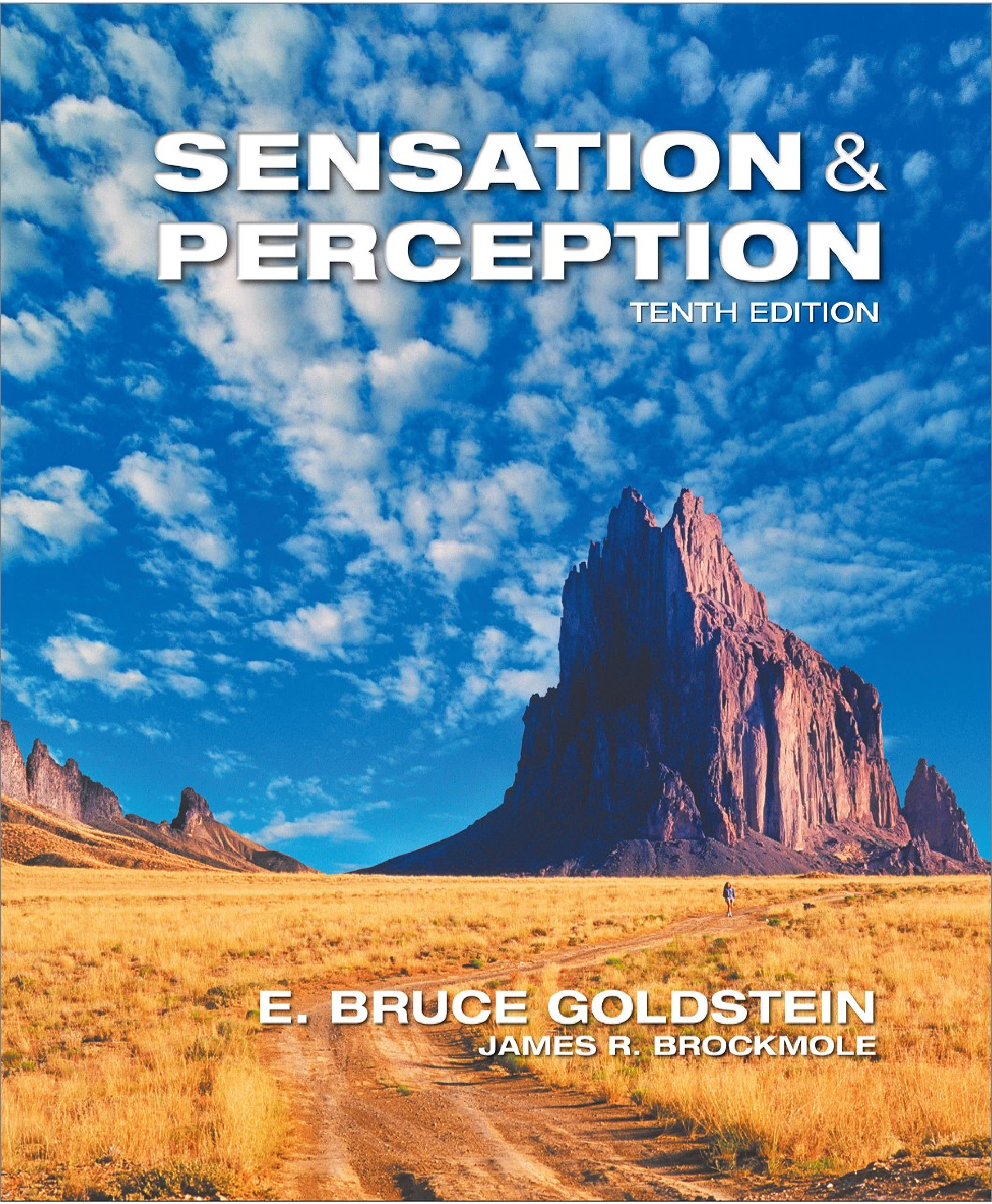
SENSATION & PERCEPTION

TENTH EDITION



E. BRUCE GOLDSTEIN

JAMES R. BROCKMOLE

TENTH EDITION

Sensation and Perception

E. Bruce Goldstein
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and

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To Barbara: It's been a long and winding road, but we made it all the way to the 10th edition! Thank you for your unwavering love and support through all of the editions of this book.

© Bruce Goldstein

I also dedicate this book to the editors I have had along the way, especially Ken King, who convinced me to write the book in 1976, and also those that followed: Marianne Taflinger, Jaime Perkins, and Tim Matray. Thank you all, for believing in my book and supporting its creation.

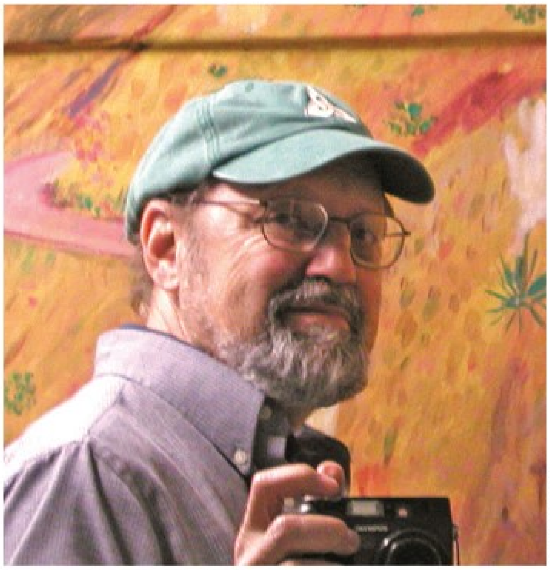
Finally, I dedicate this book to the memory of Anne Draus (1952–2014) of Scratchgravel Publishing Services, whose caring about books was evident as she shepherded many previous editions of this book from manuscript to finished book. But Anne was more than a production service. She was a warm, caring person, who is greatly missed.

Bruce Goldstein

To Jessica, for her smile, laughter, hugs, and secret-recipe spaghetti sauce.

James Brockmole

About the Authors



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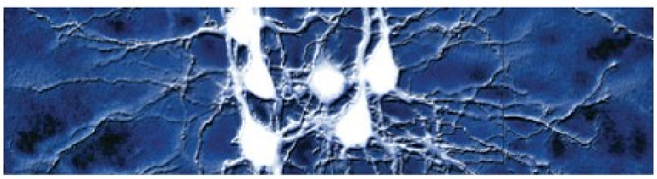

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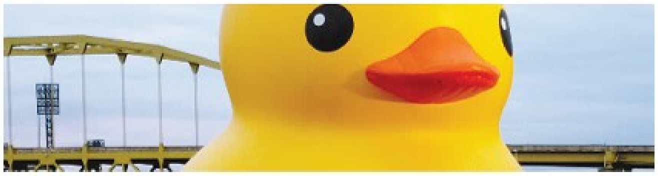

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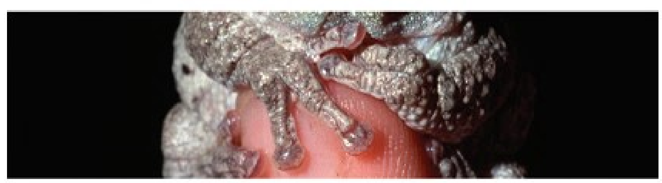

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Preface

by Bruce Goldstein

When I first began working on this book in 1976, Hubel and Wiesel were studying feature detectors in the striate cortex and were five years away from receiving their Nobel Prize; one of the hottest new discoveries in perception was that the response properties of neurons in young kittens could be influenced by experience; and little was known about the mechanisms responsible for odor perception. Today, specialized areas in the visual cortex have been mapped using brain imaging; neurons have been identified throughout the cortex that respond to complex visual stimuli; and researchers are exploring not only the mechanisms for perceiving objects but also mechanisms linking our perception of objects to how we physically interact with them. Additionally, the idea that experience can shape both perception and neural responding has been widely embraced and expanded beyond young kittens to include adult humans, and genetic methods and neural recording have revealed specialized olfactory receptors and cortical mechanisms of smell and taste.

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*, which came out in 1980, 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, most of which appeared in the ninth 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. See list on page xiv.
- **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. See list on page xv.
- **Something to Consider.** This end-of-chapter feature offers the opportunity to consider especially interesting phenomena and new findings. Some examples: Why Is the Difference Between Physical and Perceptual Important? (Chapter 1); Distracted Driving (Chapter 6); Connections Between Hearing and Vision (Chapter 12); The Proust Effect (Chapter 15).
- **Developmental Dimensions**. The *Developmental Dimension* feature, which was introduced in the ninth edition, has proven to be popular and so has been continued and slightly expanded in this edition. This feature, which appears at the end of chapters, focuses on perception in infants and young children.
- **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.
- **Full-Color Illustrations.** Perception, of all subjects, should be illustrated in color, so I was especially pleased when in 2007 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 more than 500 figures in this edition, including 85 new to this edition.

- **MindTap** for Sensation and Perception engages and empowers students to produce their best work—consistently. For those courses that include MindTap, the textbook is supplemented with videos, activities, apps, and much more. MindTap creates a unique learning path that fosters increased comprehension and efficiency.

  For students:

  - MindTap delivers real-world relevance with activities and assignments that help students build critical thinking and analytic skills that will transfer to other courses and their professional lives.
  - MindTap helps students stay organized and efficient with a single destination that reflects what's important to the instructor, along with the tools students need to master the content.
  - MindTap empowers and motivates students with information that shows where they stand at all times—both individually and compared to the highest performers in class.

  Additionally, for instructors, MindTap allows you to:

  - Control what content students see and when they see it with a learning path that can be used as is, or matched to your syllabus exactly.
  - Create a unique learning path of relevant readings, multimedia, and activities that move students up the learning taxonomy from basic knowledge and comprehension to analysis, application, and critical thinking.
  - Integrate your own content into the MindTap Reader, using your own documents or pulling from sources like RSS feeds, YouTube videos, websites, Google Docs, and more.
  - Use powerful analytics and reports that provide a snapshot of class progress, time in course, engagement, and completion.

  In addition to the benefits of the platform, MindTap for Sensation and Perception includes:

  - **Exploration.** The MindTap *Exploration* feature enables students to view experimental stimuli, perceptual demonstrations, and short film clips about the research being discussed. These features have been updated in this edition, and new items have been added to the labs carried over from the ninth edition. Most of these items have been generously provided by researchers in vision, hearing, and perceptual development.

Changes in This Edition

This edition offers many improvements in organization, designed to make the text read more smoothly and flow more logically. In addition, each chapter has been updated to highlight new advances in the field, supported by over 190 new references. Here are a few examples of new material that has been added in this edition.

Perceptual Principles (Chapters 1–4)

- New discussion emphasizing the difference between physical and perceptual
- New research that questions the lateral inhibition explanation of the Chevreul and Hermann grid illusions (Geier & Hudach, 2010)
- Distributed mapping of visual categories across the cortex (Huth et al., 2012)

Visual Qualities (Chapters 5–10: Object and Scene; Attention, Action, Motion, Color, Depth, and Size)

- Bayesian inference and object perception (Geisler, 2011; Tanenbaum et al., 2011)
- Lateralization of FFA response to faces (Meng et al., 2012)
- Parahippocampal Place Area responds to sense of 3D space (Mullally & Maguire, 2011)
- Attention synchronizes neural activity in the cortex (Baldauf & Desimone, 2014; Bosman et al., 2012)
- Distracted driving (Hickman & Hanowski, 2012; Strayer et al., 2013)
- 2014 Nobel Prize research on the brain's GPS (O'Keefe, Moser and Moser's research; Moser, 2014)
- Revised description of Reichardt motion detectors
- Expanded discussion of Newton's color experiments and history of trichromatic and opponent-process theories
- Discussion of crossed and uncrossed disparity

Hearing (Chapters 11–12: Pitch, Location, Organization)

- Physiology of pitch perception updated to reflect shift in thinking from Bekesy place theory to filtering action of basilar membrane, and emphasis on temporal factors
- Pitch perception of resolved and unresolved harmonics (Oxenham, 2013)
- Localization of pitch in auditory cortex (Norman-Haignere et al., 2013)
- Hidden hearing loss (Kujawa & Liberman, 2009; Plack et al., 2014)
- New section on music perception, emphasizing rhythm, musical organization, and motor response to music (Chen et al., 2008; Grahn & Rowe, 2009; Krumhansl, 1985; Patel et al., 1996)

Speech (Chapter 13)

- Perceiving degraded speech (Davis et al., 2005)
- Cortical response to phonemes and phonetic features (Mesgarani et al., 2014)
- Link between speech production and perception in the cortex (Silbert et al., 2014)
- Social gating hypothesis of infant speech perception (Kuhl, 2014)

The Skin Senses (Chapter 14)

- Response of SA1 and PC fibers to coarse and fine textures (Weber et al., 2013)
- Effect of expectation on pain reduction by drugs (Bingel et al., 2011)

- Comparing social pain and physical pain (Eisenberger, 2014; Woo et al., 2014)

The Chemical Senses (Chapter 15)

- Social effects of anosmia (Croy et al., 2013)
- Revised estimate of the number of odors that can be discriminated (Bashid et al., 2014)
- Diffuse representation of odorants in piriform cortex (Omanski et al., 2014)

A Note on the Creation of This Edition

I wrote the first nine editions of this book myself, but with the addition of James Brockmole of the University of Notre Dame, this edition became a team effort. Taking the ninth edition as the starting point, I revised Chapters 1–5 and 11–15, and Jim revised Chapters 6–10. Having Jim revise these chapters had a number of benefits. First, he brought new ideas to the material, which are reflected in changes such as updating the description of the Reichardt motion detector, adding historical highlights about Newton, Helmholtz, and Hering to the discussion of color vision, and creating a number of new *Developmental Dimensions*. Second, the process of revising all of the chapters was collaborative. We read and commented on each other's chapters and made suggestions about new material to add and old material that needed to be omitted. A third collaborator, who was crucial to the success of this project, was my longtime developmental editor, Shannon LeMay-Finn, who made sure we explained things clearly and in the same style throughout the book. The goal was to create a book that instructors would easily recognize because of its similarity to the previous editions, but that also contains new research and reflects changing trends in the field.

Acknowledgments

It is a pleasure to acknowledge the following people who worked tirelessly to turn the manuscript into an actual book. Without these people, this book would not exist, and both Jim and I are grateful to all of them.

- Tim Matray, editor, for providing resources to support the book, and, most important, for your willingness to listen to my concerns and to provide advice and support regarding various situations that came up as I was writing the book.
- Shannon LeMay-Finn, developmental editor extraordinaire, who has spoiled me with her attention to details, and with queries and suggestions that often amazed me. Many of the details of this edition of the book owe their existence to Shannon's perceptive feedback. Also thank you, Shannon, for your humor, for your appreciation of my humor, and for becoming interested in perception.
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- Michelle Clark, senior content project manager, who coordinated all of the elements of the book during production and made sure everything happened when it was supposed to so the book would get to the printer on time.
- Joshua Taylor, associate content vendor services manager, for coordinating the Instructor's Manual, Test Bank, and PowerPoint slides.

In addition to the help I received from all of these people on the editorial and production side, I also received a great deal of help from perception researchers. One of the things I have learned in my years of writing is that other people's advice is crucial. The field of perception is a broad one, and I rely heavily on the advice of experts in specific areas to alert me to emerging new research and to check the content for accuracy. The following is a list of "expert reviewers." Some checked entire chapters for accuracy and completeness (indicated by *) and others checked portions of chapters that related directly to their research.

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Chapter 6

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Chapter 15

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I also thank the following people who donated photographs and research records for illustrations that are new to this edition.

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Massachusetts Institute of Technology

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University of Minnesota

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George Washington University

Pawan Sinha
Massachusetts Institute of Technology

I also thank Michael Hout of the University of New Mexico for tracking down many new demonstrations for the Exploration feature of MindTap, and the many researchers who contributed the demonstrations. These researchers are credited in the online Exploration feature.

Perception is a miracle. Somehow, the markings on this page become a sidewalk, stone walls, and a quaint ivy-covered house. Even more miraculous is that if you were standing in the real scene, the flat image on the back of your eye would be transformed into three-dimensional space that you could walk through. This book explains how this miracle occurs.

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CHAPTER 1

Introduction to Perception

CHAPTER CONTENTS

Some Questions We Will Consider:

- Why should you read this book? (p. 4)
- What is the sequence of steps from looking at a stimulus like a tree to perceiving the tree? (p. 5)
- What is the difference between perceiving something and recognizing it? (p. 8)
- How do perceptual psychologists go about measuring the varied ways that we perceive the environment. (p. 13)

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 number of elegant ways. 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 creating 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 about **perception**—conscious experience that results from stimulation of the senses. Our goal in this book is to understand how humans and animals perceive, 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 the result of the activity in your nervous system and your knowledge gained from past experience.

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 by activating *sensory receptors* in your body designed to respond to light energy, sound energy, chemical stimuli, and pressure on the skin. When you run your fingers over the pages of this book, you feel the page and its texture because the pressure and movement are activating small receptors just below 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 from 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.[1] In her email, "Jenny" made a

[1] Who is "I"? In various places in the book you will see first-person references such as this one ("*I* received an email") or others, like "a student in *my* class," or "*I* tell my students," or "*I* had an interesting experience." Because this book has two authors, you may wonder who *I* or *my* is. The answer is that, unless otherwise noted, it is author B. G., because most of the first-person references in this edition are carried over from the 9th edition, which was written by B. G.

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 from 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 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 this process is involved in everything we will be describing in this book, it is important to note that Figure 1.1 is a simplified version of what happens. First, many things happen within each "box." For example, "neural processing," 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. In addition, there is an arrow from "action" back to the stimulus. This turns the perceptual process into a "cycle" in which taking action, for example, walking toward the tree, changes the observer's view of the tree.

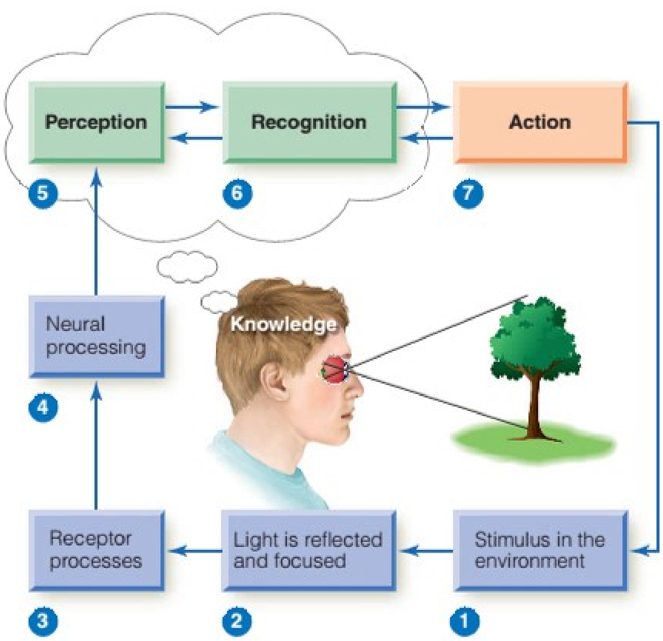


Figure 1.1 The perceptual process. These seven steps, plus "knowledge" inside the person's brain, summarize the major events that occur between the time a person looks at the stimulus in the environment (the tree in this example) and perceives the tree, recognizes it, and takes action toward it. Figures 1.3–1.6 describe the steps in the perceptual process in more detail.

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.

But What About "Sensation"?

Before we begin describing the stages of the perceptual process, let's consider something that may have occurred to you: Why is Figure 1.1 called the *perceptual* process, when the title of this book is *Sensation and Perception*? To answer this question, let's consider the terms *sensation* and *perception*. When a distinction is made between *sensation* and *perception*, **sensation** is often identified as involving simple "elementary" processes that occur right at the beginning of a sensory system, as when light stimulates receptors in the eye. In contrast, *perception* is identified with complex processes that involve higher-order mechanisms such as interpretation and memory that involve activity in the brain. It is therefore often stated, especially in introductory psychology textbooks, that *sensation* involves detecting elementary properties of a stimulus (Carlson, 2010), and perception involves the higher brain functions involved in interpreting events and objects (Myers, 2004).

Keeping this distinction in mind, let's consider the displays in **Figure 1.2**. **Figure 1.2a** is extremely simple—a single dot. Let's for the moment assume that this simplicity means that there is no interpretation or higher-order processes, so sensation is involved. Looking at **Figure 1.2b**, with three dots, we might now think that we are dealing with perception, because we interpret the three dots as creating a triangle. Going even further, we can say that **Figure 1.2c**, which is made up of many dots, is a "house." Surely this must be perception because it involves many dots and our past experience with houses. But let's return to Figure 1.2a, which we called a dot. As it turns out, even a stimulus this simple can be seen in more than one

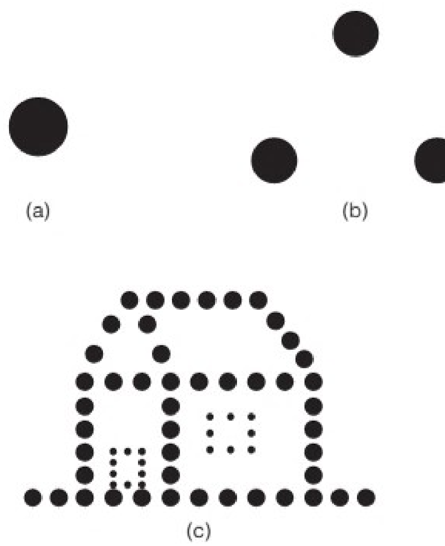


Figure 1.2 (a) One dot, (b) a triangle, (c) a house. What do these stimuli tell us about sensations and perceptions? See text for discussion.

way. Is this a black dot on a white background or a hole in a piece of white paper? Now that interpretation is involved, does our experience with Figure 1.2a become *perception*?

This example illustrates that deciding what is *sensation* and what is *perception* is not always obvious. As we will see in this book, there are experiences that depend heavily on processes that occur right at the beginning of a sensory system, in the sensory receptors or nearby, and there are other experiences that depend on interpretation and past experiences, using information stored in the brain. But this book takes the position that calling some processes *sensation* and others *perception* doesn't add anything to our understanding of how our sensory experiences are created, so the term *perception* is used almost exclusively throughout this book.

Perhaps the main reason not to use the term *sensation* is that, with the exception of papers on the history of perception research (Gilchrist, 2012), the term *sensation* appears only rarely in modern research papers (for example, papers on the sense of taste occasionally refer to taste *sensations*), whereas the term *perception* is extremely common. Despite the fact that introductory psychology books may distinguish between sensation and perception, modern perception researchers don't make this distinction.

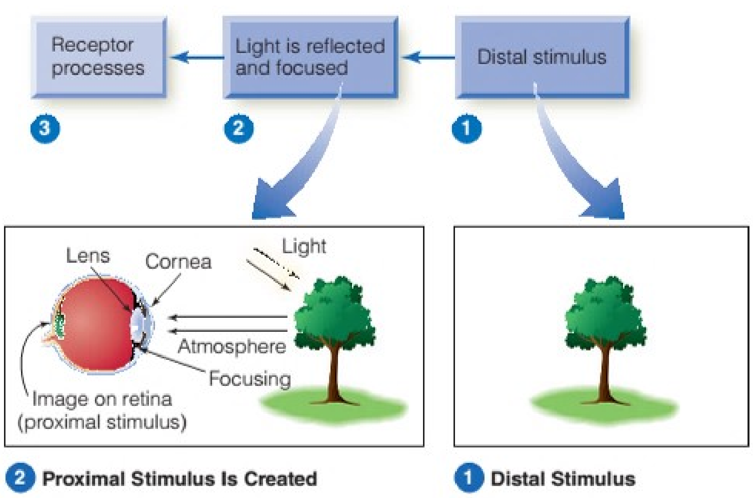
So why is this book called *Sensation and Perception*? Blame history. Sensation was discussed in the early history of perceptual psychology, and courses and textbooks followed suit by including *sensation* in their titles. But while researchers eventually stopped using the term *sensation*, the titles of the courses and books remained the same. So sensations are historically important (we will discuss this briefly in Chapter 5), but as far as we are concerned, everything that involves understanding how we experience the world through our senses comes under the heading of perception. With that bit of terminology out of the way, we are now ready to consider Steps 1 and 2 of the perceptual process, by accompanying someone who is observing a tree in a field.

Distal and Proximal 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 in which stimuli in the environment reach receptors in the eye (**Figure 1.3**).

We begin with the tree that the person is observing, which we call the **distal stimulus** (Step 1). It is called distal because it is "distant"—out there in the environment. 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 and reaching

Figure 1.3 Steps 1 and 2 of the perceptual process. Step 1: Information about the tree (the *distal stimulus*) is carried by light. Step 2: The light 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 the *proximal stimulus*, the image of the tree on the retina, which is a representation of the tree.



the visual receptors (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 distal 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 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 enters 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. This image on the retina is the **proximal stimulus**, so called because it is "in proximity" to the receptors (Step 2). If the eye's optics are not working properly, this proximal stimulus—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 the resulting activity in the person's nervous system.*

The distinction between the distal stimulus (Step 1) and the proximal stimulus (Step 2) illustrates both transformation and representation. The distal stimulus (the tree) is *transformed* into the proximal stimulus, 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 (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 different properties of stimuli (**Figure 1.4**).

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

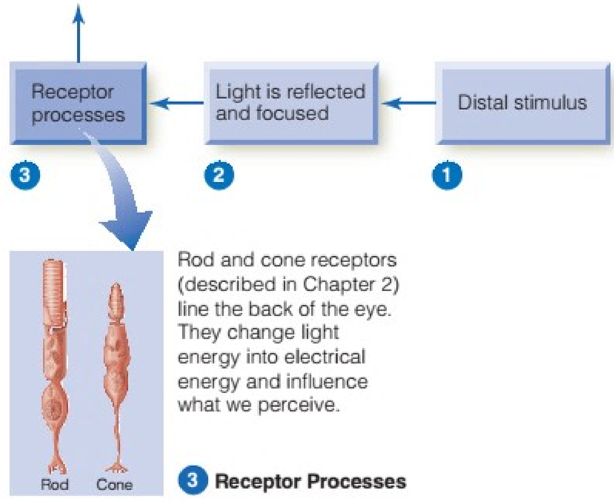


Figure 1.4 Step 3 of the perceptual process. *Receptor processes* include transduction (the transformation of light energy into electrical energy) and the shaping of perception by the properties of visual pigments in the receptor's outer segments. The end result is an electrical representation of the tree.

example of transduction occurs when you touch the "withdrawal" 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 dispense 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 in two ways: (1) The ability to see dim light depends on having a high concentration of light-sensitive pigment in the receptors; and (2) there are different types of pigments, which respond best to light in different parts of the visible spectrum. 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 the different pigments influence perception in Chapter 2.

Neural Processing (Step 4)

Once transduction occurs, the tree becomes represented by electrical signals in thousands of visual receptors. But what happens to these signals? As we will see in Chapter 2, they travel through a vast interconnected network of neurons that (1) *transmit* signals from the receptors, through the retina, to the brain, and then within the brain; and (2) *change* (or *process*) these signals as they are transmitted. These changes occur because of interactions between neurons as the signal travels from the receptors to the brain. Because of this processing, some signals become reduced or are prevented from getting through, and others are amplified so they arrive at the brain with added strength. This processing then continues as signals travel to various places in the brain.

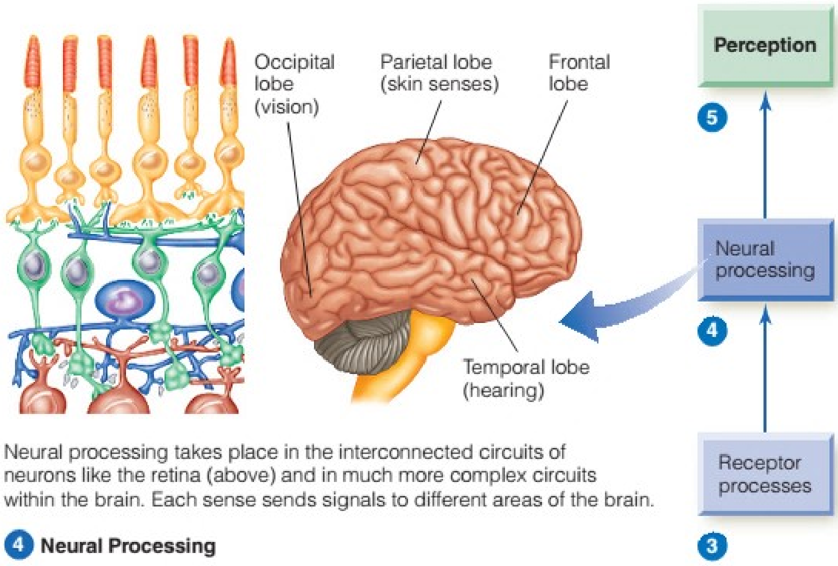


Figure 1.5 Step 4 of the perceptual process. *Neural processing* involves interactions between the electrical signals traveling in networks of neurons early in the system, in the retina; later, on the pathway to the brain; and finally, within the brain.

The changes in these signals that occur as they are transmitted through this maze of neurons is called **neural processing** (**Figure 1.5**). 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 looking at the tree created an image of the tree inside the eye, which was then changed into electrical signals in the visual receptors. A similar process 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, 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 1.5). 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**. As we study each sense in detail, we will see that once signals reach the primary receiving areas, they are then transmitted to many other structures in the brain. For example, 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.

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*.

Behavioral Responses (Steps 5–7)

Finally, after all that reflection, focusing, transduction, transmission, and processing, we reach the behavioral responses (**Figure 1.6**). This transformation is perhaps the most miraculous of all, because *electrical signals* (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.

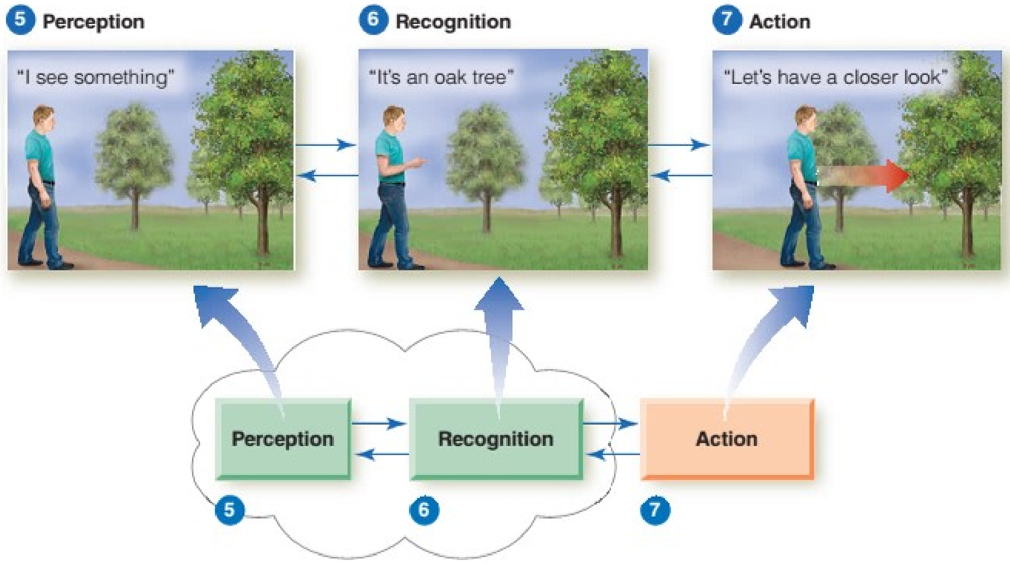


Figure 1.6 Steps 5–7 of the perceptual process. The behavioral responses: *perception, recognition,* and *action.*

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 moves his eyes and head to look 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 distal stimulus and "ends" with perception, recognition, and action, the overall process is dynamic and continually changing.

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 brain in Figure 1.1 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.

DEMONSTRATION | Perceiving a Picture

After looking at the drawing in **Figure 1.7**, close your eyes, turn to page 11, and open and shut your eyes rapidly to briefly expose the picture in **Figure 1.11**. Decide what the picture is; then open your eyes and read the explanation below it. Do this now, before reading further.

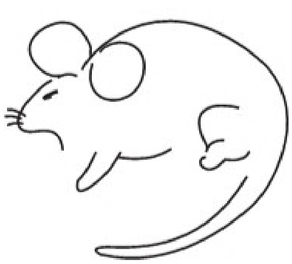


Figure 1.7 See "Demonstration: Perceiving a Picture" for instructions. (Adapted from Bugelski & Alampay, 1961)

Did you identify Figure 1.11 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 1.7 usually identify Figure 1.11 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 your ability to **categorize**—to place objects into categories. 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, perception involves activation of the receptors. The woman sees the moth on the tree in **Figure 1.8** 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.

To experience top-down processing in action, try reading the following sentence:

M*RY H*D * L*TTL* L*MB

If you were able to do this, even though all of the vowels have been omitted, you probably used your knowledge of English words, how words are strung together to form sentences, and your familiarity with the nursery rhyme to create the sentence (Denes & Pinson, 1993).

Students often ask whether top-down processing is always involved in perception. The answer to this question is that it is "very often" involved. There are some situations, typically involving very simple stimuli, in which top-down processing may not be involved. For example, perceiving a single flash of easily visible light is probably not affected by a person's prior experience. However, as stimuli become more complex, the role of top-down processing increases. In fact, a person's past experience is usually involved in perception of real-world scenes, even though in most cases the person is unaware of this influence. One of the themes of this book is that our knowledge of how things usually appear in the environment can play an important role in determining what we perceive.

Studying the Perceptual Process

The goal of perceptual research is to understand each of the steps in the perceptual process that lead from the stimulus to the behavioral responses of perception, recognition, and action. (For simplicity, we will use the term *perception* to stand for all of these behavioral outcomes in the discussion that follows.) One way the perceptual process has been studied is by determining the following three relationships, shown in **Figure 1.9**:

- Relationship A: The stimulus–perception relationship
- Relationship B: The stimulus–physiological relationship
- Relationship C: The physiology–perception relationship

To illustrate how these relationships have been measured in actual experiments, we consider how researchers have studied a

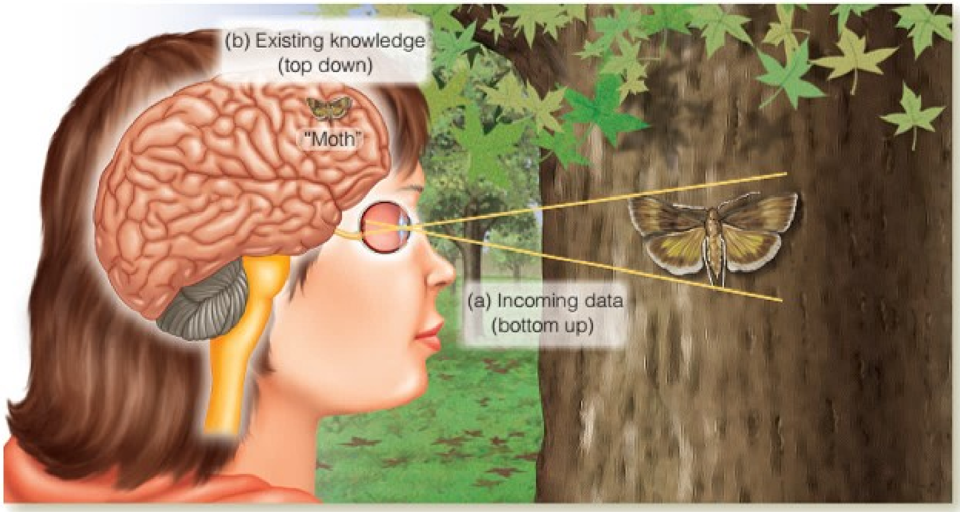


Figure 1.8 Perception is determined by an interaction between bottom-up processing, which starts with the image on the receptors, and top-down processing, which brings the observer's knowledge into play. In this example, (a) the image of the moth on the woman's retina initiates bottom-up processing; and (b) her prior knowledge of moths contributes to top-down processing.