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# Neurobiology For Dummies®

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## Learn to:

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- Navigate neurological disorders and treatments
- Score high in your neurobiology class
- Understand neurological diseases

**Frank Amthor, PhD**

*Author of* Neuroscience For Dummies®

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by Frank Amthor, PhD

For Dummies
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**Neurobiology For Dummies®**

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



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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

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# 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.

*Sidebars* (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

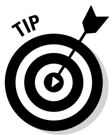
As I wrote this book, I made some assumptions about you, the reader:

- 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

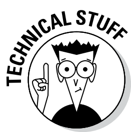
I use icons in this book to help you find specific kinds of information. They include the following:




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


web extras

*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.

REMEMBER

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 though 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.