem controls vital body functions 40

### Specialized Support Systems Protect and Nourish the Brain 41

The brain floats within layers of membranes 41

The brain relies on two fluids for survival 42

**SIGNS&SYMPTOMS:** Stroke 43

### Brain-Imaging Techniques Reveal the Structure and Function of the Human Brain 44

- CT uses X-rays to reveal brain structure 44
- MRI maps density to deduce brain structure with high detail 44
- Functional MRI uses local changes in metabolism to identify active brain regions 44
- PET tracks radioactive substances to produce images of brain activity 45

- researchers at work** Subtractive analysis isolates specific brain activity 46
- Magnetism can be used to study the brain 47
- CHAPTER 2 VISUAL SUMMARY** 48



## CHAPTER 3 Neurophysiology: The Generation, Transmission, and Integration of Neural Signals 50

### Electrical Signals Are the Vocabulary of the Nervous System 52

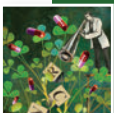
- A balance of electrochemical forces produces the resting potential of neurons 52
- A threshold amount of depolarization triggers an action potential 55
- Ionic mechanisms underlie the action potential 57
- Action potentials are actively propagated along the axon 59
- BOX 3.1** *How Is an Axon Like a Toilet?* 61
- Synapses cause local changes in the postsynaptic membrane potential 62
- Spatial summation and temporal summation integrate synaptic inputs 63

### Synaptic Transmission Requires a Sequence of Events 65

- Action potentials cause the release of transmitter molecules into the synaptic cleft 66
- Receptor molecules recognize transmitters 67
- The action of synaptic transmitters is stopped rapidly 68
- Neural circuits underlie reflexes 69

### EEGs Measure Gross Electrical Activity of the Human Brain 70

- Electrical storms in the brain can cause seizures 71
- researchers at work** Surgical probing of the brain revealed a map of the body 73
- SIGNS & SYMPTOMS:** Multiple Sclerosis 74
- CHAPTER 3 VISUAL SUMMARY** 76



## CHAPTER 4 The Chemistry of Behavior: Neurotransmitters and Neuropharmacology 78

### Electrical Signals Are Turned into Chemical Signals at Synapses 80

- Receptor proteins recognize transmitters and their mimics 81
- Many neurotransmitters have been identified 82
- researchers at work** The first transmitter to be discovered was acetylcholine 83

### Neurotransmitter Systems Form a Complex Array in the Brain 84

- The most abundant excitatory and inhibitory neurotransmitters are amino acids 85

- Four amine neurotransmitters modulate brain activity 86
- Many peptides function as neurotransmitters 87
- Some neurotransmitters are gases 87

### Drugs Fit Like Keys into Molecular Locks 88

- The effects of a drug depend on its dose 90
- Drug doses are administered in many different ways 90
- Repeated treatments can reduce the effectiveness of drugs 92

### Drugs Affect Each Stage of Neural Conduction and Synaptic Transmission 92

- Some drugs alter presynaptic processes 92
- Some drugs alter postsynaptic processes 94
- Drugs That Affect the Brain Can Be Divided into Functional Classes 95**
- Psychoactive drugs may relieve severe symptoms 95
- Psychoactive drugs can affect conscious experience 97

## **Drug Abuse Is Pervasive 102**

Several perspectives help us understand drug abuse 103

**SIGNS&SYMPTOMS:** Medical Interventions for Substance Abuse 106

**CHAPTER 4 VISUAL SUMMARY 108**



## **CHAPTER 5 The Sensorimotor System 110**

### **PART I Sensory Processing and the Somatosensory System 112**

**Receptor Cells Convert Sensory Signals into Electrical Activity 113**

**Sensory Information Processing Is Selective and Analytical 115**

Sensory events are encoded as streams of action potentials 115

Sensory neurons respond to stimuli falling in their receptive fields 116

Receptors may show adaptation to unchanging stimuli 117

Sometimes we need receptors to be quiet 117

**Successive Levels of the CNS Process Sensory Information 118**

Sensory cortex is highly organized 119

Sensory brain regions influence one another and change over time 120

### **PART II Pain: The Body's Emergency Signaling System 121**

**Human Pain Varies in Several Dimensions 121**

**A Discrete Pain Pathway Projects from Body to Brain 121**

Peripheral receptors get the initial message 122

Special neural pathways carry pain information to the brain 123

### **Pain Control Can Be Difficult 124**

Analgesic drugs are highly effective 124

Electrical stimulation can sometimes relieve pain 125

Placebos effectively control pain in some people, but not all 125

Activation of endogenous opioids relieves pain 125

### **PART III Movement and the Motor System 126**

**Behavior Requires Movements That Are Precisely Programmed and Monitored 127**

**A Complex Neural System Controls Muscles to Create Behavior 129**

Muscles and the skeleton work together to move the body 129

Sensory feedback from muscles, tendons, and joints governs movement 131

The spinal cord mediates "automatic" responses and receives inputs from the brain 133

Motor cortex plans and executes movements—and more 135

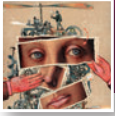
**researchers at work** Mirror neurons in premotor cortex track movements in others 138

Extrapyramidal systems regulate and fine-tune motor commands 138

Damage to extrapyramidal systems impairs movement 140

**SIGNS&SYMPTOMS:** Hazards of Painlessness 141

**CHAPTER 5 VISUAL SUMMARY 143**



## CHAPTER 6 Hearing, Balance, Taste, and Smell 144

### PART I Hearing and Balance 146

**BOX 6.1** *The Basics of Sound* 146

#### Each Part of the Ear Performs a Specific Function in Hearing 147

The external ear captures, focuses, and filters sound 147

The middle ear concentrates sound energies 148

The cochlea converts vibrational energy into neural activity 149

**researchers at work** Georg von Békésy and the cochlear wave 150

The hair cells transduce movements of the basilar membrane into electrical signals 151

#### Auditory System Pathways Run from the Brainstem to the Cortex 153

#### Our Sense of Pitch Relies on Two Signals from the Cochlea 155

#### Brainstem Systems Compare the Ears to Localize Sounds 156

#### The Auditory Cortex Specializes in Processing Complex Sound 157

#### Deafness Is a Widespread Problem 159

**SIGNS&SYMPTOMS:** Restoring Auditory Stimulation in Deafness 161

#### The Inner Ear Provides Our Sense of Balance 162

#### Some Forms of Vestibular Excitation Produce Motion Sickness 163

### PART II The Chemical Senses: Taste and Smell 164

#### The Human Tongue Detects Five Basic Chemical Tastes 164

Tastes excite specialized receptor cells on the tongue 164

The five basic tastes are signaled by specific sensors on taste cells 165

Taste information is transmitted to several parts of the brain 167

#### Chemicals in the Air Elicit Odor Sensations 168

The sense of smell starts with receptor neurons in the nose 168

Olfactory information projects from the olfactory bulbs to several brain regions 170

Many vertebrates possess a vomeronasal system 170

#### CHAPTER 6 VISUAL SUMMARY 172



## CHAPTER 7 Vision: From Eye to Brain 174

#### The Visual System Extends from the Eye to the Brain 176

The vertebrate eye acts in some ways like a camera 176

Visual processing begins in the retina 177

Photoreceptors respond to light by releasing less neurotransmitter 179

Different mechanisms enable the eyes to work over a wide range of light intensities 180

Acuity is best in foveal vision 181

Neural signals travel from the retina to several brain regions 183

The retina projects to the brain in a topographic fashion 185

#### Neurons at Different Levels of the Visual System Have Very Different Receptive Fields 186

Photoreceptors excite some retinal neurons and inhibit others 186

Neurons in the retina and the LGN have concentric receptive fields 187

**researchers at work** Neurons in the visual cortex have varied receptive fields 190

The hierarchical model is supplanted by a more efficient analysis 192

Neurons in the visual cortex beyond area V1 have complex receptive fields and help identify forms 193

Perception of visual motion is analyzed by a special system that includes cortical area V5 195

### **Color Vision Depends on Special Channels from the Retinal Cones through Cortical Area V4 195**

Color is created by the visual system 195

Color perception requires receptor cells that differ in their sensitivities to different wavelengths 197

**BOX 7.1** *Most Mammalian Species Have Some Color Vision* 199

Some retinal ganglion cells and LGN cells show spectral opponency 200

Some visual cortical cells and regions appear to be specialized for color perception 201

### **The Many Cortical Visual Areas Are Organized into Two Major Streams 202**

### **Visual Neuroscience Can Be Applied to Alleviate Some Visual Deficiencies 204**

Impairment of vision often can be prevented or reduced 204

Increased exercise can restore function to a previously deprived or neglected eye 204

**SIGNS&SYMPTOMS:** Robot Eyes? 205

**CHAPTER 7 VISUAL SUMMARY** 206



## **CHAPTER 8 Hormones and Sex 208**

### **PART I The Endocrine System 210**

#### **Hormones Act in a Great Variety of Ways throughout the Body 210**

**researchers at work** Our current understanding of hormones developed in stages 211

Hormones are one of several types of chemical communication 212

Hormones can be classified by chemical structure 212

#### **Hormones Act on a Wide Variety of Cellular Mechanisms 214**

Hormones initiate actions by binding to receptor molecules 214

**BOX 8.1** *Techniques of Modern Behavioral Endocrinology* 215

Hormones can have different effects on different target organs 216

#### **Each Endocrine Gland Secretes Specific Hormones 217**

The posterior pituitary releases two hormones directly into the bloodstream 218

Posterior pituitary hormones can affect social behavior 219

Feedback control mechanisms regulate the secretion of hormones 220

Hypothalamic releasing hormones govern the anterior pituitary 221

Two anterior pituitary tropic hormones act on the gonads 222

The gonads produce steroid hormones, regulating reproduction 223

Hormonal and neural systems interact to produce integrated responses 224

### **PART II Reproductive Behavior 226**

#### **Reproductive Behavior Can Be Divided into Four Stages 226**

Copulation brings gametes together 228

**researchers at work** Gonadal steroids activate sexual behavior 229

#### **The Neural Circuitry of the Brain Regulates Reproductive Behavior 230**

Estrogen and progesterone act on a lordosis circuit that spans from brain to muscle 231

Androgens act on a neural system for male reproductive behavior 231

Parental behaviors are governed by several sex-related hormones 233

#### **The Hallmark of Human Sexual Behavior Is Diversity 234**

Hormones play only a permissive role in human sexual behavior 236

**PART III Sexual Differentiation and Orientation 236**

**Genetic and Hormonal Mechanisms Guide the Development of Masculine and Feminine Structures 237**

- Sex chromosomes direct sexual differentiation of the gonads 237
- Gonadal hormones direct sexual differentiation of the body 237
- Changes in sexual differentiation processes result in predictable changes in development 238
- Dysfunctional androgen receptors can block the masculinization of males 239
- Some people seem to change sex at puberty 240
- How should we define gender—by genes, gonads, genitals? 241

**researchers at work** Gonadal hormones direct sexual differentiation of behavior and the brain 241

Early testicular secretions result in masculine behavior in adulthood 242

Several regions of the nervous system display prominent sexual dimorphism 243

Social influences also affect sexual differentiation of the nervous system 246

**Do Fetal Hormones Masculinize Human Behaviors in Adulthood? 247**

What determines a person’s sexual orientation? 248

**SIGNS&SYMPTOMS:** Psychosocial Dwarfism 251

**CHAPTER 8 VISUAL SUMMARY 252**



**CHAPTER 9 Homeostasis 254**

**PART I Principles of Homeostasis 256**

**Homeostatic Systems Share Several Key Features 256**

- Internal states are governed through negative feedback 256
- Redundancy is a feature of many homeostatic systems 257
- Behavioral mechanisms are crucial for homeostasis 258

**PART II Fluid Regulation 259**

**Water Moves between Two Major Body Compartments 260**

**Two Internal Cues Trigger Thirst 261**

- Hypovolemic thirst is triggered by a loss of water volume 262
- Osmotic thirst occurs when the extracellular fluid becomes too salty 263
- We don’t stop drinking just because the throat and mouth are wet 263

**Water Balance Depends on the Regulation of Salt in the Body 263**

**PART III Food and Energy Regulation 264**

**Nutrient Regulation Helps Prepare for Future Needs 264**

**Insulin Is Essential for Obtaining, Storing, and Using Food Energy 266**

**The Hypothalamus Coordinates Multiple Systems That Control Hunger 267**

**researchers at work** Lesion studies showed that the hypothalamus is crucial for appetite 268

Hormones from the body drive a hypothalamic appetite controller 269

Other systems also play a role in hunger and satiety 271

**Obesity Is Difficult to Treat 272**

**Eating Disorders Can Be Life-Threatening 274**

**SIGNS&SYMPTOMS:** Fat-Busting Surgery 275

**CHAPTER 9 VISUAL SUMMARY 277**





## CHAPTER 10 Biological Rhythms and Sleep 278

### PART I Biological Rhythms 280

#### Many Animals Show Daily Rhythms in Activity 280

Circadian rhythms are generated by an endogenous clock 280

#### The Hypothalamus Houses a Circadian Clock 282

**researchers at work** Transplants prove that the SCN produces a circadian rhythm 283

In mammals, light information from the eyes reaches the SCN directly 284

Circadian rhythms have been genetically dissected in flies and mice 285

### PART II Sleeping and Waking 288

#### Human Sleep Exhibits Different Stages 288

We do our most vivid dreaming during REM sleep 291

Different species provide clues about the evolution of sleep 292

#### Our Sleep Patterns Change across the Life Span 292

Mammals sleep more during infancy than in adulthood 293

Most people sleep appreciably less as they age 294

#### Manipulating Sleep Reveals an Underlying Structure 294

Sleep deprivation impairs cognitive functioning but does not cause insanity 294

**BOX 10.1** *Sleep Deprivation Can Be Fatal* 295

Sleep recovery may take time 296

#### What Are the Biological Functions of Sleep? 297

Sleep conserves energy 297

Sleep enforces niche adaptation 297

Sleep restores the body and brain 297

Sleep may aid memory consolidation 298

Some humans sleep remarkably little, yet function normally 298

#### At Least Four Interacting Neural Systems Underlie Sleep 299

**researchers at work** The forebrain generates slow wave sleep 299

The reticular formation wakes up the forebrain 300

The pons triggers REM sleep 301

A hypothalamic sleep center was revealed by the study of narcolepsy 302

#### Sleep Disorders Can Be Serious, Even Life-Threatening 304

Some minor dysfunctions are associated with sleep 305

Insomniacs have trouble falling asleep or staying asleep 305

Although many drugs affect sleep, there is no perfect sleeping pill 306

**SIGNS&SYMPTOMS:** REM Behavior Disorder 307

**CHAPTER 10** VISUAL SUMMARY 308



## CHAPTER 11 Emotions, Aggression, and Stress 310

### PART I Emotional Processing 312

#### Broad Theories of Emotion Emphasize Bodily Responses 312

Do emotions cause bodily changes, or vice versa? 312

**BOX 11.1** *Lie Detector?* 313

**researchers at work** Stanley Schachter proposed a cognitive interpretation of stimuli and visceral states 314

#### Facial Expressions Suggest a Core Set of Emotions 316

Facial expressions have complex functions in communication 316

Facial expressions are mediated by muscles, cranial nerves, and CNS pathways 318  
 How did emotion and emotional displays evolve? 319

**Do Distinct Brain Circuits Mediate Emotions? 320**

Electrical stimulation of the brain can produce emotional effects 320  
 Brain lesions also affect emotions 321  
 The amygdala governs a fear circuit 322  
 The two cerebral hemispheres process emotion differently 325  
 Different emotions activate different regions of the human brain 325

**PART II Aggression and Stress 327**

**Neural Circuitry, Hormones, and Synaptic Transmitters Mediate Violence and Aggression 327**

Androgens seem to increase aggression 327  
 Brain circuits mediate aggression 328  
 The biopsychology of human violence is a topic of controversy 329

**Stress Activates Many Bodily Responses 330**

The stress response progresses in stages 330  
 There are individual differences in the stress response 332  
 Stress and emotions influence the immune system 333  
 Why does stress suppress the immune system? 333

**SIGNS&SYMPTOMS:** Long-term consequences of childhood bullying 335

**CHAPTER 11 VISUAL SUMMARY 336**



**CHAPTER 12 Psychopathology: The Biology of Behavioral Disorders 338**

**The Toll of Psychiatric Disorders Is Huge 340**

**Schizophrenia Is a Major Neurobiological Challenge in Psychiatry 341**

Schizophrenia is characterized by an unusual array of symptoms 341  
 Schizophrenia has a heritable component 341  
**researchers at work** An integrative model of schizophrenia emphasizes the interaction of multiple factors 344  
 The brains of some patients with schizophrenia show structural and functional changes 346  
 Antipsychotic medications revolutionized the treatment of schizophrenia 348

**BOX 12.1** *Long-Term Effects of Antipsychotic Drugs* 349

**Depression Is the Most Prevalent Disorder of Mood 352**

Inheritance is an important determinant of depression 353  
 The brain changes with depression 353  
 A wide variety of treatments are available for depression 354

**SIGNS&SYMPTOMS:** Mixed Feelings about SSRIs 355

Why do more females than males suffer from depression? 356  
 Sleep characteristics change in affective disorders 357  
 Scientists are still searching for animal models of depression 358

**In Bipolar Disorder, Mood Cycles between Extremes 358**

**There Are Several Types of Anxiety Disorders 360**

Drug treatments provide clues to the mechanisms of anxiety 360

**In Posttraumatic Stress Disorder, Horrible Memories Won't Go Away 361**

**In Obsessive-Compulsive Disorder, Thoughts and Acts Keep Repeating 362**

**BOX 12.2** *Tics, Twitches, and Snorts: The Unusual Character of Tourette's Syndrome* 364

**CHAPTER 12 VISUAL SUMMARY 366**



## CHAPTER 13 Memory, Learning, and Development 368

### PART I Types of Learning and Memory 370

#### There Are Several Kinds of Learning and Memory 370

For patient H.M., the present vanished into oblivion 370

**researchers at work** Which brain structures are important for declarative memory? 373

Damage to the mammillary bodies can also cause amnesia 374

Brain damage can destroy autobiographical memories while sparing general memories 375

#### Different Forms of Nondeclarative Memory Involve Different Brain Regions 376

Different types of nondeclarative memory serve varying functions 376

Animal research confirms the various brain regions involved in different attributes of memory 377

Brain regions involved in learning and memory: A summary 378

#### Successive Processes Capture, Store, and Retrieve Information in the Brain 379

##### BOX 13.1 Emotions and Memory 380

STM and LTM appear to be different processes 381

Long-term memory has vast capacity but is subject to distortion 382

### PART II Neural Mechanisms of Memory 383

#### Memory Storage Requires Neuronal Remodeling 383

Plastic changes at synapses can be physiological or structural 383

Varied experiences and learning cause the brain to change and grow 384

Invertebrate nervous systems show synaptic plasticity 386

Classical conditioning relies on circuits in the mammalian cerebellum 388

#### Synaptic Plasticity Can Be Measured in Simple Hippocampal Circuits 389

NMDA receptors and AMPA receptors collaborate in LTP 390

Is LTP a mechanism of memory formation? 392

### PART III Development of the Brain 393

#### Growth and Development of the Brain Are Orderly Processes 395

#### Development of the Nervous System Can Be Divided into Six Distinct Stages 395

Cell proliferation produces cells that become neurons or glial cells 396

In the adult brain, newly born neurons aid learning 397

The death of many neurons is a normal part of development 398

An explosion of synapse formation is followed by synapse rearrangement 399

#### Genes Interact with Experience to Guide Brain Development 401

Genotype is fixed at birth, but phenotype changes throughout life 401

Experience regulates gene expression in the developing and mature brain 402

#### The Brain Continues to Change as We Grow Older 404

Memory impairment correlates with hippocampal shrinkage during aging 404

Alzheimer's disease is associated with a decline in cerebral metabolism 404

**SIGNS & SYMPTOMS:** Imaging Alzheimer's Plaques 405

**CHAPTER 13 VISUAL SUMMARY** 407



**CHAPTER 14**  
**Attention and Consciousness 408**

**PART I Attention 410**

**Attention Focuses Cognitive Processing on Specific Objects 410**

There are limits on attention 410

**Attention May Be Endogenous or Exogenous 412**

**researchers at work** We can choose which stimuli we will attend to 412

**BOX 14.1 Reaction-Time Responses, from Input to Output 414**

Some stimuli are hard to ignore 414

We use visual search to make sense of a cluttered world 416

**The Electrical Activity of the Brain Provides Clues about Mechanisms of Attention 417**

Distinctive patterns of brain electrical activity mark voluntary shifts of attention 417

Reflexive visual attention has its own electrophysiological signature 419

Attention affects the activity of individual neurons 420

**Many Brain Regions Are Involved in Processes of Attention 422**

Two subcortical systems guide shifts of attention 422

Several cortical areas are crucial for generating and directing attention 422

Brain disorders can cause specific impairments of attention 424

**SIGNS & SYMPTOMS:** Difficulty with Sustained Attention Can Sometimes Be Relieved with Stimulants 425

**PART II Consciousness 426**

**Consciousness Is a Mysterious Product of the Brain 426**

Which brain regions are active when we are conscious? 427

Some aspects of consciousness are easier to study than others 428

**BOX 14.2 Building a Better Mind Reader 431**

**The Frontal Lobes Govern Our Most Complex Behaviors 432**

Frontal lobe injury in humans leads to emotional, motor, and cognitive changes 433

**BOX 14.3 Neuroeconomics Identifies Brain Regions Active during Decision Making 435**

**CHAPTER 14 VISUAL SUMMARY 436**



**CHAPTER 15**  
**Brain Asymmetry, Spatial Cognition, and Language 438**

**PART I Cerebral Asymmetry 440**

**The Left and Right Brains Are Different 440**

Disconnection of the cerebral hemispheres reveals their individual processing specializations 440

The two hemispheres process information differently in the human brain 442

Does the left hemisphere hear words and the right hemisphere hear music? 443

How does handedness relate to brain asymmetry? 444

**Right-Hemisphere Damage Impairs Spatial Cognition 445**

**BOX 15.1 The Wada Test 446**

In prosopagnosia, faces are unrecognizable 446

**Language Disorders Result from Region-Specific Brain Damage 448**

Damage to a left anterior speech zone causes nonfluent (or Broca's) aphasia 449

Damage to a left posterior speech zone causes fluent (or Wernicke's) aphasia 450

Widespread left-hemisphere damage can obliterate language capabilities 450

Disconnection of language regions may result in specific verbal problems 452

**BOX 15.2 Studying Connectivity in the Living Brain 453**

**Brain Mapping Helps Us Understand the Organization of Language in the Brain 454**

Cortical stimulation mapping shows localized functions within language areas 454

**researchers at work** Noninvasive stimulation mapping reveals details of the brain's language areas 455

Functional neuroimaging technologies let us visualize activity in the brain's language zones during speech 456

**PART II Speech and Language 458****Some Aspects of Language Are Innate, but Others Must Be Learned 458**

Can nonhuman primates acquire language with training? 460

Vocal behavior is a feature of many different species 462

**Appendix A-1****Glossary G-1****Illustration Credits IC-1****Reading Skills Are Difficult to Acquire and Frequently Impaired 464**

Brain damage may cause specific impairments in reading 464

Some people struggle throughout their lives to read 464

**PART III Recovery of Function 466**

**BOX 15.3** *Contact Sports Can Be Costly* 466

**Stabilization and Reorganization Are Crucial for Recovery of Function 467****Rehabilitation and Retraining Can Help Recovery from Brain and Spinal Cord Injury 468**

**SIGNS&SYMPTOMS:** The Amazing Resilience of a Child's Brain 469

**CHAPTER 15** VISUAL SUMMARY 470

**References R-1****Author Index AI-1****Subject Index SI-1**

# Preface

It's getting difficult to browse the internet, open a newspaper, or flip through a magazine without encountering reports of astonishing discoveries about the brain's structure, function, and—alas—malfunction. The main reason for all this coverage is that the subject matter is intrinsically fascinating; who has not pondered their own consciousness, marveled at their many sensory experiences, or wondered how a small and lumpy organ can process so much information? But another reason neuroscience is in the news so frequently is simply that it has become one of the most active branches of science. The pace of discoveries about brain and behavior has increased at an exponential rate over the last few decades.

Every new edition of one of our books requires substantial updating because so much is happening all the time. (It's exciting, but boy, do we read a lot of reports and articles!) In fact, by far the hardest part of our job as authors lies in deciding which discoveries to include and which to (reluctantly) leave out: As the Red Queen remarked to Alice in Wonderland, "it takes all the running you can do, to keep in the same place." Our website ([2e.mindsmachine.com/news](http://2e.mindsmachine.com/news)) boasts a collection of more than 20,000 news stories, all drawn from the mainstream media, that relate to the topics covered in the book. You can follow updates on the website, via email, or Facebook ([www.facebook.com/biopsychology](http://www.facebook.com/biopsychology)).

While we are sampling from this almost boundless scientific smorgasbord, we have to watch our weight. Our goal for *The Mind's Machine*, Second Edition is to introduce you to the *basics* of behavioral neuroscience in a way that focuses on the foundational topics in the field—with a generous sprinkling of the newest and most fascinating discoveries—and leaves you with an appetite for more. Whether you are beginning a program of study centered on the brain and behavior, or are just adding some breadth to your education, you will find that behavioral neuroscience now permeates all aspects of modern psychology, along with related life sciences like physiology, biology, and the health sciences. But that's not all. The tools and techniques of behavioral neuroscience are also creating new ways of looking at questions in many nontraditional areas, such as economics, the performing arts, anthropology, sociology, computer science, and engineering. Researchers are beginning to probe mental processes that seemed impenetrable only a decade or two ago: the neural bases of decision making, love and attachment,

memory and learning, consciousness, and much of what we call the mind. A few examples of formerly mysterious questions that are being answered with cutting-edge research include:

- Do prenatal events influence the probability that a child will develop a heterosexual or homosexual orientation?
- Does the brain make new neurons throughout life, in numbers large enough to make a functional difference?
- Can we improve memory performance with some drugs, and use other drugs to erase unwanted, traumatic memories?
- What happens in the brain as we develop trust in another person?
- Does strong liking for sweet foods involve the same brain mechanisms as addiction to drugs?
- How can we share so many genes with chimpanzees and other primates, and yet be so different from them?
- How can recent discoveries about the neural control of appetite help us to curb the obesity epidemic?
- Does a gene that predisposes for Alzheimer's disease in old age actually improve cognitive functioning earlier in life?

Understanding the research probing these sorts of questions requires some familiarity with the physiology of behavior and experience. Our aim in *The Mind's Machine*, Second Edition is to provide a foundation that places these and other important problems in a unified scientific context.

We've found that students enrolled in our courses have diverse academic backgrounds and personal interests. In this book, we've tried to avoid making too many assumptions about our readers, and have focused on providing both behavioral and biological perspectives on major topics. If you've had some high-school level biology you should have no trouble with most of the material in the book.

For those readers who have more experience in science—or who want more detail—we have peppered the chapters with embedded links to more advanced material located on our website. These links, called A Step Further, are just one of several novel features we have included to aid your learning. Throughout the book you will find QR codes (small square bar codes) that will link your smartphone to animated versions of many figures, video clips, and more. (You'll need to download an app to read

the codes; a variety of free or inexpensive Code Readers are available for the major smartphones like iPhone, Android, and Blackberry.) Or you may use your computer to go to the web address provided below every QR code.

Each chapter also features a segment called Researchers at Work, which illustrates the nuts and bolts of experimentation through real-world examples, and a new segment called Signs & Symptoms that relates a real-world clinical issue relevant to the chapter topic. Every few pages, you will find a feature called How’s it Going?, with self-test questions that will help you to gauge your progress. And every chapter ends with a Visual Summary, an innovative combination of the main points and figures from the chapter, which you can also view in an interactive format on the companion website. We encourage you to explore the website for the book (2e.mindsmachine.com), which contains a free comprehensive set of study questions. This website is a powerful companion to the textbook that enhances the learning experience with a variety of multimedia resources.

The chapter lineup in this edition of *The Mind’s Machine* encompasses several major themes. In the opening chapters, we trace the origins of behavioral neuroscience and introduce you to the structure of the brain, both as seen by the naked eye and as revealed by the microscope. We discuss how the cells of the brain use electrical signals to process information, and how they transmit that information to other cells within larger circuits. Along the way we’ll look at the ways in which drugs affect nerve cells in order to change behavior, as well as some of the remarkable technology that lets us study the activity of the conscious brain as it perceives and thinks.

In the middle part of the book we look at the neural systems that underlie fundamental capabilities like feeling, moving, seeing, smelling, and hearing. We’ll also consider biological and behavioral aspects of “mission-critical” functions such as feeding, sleeping, and sexual behavior. And we’ll look at how the endocrine system acts as an interface between the brain and the rest of the body, as well as the reverse—ways in which the environment and behavior alter hormones and thus alter brain activity.

In the latter part of the book we turn to some of the high-level emotional and cognitive processes that color our lives and define us as individuals. We’ll survey the systems that allow us to learn and remember information and skills, and the brain systems dedicated to language and spatial cognition. Research on processes of attention has made great progress in recent years, and we’ll also consider consciousness and decision-making from a neuroscientific perspective. Finally, we’ll review some of the consequences of brain dysfunction, ranging from psychopathology to behavioral manifestations of brain damage, and some of the innovative strategies being developed to counter these problems.

As you make your way through the book, you’ll learn that one of the outstanding features of the brain is its ability to remodel. Every new experience, every piece of information that you learn, every skill that you master, causes changes in the brain that can alter your future behavior. The changes may involve physical alterations in the connections between cells, or in the chemicals they use to communicate, or even the addition of whole new cells and circuits. It’s a property that we neuroscientists refer to as “plasticity.” And it’s something that we aim to exploit—if we’ve done our job properly, *The Mind’s Machine*, Second Edition should cause lots of changes in *your* brain. We hope you enjoy the process.



Neil V. Watson



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S. Marc Breedlove



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We welcome feedback on any aspect of *The Mind’s Machine*, Second Edition. Simply drop us a line at [mindsmachine@sinauer.com](mailto:mindsmachine@sinauer.com).

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Finally, we would like to thank all our colleagues whose ideas and discoveries make behavioral neuroscience so much fun.



# Media and Supplements

to accompany  
**The Mind's Machine**  
Second Edition

## For the Student

*Companion Website*  
[2e.mindsmachine.com](http://2e.mindsmachine.com)

*The Mind's Machine*, Second Edition Companion Website contains a wide range of study and review resources to help students master the material presented in the textbook and to help engage them in the subject with fascinating examples. Access to the site is free and requires no passcode. (Instructor registration is required in order for students to access the online quizzes.) Tightly integrated with the text, with content corresponding to every major heading in the book, this online resource greatly enhances the learning experience. Key resources are linked throughout the textbook via QR codes and direct Web addresses, making access to animations and videos easy from any smartphone, tablet, or computer.

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- Chapter outlines
- Extensive study questions
- Animations, videos, and activities
- Online, interactive versions of the visual summaries
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*Biological Psychology NewsLink*  
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This invaluable online resource helps students make connections between the science of biological psychology and their daily lives, and keeps them apprised of the latest developments in the field. The site includes links to thousands of news stories, all organized both by keyword and by textbook chapter. The site is updated 3–4 times per week. Find us on Facebook ([facebook.com/Biopsychology](https://facebook.com/Biopsychology)).

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# The Mind's Machine

Foundations of Brain and Behavior

SECOND EDITION



chapter

# 1

# An Introduction to Brain and Behavior

## Nature and Nurture: Building the Mind's Machine

We humans have a long history of using contemporary technology as a metaphor for the mysterious workings of the brain. Scholars of old, influenced by inventions such as aqueducts, plumbing, and ornamental fountains, proposed that behavior was the result of liquid “animal spirits” jetting around within the body. Later thinkers emphasized the possible importance of wires, switches, and relays: the technology of their day. Today it is commonplace to see the brain described as a computer, with “hardware” and “software.” Perhaps tomorrow’s neuroscientists will describe the brain in terms of holograms, quantum devices, or a technology that has yet to be imagined.

Modern research aims to describe the complicated machine within each of our heads, but we also want to know how the operation of the brain produces the *mind*—the perceptions, emotions, thoughts, self-awareness, and other cognitive processes that inform our behavior. During the twentieth century, a lot of ink was spilled over the “nature-nurture” con-

trovery, with scholars arguing passionately about the extent to which mental characteristics and abilities are the result of learning experiences versus innate, “hardwired” genetic programs.

The two perspectives have often been presented as mutually incompatible alternatives, but thanks to more-powerful techniques, we have come to realize that there is nothing controversial about nature versus nurture: they are two sides of the same coin. Consider the case of rat pups who have inattentive mothers. As adults, the formerly neglected pups show elevated stress hormone responses to stressors that have little effect on rats that were not neglected as pups (T. Y. Zhang and Meaney, 2010). How does this lasting reactivity develop—through experience or as a result of innate biological factors? Both, it turns out. As we’ll see later in this chapter, and throughout the book, the mind and its machine are shaped by a precise combination of genes and experience, inextricably tied together.

To see the video  
**Nature and Nurture**,  
go to



[2e.mindsmachine.com/1.1](http://2e.mindsmachine.com/1.1)



**T**here are now almost 7.5 billion of us, and while we can debate whether to fear or celebrate that number, there is no doubt that each of those billions of human brains will at times contemplate its own existence and meaning. How does the operation of a three-pound organ generate our sense of self, express our unique personalities, record information, and guide our actions? Evolution has shaped our bodies and brains so that we closely resemble one another, yet our brains remain malleable throughout life, continually remolded by our environments, experiences, and interactions with other people. So, through a remarkable intersection of genetic heritage and environmental influences, 7.5 billion unique individuals have been formed, and we literally change each other's minds on a daily basis.

Our goal in this book is to introduce you to some of the many ways in which the structures and actions of the brain produce mind and behavior, and also the reverse: some of the many ways in which experiences change the brain. We hope to kindle in you the same interest and excitement that we experienced as students (and still feel today) when reading and thinking about the biology of behavior. Let's start by considering the aims and scope of the science called *biological psychology* or *behavioral neuroscience*.



**FIGURE 1.1** How Biological Psychology Relates to Other Fields

## What's in a Name?

**neuroscience** The scientific study of the nervous system.

**biological psychology** Also called *behavioral neuroscience*, *brain and behavior*, and *physiological psychology*. The study of the biological bases of psychological processes and behavior.

The general field of **neuroscience**—the scientific study of the nervous system—is divided into many subdisciplines because the topic is so vast. The first scholars to study the relationships between brain and behavior called themselves philosophers, because it was philosophy that established the scientific method as our best tool for finding new knowledge. Philosophers had long been concerned with the sources of human behavior, so **biological psychology**, the field that relates behavior to bodily processes, naturally evolved from those beginnings. The names *behavioral neuroscience*, *brain and behavior*, and *physiological psychology* are all synonyms for *biological psychology*, but whichever name is used, the main goal of this field is to understand the brain structures and functions that respond to experiences and generate behavior.

Researchers with dramatically varied backgrounds—psychologists, biologists, physiologists, engineers, neurologists, psychiatrists, and many others—together make up the field of biological psychology. It is a field that spans both academia and industry, with focus that ranges from pure research on basic processes to entirely applied work directly translating findings into goods and services (Hitt, 2007). The diverse branches of science that overlap with biological psychology are mapped in

**FIGURE 1.1.**

To see the  
Brain Explorer,  
go to



2e.mindsmachine.com/1.2

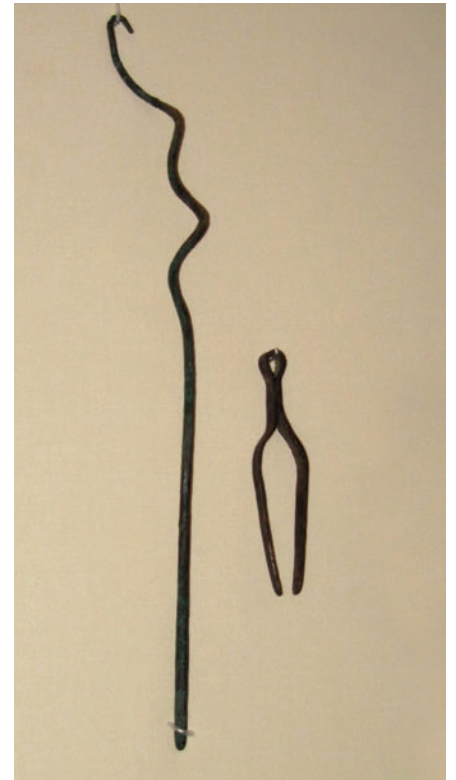
## The Science of Brain and Behavior Spans Past, Present, and Future

An early textbook famously opened with the observation that, as a science, “psychology has a long past but only a short history” (Ebbinghaus, 1908). That’s certainly an apt description of biological psychology. The modern era of biological psychology—characterized by objective experimentation and use of the scientific method to test hypotheses—has a formal history of only 100 years or so. But curiosity about the genesis of behavior reaches much further into the past, shaped by religious ideas, folk knowledge, and ancient observations about the biology of humans and nonhuman animals. Where does behavior come from?

### *The behavioral role of the brain was uncertain to early scholars*

The elaborate preparation of tombs and careful mummification of important people in ancient Egypt (especially about 1500–1000 BCE) reflected the belief that the dead would enter an afterlife that entailed both struggle and—for the adequately equipped individual—great reward. So, in addition to embalming the body with special salts and oils, the usual practice was to preserve four important organs in alabaster jars in the tomb: liver, lungs, stomach, and intestines. The heart, being especially esteemed, was preserved in its place within the body. The brain, however, was plucked out and unceremoniously discarded; apparently it was considered to be of no particular value in the afterlife.

There is little or no mention of the brain in the Quran, and it is likewise never mentioned in either the Old Testament or New Testament of the Bible, but the heart is mentioned hundreds of times, along with several references each to the liver, the stomach, and the bowels as the seats of passion, courage, and pity, respectively. Aristotle (about 350 BCE), the most prominent scientist of ancient Greece, likewise considered mental capacities to be properties of the heart. When we call people *kindhearted*, *openhearted*, *fainthearted*, *hardhearted*, or *heartless*, and when we speak of learning *by heart*, we are using language echoing this ancient notion. Aristotle thought the brain was little more than a cooling system for hot blood from the heart. But Aristotle’s near contemporary, the great Greek physician Hippocrates (about 400 BCE), already suspected that Aristotle’s view was—ahem—wrongheaded, and he instead ascribed emotion, perception, and thought to the functioning of the brain.



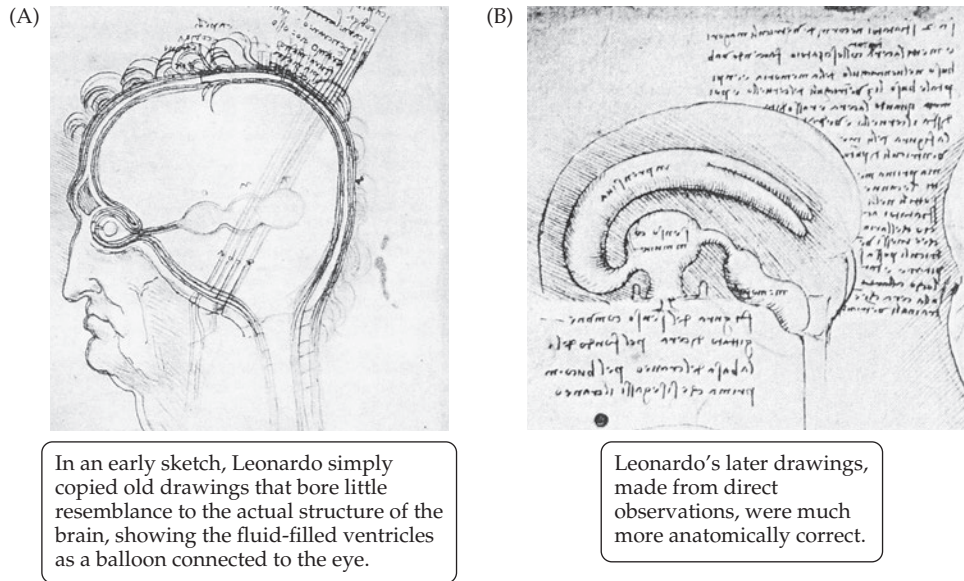
**Brain Removal Kit** It seems the ancient Egyptians had little regard for the brain. During the mummification process, embalmers used specialized tools, like these examples in the British Museum, to first break up the small bones behind the nose and then extract the brain through the opening. Unlike other major organs, the brain was discarded, and the cranium was stuffed with linen or straw. (Photograph by Neil Watson.)



### **A Brain on the Ceiling of the Sistine Chapel?**

Between 1508 and 1512, Michelangelo painted the Sistine Chapel in the Vatican. In one panel of Michelangelo’s masterpiece, God is depicted reaching out to bestow the gift of life upon humanity, through Adam. But neuroscientists have noted that the oddly shaped drapery behind God, and the arrangement of his attendants, closely resembles the human brain (Meshberger, 1990); compare it with the sagittal view in Figure 2.16. A keen student of anatomy, Michelangelo probably knew perfectly well what a dissected human brain looks like. So, was Michelangelo having some fun, making a subtle commentary about the origins of human behavior? We probably will never know. But we can all agree that our uniquely human qualities—language, reason, emotion, and the rest—are products of the brain.

**FIGURE 1.2** Leonardo da Vinci's Changing View of the Brain



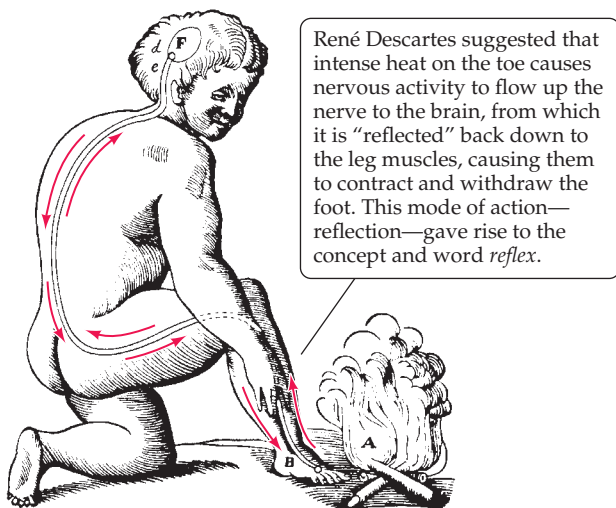
**dualism** The notion, promoted by René Descartes, that the mind has an immaterial aspect that is distinct from the material body and brain.

By the second century CE, this brain-centered view of mental processes had become more entrenched, appearing in the writings of the Greco-Roman physician Galen (the “Father of Medicine”). Galen’s experiences in treating head injuries of gladiators lead him to propose that behavior results from the movement of “animal spirits” from the brain through nerves to the body, but his understanding of the relevant anatomy was poor. Not until much later were techniques developed for making highly detailed anatomical studies of the fine structure of the brain.

Skillfully applying newly developed innovations in drawing technique, Renaissance painter and scientist Leonardo da Vinci (1452–1519) produced exquisite neuro-anatomical illustrations of nerves and brain structures (FIGURE 1.2). Religious dogma dominated Renaissance science—just ask Galileo—with the result that scientific writing from that era often presents the brain as a mysterious and intricate gift from God. But perhaps some thinkers of the day secretly held a more secular view of neuroscience; for example, it has been observed that the depiction of God on the ceiling of the Sistine Chapel, painted by Michelangelo (1475–1564) (see the photo on the previous page), bears a striking resemblance to a midline view of the human brain (Meshberger, 1990). It is believed that Michelangelo was conducting dissections of cadavers at about the time that the painting was created.

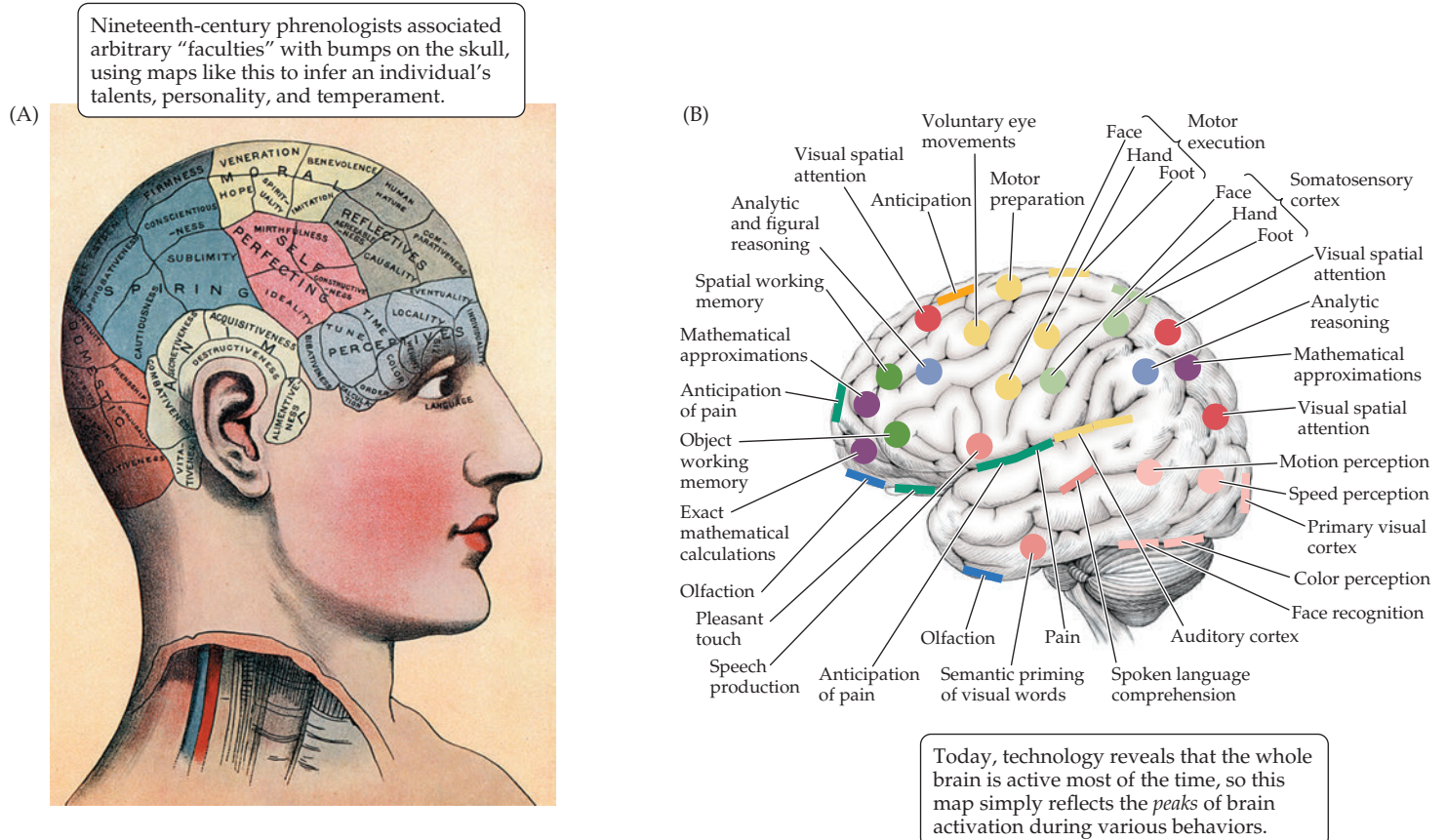
In any event, weighing religious notions of the soul against increasingly mechanistic views of the brain became a major pre-occupation for later scholars. Among his many contributions to math and science, René Descartes (1596–1650) tried to explain how the control of behavior might resemble the workings of a machine, proposing the concept of spinal reflexes and a neural pathway for them (FIGURE 1.3). But Descartes also argued (perhaps in order to deflect criticism) that free will and moral choice could not arise from a mere machine. So Descartes asserted that humans, at least, had a nonmaterial soul as well as a material body and that the soul governed behavior through a point of contact (possibly the pineal gland) in the brain. This notion of **dualism** spread widely and left other thinkers with the task of trying to explain how a nonmaterial soul could exert influence over a material body and brain. Today, biological psychologists reject dualism in favor of the much simpler view that the workings of the mind can be understood as purely physical processes taking place in the material brain.

Thanks in large part to systematic studies of the relation between various disorders and damage to regions of the human



**FIGURE 1.3** An Early Account of Reflexes





**FIGURE 1.4** Old and New Phrenology (Part B after Nichols and Newsome, 1999.)

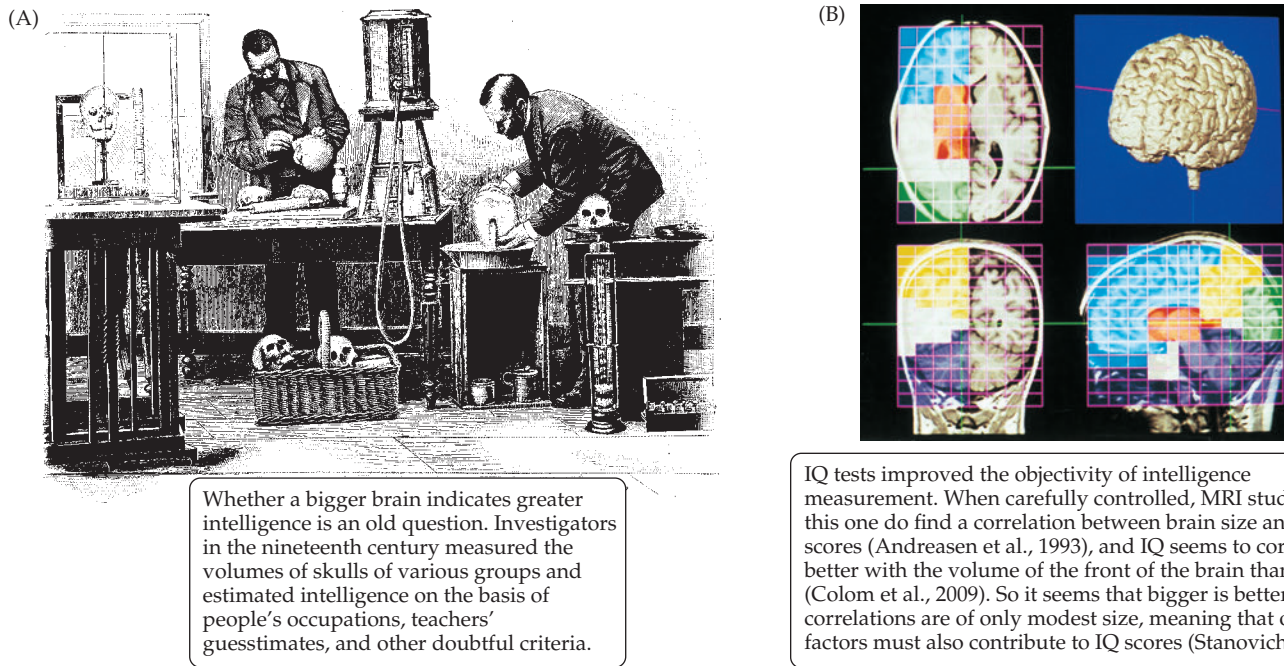
brain that were conducted by the English physician Thomas Willis (1621–1675), the notion that the brain coordinates and controls behavior eventually became widely accepted (Zimmer, 2004). A pseudoscientific fad of the early 1800s called **phrenology** (**FIGURE 1.4A**) capitalized on the emerging idea that specific behaviors, feelings, and personality traits were controlled by corresponding specific regions of the brain. Although phrenology was plainly wrong in several fundamental ways—for example, phrenologists believed they could “read” a person’s character by feeling the bumps on that person’s head—the field helped establish the concept of **localization of function**, which asserts that different brain regions specialize in specific behaviors.

Later researchers found that damage to specific regions of the brain causes predictable impairments in people; for example, Paul Broca (1824–1880) noted that damage to a particular region of the left side of the brain reliably causes problems with speech production (see Chapter 15). Neuroscientists today accept that the localization of function within the brain is more or less true. Although the whole brain is active most of the time, when we are performing particular tasks, certain brain regions become *even more* activated, and different tasks activate different brain regions. So modern functional maps of the human brain track the locations where these *peaks* of activation occur (**FIGURE 1.4B**). A parallel concern that harks back to the phrenologists has been the importance of brain size to intellectual function. After a couple of centuries of study, the evidence indicates that while the overall size of your brain matters, it matters a lot less than you might expect (**FIGURE 1.5**).

In 1890, William James’s book *Principles of Psychology* signaled the beginnings of a modern approach to biological psychology. In James’s work, psychological ideas such as consciousness and other aspects of human experience came to be seen as properties of the nervous system. A true biological psychology began to emerge from this approach.

**phrenology** The belief that bumps on the skull reflect enlargements of brain regions responsible for certain behavioral faculties.

**localization of function** The concept that different brain regions specialize in specific behaviors.



Whether a bigger brain indicates greater intelligence is an old question. Investigators in the nineteenth century measured the volumes of skulls of various groups and estimated intelligence on the basis of people's occupations, teachers' guesstimates, and other doubtful criteria.

IQ tests improved the objectivity of intelligence measurement. When carefully controlled, MRI studies like this one do find a correlation between brain size and IQ scores (Andreassen et al., 1993), and IQ seems to correlate better with the volume of the front of the brain than the back (Colom et al., 2009). So it seems that bigger is better, but the correlations are of only modest size, meaning that other factors must also contribute to IQ scores (Stanovich, 2009).

**FIGURE 1.5** Does Size Matter? (Part A from the Bettmann Archive; B courtesy of Nancy Andreasen.)

### Advances in experimental methodology propel modern biological psychology

By the beginning of the twentieth century, researchers were applying newly developed tools to study mental processes that had previously seemed unknowable. Rapid progress was made in developing techniques for measuring learning and memory in humans and animals, and Russian physiologist Ivan P. Pavlov (1849–1936) made his landmark discoveries of classical conditioning in animals—Nobel Prize–winning work that influences scientists to this day.

This rapid progress prompted a parallel interest in understanding the neural basis of learning, marked by one of the first true biological psychology research programs: the “search for the engram” by Karl Lashley (1890–1958). Although he would not accomplish his goal of linking a specific brain region to the formation of a specific long-term memory (an “engram”), Lashley gave us the idea (now well established) that memory is not localized to only one region of the brain.

One of Lashley's students, Donald O. Hebb (1904–1985), had a particularly profound impact on biological psychology. Hebb showed that cognitive processing could be accomplished by networks of active neurons, molded by repeated activation patterns into functional circuits. His hypothesis about how neurons strengthen their connections as a consequence of experiences led to the idea of the *Hebbian synapse*, a type of plastic (changeable) connection between neurons that remains a hot topic in neuroscience, as discussed in Chapter 13.

Present-day biological psychologists may draw on several different theoretical perspectives. Here are some of the major ones:

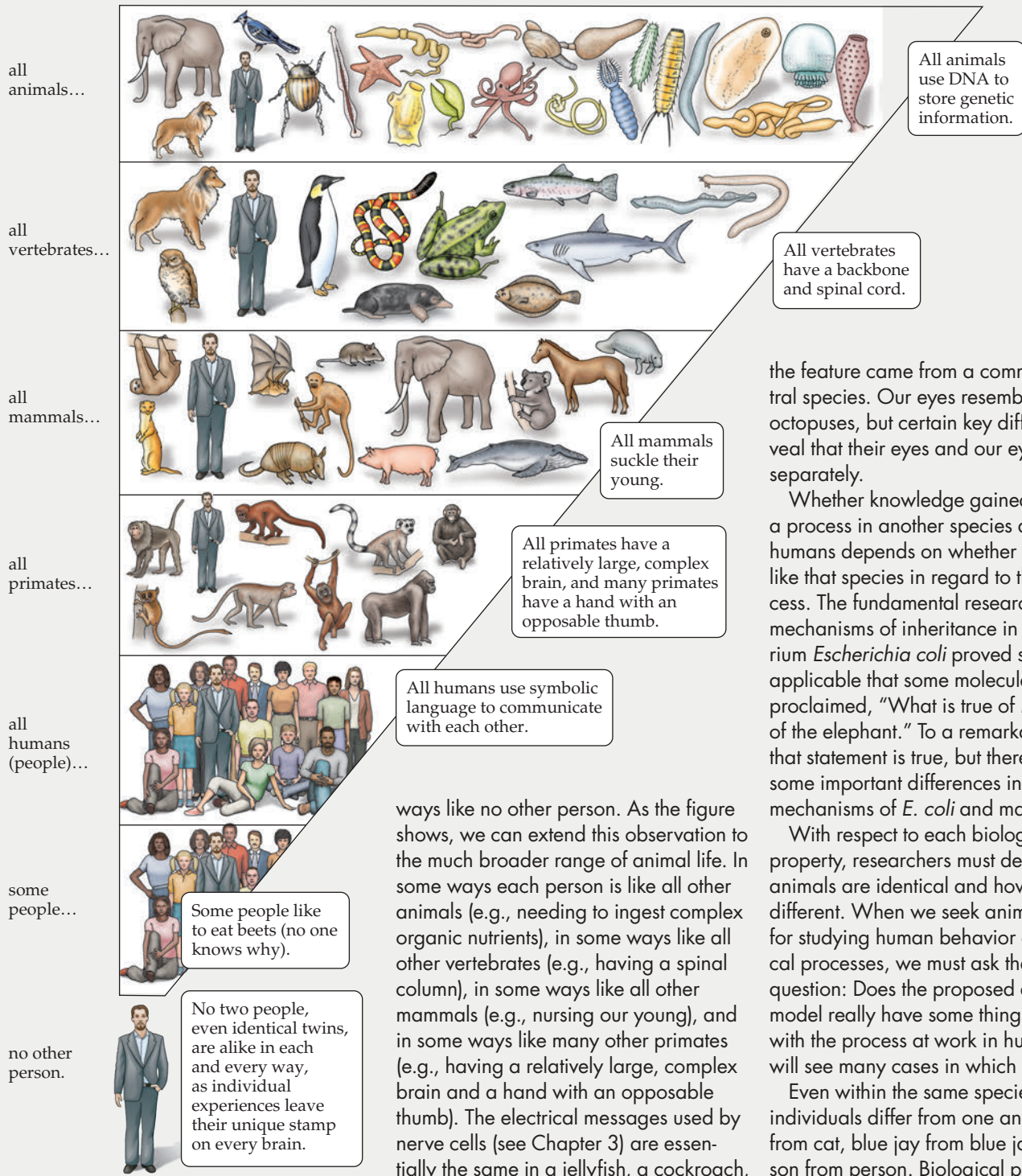
1. *Systematic description of behavior* Until we describe what we want to study, we cannot accomplish much. Depending on our goals, we may describe behavior in terms of detailed acts or processes, or in terms of results or functions. To be useful for scientific study, a description must be precise, using accurately defined terms and units.
2. *The evolution of brain and behavior* Darwin's theory of evolution through natural selection is central to all modern biology and psychology. Biological psychologists employ evolutionary theory in two ways: by evaluating *similarities* among species due to shared ancestry, and by looking for species-specific *differences* in behavior and biology that have evolved as adaptations to different environments (**BOX 1.1**). We will discuss many examples of both perspectives in this book.

**conserved** In the context of evolution, referring to a trait that is passed on from a common ancestor to two or more descendant species.

**BOX 1.1**

**We Are All Alike, and We Are All Different**

Each person has some characteristics shared by...



How do similarities and differences among people and animals fit into biological psychology? Each person is in some ways like all other people, in some ways like some other people, and in some

ways like no other person. As the figure shows, we can extend this observation to the much broader range of animal life. In some ways each person is like all other animals (e.g., needing to ingest complex organic nutrients), in some ways like all other vertebrates (e.g., having a spinal column), in some ways like all other mammals (e.g., nursing our young), and in some ways like many other primates (e.g., having a relatively large, complex brain and a hand with an opposable thumb). The electrical messages used by nerve cells (see Chapter 3) are essentially the same in a jellyfish, a cockroach, and a human being, and many species employ identical hormones. Species share these **conserved** characteristics because the features first arose in a shared ancestor. But mere similarity of a feature between species does not guarantee that

the feature came from a common ancestral species. Our eyes resemble those of octopuses, but certain key differences reveal that their eyes and our eyes evolved separately.

Whether knowledge gained about a process in another species applies to humans depends on whether we are like that species in regard to that process. The fundamental research on the mechanisms of inheritance in the bacterium *Escherichia coli* proved so widely applicable that some molecular biologists proclaimed, "What is true of *E. coli* is true of the elephant." To a remarkable extent, that statement is true, but there are also some important differences in the genetic mechanisms of *E. coli* and mammals.

With respect to each biological property, researchers must determine how animals are identical and how they are different. When we seek animal models for studying human behavior or biological processes, we must ask the following question: Does the proposed animal model really have some things in common with the process at work in humans? We will see many cases in which it does.

Even within the same species, however, individuals differ from one another: cat from cat, blue jay from blue jay, and person from person. Biological psychology seeks to understand individual differences as well as similarities. Therefore, the way in which each person is able to process information and store the memories of these experiences is another part of our story.