

Making Everything Easier!™

Neurobiology

FOR
DUMMIES®
A Wiley Brand

Learn to:

- Get a handle on neuroanatomy
- Navigate neurological disorders and treatments
- Score high in your neurobiology class
- Understand neurological diseases

Frank Amthor, PhD

Author of Neuroscience For Dummies®



Get More and Do More at Dummies.com®



Start with **FREE** Cheat Sheets

Cheat Sheets include

- Checklists
- Charts
- Common Instructions
- And Other Good Stuff!

To access the Cheat Sheet created specifically for this book, go to
www.dummies.com/cheatsheet/neurobiology

Get Smart at Dummies.com

Dummies.com makes your life easier with 1,000s of answers on everything from removing wallpaper to using the latest version of Windows.

Check out our

- Videos
- Illustrated Articles
- Step-by-Step Instructions

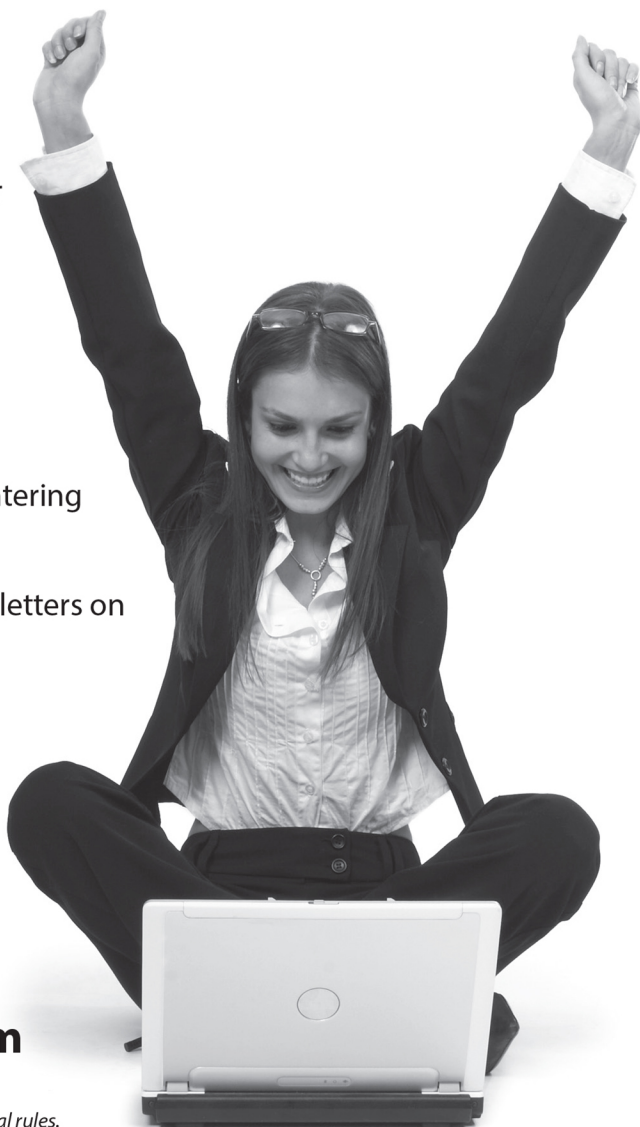
Plus, each month you can win valuable prizes by entering our Dummies.com sweepstakes. *

Want a weekly dose of Dummies? Sign up for Newsletters on

- Digital Photography
- Microsoft Windows & Office
- Personal Finance & Investing
- Health & Wellness
- Computing, iPods & Cell Phones
- eBay
- Internet
- Food, Home & Garden

Find out “HOW” at Dummies.com

*Sweepstakes not currently available in all countries; visit Dummies.com for official rules.



Neurobiology

FOR
DUMMIES[®]
A Wiley Brand

by Frank Amthor, PhD

FOR
DUMMIES[®]
A Wiley Brand

Neurobiology For Dummies®

Published by: **John Wiley & Sons, Inc.**, 111 River Street, Hoboken, NJ 07030-5774, www.wiley.com

Copyright © 2014 by John Wiley & Sons, Inc., Hoboken, New Jersey

Published simultaneously in Canada

No part of this publication may be reproduced, stored in a retrieval system or transmitted in any form or by any means, electronic, mechanical, photocopying, recording, scanning or otherwise, except as permitted under Sections 107 or 108 of the 1976 United States Copyright Act, without the prior written permission of the Publisher. Requests to the Publisher for permission should be addressed to the Permissions Department, John Wiley & Sons, Inc., 111 River Street, Hoboken, NJ 07030, (201) 748-6011, fax (201) 748-6008, or online at <http://www.wiley.com/go/permissions>.

Trademarks: Wiley, For Dummies, the Dummies Man logo, Dummies.com, Making Everything Easier, and related trade dress are trademarks or registered trademarks of John Wiley & Sons, Inc., and may not be used without written permission. All other trademarks are the property of their respective owners. John Wiley & Sons, Inc., is not associated with any product or vendor mentioned in this book.

LIMIT OF LIABILITY/DISCLAIMER OF WARRANTY: WHILE THE PUBLISHER AND AUTHOR HAVE USED THEIR BEST EFFORTS IN PREPARING THIS BOOK, THEY MAKE NO REPRESENTATIONS OR WARRANTIES WITH RESPECT TO THE ACCURACY OR COMPLETENESS OF THE CONTENTS OF THIS BOOK AND SPECIFICALLY DISCLAIM ANY IMPLIED WARRANTIES OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE. NO WARRANTY MAY BE CREATED OR EXTENDED BY SALES REPRESENTATIVES OR WRITTEN SALES MATERIALS. THE ADVISE AND STRATEGIES CONTAINED HEREIN MAY NOT BE SUITABLE FOR YOUR SITUATION. YOU SHOULD CONSULT WITH A PROFESSIONAL WHERE APPROPRIATE. NEITHER THE PUBLISHER NOR THE AUTHOR SHALL BE LIABLE FOR DAMAGES ARISING HEREFROM.

For general information on our other products and services, please contact our Customer Care Department within the U.S. at 877-762-2974, outside the U.S. at 317-572-3993, or fax 317-572-4002. For technical support, please visit www.wiley.com/techsupport.

Wiley publishes in a variety of print and electronic formats and by print-on-demand. Some material included with standard print versions of this book may not be included in e-books or in print-on-demand. If this book refers to media such as a CD or DVD that is not included in the version you purchased, you may download this material at <http://booksupport.wiley.com>. For more information about Wiley products, visit www.wiley.com.

Library of Congress Control Number: 2013954238

ISBN 978-1-118-68931-8 (pbk); ISBN 978-1-118-69146-5 (ebk)

Manufactured in the United States of America

10 9 8 7 6 5 4 3 2 1

Contents at a Glance

<i>Introduction</i>	<i>1</i>
<i>Part I: Getting Started with Neurobiology.....</i>	<i>5</i>
Chapter 1: Welcome to the World of Neurobiology	7
Chapter 2: Building Neurons from Molecules	23
Chapter 3: Gating the Membrane: Ion Channels and Membrane Potentials	47
Chapter 4: Sending Signals: Chemical Release and Electrical Activation.....	67
<i>Part II: Neuroanatomy: Organizing the Nervous System</i>	<i>83</i>
Chapter 5: Movement Basics: Muscles and Motor Neurons	85
Chapter 6: The Spinal Cord and the Autonomic Nervous System.....	101
Chapter 7: The Busy Brain: Brainstem, Limbic System, Hypothalamus, and Reticular Formation	123
Chapter 8: Generating Behavior: Basal Ganglia, Thalamus, Motor Cortex, and Frontal Cortex.....	145
Chapter 9: Topping It Off: The Neocortex	159
<i>Part III: Perceiving the World, Thinking, Learning, and Remembering</i>	<i>183</i>
Chapter 10: Looking at Vision and Hearing	185
Chapter 11: Feeling, Smelling, and Tasting.....	211
Chapter 12: Memory and Learning	233
Chapter 13: The Frontal Lobes and Executive Brain.....	253
Chapter 14: Language, Intelligence, Emotions, and Consciousness.....	265
<i>Part IV: Developmental, Neurological, and Mental Disorders and Treatments</i>	<i>283</i>
Chapter 15: Developing the Brain and Nervous System.....	285
Chapter 16: Movement Disorders	309
Chapter 17: Brain Dysfunction and Mental Illness	325
Chapter 18: Making Better Brains	341

<i>Part V: The Part of Tens</i>	355
Chapter 19: The Ten Most Important Brain Circuits.....	357
Chapter 20: Ten Technologies Revolutionizing Brain Science	365
<i>Index</i>	373

Table of Contents

<i>Introduction</i>	1
About This Book	2
Foolish Assumptions	2
Icons Used in This Book	3
Beyond the Book	3
Where to Go from Here	4
 <i>Part 1: Getting Started with Neurobiology</i>	5
 Chapter 1: Welcome to the World of Neurobiology	7
Introducing Neurons	8
Evolving cells on early earth	8
Multicellularity: Sensing and moving	9
Cellular motors	10
Coordinating responses in simple circuits	11
Organizing the Nervous System	12
Movement basics: Muscles and motor systems	13
The spinal cord and autonomic nervous system	13
The brainstem, limbic system, hypothalamus, and reticular formation	14
Basal ganglia, cerebellum, motor and premotor cortex, and thalamus	15
The neocortex	16
Perceiving the World, Thinking, Learning, and Remembering	17
Looking at vision and audition	17
Feeling, smelling, and tasting	18
Learning and memory: Circuits and plasticity	18
The frontal lobes and executive brain	19
Language, emotions, lateralization, and thought	19
Developmental, Neurological, and Mental Disorders and Treatments	20
Developing the brain and nervous system	21
Movement disorders and symptoms	21
Neural dysfunctions and mental illness	22
Repair and enhancement with artificial brains	22

Chapter 2: Building Neurons from Molecules 23

Getting into Genetics.....	23
Introducing inheritance	24
Greeting chromosomes and genes	25
Replicating DNA and the cell life cycle	26
Coding for proteins: RNA and DNA.....	27
Regulating genes	29
Meeting Cell Molecules: Important Ions and Proteins	31
Eyeing important ions	32
Sizing up proteins	33
Going through membrane proteins	33
Peeking at the Parts of a Cell.....	33
Cytoplasm and organelles	34
Nucleus.....	34
Secretion and hormones.....	35
Setting Boundaries: Cell Membrane Lipids	36
Focusing on phospholipid chemistry.....	37
Seeing cells' differences	39
Regulating Water and Cell Volume.....	40
Observing osmotic pressure	40
Responding to osmotic challenges.....	40
Moving water with aquaporins	41
Knowing the Neuron: Not Just Another Cell	41
Noticing neuron anatomy	41
Understanding what neurons do	43
When Things Go Wrong: Genetics and Neurological Illness	44
Mutations and transcriptional errors	44
Modifying genes: Fixing or Frankenstein?.....	46

Chapter 3: Gating the Membrane: Ion Channels and Membrane Potentials 47

Looking at Membrane Channels	47
Talking about transporters.....	48
Checking out channels	48
Getting a Charge Out of Neurons.....	50
Pumping Ions for Information	50
Sodium-potassium pump	50
Other important pumps	52
Discovering Diffusion and Voltage	52
The Nernst equation.....	53
The Goldman–Hodgkin–Katz equation.....	54
Signaling with Electricity in Neurons	56
Exploring potential	56
Controlling ion permeability: Gated channels	56

Making Spikes with Sodium and Potassium Channels	57
Getting back to resting potential	57
Voltage-dependent channels	58
Reaching action potential	58
Cable properties of neurons: One reason for action potentials.....	61
Insulating with Glial Cells	65

Chapter 4: Sending Signals: Chemical Release and Electrical Activation..... 67

Looking at Synaptic Transmission	67
Checking out chemical synapses and neurotransmitter release	68
Eyeing electrical synapses at gap junctions.....	72
Being Receptive to Neurotransmitter Receptors	74
Introducing ionotropic receptors.....	75
Meeting metabotropic receptors and second messenger systems.....	76
Making connections with the neuromuscular junction	78
Dividing and Conquering: Interneurons and Circuits	79
Pooling sensory input	80
Coordinating motor output	81
Comparing brains to computers.....	81

Part II: Neuroanatomy: Organizing the Nervous System..... 83

Chapter 5: Movement Basics: Muscles and Motor Neurons 85

Making a Move: Muscle Types and What They Do.....	86
Processing with smooth muscle.....	86
Striated muscle for hearts and limbs	86
Twitching fast and slow: Muscle composition.....	88
Pulling Your Weight: How Muscle Cells Contract	88
Releasing acetylcholine.....	89
Patterning muscle contractions.....	89
Alpha motor neurons	90
The motor unit	90
Sliding filaments: Actin and myosin	91
Controlling Muscle Contraction	92
Modulating firing rate.....	93
Recruiting motor neurons	94
Knowing Where Your Limb Is Located	94
Muscle spindle and gamma motor neurons	95
Golgi tendon organs	95
Joint receptors for position.....	95

Reflexing without Reflecting	96
Withdrawing a limb	96
Staying put	96
Seeing the spinal flexor reflex	97
Keeping the spinal cord in the loop	97
Monosynaptic and polysynaptic reflexes	97
Overriding a reflex	98
Exercise and Aging	99
Use it or lose it: The effects of exercise	99
Slowing down with age	99
Muscle mass in men and women	100

Chapter 6: The Spinal Cord and the Autonomic Nervous System. . . 101

Segmenting the Spine	102
Cervical nerves	103
Thoracic nerves	105
Lumbar nerves	105
Sacral nerves	105
Spinal membranes	106
Spying on the Spinal Cord	106
Dorsal inputs, ventral outputs	107
Reflecting on what hit you: The basic spinal reflex	109
Spinal pattern generators	110
Feeling and Acting: The Peripheral Nervous System	112
Getting stimulated by neural sensors	112
Moving around: Neural effectors	113
Correcting Errors: The Cerebellum	114
Cerebellar structure	115
Stepping in holes and what to do about it	116
Carrying the load: Feed-forward force calibration	117
Cerebellar circuits	118
Fighting or Fleeing: The Autonomic Nervous System	119
The two main subdivisions of the autonomic nervous system ...	119
The autonomic nervous system input and output	121

Chapter 7: The Busy Brain: Brainstem, Limbic System, Hypothalamus, and Reticular Formation. 123

The Brainstem: Medulla, Pons, Midbrain	124
Meeting the medulla	125
Presenting the pons	127
Mentioning the midbrain	128
Counting the Cranial Nerves	129
Controlling Your Motives: The Limbic System	131
Mesocortex and allocortex versus neocortex	133
Organizing thoughts and activities: The cingulate gyrus	133
Making memories: The hippocampus	134
The amygdala	136

Regulating the Autonomic Nervous System: The Hypothalamus	137
Sleeping and waking: Circadian rhythms.....	137
Hypothalamic body function regulation.....	140
The insula (insular cortex).....	141
Reading Up on the Reticular Formation	142
Starting with the spine	142
Moving through the brainstem	143
Continuing through the thalamus and cortex.....	144

Chapter 8: Generating Behavior: Basal Ganglia, Thalamus, Motor Cortex, and Frontal Cortex. 145

The Basal Ganglia and Its Nuclei	146
Striatum inputs and output to the thalamus.....	147
The basal ganglia neural circuit.....	148
Controlling Muscles: The Primary Motor Cortex	148
The homunculus	149
Population coding.....	149
Coordinating Muscle Groups: Central Control	150
The supplementary motor area and learned sequences.....	150
Externally monitored performance and the premotor cortex.....	151
The frontal eye fields and superior colliculus	151
The Thalamus: Gateway to the Neocortex.....	152
Reaching all the senses.....	152
Paying attention to the pulvinar	154
Moving through motor pathways	155
Reticular zones of the thalamus	155
Focusing on Goals with the Prefrontal Cortex.....	156
Making plans with the lateral prefrontal cortex	156
Processing emotions with the orbitofrontal cortex	157
Anterior and posterior cingulate cortex.....	157
Knowing, or Not Knowing, Who's In Control	158

Chapter 9: Topping It Off: The Neocortex 159

Looking Inside the Skull: The Neocortex and Its Lobes.....	159
Noticing uniform structure and circuits	162
Communicating with the diencephalon and the rest of the nervous system	163
Getting to the Brain You Have Today: The Neocortex versus Your Reptilian Brain	165
Looking at how cortical areas developed.....	167
Enlarging the frontal lobes for complex behavior	168
Setting and accomplishing goals	168
Making Decisions: The Lateral Prefrontal Cortex.....	170
Keeping it all in mind.....	170
Changing your plans.....	170
Dialing that number: Working memory.....	171
Recalling that number: Long-term memory and executive control	172



Doing the Right Thing	173
Responding with the orbitofrontal cortex and learned emotional reactions.....	173
Getting that bad feeling: The amygdala, emotional learning, and cortical connections	174
Going with your gut	175
Seeing Both Sides: The Left and Right Hemispheres	176
Specializing for language	177
Taking in the big picture: Spatial processing.....	178
Managing with two brains in one head	178
Appreciating the style of each hemisphere.....	178
Gender and the Brain	180
Sizing up the male and female brain.....	180
Zeroing in on certain areas	180
Lateralization.....	180
Thinking in different styles	181
Knowing the role of hormones.....	181

Part III: Perceiving the World, Thinking, Learning, and Remembering..... 183

Chapter 10: Looking at Vision and Hearing 185

Imaging and Capturing Light: Vision.....	185
Making movies on the retina: Optics and eye movements.....	186
Converting photons to chemical reactions: Photoreception.....	187
Joining the Nervous System: Photoreceptor Output	190
Converting light to contrast: Bipolar and horizontal cells	191
Making nerve pulses in the retina.....	194
Sending the Message to the Brain	196
Relaying at the thalamus.....	196
Parallel processing in diverse visual centers.....	198
Fanning Out in the Occipital Lobe.....	198
Layering and concurrent processing in V1	198
Selecting for orientation and movement	199
Streaming the Message to the Temporal and Parietal Lobes	199
Seeing complex shapes and colors in the ventral stream	200
Seeing where and how-to in the dorsal stream.....	200
Communicating between dorsal and ventral streams	201
Seeing without meaning: Agnosias	201
Listening In: Capturing Sound Waves	202
Good vibrations: Gathering and transmitting sound to the brain.....	202
Toning up: Frequency transduction in the Organ of Corti	204

Channeling Sounds to the Brain	205
Comparing and relaying in the superior olive, inferior colliculus, and thalamus	206
Analyzing sounds in the superior temporal lobe	206
Losing Hearing	208
Conductive versus neural hearing loss.....	208
Eh? Aging, environment, and hearing loss	208
Aiding hearing: Amplifying and replacing.....	209
Ringing and tinnitus.....	209
Balancing via the Vestibular System: “Hearing” the Fluid Sloshing in Your Head	210

Chapter 11: Feeling, Smelling, and Tasting 211

Getting in Touch with the Skin	211
Feeling your way with mechanoreceptors	212
Avoiding pain: Axonal endings for temperature and skin damage	214
Locating your limbs with skin, muscle, and joint receptors	216
Spinal processing and cranial nerves.....	217
Sending the message to the thalamus.....	217
Recognizing What We Touch at Somatosensory Cortex	218
Mapping senses with the homunculus.....	219
Specialized somatosensory areas.....	219
Perceiving pain.....	220
Sniffing Out the World around You	221
Nosing around: Olfactory receptors.....	222
Exploring the olfactory bulb.....	222
Reaching the cortex before the thalamus.....	223
Smelling badly versus smelling bad	225
Communicating with pheromones	225
Tasting Basics: Sweet, Sour, Salt, and Bitter Receptors	226
Coding for taste: Labels versus patterns	227
Understanding the umami problem	228
Tasting with the Brain.....	229
Projecting taste to the thalamus.....	229
Discriminating taste in the cortex	230
Combining taste and smell for flavor	230
Losing taste through injuries	231
Feeling full.....	231
Monitoring Internal Body Functions with Internal Chemoreceptors ...	232

Chapter 12: Memory and Learning 233

Evolving with Adaptation and Instinct	233
Moving through evolution	234
Going into development.....	234
Looking at learning	234

Implicit (Non-Declarative) Memory	235
Getting used to habituation.....	236
Responding to sensitization	236
Preparing for priming.....	237
Conditioning classically and operantly.....	237
Learning motor sequences: Procedural memory	239
The Long and Short of It: Immediate versus Permanent Memory	240
Sensory/iconic memory	241
Working/short-term memory	242
Explicit (declarative) memory	243
Memory Mechanisms and Brain Loci.....	244
Associating context with results in the hippocampus.....	244
Remembering pain with the amygdala.....	247
Learning by Changing Synaptic Strengths.....	247
Increasing response: NMDA receptor changes	247
Making presynaptic strength changes	248
Animal versus computer memory	248
Forgetting It: Amnesia and Other Memory Loss.....	249
Losing yourself in amnesia	249
Damaging the hippocampus	250
Ignoring consequences: Frontal lobe damage.....	250
Examining Alzheimer's disease.....	250
Improving Your Learning.....	251
Studying hard versus studying well: Schedules.....	252
Traveling the path to better memory.....	252
Chapter 13: The Frontal Lobes and Executive Brain	253
Reflexes versus Conscious or Goal-Generated Action.....	254
Turning ideas and goals into action	255
Representing actions at multiple levels	256
Deciding How to Do It: The Frontal Lobes and Action Execution	256
Originating abstract plans	256
Converting plans to body control.....	257
Initiating Action in the Basal Ganglia.....	258
Preparing for action.....	258
Patterning and oscillating.....	259
Coordinating through the Supplementary and Premotor Cortices	259
Feeding back to guide movement	260
Learning motor sequences: Supplementary motor cortex.....	260
Learning motor sequences	261
Mirroring Others: Mirror Neurons	263
Defining mirroring behaviors	264
Imitating others as a function of mirroring	264
Chapter 14: Language, Intelligence, Emotions, and Consciousness	265
Adapting Our Brains for Language	265
Knowing how the brain is organized.....	266
Thinking thanks to the neocortex.....	266

Sensory processing in occipital, parietal, and temporal lobes....	268
Specializing for memory	268
Following Thought through Sensory Pathways and Hierarchies	269
Relaying to the thalamus and cortex.....	269
Projecting back to the thalamus	270
Gating and integrating functions	272
Speaking Your Mind: Language, Vision, and the Brain Hemispheres ...	272
Comparing communication and language.....	273
Locating language in the brain.....	273
Losing language from neural dysfunction	274
Examining visual processing asymmetries.....	275
Considering where consciousness lives	275
Defining Intelligence.....	276
Math, language, and social intelligence	276
Intelligence components for decisions, abstract thinking, problem solving.....	277
Investigating intelligence factors.....	278
Emotional Intelligence	278
Feeling the basic emotions	279
Reacting quickly.....	280
Understanding Consciousness	281
Learning language instinctually	282
Developing internal language and consciousness.....	282

Part IV: Developmental, Neurological, and Mental Disorders and Treatments..... 283

Chapter 15: Developing the Brain and Nervous System 285

Dividing and Differentiating after Conception	285
Meiosis, gametes, and zygotes.....	286
Partitioning the body: Endoderm, mesoderm, ectoderm.....	288
Descending from the ectoderm into the nervous system	290
Covering the brain with meninges: Dura, arachnoid, and pia.....	292
Polarizing the Brain: Ganglia versus Brains.....	293
Basic body plan.....	293
Differentiating the spinal cord from the brain proper	293
Differentiating into the hindbrain, midbrain, and forebrain	294
Layering the Neocortex	294
Migrating along radial glia and other glial roles	295
Differentiating at journey's end	297
What's so magic about six layers?.....	299
Forming neurons: Dendrites and axons.....	300
Cortical maps	300

Developmental Neural Disorders	303
Tracing genetic development using mice	304
Known single mutation disorders.....	304
Multi-locus mutation disorders.....	305
Birth defects	305
Aging effects over the lifespan.....	306
Aging and brain dysfunctions	307

Chapter 16: Movement Disorders 309

When the Wheels Come Off: Motor Disorders	309
Major early developmental disorders.....	310
Injuries and diseases	310
Lifespan motor disorders	311
Failing Forces: Muscle Diseases.....	312
Muscular dystrophy	312
Inflammatory myopathies.....	313
Neuromuscular Junction Disorders	313
Myasthenia gravis	313
Lambert–Eaton syndrome	314
Toxins.....	314
Motor Neuron Damage.....	315
Amyotrophic lateral sclerosis	315
Multiple sclerosis.....	316
Viral infections	316
Hijacking pinocytosis	317
Basal Ganglia and Other Diseases	317
Parkinson’s disease	317
Huntington’s disease	319
Neuropathies: Losing peripheral sensation	319
Strokes and Injuries.....	320
Suffering a stroke	320
Injuring the brain	322
Spinal cord injuries.....	322
Substituting machines: Motor prostheses.....	324

Chapter 17: Brain Dysfunction and Mental Illness 325

Understanding Mental Illness as Neural Dysfunction	325
Building brains	326
Developing while growing.....	326
Turning thoughts into synapses	327
Exploring the Genetic Causes of Brain Dysfunction	327
Mutations at single locations	328
Down syndrome.....	329
Autism	329
Knowing How the Nervous System Can Be Damaged in Utero.....	329
Fetal alcohol syndrome.....	330
Maternal stress and infections.....	330

Mixing Genetic and Developmental Components	330
Depression and mania.....	331
Schizophrenia.....	335
Obsessive compulsive disorder.....	337
Post traumatic stress disorder	338
Epilepsy.....	338
Eating and Drinking for Brain Function	339
Naturally occurring psychoactive substances.....	339
Feeding the brain properly.....	339
Looking at commonly abused drugs	340

Chapter 18: Making Better Brains 341

Fixing the Brain with Surgery, Electricity, and Magnetism	341
Lobotomies and other brain surgery	342
Electroconvulsive therapy.....	342
Deep brain stimulation.....	343
Transcranial magnetic stimulation.....	343
Transcranial direct current stimulation	344
Meditation, lighting, and soothing sounds	344
Repairing Brain Damage	345
Genes and growth factors.....	345
Stem cells.....	346
Brain–Machine Interfaces.....	347
Inputting information to the brain.....	347
Reading the brain’s output code.....	348
Augmenting Brain Function.....	348
Stimulation and function enhancement	349
Genetic modification	350
Simulating Brain Function on Computers	350
Comparing brain and computer power.....	350
Crunching the numbers by computer and human brain.....	351
Downloading the Brain	352
Reading out what’s in your brain.....	352
Inserting knowledge and memories into the brain.....	353
Is the singularity near? Is super-machine intelligence about to occur?	354

Part V: The Part of Tens 355

Chapter 19: The Ten Most Important Brain Circuits 357

The Reticular Formation in the Brainstem.....	357
The Spinal Reflex	358
The Thalamic Relay to the Cortex.....	359
Cerebellar Modulation of Motion Sequences.....	359
Hippocampal Reciprocal Activation with the Cortex	360

The Amygdala Orbitofrontal Cortex Loop.....	360
The Spinal Pattern Generator	361
The Conscious Triangle: Frontal and Sensory Cortex with the Thalamus	362
The Basal Ganglia Thalamus Loop	363
The Anterior Cingulate and Pulvinar Central Executives.....	363

Chapter 20: Ten Technologies Revolutionizing Brain Science 365

Optogenetics: Controlling Neurons with Light	365
Transcranial Magnetic Stimulation and Transcranial Direct Current Stimulation	366
Genetic Disease Models: Knockouts and Knockins.....	367
Brain Imaging: Optical, Magnetic, and Electrical.....	367
Interfacing Brains with Computers	368
Deep Brain Stimulation	369
Multi-Electrode Array Recording.....	370
Fluorescence and Confocal Microscopy.....	370
Advances in Electrophysiological Recording	371
Tissue Culture and Brain Slices	372

<i>Index</i>	373
---------------------------	------------

Introduction



Life existed for a long time on earth before human intelligence. Does our planet just happen to be the only one whose conditions make life possible? Or are we one of billions of planets that sustain life? If little green men in flying saucers showed up, we could ask them the answer. But failing that, and without any conclusive evidence, we don't really know.

The data we do have that we can examine is that life originated at least once here on earth very shortly after conditions appeared to be suitable to support it. More than three billion years after that, we humans appeared as a result of an almost uncountable number of life cycles, mutations, and reproductions.

This book is about the essential essence of humans as an intelligent life form — the nervous system. We can and do ask many questions about the nervous system, but here are three of the big ones:

- ✓ What does our nervous system have in common with that of other animals?
- ✓ How is our nervous system different from that of other animals?
- ✓ What differences between humans are associated with differences in their nervous systems?

Neurobiologists have some answers to all three of these questions. We know that neurons are specialized cells with some functions specific to neurons, and others similar to most other cells on earth. We also know that nervous systems have similar organizational themes and methods of communication across all animal species. On the other hand, the nervous systems of mammals and primates are vastly more complicated than those of invertebrates and even of cold-blooded vertebrates. Finally, we know that small genetic differences and life experiences can produce significant changes in the behavior of identical twins that otherwise have almost identical brains.

This book attempts to explain in ordinary language how neurons work, how neurons make nervous systems, and how nervous systems produce intelligence and complex behavior.

About This Book

This book starts with basic concepts and builds off of them. It first discusses cells and their origin and functions, then deals with basic brain anatomy made from those cells, and finally describes specialized systems for sensation, movement, and cognition.

The way this book is organized allows you to find the information you need quickly, whether you want to look up information on a neural dysfunction of a friend or relative who has Alzheimer's or Parkinson's diseases or you want to find out what the brain's thalamus actually does.

Besides being a resource for any non-scientist inquisitive about the brain and nervous system, this book may be a useful accompanying text for students in undergraduate neurobiology courses because it's both modular and functional. For example, many books talk about brain anatomy using massively long lists of obscurely named brain nuclei and tracts, but they don't try to help you understand all these components as a functional system. Perception and behavioral neuroscience courses often neglect important aspects of cognitive processing, while cognitive science texts often give you little information about how neural activity actually supports cognition. This book is different. This book uses plain language and some very simple diagrams to show how important parts of the brain and nervous system function.

*Sidebar*s (text in gray boxes) and anything marked with a Technical Stuff icon are skippable. Also, within this book, you may notice some web addresses breaking across two lines of text. If you're reading this book in print and you want to visit one of these web pages, simply key in the web address exactly as it's noted in the text, pretending as though the line break doesn't exist. If you're reading this as an e-book, you've got it easy — just click the web address to be taken directly to the web page.

Foolish Assumptions

As I wrote this book, I made some assumptions about you, the reader:

- ✔ You may be looking for information about a neurological disease or dysfunction, possibly affecting someone you know. You want access this information quickly in easy-to-understand chunks.
- ✔ You may be taking a college or professional course that covers some aspect of brain function, but the course or the text for the course doesn't provide enough background information.

- ✓ You may be a beginning student in neuroscience, neurology, or neurosurgery who has already learned what's in this book but you need to look up the basics quickly, maybe to explain it to a layperson. (**Warning:** If your patients notice you rifling through a copy of this book before recommending treatment options, they might request a second opinion.)

Icons Used in This Book

I use icons in this book to help you find specific kinds of information. They include the following:



Anything marked with a Tip icon is a piece of information about an area of neurobiology that's often misunderstood or easily confused.



The Remember icon highlights key concepts and principles that you need to remember to understand other areas of neurobiology.



The Research icon is about key studies that led to our current understanding of neurobiology. Sometimes pieces of research are just beautiful in their own right for their elegance and simplicity. Research info bits are nice to drop in conversations at cocktail parties — if you party with people nerdy enough to know a fair amount of neurobiology, at least.



The Technical Stuff icon is about a recent or surprising finding that is not necessarily crucial to understand the chapter but is interesting or counterintuitive in its own right. You can skip these paragraphs and get by just fine, but you may miss some of the more interesting products of research.

Beyond the Book

In addition to the material in the print or e-book you're reading right now, this product also comes with some access-anywhere goodies on the web. Check out the free Cheat Sheet at www.dummies.com/cheatsheet/neurobiology for interesting information on whether paralysis can be cured, whether the mind can be downloaded, whether cyborgs are possible, and more.

Also, check out www.dummies.com/extras/neurobiology for articles on everything from where consciousness exists in the brain to how vision can be restored to the blind.

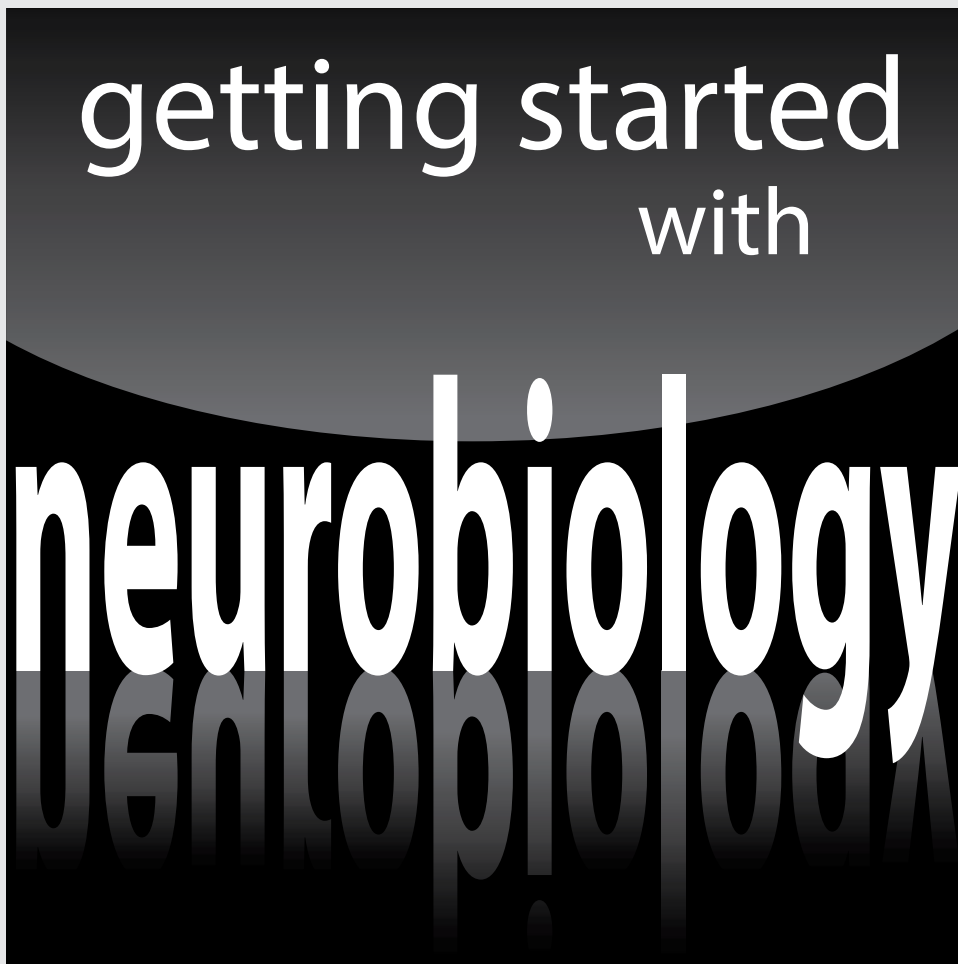
Where to Go from Here

You can start reading this book anywhere — you don't have to read it in order from beginning to end. Still, Chapter 1 is a great place to start if you're looking for an introduction to neurobiology. For more on common diseases and disorders, turn to Part IV. And if you're short on time, Chapters 19 and 20 pack a powerful punch in not many pages.

I'm always interested in hearing from readers, so whether you find an error or you'd like to make any other comments about this book, feel free to contact me at amthorfr@gmail.com.

Part I

Getting Started with Neurobiology



For Dummies can help you get started with lots of subjects. Visit www.dummies.com to learn more and do more with *For Dummies*.

In this part . . .

- ✓ Find out what makes neurons different from other cells in the body.
- ✓ Discover the genetics common to all cells and what happens when neurons have genetic mutations.
- ✓ See what neurons need in order to be able to detect and respond to other neurons, substances in the environment, and energy.
- ✓ Look at how neurons communicate with each other using electrical current flowing through ion channels.

Chapter 1

Welcome to the World of Neurobiology

In This Chapter

- ▶ Getting to know the neuron
 - ▶ Finding out how the nervous system is organized
 - ▶ Feeling cerebral with thoughts, learning, and memory
 - ▶ Seeing the effects of mental illness and developmental problems
-

What makes you *you*? Your brain, most people would answer. Then what is it about your brain that makes you *you*? The brain is made of neurons. Worms have brains with neurons. So do dogs and monkeys. What about the brain distinguishes these animals from each other, and for that matter, one human from another? Is it more neurons, different neurons, special neural circuits?

Neurobiologists would like to answer all these questions, but they can't yet. Thousands of them at universities all over the world are working on these problems. They have many hypotheses and data sets. This book, in a way, is a progress report on their efforts.

Virtually all neurobiologists believe that intelligence comes from nervous systems that are broadly programmed by genes and fine-tuned by experience. Generally, the human genetic program creates a brain with more neurons than any other animal, allowing for richer experience to produce a unique kind of intelligence.

This chapter gives an overview of the brain, its functions, and its parts. It also looks at why humans are like many other animals, such as primates, because of similarities in our brains, and what differences in the human brain may distinguish us from other species, and from each other.

Introducing Neurons

Neurobiology is the study of neurons and nervous systems, such as brains. *Neurons* are cells. Like other cells, neurons interact with the external world and other cells through specialized receptors in their membranes and through biochemical processes inside their cytoplasm and nucleus.

Neural capabilities evolved from those of single-celled organisms, like bacteria and paramecia, which use membrane sensors to detect food and toxins, and cilia to move toward food and away from toxins. Single-cell organisms may also change their internal metabolism upon ingesting particular substances from the environment.



Multicellular organisms consist of different types of cells that are specialized to do things like secrete hormones or digestive enzymes. They depend on other cells for nutrients, waste removal, and the maintenance of a supportive environment. Neurons are specialized cells in multicellular organisms that, among other things, enable rapid communication across the large distances from one end of an animal to another. This allows the animals to perform coordinated movements and to act upon sensing the surrounding environment.

Evolving cells on early earth

According to astronomers and astrophysicists, the universe as we know it came into existence about 14 billion years ago. After several cycles of star formation, our solar system, including the earth, formed about 4.5 billion years ago. The earth was too hot for life for about a billion years, as it continued to be bombarded by the solar system debris from which it was formed.

Eventually most of the solar system debris stuck to one or another planet, or stabilized in relevantly permanent orbits such as the asteroid belt between Mars and Jupiter. Earth cooled for about 1 billion years, and life arose. No one knows how. Some scientists are suspicious that life arose almost as soon as the earth was cool enough, suggesting either that it must occur almost automatically given the right conditions, or it came from elsewhere and established a foothold as soon as it was possible.

Looking at the origin of single cells

The living things that arose at the 1-billion-year mark were single-celled *prokaryote* cells that lack a nucleus, such as bacteria we have today. Life stayed unicellular for a long time after that. This doesn't mean that no progress was made, though. Undoubtedly the single cells that existed at the time of evolution to multicellularity were more sophisticated and diverse than those that could be found when life originated.

Catalyzing reactions in the primordial soup

All life forms carry out metabolism, using energy to build proteins and other cell constituents. The proteins in all cells are coded for by the same DNA coding scheme (see Chapter 2), one piece of evidence that argues for a common origin of all life. A particularly important type of protein that all cells make is an enzyme. Enzymes cause specific reactions such as cleaving proteins at a particular place or joining proteins to other molecules.



Many of the DNA sequences, proteins, and reactions that exist in multicellular organisms are similar to those in single-celled organisms. This apparent conservation of biochemistry is an important argument for life having a common origin.

Separating inside from out: Membranes

A fundamental property of cells is that they have membranes that separate their insides from the external environment. What makes a cell what it is and does relies significantly on the receptors it has in its membrane and how they respond to external substances and energy inputs.

Cellular responses to substances that bind membrane receptors include biochemical cascades inside the cell, and, in neurons particularly, electrical activity. A significant percentage of all animal genes code for proteins that compose hundreds of different types of membrane receptors.

Comparing eukaryotes to prokaryotes

About 1 to 2 billion years after single-cell life arose, some single-cell life forms developed nuclei and became what are called *eukaryotes* (cells that have a nucleus). Soon after eukaryotes appeared, multicellular organisms came on the scene.

Plant-like multicellular organisms probably arose from aggregations of single cells in shallow ocean areas. These multicellular organisms diversified over more than a billion years. About half a billion years ago, 4 billion years after the earth formed, land plants and animals that we would recognize as such appeared from these multicellular ancestors.

Multicellularity: Sensing and moving

Multicellularity has advantages and disadvantages. Multicellular organisms can be big, have specialized sensors, and move around and ingest single-celled organisms. But movement requires coordination, and the environment of the cells at the periphery of the organisms is quite different from that of those in the middle.



Multicellularity allowed organisms to have cells specialized not only for niches in the external environment, but also for the internal environment created by the structure of the organism itself. Neural cells evolved as sensors, movers (muscles), and communicators.

Detecting food, waste, and toxins

Neurons have some functions that are like all other cells, including those of many single-celled organisms. These include taking in energy through glucose, and oxygen to fuel metabolism. Neurons also excrete metabolic waste products and carbon dioxide. Many of these functions are carried out by membrane receptors and transporters, some of which are highly conserved across the evolution of life on earth. But neurons adapted many functions that single cells use to interact with the environment in order to interact with each other.

Detecting other cells: Hormones and neurotransmitters

Even primitive single-celled and small multicellular organisms respond to the effects of other organisms around them. This happens via their metabolic waste products that signal overcrowding or the depletion of food resources. Neurons evolved the ability to include some specific substances in their waste excretions to signal to other neurons about the state of some part of the organism.



These signaling substances evolved to be secreted specifically into the extracellular space around cells in multicellular organisms as hormones. The next step was the extension of a cellular process, such as an axon, from one cell to the vicinity of several distant specific cells where a specific signaling substance, called a *neurotransmitter*, was released. Now, instead of a multicellular signaling soup, there are circuits.

Detecting energy

Although single-celled organisms have membrane receptors that can detect light, heat, and pressure, multicellular organisms devote large, complex cell systems for detecting these and other forms of environmental energy. Cellular systems allow the production of lenses in the visual system for seeing and mechanical amplification in the auditory system for hearing, to name but two examples. Cellular systems in multicellular organisms allow energy detection to be amplified and differentiated, which supports nuanced, complex behavioral outcomes based on the detection.

Cellular motors

Single cells move via cilia, flagella, and other mechanisms such as amoeboid movement. Multicellular organisms use cilia to move substances within the body, but moving the entire body requires other mechanisms.

Cilia and flagella

Cilia are common in multicellular organisms. Motile cilia on cells in the lungs remove debris by carrying it up the windpipe. Immotile or primary cilia have evolved in many multicellular animals into sensory receptors, such as photoreceptor outer segments where the light-absorbing photopigment molecules are located. Auditory hair cells and some olfactory receptors may also be derived from cilia. Flagella are used by sperm cells to propel themselves. However, moving an entire large body via cilia or flagella is not very effective, particularly on land.

Contraction

Animals evolved specialized cells called muscle cells, for movement. Muscle cells work by contracting. In voluntary skeletal muscle, muscle cells contract by being driven by motor neurons. A large group of contracting muscle cells pulls on a tendon that is attached to a bone, moving the joint.



Neurons are necessary for coordinated movement in multicellular animals. Different muscles must be contracted in an organized manner, and information from the senses must be sent to remote parts of the body neurons to coordinate movement.

Neurons accomplish their role of coordinating and communicating activity across the body through chemical communication and electricity. The electrical properties of neurons allow them to communicate information precisely across long distances to specific target cells. In the case of connections to muscles, motor neurons produce movement by inducing their target muscle cells to contract.

Coordinating responses in simple circuits

Nervous systems are complex and hard to study. The human brain has been estimated to contain about 100 billion cells (a recent estimate that used a novel method of counting neural nuclei in emulsified brains produced a figure of 86 billion). All these neurons likely have from 100 trillion to a quadrillion synapses between them. This presents the challenges that we don't know how single cells work, really, and we don't know or cannot even count all the connections between them. So, where do we start?

People often wonder why scientists study the nervous systems of flies, worms, and squids. The reason is that these systems often have advantages in that the cells are fewer, bigger, or more amenable to genetic manipulation. Hodgkin and Huxley won the Nobel Prize for deducing the ionic basis of the action potential in the squid giant axon, which is almost a millimeter in diameter and can be handled and impaled with microelectrodes. It is also possible to squeeze out its internal contents and replace them with a specified salt solution by which it could be determined which ions flow which way through the membrane during electrical activity.

Many invertebrates such as worms and insects have less than a few thousand neurons that are more or less the same from animal to animal. Individual neurons in specific places are even numbered and named in some species. This vastly simplifies the problem of working out a complete neural circuit, including which neurotransmitters are used by which neurons to activate other neurons, and how all the electrical activity is integrated.



Recent progress has been made in making model systems from mammals, using either brain slices or neural tissue cultures that can be mounted on a microscope and recorded and stimulated under well-controlled conditions.

Robotics and bionics

Many scientists feel that we only understand a system when we can simulate it. This involves creating an artificial nervous system that simulates some properties of real ones. In robotics, behavior is simulated. A robot may perform some task, like welding in a car factory, that is otherwise done by intelligent humans. The electronic controllers of such robots can involve the use of neuron-like elements called artificial neural nets (ANNs) that emulate biological control systems. However, most controllers are written in standard computer languages using mathematical algorithms that may function quite differently from biological organizations.

Bionics is the field of applying biological principles of operation to man-made devices. An airplane is a bionic derivative of bird flight, which, however, differs in using engines for thrust rather than flapping wings. A recent use of bionics in computation involves devices called *memristors* that are integrated circuit devices that act like modifiable synapses between neurons. At this point, it's unclear whether memristors devices will have advantages for computing compared to traditional electronic computation done with transistors. They may, however, become a useful tool for simulating complex nervous systems to understand them.

Organizing the Nervous System

The study of the nervous system intrinsically involves many fields. Neurobiology, our focus here, depends on physiology, anatomy, biochemistry, molecular biology, cognitive and behavioral psychology, and artificial intelligence. The basic goals of neurobiology are to describe how the nervous system operates in terms of what the system does, how it's built, and how it works. We try to do these things by considering first various subsystems of the brain and nervous system, and then looking carefully at function in the neural circuitry within those subsystems.