NINTH EDITION

# SENSATION and PERCEPTION

E. Bruce Goldstein




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E. Bruce Goldstein

*University of Pittsburgh*
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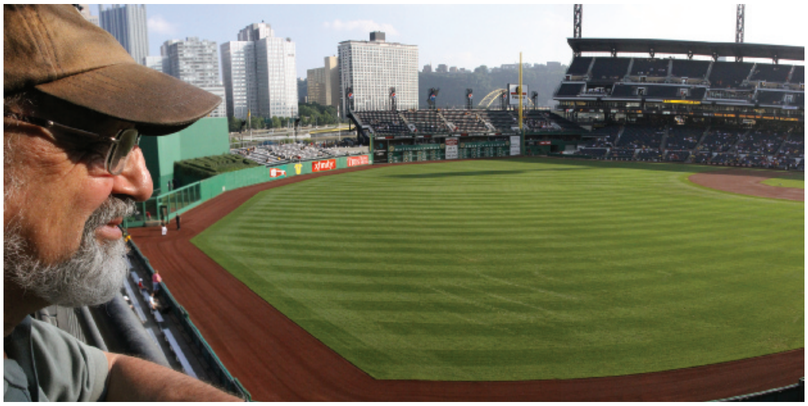
To my wife, Barbara, more than ever

and

To all of the students and teachers whose suggestions helped shape this edition

# About the Author



Christopher Baker

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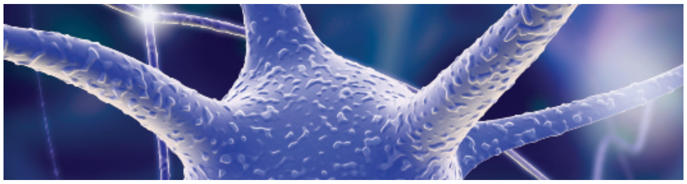

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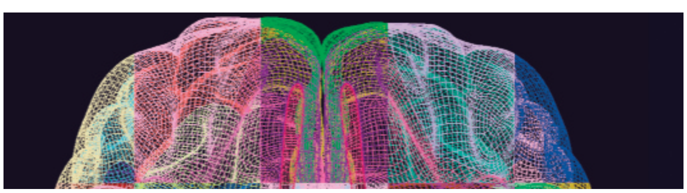

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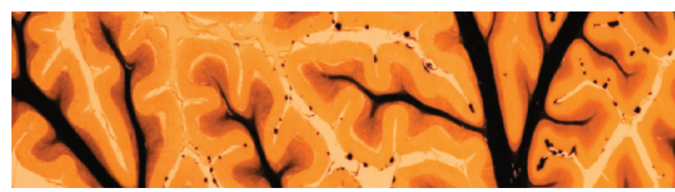

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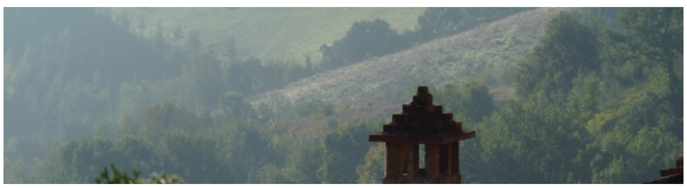

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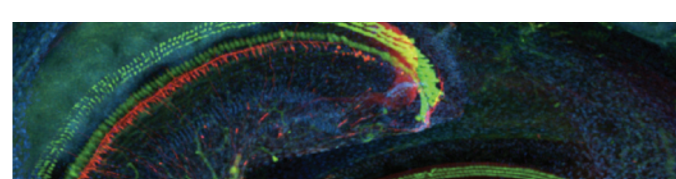


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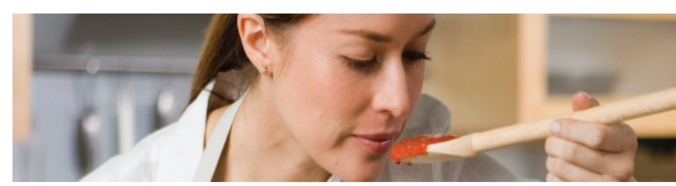

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# Preface

When I first began working on this book, Hubel and Wiesel were mapping orientation columns in the striate cortex and were five years away from receiving their Nobel Prize; Amoore's stereochemical theory, based largely on psychophysical evidence, was a prominent explanation for odor recognition; and one of the hottest new discoveries in perception was that the response properties of neurons could be influenced by experience. Today, specialized areas in the human brain have been mapped using brain imaging, olfactory receptors have been revealed using genetic methods, and the idea that the perceptual system is tuned to regularities in the environment is now supported by a wealth of both behavioral and physiological research.

But some things haven't changed. Teachers still stand in front of classrooms to teach students about perception, and students still read textbooks that reinforce what they are learning in the classroom. Another thing that hasn't changed is that teachers prefer texts that are easy for students to read, that present both classic studies and up-to-date research, and that present both the facts of perception and overarching themes and principles.

When I began teaching perception, I looked at the textbooks that were available and was disappointed, because none of them seemed to be written for students. They presented "the facts," but not in a way that seemed very interesting or inviting. I therefore wrote the first edition of *Sensation and Perception* with the idea of involving students in their study of perception by presenting the material as a story. The story is a fascinating one, because it is a narrative of one discovery following from another, a scientific "whodunit" in which the goal is to uncover the hidden mechanisms responsible for our ability to perceive.

Though my goal in writing this book has been to tell a story, this is, after all, a textbook designed for teaching. So in addition to presenting the story of perceptual research, this book also contains a number of features, all of which appeared in the eighth edition, that are designed to highlight specific material and to help students learn.

## Features

- **Demonstrations.** *Demonstrations* have been a popular feature of this book for many editions. They are integrated into the flow of the text and are easy enough to be carried out with little trouble, thereby maximizing the probability that students will do them. Some examples: Becoming Aware of the Blind Spot (Chapter 2); Shape From Shading (Chapter 5); Perceiving Degraded Sentences (Chapter 13); "Tasting" With and Without the Nose (Chapter 15).
- **Methods.** It is important not only to present the facts of perception, but also to make students aware of how these facts were obtained. Highlighted *Methods* sections, which are integrated into the ongoing discussion, emphasize the importance of methods, and the highlighting makes it easier to refer back to them when referenced later in the book. Examples: Measuring Dark Adaptation (Chapter 2); Double Dissociations in Neuropsychology (Chapter 4); Measuring Tactile Acuity (Chapter 14); 2-Deoxyglucose Technique (Chapter 15).
- **Something to Consider.** This end-of-chapter feature offers the opportunity to consider especially interesting phenomena and new findings. Examples: The Mind–Body Problem (Chapter 3); Attention in Autism (Chapter 6); Connections Between Hearing and Vision (Chapter 12); The Proust Effect (Chapter 15).
- **Test Yourself.** *Test Yourself* questions appear in the middle and at the end of each chapter. These questions are broad enough that students have to unpack the questions themselves, thereby making students more active participants in their studying.
- **Think About It.** The *Think About It* section at the end of each chapter poses questions that require students to apply what they have learned and that take them beyond the material in the chapter.
- **Virtual Lab.** The *Virtual Lab* feature of this book enables students to view experimental stimuli, perceptual demonstrations, and short film clips about the research being discussed. The Virtual Lab has been updated in this edition. More than 50 new items have been added to the labs carried over from the eighth edition. Most of these

new items have been generously provided by researchers in vision, hearing, and perceptual development. Each item is indicated in the chapters by this icon: VL. Students can access the Virtual Lab through Psychology CourseMate at www.cengagebrain.com.

- **Full-Color Illustrations.** Perception, of all subjects, should be illustrated in color, so I was especially pleased when the seventh edition became "full-color." What pleases me about the illustrations is not only how beautiful the color looks, but how well it serves pedagogy. There are 560 figures, 160 of them new to this edition.

# Changes in This Edition

Here are some of the changes in this edition, which have been made both to make the book easier to read and to keep current with the latest research.

## Taking Student Feedback Into Account

In past revisions, I have made changes based on feedback that professors have provided based on their knowledge of the field and their experience in teaching from the book. Beginning with the seventh edition, I began making use of feedback provided by students based on their experience in using the book. I continued this practice for the eighth edition and now this one, by asking each of the 150 students in my class to write a paragraph for each chapter in the eighth edition in which they described one thing they felt could be made clearer. My students identified where and why they were having problems, and often suggested changes in wording or organization. When just one or two students commented on a particular section, I often used their comments to make improvements, but I paid the most attention when many students commented on the same material. I could write a "Top Ten" list of sections students thought should be revised, but instead I'll just say that student feedback resulted in numerous changes to every chapter in the book. Because of these changes, this is the most "student friendly" edition yet.

## Improving Organization

The organization of every chapter was evaluated to achieve a clearer and more logical flow from one topic to the next. Here are a few of the more extensive organizational changes:

### Chapters 2–3 (The Beginnings of Perception; Neural Processing and Perception)

These chapters introduce students to a way of thinking about studying perception that sees perceptual experience as central, while also looking for underlying physiological mechanisms. In the eighth edition, many of the physiological principles, including neural processing, receptive fields, coding, and the mind–body problem, were introduced in Chapter 2 (The Physiological Basis of Perception). Many students and reviewers felt this was "too much too soon," without proper concern for the connections to perception.

In this edition, the physiological material is introduced more gradually and within the context of the overall perceptual process. Chapter 2 opens by describing light, focusing, and how receptors affect perception. Electrical signals in neurons are then introduced, emphasizing the basic properties of action potentials. Chapter 3 then introduces neural processing, receptive fields, and the sensory code, while continually referring back to perception. This treatment reflects the general philosophy of the book, which is that neural processes are important, but only to the degree that they illuminate our understanding of perception.

### Chapter 6 (Visual Attention)

This chapter has been completely reorganized. It opens with a discussion of what directs our attention and what happens when we attend; what happens when we don't attend (i.e., inattentional blindness) is now discussed later in the chapter. Also, physiological material has been integrated into the chapter rather than being placed in a separate section.

### Chapter 8 (Perceiving Motion)

The corollary discharge/coincidence detector approach has been moved nearer to the beginning of the chapter, followed by a discussion of the aperture problem and higher-order motion perception.

### Chapter 15 (The Chemical Senses)

The position of olfaction and taste have been reversed, with taste now opening the chapter and olfaction at the end. This results in a smoother transition to flavor perception, which is closely related to olfaction.

### Developmental Dimensions

A new feature, *Developmental Dimension*, appears at the end of ten of the chapters. This feature includes material that appeared in Chapter 16, "Perceptual Development," in the eighth edition, plus new material. Some examples:

- Chapter 2 (The Beginnings of Perception): Infant visual acuity
- Chapter 5 (Perceiving Objects and Scenes): Infant face perception
- Chapter 6 (Visual Attention): Attention and perceptual completion
- Chapter 9 (Perceiving Color): Infant color vision
- Chapter 11 (Hearing): Infant hearing: audibility curve and voice recognition
- Chapter 13 (Speech Perception): Infant speech perception
- Chapter 15 (The Chemical Senses): Infant chemical sensitivity

## Adding New Content

Every chapter has been updated. This updating is reflected in the inclusion of more than 100 new references, most of them to recent research. In addition, some earlier research has been added and some descriptions from the eighth edition have been updated. Here is a partial list of new "cutting-edge" research that has been added:

#### Chapter 4 (Cortical Organization)

- Response of human hippocampus neurons to remembering previously seen film clips (Gelbard-Sagiv et al., 2008)

#### Chapter 5 (Perceiving Objects and Scenes)

- "Brain reading" using fMRI voxel activation pattern to predict what a person is looking at (Naselaris et al., 2009)

#### Chapter 6 (Visual Attention)

- Attention in a dynamic environment (Jovancevic-Misic & Hayhoe, 2009)
- Attention maps in the brain (Datta & DeYoe, 2009)
- Load theory and inattentional blindness (Lavie, 2010)

#### Chapter 7 (Taking Action)

- Brain damage and wayfinding (Maguire et al., 2006; Schinazi & Epstein, 2010)
- Landmarks and wayfinding (Hamid et al., 2010)
- Parietal lobe neurons in monkey that respond to type of grip (Fattori et al., 2010)

#### Chapter 8 (Perceiving Motion)

- Event boundaries (Zacks et al., 2009)

#### Chapter 9 (Perceiving Color)

- Effect of seasonal wavelength distributions on color perception of scenes (Webster, 2011)
- Types of opponent neurons in the cortex (Johnson, Hawken, & Shapley, 2008; Tanigawa et al., 2010)

#### Chapter 10 (Perceiving Depth and Size)

- Creating depth perception in 3-D movies and TV
- Gaining stereovision as an adult: the case of "Stereo Sue" (Barry, 2011; Sacks, 2010)
- Infant perception of depth from cast shadows (Yonas & Granrud, 2006).

#### Chapter 11 (Hearing)

- Revised in collaboration with Christopher Plack, University of Manchester, author of *The Sense of Hearing* (Psychology Press, 2005). The revised chapter reflects current auditory research that emphasizes the temporal coding of pitch.

#### Chapter 12 (Auditory Localization and Organization)

- Broad interaural time difference tuning curves in mammals (Pecka et al., 2008; Recanzone et al., 2011)
- How lesioning or cooling the auditory cortex affects localization (Malhotra et al., 2008; Nodal et al., 2010)
- Rhythmic grouping and movement (Nozaradan et al., 2011; Trainor et al., 2009); grouping and language (Iversen & Patel, 2008)
- Brain activity in blind people during echolocation (Thaler et al., 2011)

#### Chapter 13 (Speech Perception)

- Effect of transcranial magnetic stimulation (TMS) of motor areas of the cortex on perceiving specific phonemes (D'Ausilio et al., 2009)
- "Brain reading" using the response of human temporal lobe neurons to predict the speech stimulus a person is hearing (Pasley et al., 2012)

#### Chapter 14 (The Cutaneous Senses)

- Updated treatment of somatosensory "mirror" phenomena (Keysers et al., 2010; Meyer et al., 2011; Osborn & Derbyshire, 2010)

#### Chapter 15 (The Chemical Senses)

- Chemotopic coding in the olfactory bulb (Johnson et al., 2010; Murthy, 2011)
- "Random" nature of odorant activation in the piriform cortex and the role of learning in the recognition of odor objects (Shepard, 2012; Wilson & Sullivan, 2011)
- Central neural interactions of taste and olfaction in determining flavor perception (Rolls et al., 2010; Small, 2012)
- Effect of pre- and postnatal learning on infant flavor preferences (Beauchamp & Mennella, 2009)

#### Epilogue

The Epilogue, at the end of the book, is new to this edition. It reinforces key concepts discussed in the book by highlighting a number of principles of perception that hold across senses.

# Supplement Package

## Instructor's Manual With Test Bank

For each chapter, this manual contains a detailed chapter outline, learning objectives, a chapter summary, key terms with page references, summary of virtual labs, and suggested websites, videos, demonstrations, activities, and lecture topics. The test bank includes 40 multiple-choice questions (with correct answer, page reference, and question type) and 5 to 10 essay questions per chapter.

## Psychology CourseMate

Cengage Learning's Psychology CourseMate brings course concepts to life with interactive learning, study, and exam preparation tools that support the printed textbook. CourseMate includes an integrated ebook, glossaries, flashcards, quizzes, videos, virtual labs, and more—as well as EngagementTracker, a first-of-its-kind tool that monitors student engagement in the course. The accompanying instructor website, available through login.cengage.com, offers access to password-protected resources such as an electronic version of the instructor's manual, test bank files, and PowerPoint® slides. CourseMate can be bundled with the student text. Contact your Cengage sales representative for information on getting access to CourseMate.

## Virtual Lab

The *Virtual Lab* enables students to view experimental stimuli, perceptual demonstrations, and short film clips about the research being discussed. Items are indicated in the chapters by this icon: VL. Students can access the Virtual Lab through Psychology CourseMate at www.cengagebrain.com.

## PowerLecture With ExamView®

This one-stop digital library and presentation tool includes preassembled Microsoft® PowerPoint® lecture slides. In addition to a full Instructor's Manual and Test Bank, PowerLecture also includes ExamView® testing software with all the test items from the printed Test Bank in electronic format, enabling you to create customized tests in print or online, and all of your media resources in one place, including an image library of graphics from the book and videos.

## WebTutor™

Jumpstart your course with customizable, rich, text-specific content within your Course Management System. Whether you want to Web-enable your class or put an entire course online, WebTutor™ delivers. WebTutor™ offers a wide array of resources, including access to the ebook, glossaries, flashcards, quizzes, videos, virtual labs, and more.

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# Sensation and Perception


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# Introduction to Perception

## CHAPTER CONTENTS

**Why Read This Book?**

**The Perceptual Process**
Stimuli (Steps 1 and 2)
Receptor Processes/Transduction (Step 3)
Neural Processing (Step 4)
Behavioral Responses (Steps 5–7)
Knowledge

**How to Approach the Study of Perception**

**Measuring Perception**
Measuring Thresholds
Estimating Magnitude
Beyond Thresholds and Magnitudes

SOMETHING TO CONSIDER: **Threshold Measurements Can Be Influenced by How a Person Chooses to Respond**

**The Road From Here**

**Think About It**

VL The Virtual Lab icons direct you to specific animations and videos designed to help you visualize what you are reading about. Virtual Labs are listed at the end of the chapter, keyed to the page on which they appear, and can be accessed through Psychology CourseMate. Virtual Labs begin in Chapter 2.

◀ The Metropolitan Cathedral of Santiago, Chile, is represented here by its reflection on the glass façade of a modern building. The process of perception involves representations, such as when an object is represented by its image on the retina. Sometimes these representations are fragmented or distorted, as is this representation of the Cathedral, but somehow the perceptual system transforms these representations into the conscious experiences we call perceptions. This chapter begins describing how this process occurs.

## Some Questions We Will Consider:

- Why should you read this book? (p. 4)
- How are your perceptions determined by processes that you are unaware of? (p. 5)
- What is the difference between perceiving something and recognizing it? (p. 8)
- How can we measure perception? (p. 12)

Imagine that you have been given the following hypothetical science project.

***Project:*** Design a device that can *locate*, *describe*, and *identify* all objects in the environment, including their distance from the device and their relationships to each other. In addition, make the device capable of traveling from one point to another, avoiding obstacles along the way.

***Extra credit:*** Make the device capable of having *conscious experience*, such as what people experience when they look out at a scene.

***Warning:*** This project, should you decide to accept it, is extremely difficult. It has not yet been solved by the best computer scientists, even though they have access to the world's most powerful computers.

***Hint:*** Humans and animals have solved these problems in a particularly elegant way. They use (1) two spherical sensors called "eyes," which contain a light-sensitive chemical, to sense light; (2) two detectors on the sides of the head, called "ears," which are fitted with tiny vibrating hairs to sense pressure changes in the air; (3) small pressure detectors of various shapes imbedded under the skin to sense stimuli on the skin; and (4) two types of chemical detectors to detect gases that are inhaled and solids and liquids that are ingested.

***Additional note:*** Designing the detectors is just the first step in designing the system. An information processing system is also needed. In the case of the human, this information processing system is a "computer" called the brain, with 100 billion active units and interconnections so complex that they have still not been completely deciphered. Although the detectors are an important part of the project, the design of the computer is crucial, because the information that is picked up by the detectors needs to be analyzed. Note that the operation of the human system is still not completely understood and that the best scientific minds in the world have made little progress with the extra credit part of the problem. Focus on the main problem first, and leave conscious experience until later.

The "science project" just described is what this book is about. Our goal is to understand the human model, starting with the detectors—the eyes, ears, skin receptors, and receptors in the nose and mouth—and then moving on to the computer—the brain. We want to understand how we sense things in the environment and interact with them. The paradox we face is that although we still don't understand perception, perceiving is something that occurs almost effortlessly. In most situations, we simply open our eyes and see what is around us, listen and hear sounds, eat and taste, without expending any particular effort.

Because of the ease with which we perceive, many people see perception as something that "just happens" and don't see the feats achieved by our senses as complex or amazing. "After all," the skeptic might say, "for vision, a picture of the environment is focused on the back of my eye, and that picture provides all the information my brain needs to duplicate the environment in my consciousness." But the idea that perception is not very complex is exactly what misled computer scientists in the 1950s and 1960s to propose that it would take only about a decade or so to create "perceiving machines" that could negotiate the environment with humanlike ease. That prediction, made half a century ago, has yet to come true, even though a computer defeated the world chess champion in 1997 and defeated two *Jeopardy!* champions in 2010. From a computer's point of view, perceiving a scene is more difficult than playing world championship chess or accessing vast amounts of knowledge to answer quiz questions. In this chapter, we will consider a few practical reasons for studying perception, how perception occurs in a sequence of steps, and how to measure perception.

## Why Read This Book?

The most obvious answer to the question "Why read this book?" is that it is required reading for a course you are taking. Thus, it is probably an important thing to do if you want to get a good grade. But beyond that, there are a number of other reasons for reading this book. For one thing, it will provide you with information that may be helpful in other courses and perhaps even your future career. If you plan to go to graduate school to become a researcher or teacher in perception or a related area, this book will provide you with a solid background to build on. In fact, many of the research studies you will read about were carried out by researchers who read earlier editions of this book when they were undergraduates.

The material in this book is also relevant to future studies in medicine or related fields, because much of our discussion is about how the body operates. Medical applications that depend on an understanding of perception include devices to restore perception to people who have lost vision or hearing and treatments for pain. Other applications include robotic vehicles that can find their way through unfamiliar environments, face recognition systems that can identify people as they pass through airport security, speech recognition systems that can understand what someone is saying, and highway signs that are visible to drivers under a variety of conditions.

But reasons to study perception extend beyond the possibility of useful applications. Studying perception can help you become more aware of the nature of your own perceptual experiences. Many of the everyday experiences that you take for granted—such as tasting food, looking at a painting in a museum, or listening to someone talking—can be appreciated at a deeper level by considering questions such as "Why do I lose my sense of taste when I have a cold?" "How do artists create an impression of depth in a picture?" and "Why does an unfamiliar language sound as if it is one continuous stream of sound, without breaks between words?" This book will not only answer these questions but will answer other questions that you may not have thought of, such as "Why don't I see colors at dusk?" and "How come the scene around me doesn't appear to move as I walk through it?" Thus, even if you aren't planning to become a physician or a robotic vehicle designer, you will come away from reading this book with a heightened appreciation of both the complexity and the beauty of the mechanisms responsible for your perceptual experiences, and perhaps even with an enhanced awareness of the world around you.

Because perception is something you experience constantly, knowing about how it works is interesting in its own right. To appreciate why, consider what you are experiencing right now. If you touch the page of this book, or look out at what's around you, you might get the feeling that you are perceiving exactly what is "out there" in the environment. After all, touching this page puts you in direct contact with it, and it seems likely that what you are seeing is what is actually there. But one of the things you will learn as you study perception is that everything you see, hear, taste, feel, or smell is created by the mechanisms of your senses.

Think about what this means. There are things out there that you want to see, hear, taste, smell, and feel. But the only way to achieve this is for these things to stimulate receptors designed to pick up light, sound energy, taste and smell stimuli, or touch stimuli. When you run your fingers over the pages of this book, you're feeling the page and its texture because the pressure and movement across the skin are activating small receptors just beneath the skin. Thus, whatever you are feeling depends on the activation of these receptors. If the receptors weren't there, you would feel nothing, or if they had different properties, you might feel something different than what you feel now. This idea that *perception depends on the properties of the sensory receptors* is one of the themes of this book.

A few years ago, I received an email from a student (not one of my own, but from another university) who was using an earlier edition of this book. In her email, "Jenny" made a number of comments about the book, but the one that struck me as being particularly relevant to the question "Why read this book?" is the following: "By reading your book, I got to know the fascinating processes that take place every second in my brain, that are doing things I don't even think about." Your reasons for reading this book may turn out to be totally different than Jenny's, but hopefully you will find out some things that will be useful, or fascinating, or both.

# The Perceptual Process

Perception happens at the end of what can be described, with apologies to the Beatles, as a long and winding road (McCartney, 1970). This road begins outside of you, with stimuli in the environment—trees, buildings, birds chirping, smells in the air—and ends with the behavioral responses of perceiving, recognizing, and taking action. We picture this journey from stimuli to responses by the seven steps in **Figure 1.1**, called the **perceptual process**. The process begins with a stimulus

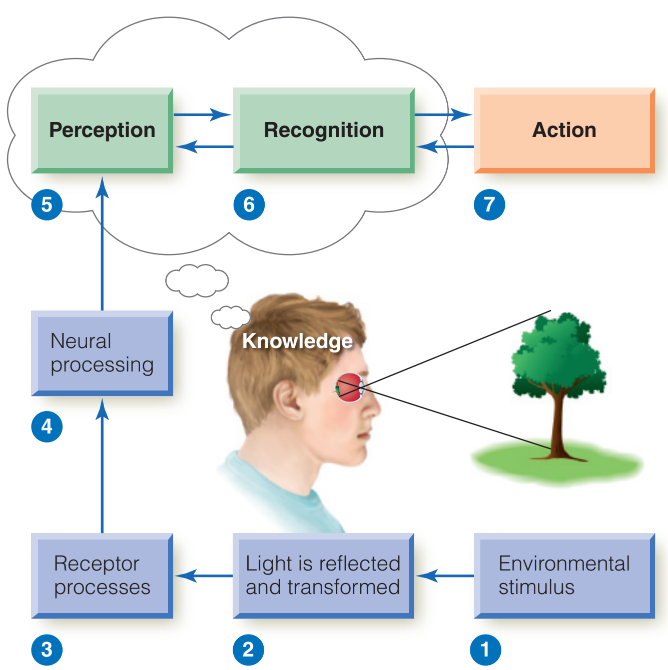



**Figure 1.1** The perceptual process. These seven steps, plus "knowledge" inside the person's head, summarize the major events that occur between the time a person looks at an environmental stimulus (the tree in this example) and perceives the tree, recognizes it, and takes action toward it. Figures 1.2–1.5 describe the steps in the perceptual process in more detail. © Cengage Learning 2014

in the environment (a tree in this example) and ends with the conscious experiences of perceiving the tree, recognizing the tree, and taking action with respect to the tree.

Because we will be referring to this process in this chapter and the ones that follow, it is important to note that it is a simplified version of what happens. First, many things happen within each "box." For example, we could go far beyond "tree" to describe our example of an environmental stimulus. The tree has a particular configuration; its different parts reflect light in different ways (and so appear to have different colors, textures, and shapes); and it can be viewed from different angles. This complexity is even more obvious for boxes further down the line, such as "neural processing," which involves understanding not only how cells called neurons work, but how they interact with each other and how they operate within different areas of the brain.

Another reason we say the series of boxes in Figure 1.1 is simplified is that steps in the perceptual process do not always unfold in a one-follows-the-other order. For example, research has shown that perception ("I see something") and recognition (That's a tree") may not always happen one after another, but could happen at the same time, or even in reverse order (Gibson & Peterson, 1994). And when perception or recognition leads to action ("Let's have a closer look at the tree"), that action could change perception and recognition ("Looking closer shows that what I thought was an oak tree turns out to be a maple tree"). This is why there are reverse arrows between perception, recognition, and action.

Even though the process is simplified, Figure 1.1 provides a good way to think about how perception occurs and introduces some important principles that will guide our discussion of perception throughout this book. In the first part of this chapter, we will briefly describe each stage of the process; in the second part, we will consider ways of measuring the relationship between stimuli and perception. We begin the long and winding road that is the perceptual process by accompanying someone who is observing a tree in a field.

## Stimuli (Steps 1 and 2)

There are stimuli within the body that produce internal pain and enable us to sense the positions of our body and limbs. But for the purposes of this discussion, we will focus on stimuli that exist "out there" in the environment, and we will consider what happens to stimuli in the first two steps of the perceptual process (**Figure 1.2**). We begin with the **environmental stimulus**, the tree that the person is observing (Step 1). The person's perception of the tree is based not on the tree getting into his eye (ouch!), but on light reflected from the tree (Step 2). The reflection of light from the tree introduces one of the central principles of perception, the **principle of transformation**, which states that *stimuli and responses created by stimuli are transformed, or changed, between the environmental stimulus and perception*.

The first transformation occurs when light hits the tree and is then reflected from the tree to the person's eyes. The

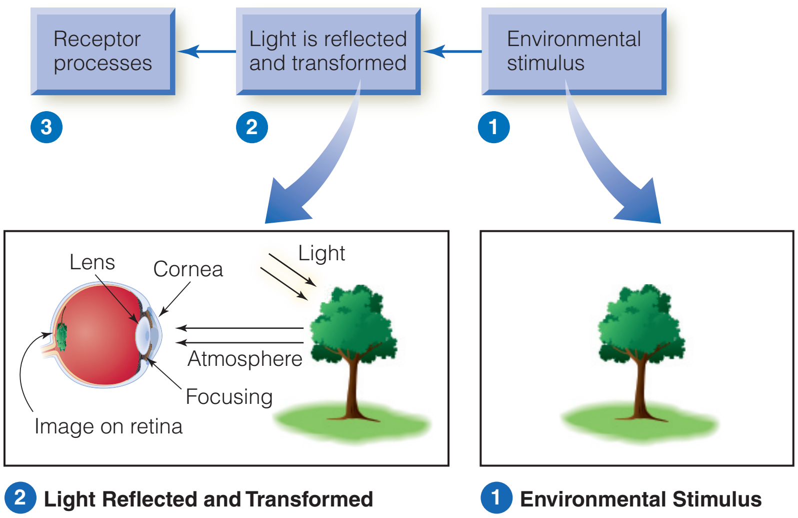



**Figure 1.2** Steps 1 and 2 of the perceptual process. Step 1: *Environmental stimulus*. The tree is the stimulus. Step 2: *Light is reflected and transformed*. Information about the tree (the environmental stimulus) is carried by light, which is transformed when it is reflected from the tree, when it travels through the atmosphere, and when it is focused by the eye's optical system. The result is an image of the tree on the retina, which serves as a representation of the tree.


nature of the reflected light depends on properties of the light energy hitting the tree (is it the midday sun, light on an overcast day, or a spotlight illuminating the tree from below?), properties of the tree (its textures, shape, the fraction of light hitting it that it reflects), and properties of the atmosphere through which the light is transmitted (is the air clear, dusty, or foggy?).

When this reflected light reaches the eye, it is transformed as it is focused by the eye's optical system, which is the *cornea* at the front of the eye and the *lens* directly behind it. If these optics are working properly, they form a sharp image of the tree on the *receptors* of the person's *retina*, a 0.4-mm thick network of nerve cells that covers the back of the eye and that contains the receptors for vision. If the eye's optics are not working properly, the image that reaches the retina may be blurred.

The fact that an image of the tree is focused on the retina introduces another principle of perception, the **principle of representation**, which states that *everything a person perceives is based not on direct contact with stimuli but on representations of stimuli that are formed on the receptors and on activity in the person's nervous system.*

The distinction between the environmental stimulus (Step 1) and the stimulus on the receptors (Step 2) illustrates both transformation and representation. The environmental stimulus (the tree) is *transformed* into the image on the retina, and this image *represents* the tree in the person's eyes. But this transformation from "tree" to "image of the tree on the retina" is just the first in a series of transformations. The next transformation occurs within the receptors at the back of the eye.

## Receptor Processes/Transduction (Step 3)

**Sensory receptors** are cells specialized to respond to environmental energy, with each sensory system's receptors specialized to respond to a specific type of energy. Visual receptors respond to light, auditory receptors to pressure changes in the air, touch receptors to pressure transmitted through the skin, and smell and taste receptors to chemicals entering the nose and mouth. When the visual receptors that line the back of the eye receive the light reflected from the tree, they do two things: (1) They transform environmental energy into electrical energy; and (2) they shape perception by the way they respond to stimuli (**Figure 1.3**).

Visual receptors transform light energy into electrical energy because they contain a light-sensitive chemical called **visual pigment**, which reacts to light. The transformation of one form of energy (light energy in this example) to another form (electrical energy) is called **transduction**. Another example of transduction occurs when you touch the "withdrawal"

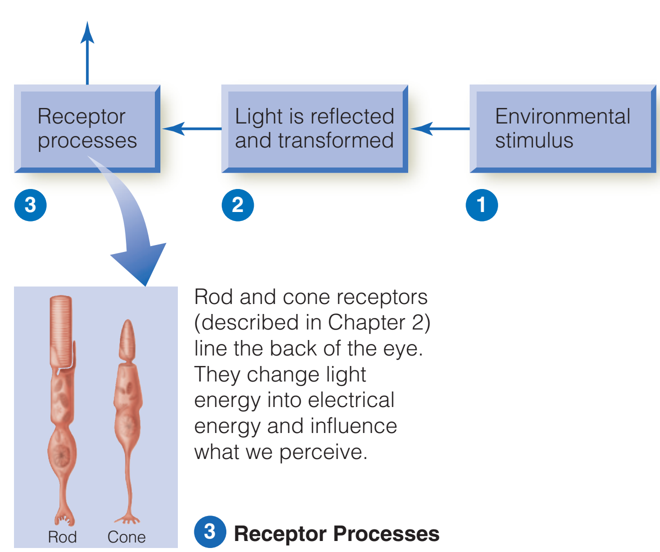



**Figure 1.3** Step 3: *Receptor processes*. These processes include transduction (the transformation of light energy into electrical energy) and the shaping of perception by the properties of visual pigments in the receptor's outer segments. The end result is an electrical representation of the tree. 

button or icon on an ATM. The pressure exerted by your finger is transduced into electrical energy, which causes a device that uses mechanical energy to push your money out of the machine.

Transduction by the visual pigments is crucial for perception, because without it information about the representation of the tree formed on the retina would not reach the brain and perception would not occur. In addition, the visual pigments shape perception, both because the ability to see dim light depends on having a high concentration of pigment in the receptors and because there are different types of pigments. Some pigments respond better to light in the blue-green part of the spectrum; others respond better to the yellow-red part of the spectrum. We will describe both transduction and how the properties of pigments influence perception in Chapter 2.

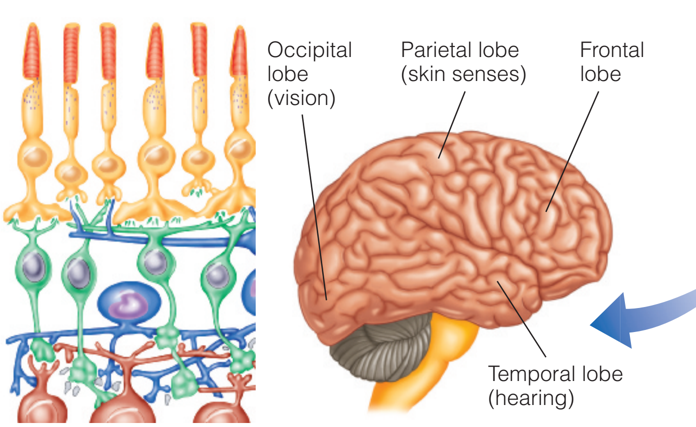
## Neural Processing (Step 4)

Once transduction occurs, the tree is represented by electrical signals in thousands of visual receptors, and these signals enter a vast interconnected network of neurons, first in the retina, then out the back of the eye, and then in the brain. This complex network of neurons (1) *transmits signals* from the receptors, through the retina, to the brain, and then within the brain; and (2) *changes* (or *processes*) these signals as they are transmitted. These changes occur because the pathway from receptors to the brain is typically far from a straight line. Instead, there are multiple routes, with some signals traveling in opposite directions, some signals becoming reduced or prevented from getting through, and others being amplified so they arrive at the brain with added strength.

The changes in these signals that occur as they are transmitted through this maze of neurons is called **neural processing** (**Figure 1.4**). Processing will be described in more detail in Chapters 2 and 3. For now, the main point is that processing continues the process of transformation that began when the tree was transformed into a small image inside the eye, which was then transformed into electrical signals in the visual receptors. A similar process of transduction followed by transmission occurs for other senses as well. For example, sound energy (pressure change in the air) is transformed into electrical signals inside the ear and is transmitted out of the ear along the auditory nerve and then through a series of structures on the way to the brain.

Electrical signals from each sense arrive at the **primary receiving area** for that sense in the cerebral cortex of the brain (as shown in Figure 1.4). The cerebral cortex is a 2-mm thick layer that contains the machinery for creating perceptions, as well as other functions, such as language, memory, and thinking. The primary receiving area for vision occupies most of the **occipital lobe**; the area for hearing is located in part of the **temporal lobe**; and the area for the skin senses—touch, temperature, and pain—is located in an area in the **parietal lobe**. The **frontal lobe** receives signals from all of the senses, and it plays an important role in perceptions that involve the coordination of information received through two or more senses. As we study each sense in detail, we will see that other areas in addition to the primary receiving areas are also associated with the neural processing of signals for each sense.

The sequence of transformations that occurs between the receptors and the brain, and then within the brain, means that the pattern of electrical signals in the brain is changed compared to the electrical signals that left the receptors. It is important to note, however, that although these signals have changed, they still represent the tree. In fact, the changes that occur as the signals are transmitted and processed are crucial for achieving the next step in the perceptual process, the *behavioral responses*.




Neural processing takes place in the interconnected circuits of neurons like the retina (above) and in much more complex circuits within the brain. Each sense sends signals to different areas of the brain.

**4 Neural Processing**

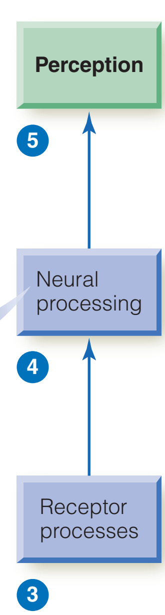



**Figure 1.4** Step 4: *Neural processing*. This involves interactions between the signals traveling in networks of neurons early in the system, in the retina; later, on the pathway to the brain; and finally, within the brain.

## Behavioral Responses (Steps 5–7)

Finally, after all that reflection, focusing, transduction, transmission, and processing, we reach the behavioral responses (**Figure 1.5**). This transformation is perhaps the most miraculous of all of the transformations in the perceptual process, because the electrical signals from Step 4 are transformed into conscious experience: The person perceives the tree (Step 5) and recognizes it (Step 6). We can distinguish between **perception**, which is conscious awareness of the tree, and **recognition**, which is placing an object in a category, such as "tree," that gives it meaning, by considering the case of Dr. P., a patient described by neurologist Oliver Sacks (1985) in the title story of his book *The Man Who Mistook His Wife for a Hat.*

Dr. P., a well-known musician and music teacher, first noticed a problem when he began having trouble recognizing his students visually, although he could immediately identify them by the sound of their voices. But when Dr. P. began misperceiving common objects, for example addressing a parking meter as if it were a person or expecting a carved knob on a piece of furniture to engage him in conversation, it became clear that his problem was more serious than just a little forgetfulness. Was he blind, or perhaps crazy? It was clear from an eye examination that he could see well, and by many other criteria it was obvious that he was not crazy.

Dr. P.'s problem was eventually diagnosed as **visual form agnosia**—an inability to recognize objects—that was caused by a brain tumor. He perceived the parts of objects but couldn't identify the whole object, so when Sacks showed him a glove, Dr. P. described it as "a continuous surface unfolded on itself. It appears to have five outpouchings, if this is the word." When Sacks asked him what it was, Dr. P. hypothesized that it was "a container of some sort. It could be a change purse, for example, for coins of five sizes." The normally easy process of object recognition had, for Dr. P., been derailed by his brain tumor. He could perceive the object and recognize parts of it, but he couldn't perceptually assemble the parts in a way that would enable him to recognize the object as a whole. Cases such as this show that it is important to distinguish between perception and recognition.

The final behavioral response is **action** (Step 7), which involves motor activities. For example, the person might decide to walk toward the tree, have a picnic under it, or climb it. Even if he doesn't decide to interact directly with the tree, he is taking action when he looks at different parts of the tree, even if he is standing in one place.

Some researchers see action as an important outcome of the perceptual process because of its importance for survival. David Milner and Melvyn Goodale (1995) propose that early in the evolution of animals, the major goal of visual processing was not to create a conscious perception or "picture" of the environment but to help the animal control navigation, catch prey, avoid obstacles, and detect predators—all crucial functions for the animal's survival.

The fact that perception often leads to action—whether it be an animal's increasing its vigilance when it hears a twig snap in the forest or a person's deciding to interact with an object or just look more closely at something that looks interesting—means that perception is a continuously changing process. For example, the image of the tree on the back of the eye changes every time the person moves his body or his eyes relative to the tree, and this change creates new representations and a new series of transformations. Thus, although we can describe the perceptual process as a series of steps that "begins" with the environmental stimulus and "ends" with perception, recognition, and action, the overall process is dynamic and continually changing.

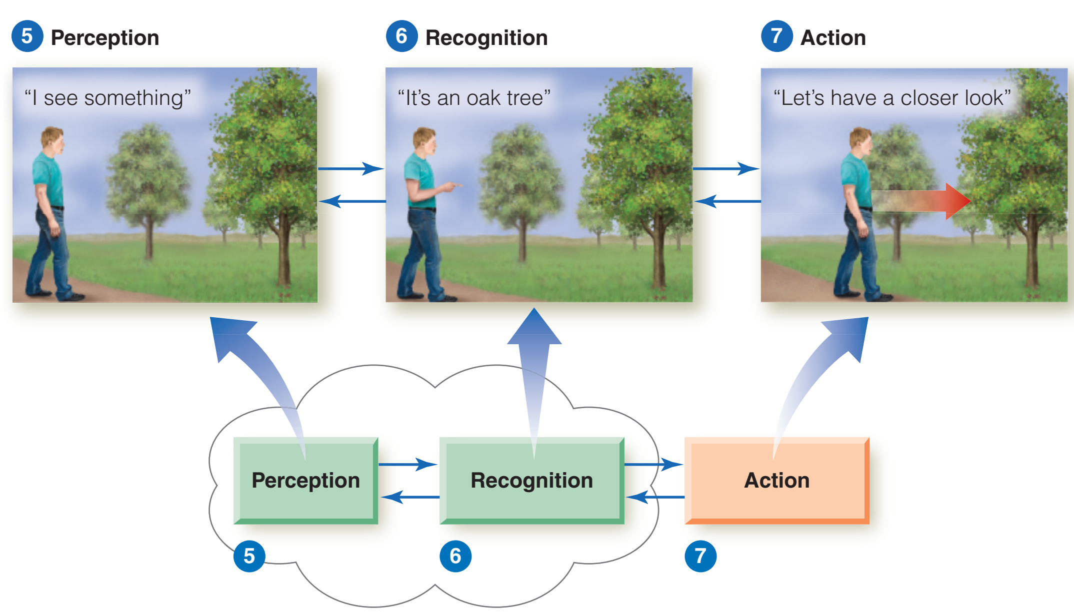



**Figure 1.5** Steps 5–7: *Behavioral responses are perception, recognition, and action.* © Cengage Learning 2014

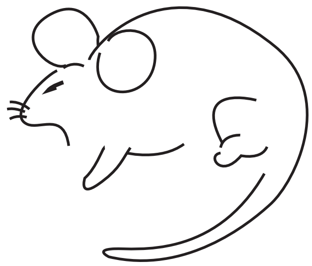


**Figure 1.6** See Demonstration: Perceiving a Picture for instructions.
Adapted from "The Role of Frequency in Developing Perceptual Sets," by B. R. Bugelski and D. A. Alampay, 1961, *Canadian Journal of Psychology, 15*, 205–211. Copyright © 1961 by the Canadian Psychological Association. Reprinted with permission.

## Knowledge

Our diagram of the perceptual process includes one more factor: *knowledge*. **Knowledge** is any information that the perceiver brings to a situation. Knowledge is placed inside the person's head in the diagram because it can affect a number of the steps in the perceptual process. Knowledge that a person brings to a situation can be information acquired years ago or, as in the following demonstration, information just recently acquired.

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**DEMONSTRATION**

**Perceiving a Picture**

After looking at the drawing in **Figure 1.6**, close your eyes, turn to page 11, and open and shut your eyes rapidly to briefly expose the picture in **Figure 1.10**. Decide what the picture is; then open your eyes and read the explanation below it. Do this now, before reading further.

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Did you identify Figure 1.10 as a rat (or a mouse)? If you did, you were influenced by the clearly rat- or mouselike figure you observed initially. But people who first observe **Figure 1.14** (page 13) instead of Figure 1.6 usually identify Figure 1.10 as a man. (Try this on someone else.) This demonstration, which is called the **rat–man demonstration**, shows how recently acquired knowledge ("that pattern is a rat") can influence perception.

An example of how knowledge acquired years ago can influence the perceptual process is the ability to categorize objects. This is something you do every time you name an object. "Tree," "bird," "branch," "car," and everything else you can name are examples of objects being placed into categories that you learned as a young child and that have become part of your knowledge base.

Another way to describe the effect of information that the perceiver brings to the situation is by distinguishing between bottom-up processing and top-down processing. **Bottom-up processing** (also called **data-based processing**) is processing that is based on the stimuli reaching the receptors. These stimuli provide the starting point for perception because, with the exception of unusual situations such as drug-induced perceptions or "seeing stars" from a bump to the head, without receptor activation there is no perception. The woman sees the moth on the tree in **Figure 1.7** because of processes triggered by the moth's image on her retina. The image is the "incoming data" that is the basis of bottom-up processing.

**Top-down processing** (also called **knowledge-based processing**) refers to processing that is based on knowledge. When the woman labels what she is seeing as a "moth" or perhaps a particular kind of moth, she is accessing what she has learned about moths. Knowledge such as this isn't always involved in perception, but as we will see, it often is—sometimes without our even being aware of it.

An example of the interaction between bottom-up and top-down processing occurs when a pharmacist reads what to you might look like an unreadable scribble on your doctor's prescription. She starts with the patterns that the doctor's handwriting creates on her retina. Once these bottom-up data have triggered the sequence of steps of the perceptual process, top-down processing can come into play as well. For example, the pharmacist might use her knowledge of the names of drugs, and perhaps past experience with this particular doctor's writing, to help her understand the unreadable (to you) squiggles on the prescription.

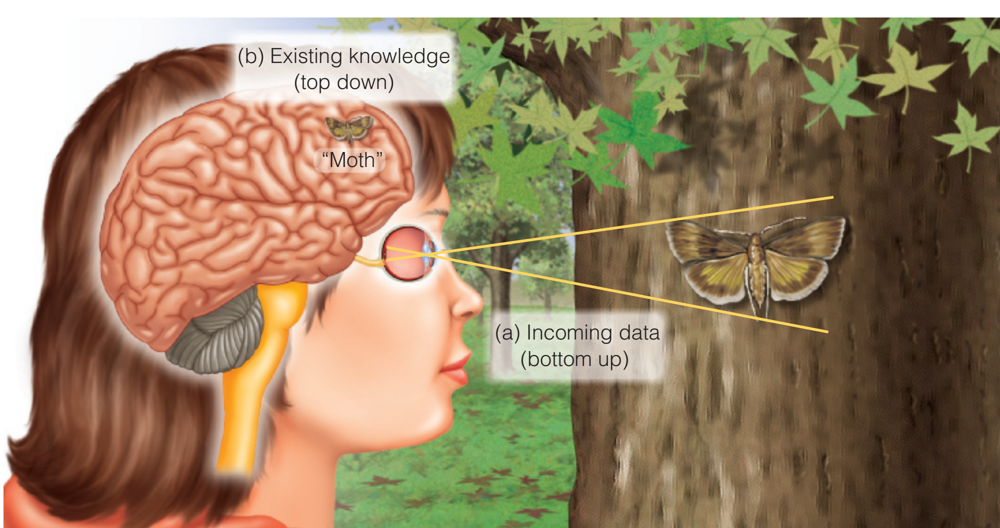


**Figure 1.7** Perception is determined by an interaction between bottom-up processing, which starts with the image on the receptors, and top-down processing, which brings the observer's knowledge into play. In this example, (a) the image of the moth on the woman's retina initiates bottom-up processing; and (b) her prior knowledge of moths contributes to top-down processing.
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