LEARNING MADE EASY

2nd Edition

Neurobiology

for dummies®

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Understand neurological disease treatments

Explore the brain and body's interconnectivity

Ace your neurobiology class

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Professor Emeritus of Psychology

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Professor of Neurobiology

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Contents at a Glance

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Introduction

This book is about the molecules and neural cells, the neurons and glia, that make up the nervous system. And it's about how neural cells communicate to produce all the functions that keep us alive and make us human. Neurobiologists can and do ask many questions about the nervous system, but here are five of the big ones:

- How are neurons and glial cells formed during development and what are their specialized functions?
- What does the human nervous system have in common with that of other animals and how does it differ?
- How do neurons combine electrical and chemical signaling to communicate with their targets?
- Which neurons, circuits, and mechanisms are involved in the functions of the nervous system, including movement, perception, survival, emotion, and cognition?
- What happens when things don't go as planned or if there is injury, trauma, or dysfunction? How can disorders of the nervous system be treated?

Neurobiologists have some answers to all these questions. We know that neurons and glia are specialized cells with some functions specific to them and others similar to many cells on earth. We 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 cold-blooded vertebrates. We know that small genetic differences and life experiences can produce significant changes in development and behavior. Finally, we know that brains aren't fixed but can undergo neuroplasticity — the basis of memory and recovery after injury.

This book attempts to explain in plain English how neurons and glial cells work, how they develop and comprise the nervous system, how neurons communicate with their targets, and how neural systems can produce complex movements and behavior, language, memory, thinking, and intelligence.

About This Book

This new edition of *Neurobiology For Dummies* starts with basic concepts and builds on them. It first discusses neurons and glial cells and their origin and functions, then deals with basic brain anatomy arising from those neural cells. It introduces the mechanisms of communication involving electrical and chemical signaling. And it 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 disease, you want to find out what the brain's thalamus actually does, or you want to know about mechanisms involved in neuroplasticity.

Besides being a resource for any nonscientist inquisitive about the brain and nervous system, this book may be a useful accompanying text for students in undergraduate and graduate 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 simple diagrams to show how neurons, glial cells, and important parts of the brain and nervous system function.

Foolish Assumptions

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

- You may be looking for information about a neurological disease or disorder, possibly affecting someone you know. You want access to 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 or specific 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

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

TIP

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

REMEMBER

The Remember icon highlights key concepts and principles that you need to remember to understand other areas of neurobiology. It also points out key studies that led to today's 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 parties — if you party with people nerdy enough to know a fair amount of neurobiology, at least.

TECHNICAL STUFF

The Technical Stuff icon is about a recent or surprising finding that isn't necessarily crucial to understand the concept 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.

We're 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 us at `amthorfr@gmail.com` and `annetheibert@gmail.com`.

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, the chapters in Part 1 are a great place to start if you're looking for an introduction to neurons, glial cells, development, and the basis of electrical and chemical signaling.

For more on cognition, common diseases, and disorders, turn to Part 3. And if you're short on time, Chapters 19 and 20 pack a powerful punch in a few pages. If you're not sure where to start, flip through the Table of Contents or index to find a topic that piques your interest and start there.

1

Getting Started with Neurobiology

IN THIS PART . . .

Find out how the nervous system is organized and what its functions are.

Look at the important molecules in neurons and glia and how genes are regulated.

Recognize how neurons and glial cells are formed and organized during development.

Appreciate the mechanisms that neurons use in electrical signaling.

See how neurons use chemical signaling to communicate.

Discover how different types of neurons and responses comprise the nervous system.

IN THIS CHAPTER

- » **Getting to know how neurons evolved**
- » **Seeing how the nervous system is organized**
- » **Meeting neurons and glial cells**
- » **Taking a tour around the brain**

Chapter 1

Welcome to the World of Neurobiology

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 and glial cells. Worms and bees have brains with neurons and glia. So do dogs and chimpanzees. 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? And what happens when these neurons, glia, and circuits are disrupted or dysfunctional?

Neurobiologists like the two of us want to answer these questions. Thousands of us at universities, research institutes, and pharmaceutical companies all over the world are working on these questions. We have many hypotheses and data sets. This book, in a way, is a progress report on the 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 cortical neurons than other animals have, allowing for richer experience to produce a unique kind of cognition and intelligence.

Here we introduce you to the basics of neurobiology and give you a jumping-off point to use this book in understanding the human nervous system.

Starting with Neurobiology — Just the Basics

Neurobiology is the study of neurons, glia, and the nervous system. It involves many fields of study including 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 neurons and glial cells do, how they're built, how they work, and what happens when their functions are disrupted.

Neurons are the detecting and signaling cells of the nervous system that use electrical and chemical signaling to communicate. *Glial* cells are the supporting cells that provide metabolic, structural, and functional support.

EVOLVING THE NERVOUS SYSTEM

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

Cells have membranes that separate their insides from the external environment. Receptors embedded in the membrane enable cells to respond to external signals. Receptor responses include biochemical cascades inside the cell, and, in neurons particularly, electrical activity.

Animals are multicellular eukaryotic organisms that evolved around 600 million years ago. Early animals evolved different types of cells that are specialized to do things like secrete hormones or digestive enzymes and undergo contraction. As animals increased cells and got bigger, their sensor cells became separated from other cells and movement required coordination.

Neurons evolved between about 600 to 550 million years ago, most likely from epithelial cells. This probably occurred when animals needed to send sensory information over longer distances and control contraction of muscles for movement. Neurons developed as electrical signaling cells that formed nerve nets in cnidarian and/or ctenophore evolution.

Later, the evolution of special sense organs and nerve ganglia occurred several times in *bilaterans* (the clade that gave rise to crustaceans, insects, and vertebrates). There's still much debate over the origin of neurons and nervous systems in the tree of life.

Neurons evolved extensions called *axons* and *dendrites* that allow them to communicate rapidly, specifically, and over long distances. Action potentials are electrical signals transmitted along the axon. The axon forms connections called synapses with its targets (the majority on dendrites) where chemical communication occurs and typically produces electrical responses. The following sections discuss when and how neurons most likely evolved during animal evolution.

Arriving at a nervous system

Electrical signaling in the form of action potentials and cell-to-cell communication evolved in single-celled organisms before multicellularity evolved. Some nonmetazoan single-celled organisms express genes for secreted molecules and synaptic-related proteins. Evolving neurons adapted functions that single cells use to interact with the environment and other cells.

The next step was the extension of an axon, from one cell to distant cells where a specific signaling substance, called a *neurotransmitter,* is released. Now, instead of a multicellular signaling soup, there are circuits. Electrical and chemical signaling allowed for rapid communication across the distances from one end of an animal to another for sensing the surrounding environment and performing coordinated movements.

Coordinating responses in simple circuits

Nervous systems are complex and hard to study. The human brain is estimated to contain about 86 billion neurons and about the same number of glial cells. An average neuron receives a thousand or more synapses, meaning there are more than a hundred trillion synapses in the human brain. Neurobiologists don’t really know yet how single neurons work and don’t know, and can’t count, all of the connections between neurons.

Studying invertebrates

People often wonder why scientists study the nervous systems of flies, worms, squids, and slugs. The reason is they have advantages in that the cells are fewer, bigger, and/or more amenable to genetic manipulation. Alan Hodgkin and Andrew Huxley won the Nobel Prize for deducing the ionic basis of the action potential in the squid giant axon. Eric Kandel won the Nobel Prize for identifying memory mechanisms in the sea slug Aplysia.

Many invertebrates such as worms and insects have several hundred to a few thousand neurons. This vastly simplifies the problem of working out a complete neural circuit, including which neurotransmitters are used by which neurons, what responses are produced and how activity is integrated.

TIP

Recent progress has been made in making model systems from mammals, studying intact brains and behavior, and using brain slices, neural tissue cultures, and brain organoids and that can be investigated using molecular biology, microscopy, and electrical techniques.

Introducing Neurons and Glia

When neurobiologists talk about the nervous system, we often use the term neural. *Neural* refers to any part of the nervous system that involves neurons or glia. Part 1 of this book gives you more detailed information about neurons and glia. Here we describe how neurons and glia are functionally organized in the nervous system.

Beginning with functional anatomy

The nervous system has two main components that are connected and communicate with each other:

- **Central nervous system (CNS):** The CNS is composed of the brain and spinal cord.
- **Peripheral nervous system (PNS):** The PNS includes the spinal nerves, cranial nerves, ganglia, and the enteric nervous system.

Neurons in the PNS are responsible for detecting and relaying sensory signals in the external world (somatic sensory system) and in the internal body (visceral sensory system). The PNS then relays that information to the CNS.

The CNS receives sensory information and uses it for perception and homeostasis. These are crucial for the other main functions of the CNS: to control the body's movements and produce survival responses and behaviors. To help control and regulate this output, the mammalian CNS also provides emotion and cognitive functions.

The CNS sends output signals from motor neurons that extend axons in the nerves (the PNS) to your muscles, organs, and glands that control their contraction, relaxation, or secretion. The output in the PNS has two main divisions: