The Mind's Machine

FOUNDATIONS OF BRAIN AND BEHAVIOR

Neil V. Watson
Simon Fraser University

S. Marc Breedlove
Michigan State University

© Sinauer Associates, Inc. This material cannot be copied, reproduced, manufactured or disseminated in any form without express written permission from the publisher.
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  48
Chapter 4  The Chemistry of Behavior: Neurotransmitters and Neuropharmacology  76
Chapter 5  The Sensorimotor System  106
Chapter 6  Hearing, Balance, Taste, and Smell  140
Chapter 7  Vision: From Eye to Brain  168
Chapter 8  Hormones and Sex  202
Chapter 9  Homeostasis: Active Regulation of the Internal Environment  248
Chapter 10  Biological Rhythms and Sleep  270
Chapter 11  Emotions, Aggression, and Stress  300
Chapter 12  Psychopathology: The Biology of Behavioral Disorders  326
Chapter 13  Memory, Learning, and Development  354
Chapter 14  Attention and Consciousness  394
Chapter 15  Language and Our Divided Brain  422
chapter 3  Neurophysiology: The Generation, Transmission, and Integration of Neural Signals  48

Electrical Signals Are the Vocabulary of the Nervous System  50
A balance of electrochemical forces produces the resting potential of neurons  50
A threshold amount of depolarization triggers an action potential  54
Ionic mechanisms underlie the action potential  55
Action potentials are actively propagated along the axon  57
BOX 3.1  Action Potentials Act, in Many Ways, like a Flushing Toilet  60
Synapses cause local changes in the postsynaptic membrane potential  60
Spatial summation and temporal summation integrate synaptic inputs  62

Synaptic Transmission Requires a Sequence of Events  64
Action potentials cause the release of transmitter molecules into the synaptic cleft  64
Receptor molecules recognize transmitters  65
The action of synaptic transmitters is stopped rapidly  66
Neural circuits underlie reflexes  67
Gross Electrical Activity of the Human Brain  69
Electrical storms in the brain can cause seizures  69
RESEARCHERS AT WORK  Surgical probing of the brain revealed a map of the body  71

chapter 4  The Chemistry of Behavior: Neurotransmitters and Neuropharmacology  76

Electrical Signals Are Turned into Chemical Signals at Synapses  79
Receptor proteins recognize transmitters and their mimics  79
Many neurotransmitters have been identified  80
RESEARCHERS AT WORK  The first transmitter to be discovered was acetylcholine  81
Neurotransmitter Systems Form a Complex Array in the Brain  82
Four amine neurotransmitters project throughout the brain  82
Some amino acids act as neurotransmitters  84
Many peptides function as neurotransmitters  84
Some neurotransmitters are gases  85
DRUGS FIT LIKE KEYS INTO MOLECULAR LOCKS  85
The effects of a drug depend on its dose  87
Drug doses are administered in many different ways  88

Repeated treatments can reduce the effectiveness of drugs  89
DRUGS AFFECT EACH STAGE OF NEURAL CONDUCTION AND SYNAPTIC TRANSMISSION  89
Some drugs alter presynaptic processes  89
Some drugs alter postsynaptic processes  91
DRUGS THAT AFFECT THE BRAIN CAN BE DIVIDED INTO FUNCTIONAL CLASSES  92
Psychoactive drugs relieve severe symptoms  92
Psychoactive drugs alter consciousness  94
DRUG ABUSE IS PERVERSIVE  100
Several perspectives help us understand drug abuse  100
BOX 4.1  The Terminology of Substance-Related Disorders  101
Drug use, abuse, and dependence can be prevented or treated in multiple ways  102

CHAPTER 3 VISUAL SUMMARY  74

CHAPTER 4 VISUAL SUMMARY  104
## TABLE OF CONTENTS

### PART I Sensory Processing and the Somatosensory System 108

- Receptor Cells Convert Sensory Signals into Electrical Activity 110
- Sensory Information Processing Is Selective and Analytical 111
- Sensory events are encoded as streams of action potentials 112
- Sensory neurons respond to stimuli falling in their receptive fields 112
- Receptors may show adaptation to unchanging stimuli 113
- Sometimes we need receptors to be quiet 113

### PART II Pain: The Body’s Emergency Signaling System 108

- Human Pain Varies in Several Dimensions 117
- A Discrete Pain Pathway Projects from Body to Brain 118
- Peripheral receptors get the initial message 118
- Special neural pathways carry pain information to the brain 119

### PART III Movement and the Motor System 122

- Behavior Requires Movements That Are Precisely Programmed and Monitored 122
- Extrapyramidal systems regulate and fine-tune motor commands 136
- Damage to extrapyramidal systems impairs movement 137

## chapter 5 The Sensorimotor System 106

### PART I Sensory Processing and the Somatosensory System 108

- Receptor Cells Convert Sensory Signals into Electrical Activity 110
- Sensory Information Processing Is Selective and Analytical 111
- Sensory events are encoded as streams of action potentials 112
- Sensory neurons respond to stimuli falling in their receptive fields 112
- Receptors may show adaptation to unchanging stimuli 113
- Sometimes we need receptors to be quiet 113

### PART II Pain: The Body’s Emergency Signaling System 108

- Human Pain Varies in Several Dimensions 117
- A Discrete Pain Pathway Projects from Body to Brain 118
- Peripheral receptors get the initial message 118
- Special neural pathways carry pain information to the brain 119

## chapter 6 Hearing, Balance, Taste, and Smell 140

### PART I Hearing and Balance 142

- Each Part of the Ear Performs a Specific Function in Hearing 143
- The external ear captures, focuses, and filters sound 143
- The middle ear concentrates sound energies 144
- The cochlea converts vibrational energy into neural activity 145
- The hair cells transduce movements of the basilar membrane into electrical signals 146
- Auditory System Pathways Run from the Brainstem to the Cortex 149
- Our Sense of Pitch Relies on Two Signals from the Cochlea 150
- Brainstem Systems Compare the Ears to Localize Sounds 151
- The Auditory Cortex Performs Complex Tasks in the Perception of Sound 152

### PART II The Chemical Senses: Taste and Smell 159

- The Human Tongue Detects Five Basic Chemical Tastes 159
- Tastes excite specialized receptor cells on the tongue 159
- Different cellular processes transduce the basic tastes 160
- Taste information is transmitted to several parts of the brain 162
- Chemicals in the Air Elicit Odor Sensations 162
- The sense of smell starts with receptor neurons in the nose 162
- Olfactory information projects from the olfactory bulbs to several brain regions 164
- Many vertebrates possess a vomeronasal system 165

© Sinauer Associates, Inc. This material cannot be copied, reproduced, manufactured or disseminated in any form without express written permission from the publisher.
## chapter 7 Vision: From Eye to Brain 168

**The Visual System Extends from the Eye to the Brain 170**
- The vertebrate eye acts in some ways like a camera 170
- Visual processing begins in the retina 172
- Photoreceptors respond to light by releasing less neurotransmitter 173
- Different mechanisms enable the eyes to work over a wide range of light intensities 174
- Acuity is best in foveal vision 175
- Neural signals travel from the retina to several brain regions 178
- The retina projects to the brain in a topographic fashion 179

**Neurons at Different Levels of the Visual System Have Very Different Receptive Fields 180**
- Photoreceptors excite some retinal neurons and inhibit others 180
- Neurons in the retina and the LGN have concentric receptive fields 181

**RESEARCHERS AT WORK Neurons in the visual cortex have varied receptive fields 184**
- Neurons in the visual cortex beyond area V1 have complex receptive fields and help identify forms 187

**Perception of visual motion is analyzed by a special system that includes cortical area V5 188**

**Color Vision Depends on Special Channels from the Retinal Cones through Cortical Area V4 189**

**Color is created by the visual system 189**

**Color perception requires receptor cells that differ in their sensitivities to different wavelengths 190**

**BOX 7.1 Most Mammalian Species Have Some Color Vision 193**
- Some retinal ganglion cells and LGN cells show spectral opponency 194
- Some visual cortical cells and regions appear to be specialized for color perception 195

**The Many Cortical Visual Areas Are Organized into Two Major Streams 196**
- Visual Neuroscience Can Be Applied to Alleviate Some Visual Deficiencies 198

**Impairment of vision often can be prevented or reduced 198**
- Increased exercise can restore function to a previously deprived or neglected eye 199

**CHAPTER 7 VISUAL SUMMARY 200**

## chapter 8 Hormones and Sex 202

**PART I The Endocrine System 204**

**Hormones Act in a Great Variety of Ways throughout the Body 204**

**RESEARCHERS AT WORK Our current understanding of hormones developed in stages 204**
- Hormones are one of several types of chemical communication 206
- Hormones can be classified by chemical structure 207

**Hormones Act on a Wide Variety of Cellular Mechanisms 208**
- Hormones initiate actions by binding to receptor molecules 208

**BOX 8.1 Techniques of Modern Behavioral Endocrinology 210**
- Hormones can have different effects on different target organs 211

**Each Endocrine Gland Secretes Specific Hormones 212**
- The posterior pituitary releases two hormones directly into the bloodstream 213

**Posterior pituitary hormones can affect social behavior 215**

**Feedback control mechanisms regulate the secretion of hormones 215**

**Hypothalamic releasing hormones govern the anterior pituitary 216**

**BOX 8.2 Stress and Growth: Psychosocial Dwarfism 218**
- Two anterior pituitary tropic hormones act on the gonads 219
- The gonads produce steroid hormones, regulating reproduction 219
- Hormonal and neural systems interact to produce integrated responses 221

**PART II Reproductive Behavior 223**

**Reproductive Behavior Can Be Divided into Four Stages 223**
- Copulation brings gametes together 225

**RESEARCHERS AT WORK Gonadal steroids activate sexual behavior 225**

**The Neural Circuitry of the Brain Regulates Reproductive Behavior 227**
Ovarian steroids act on a lordosis circuit that spans from brain to muscle  227
Androgens activate a neural system for male reproductive behavior  228
Parental behaviors are governed by several sex-related hormones  229
The Hallmark of Human Sexual Behavior Is Diversity  230
Hormones play only a permissive role in human sexual behavior  232
PART III  Sexual Differentiation and Orientation  232
Genetic and Hormonal Mechanisms Guide the Development of Masculine and Feminine Structures  233
Sex chromosomes direct sexual differentiation of the gonads  233
Gonadal hormones direct sexual differentiation of the body  233

Changes in the sequence of sexual differentiation result in predictable changes in development  234
Dysfunctional androgen receptors can block the masculinization of males  235
Some people seem to change sex at puberty  236
How should we define gender—by genes, gonads, genitals?  236
RESEARCHERS AT WORK  Gonadal hormones direct sexual differentiation of behavior and the brain  237
Several regions of the nervous system display prominent sexual dimorphism  239
Social influences also affect sexual differentiation of the nervous system  242
Do Fetal Hormones Masculinize Human Behaviors in Adulthood?  243
What determines a person’s sexual orientation?  244
CHAPTER 8 VISUAL SUMMARY  247
Different species provide clues about the evolution of sleep 283

Our Sleep Patterns Change across the Life Span 284
Mammals sleep more during infancy than in adulthood 284
Most people sleep appreciably less as they age 286

Manipulating Sleep Reveals an Underlying Structure 286
Sleep deprivation impairs cognitive functioning but does not cause insanity 286
Sleep recovery may take time 287

BOX 10.1 Sleep Deprivation Can Be Fatal 288
What Are the Biological Functions of Sleep? 289
Sleep conserves energy 289
Sleep enforces niche adaptation 289
Sleep restores the body 289
Sleep may aid memory consolidation 290

The two cerebral hemispheres process emotion differently 315
Different emotions activate different regions of the human brain 315

PART II Aggression and Stress 316
Neural Circuitry, Hormones, and Synaptic Transmitters Mediate Violence and Aggression 317
Androgens seem to increase aggression 317
Alterations in neurotransmitter levels are associated with aggression 318
The biopsychology of human violence is a topic of controversy 319

Sleep Disorders Can Be Serious, Even Life-Threatening 296
Some minor dysfunctions are associated with sleep 296
Insomniacs have trouble falling asleep or staying asleep 296
Although many drugs affect sleep, there is no perfect sleeping pill 298

CHAPTER 10 VISUAL SUMMARY 299

The Toll of Psychiatric Disorders Is Huge 328
Schizophrenia is a major neurobiological challenge in psychiatry 329
Schizophrenia is characterized by an unusual array of symptoms 329
Schizophrenia has a heritable component 329

RESEARCHERS AT WORK An integrative model of schizophrenia emphasizes the interaction of multiple factors 331
The brains of some patients with schizophrenia show structural changes 333
Functional maps reveal differences in schizophrenic brains 334

Psychopathology: The Biology of Behavioral Disorders 326
chapter 13 Memory, Learning, and Development 354

PART I Types of Learning and Memory 356
There Are Several Kinds of Memory and Learning 356
For patient H.M., the present vanished into oblivion 356
RESEARCHERS AT WORK Which brain structures are important for declarative memory? 359
Damage to the mammillary bodies can also cause amnesia 360
Brain damage can destroy autobiographical memories while sparing general memories 360
Different Forms of Nondeclarative Memory Involve Different Brain Regions 362
Different types of nondeclarative memory serve varying functions 362
Animal research confirms the various brain regions involved in different attributes of memory 363
Brain regions involved in learning and memory: A summary 365
Successive Processes Capture, Store, and Retrieve Information in the Brain 365
STM and LTM appear to be different processes 366
BOX 13.1 Emotions and Memory 367
Long-term memory has vast capacity but is subject to distortion 369

PART II Neural Mechanisms of Memory 370
Memory Storage Requires Neuronal Remodeling 370
Plastic changes at synapses can be physiological or structural 371
Varied experiences and learning cause the brain to change and grow 371
Invertebrate nervous systems show synaptic plasticity 372

Scientists are still searching for animal models of depression 344
People with bipolar disorder show repeating mood cycles 345
There Are Several Types of Anxiety Disorders 346
Drug treatment of anxiety provides clues to the mechanisms of this disorder 346
In posttraumatic stress disorder, horrible memories won’t go away 347
In obsessive-compulsive disorder, thoughts and acts keep repeating 348

BOX 12.2 Tics, Twitches, and Snorts: The Unusual Character of Tourette’s Syndrome 350

CHAPTER 12 VISUAL SUMMARY 352

Antipsychotic medications revolutionized the treatment of schizophrenia 336
BOX 12.1 Long-Term Effects of Antipsychotic Drugs 337
Mood Disorders Are a Major Psychiatric Category 340
Depression is the most prevalent mood disorder 340
Inheritance is an important determinant of depression 341
The brain changes with depression 341
A wide variety of treatments are available for depression 341
Why do more females than males suffer from depression? 343
Sleep characteristics change in affective disorders 344

Classical conditioning relies on circuits in the mammalian cerebellum 373
Synaptic Plasticity Can Be Measured in Simple Hippocampal Circuits 375
NMDA receptors and AMPA receptors collaborate in LTP 377
Is LTP a mechanism of memory formation? 379

PART III Development of the Brain 380
Growth and Development of the Brain Are Orderly Processes 380
Development of the Nervous System Can Be Divided into Six Distinct Stages 380
Cell proliferation produces cells that become neurons or glial cells 382
In the adult brain, newly born neurons aid learning 383
The death of many neurons is a normal part of development 384
An explosion of synapse formation is followed by synapse rearrangement 385

Genes Interact with Experience to Guide Brain Development 387
Genotype is fixed at birth, but phenotype changes throughout life 387
Experience regulates gene expression in the developing and mature brain 388

The Brain Continues to Change as We Grow Older 390
Memory impairment correlates with hippocampal shrinkage during aging 390
Alzheimer’s disease is associated with a decline in cerebral metabolism 390

CHAPTER 13 VISUAL SUMMARY 393
chapter 14 Attention and Consciousness 394

Attention Focuses Cognitive Processing on Specific Objects 396
There are limits on attention 397
Attention filters information early or late in sensory processing 397
Attention May Be Endogenous or Exogenous 398
RESEARCHERS AT WORK We can choose which stimuli we will attend to 398
Some stimuli are hard to ignore 400
BOX 14.1 Reaction-Time Responses, from Input to Output 400
We use visual search to make sense of a cluttered world 402
The Electrical Activity of the Brain Provides Clues about Mechanisms of Attention 403
Distinctive patterns of brain electrical activity mark voluntary shifts of attention 404
Reflexive visual attention has its own electrophysiological signature 406
Attention affects the activity of individual neurons 407

Many Brain Regions Are Involved in Processes of Attention 408
Two subcortical systems guide shifts of attention 408
Several cortical areas are crucial for generating and directing attention 409
Brain disorders can cause specific impairments of attention 411
Difficulty with sustained attention can sometimes be relieved with stimulants 412
Consciousness and Attention Are Closely Linked 413
Some aspects of consciousness are easier to study than others 414
BOX 14.2 Neuroeconomics Identifies Brain Regions Active during Decision Making 417
The Frontal Lobes Govern Our Most Complex Behaviors 417
Frontal lobe injury in humans leads to emotional, motor, and cognitive changes 418

CHAPTER 14 VISUAL SUMMARY 421

chapter 15 Language and Our Divided Brain 422

PART I Speech and Language 424
Some Aspects of Language Are Innate, but Others Must Be Learned 424
Can nonhuman primates acquire language with training? 426
Vocal behavior is a feature of many different species 427
Language Disorders Result from Region-Specific Brain Injuries 429
Damage to a left anterior speech zone causes nonfluent (or Broca’s) aphasia 430
Damage to a left posterior speech zone causes fluent (or Wernicke’s) aphasia 430
Widespread left-hemisphere damage can obliterate language capabilities 430
Disconnection of language regions may result in specific verbal problems 432
Reading Skills Are Difficult to Acquire and Frequently Impaired 434
Brain damage may cause specific impairments in reading 434
Some people struggle throughout their lives to read 434
Brain Mapping Helps Us Understand the Organization of Language in the Brain 435

Cortical stimulation mapping shows localized functions within language areas 436
RESEARCHERS AT WORK Noninvasive stimulation mapping shows that the language areas of the normal brain may contain a variety of functional zones 437
Functional neuroimaging technologies identify brain regions that are active during specific language tasks 438

PART II Cerebral Asymmetry 439
The Left and Right Brains Are Different 439
Disconnection of the cerebral hemispheres reveals their individual processing specializations 440
The two hemispheres process information differently in normal humans 441
Does the left hemisphere hear words and the right hemisphere hear music? 442
Do left-handed people have unusual brain organization? 443
Deficits in Spatial Perception Follow Right-Hemisphere Damage 444
In prosopagnosia, faces are unrecognizable 445

BOX 15.1 The Wada Test 445
PART III Recovery of Function 447
Stabilization and Reorganization Are Crucial for Recovery of Function 447
BOX 15.2 Contact Sports Can Be Costly 448

Rehabilitation and Retraining Can Help Recovery from Brain and Spinal Cord Injury 449
BOX 15.3 The Amazing Resilience of a Child’s Brain 450
CHAPTER 15 VISUAL SUMMARY 452

Appendix A–1
Glossary G–1
Illustration Credits IC–1

References R–1
Author Index AI–1
Subject Index SI–1