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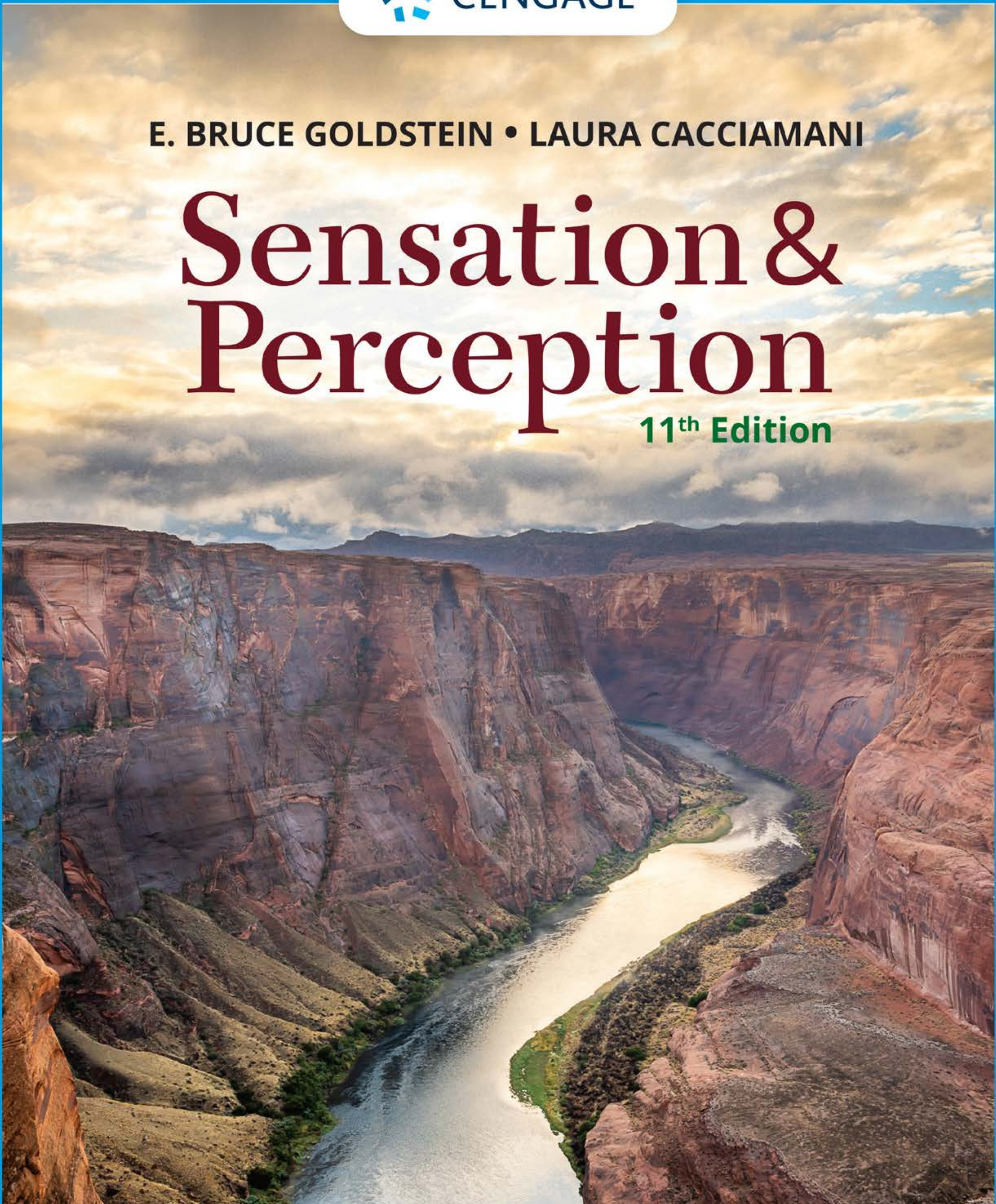
E. BRUCE GOLDSTEIN • LAURA CACCIAMANI

Sensation & Perception

11th Edition



ELEVENTH EDITION

Sensation and Perception

E. Bruce Goldstein
University of Pittsburgh
University of Arizona

and

Laura Cacciamani
California Polytechnic State University

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E. Bruce Goldstein and
Laura Cacciamani

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To Barbara: It's been a long and winding road, but we made it all the way to the 11th edition! Thank you for your unwavering love and support through all of the editions of this book.

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 1977, and also those that followed: Marianne Taflinger, Jaime Perkins, and Tim Matray. Thank you all for believing in my book and supporting its creation.

Bruce Goldstein

To Zack, for supporting me through the winding roads of academia and listening to me ramble about research on many, many occasions.

And to my mother, Debbie, for being my life-long role model and demonstrating what it means to be a compassionate, persevering, independent woman.

Laura Cacciamani

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Nesrine Majzoub

LAURA CACCIAMANI is Assistant Professor of Cognitive Neuroscience in the Department of Psychology and Child Development at California Polytechnic State University, San Luis Obispo. She received her bachelor's degree in psychology and biological sciences from Carnegie Mellon University and her MA and PhD in psychology with a minor in neuroscience from the University of Arizona. She completed a two-year postdoctoral fellowship at the Smith-Kettlewell Eye Research Institute while also lecturing at California State University, East Bay before joining the faculty at Cal Poly. Laura's research focuses on the neural underpinnings of object perception and memory, as well as the interactions between the senses. She has published papers that have used behavioral, neuroimaging, and neurostimulation techniques to investigate these topics in young adults, older adults, and people who are blind. Laura is also passionate about teaching, mentoring, and involving students in research.

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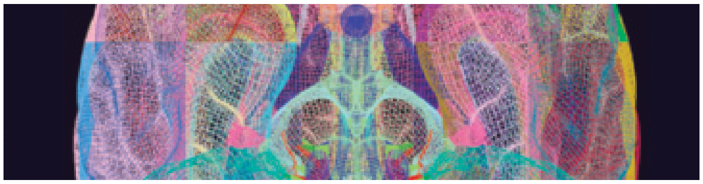

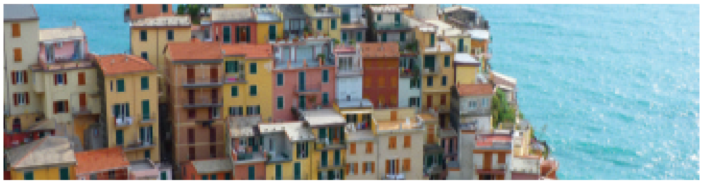

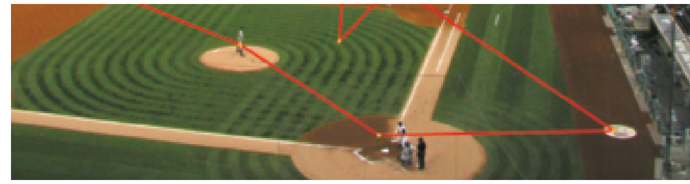

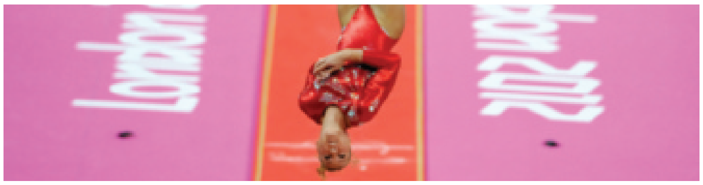

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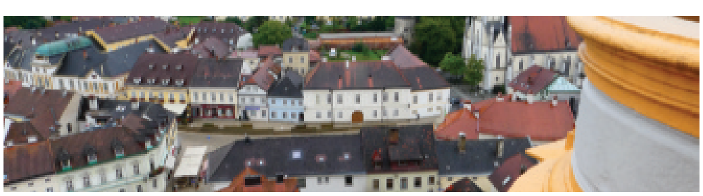

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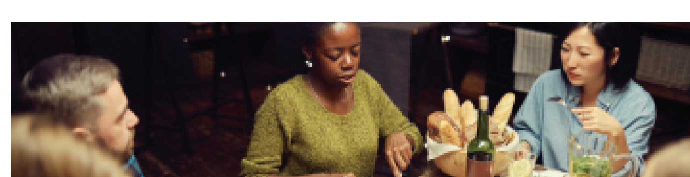

Methods

Demonstrations

Preface

by Bruce Goldstein

A long, long time ago, Ken King, the psychology editor of Wadsworth Publishing Co., knocked on the door to my office at the University of Pittsburgh, came in, and proposed that I write a textbook titled *Sensation and Perception*. This led me to begin writing the first edition of *Sensation and Perception* in 1977, the year *Star Wars* made its debut in theaters and when the first mass-market personal computer was introduced.

While Luke Skywalker was dealing with Darth Vader and was working to master the Force, I was dealing with understanding the perception literature and was working to present the results in this literature as a story that would be both interesting to students and would help them understand how perception works.

How do you tell a story in a textbook? This is a problem I grappled with when writing the first edition, because while the textbooks available at that time presented "the facts," they did so in a way that wasn't very interesting or inviting to students. I decided, therefore, that I would create a story about perception that was a narrative in which one idea followed from another and that related the results of research to everyday experience—a story describing both the historical background behind scientific discoveries and the reasoning behind scientific conclusions. The result was the first edition of *Sensation and Perception*, which was published in 1980 (**Figure P.1**). The book was popular, largely because of my decision to present not just facts, but also to present the story and reasoning behind the facts.

The producers of *Star Wars* had no idea, when they released their first movie, that it would give birth to a franchise that is still alive today. Similarly, I had no idea, when the first edition of *Sensation and Perception* was published, that it would be the first of 11 editions.

The book you are reading was, in a sense, born as the first edition was being written in 1977. But a lot has happened since then. One indication of this is the graph in **Figure P.2**, which plots the number of references in this edition by decade. Most of the references to the left of the dashed line appeared in the first edition. The ones to the right were published after the first edition.

Another measure of the evolution of this book is provided by the illustrations. The first edition had 313 illustrations. Of these, 116 have made it all the way to this edition (but transformed from black and white into color). This edition has 440 illustrations that weren't in the first edition, for a total of 556.

But enough history. Most users of this book are probably more interested in "what have you done for the book lately?" Returning to illustrations, 90 of the illustrations in this edition

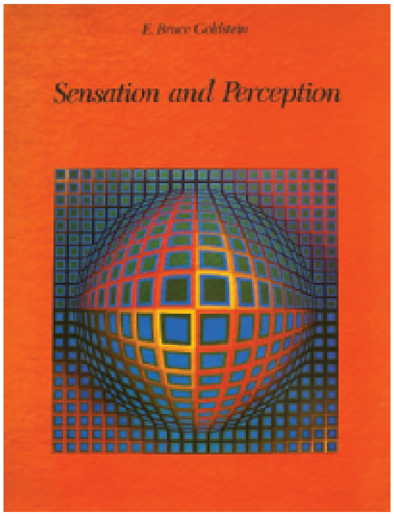

Figure P.1 The cover of the first edition of *Sensation and Perception* (1980), which featured a reproduction of the painting *Vega-Nor 1960*, by Victor Vasarely, from the Albright-Knox Art Gallery, Buffalo, New York.

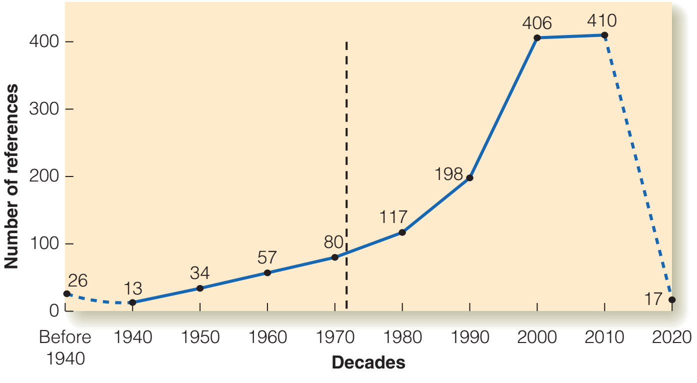

Figure P.2 The number of reference citations in this edition, by decade. For example, 1970 includes all references dated from 1970 to 1979. This means that all of the references to the right of the dashed vertical line appeared 1980 or after, and so were in editions after the first edition. The line on the right is dashed because it connects to 2020, which includes references only from 2020 and the beginning of 2021, not a whole decade.

are new since the 10th edition. There's much more that's new since the 10th edition when it comes to content, which I'll get to shortly. But first, one of the most important things about this edition is that it still contains the popular content and teaching features that have been standbys for many editions. These features are as follows:

Features

The following features focus on student engagement and learning:

- **Learning Objectives.** *Learning Objectives,* which provide a preview of what students can expect to learn from each chapter, appear at the beginning of each chapter.
- **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.

The following feature enables students to participate in perceptual activities related to what they are reading:

- **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 xv.

The following features highlight different categories of material:

- **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 xiv.
- **Something to Consider.** This end-of-chapter feature offers the opportunity to consider especially interesting phenomena and new findings. A few examples include The Puzzle of Faces (Chapter 5), Focusing Attention by Meditating (Chapter 6), The Changing Moon (Chapter 10), and Community of the Senses (Chapter 16).
- **Developmental Dimensions.** The *Developmental Dimension* feature, which was introduced in the ninth edition, has proven to be popular and so has been continued and expanded in this edition. This feature, which appears at the end of chapters, focuses on perception in infants and young children.

The following feature provides digital learning opportunities that support the material in the text:

- ***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.

New to 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 many new references. Here are a few examples of changes in this edition.

Key Terms New to This Edition

The following key terms represent methods, concepts, and topics that are new to this edition:

Aberration
Action affordance
Adaptive optical imaging
Adult-directed speech
Affective function of touch
Alzheimer's disease
Arch trajectory
Automatic speech recognition (ASR)
Cloze probability task
COVID-19
Dopamine
Duple meter
Early right anterior negativity (ERAN)
Experience sampling
Figural cues
Functional connectivity
Hand dystonia
Head-mounted eye tracking
Interpersonal touching
Meditation
Metrical structure
Microneurography
Mild cognitive impairment
Mind wandering
Multimodal interactions
Munsell color system
Music-evoked autobiographical memory (MEAM)
Musical phrases
Novelty-preference procedure
Odor-evoked autobiographical memory
Predictive coding
Predictive remapping of attention
Seed location
Semitone
Social pain
Social touch
Social touch hypothesis
Sustentacular cell
Syncopation
Syntax, musical
Task-related fMRI
Temporal structure
Triple meter

Revisions and New Material

Each chapter has been revised in two ways: (1) Organization: Chapters and sections within chapters have been reorganized to achieve smoother flow from one idea to the next; (2) Updating: Material describing new experimental results and new approaches in the field has been added. New "Developmental Dimensions" topics are indicated by DD and new "Something to Consider" topics by STC.

Perceptual Principles (Chapters 1–4)

The initial chapters, which introduce basic concepts and research approaches, have been completely reorganized to make the opening of the book more inviting to students, to create a more logical and smooth flow, and to include all of the senses up-front. Discussing a number of senses in Chapter 2 corrects a problem perceived by some teachers, who felt that the opening of the 10th edition was too "vision-centric." Chapter 2 also contains a new section discussing structural and functional connectivity.

Perceiving Objects and Scenes (Chapter 5)

- Updated section on computer vision
- Predictive coding
- Pre-wiring of functional connectivity for faces in human infants

Visual Attention (Chapter 6)

- Predictive remapping of attention
- Mere presence of smartphones can negatively impact performance.
- Head-mounted tracking devices to measure infant attention
- STC: Focusing Attention by Meditating
- DD: Infant Attention and Learning Object Names

Taking Action (Chapter 7)

- New material on proprioception
- Hippocampus-related navigation differences in non-taxi drivers
- STC: Prediction Is Everywhere
- DD: Infant Affordances

Perceiving Motion (Chapter 8)

- Changes in motion perception over the first year
- Motion and social perception
- STC: Motion, Motion, and More Motion

Perceiving Color (Chapter 9)

- Color and judging emotions of facial expressions
- Reevaluation of the idea of "unique hues"
- Social functions of color
- Color areas in cortex sandwiched between face and place areas
- #TheDress and what it tells us about individual differences and color constancy
- Novelty-preference procedure for determining infant color categorization

Perceiving Depth and Size (Chapter 10)

- Praying mantis cinema used to test binocular depth perception
- STC: The Changing Moon

Hearing (Chapter 11)

- STC: Explaining Sound to an 11-Year-Old

Hearing in the Environment (Chapter 12)

- Human echolocation
- STC: Interactions Between Hearing and Vision

Perceiving Music (Chapter 13)

- New chapter, greatly expanding coverage of music, which was part of Chapter 12 in the 10th edition
- Music and social bonding
- Therapeutic effects of music
- Infant emotional response to music
- Chemistry of musical emotions
- Effect of syncopation on music-elicited movement
- Cross-cultural similarities
- Music and prediction
- Behavioral and physiological differences between music and speech
- DD: How Infants Respond to the Beat

Perceiving Speech (Chapter 14)

- Role of motor processes in speech perception
- STC: Cochlear Implants
- DD: Infant-Directed Speech

The Cutaneous Senses (Chapter 15)

- Social touch and CT afferents
- Cortical responses to surface texture
- Top-down influences on social touch
- Pain reduction by social touching
- Pre- and post-partum touch perception
- STC: Plasticity and the Brain
- DD: Social Touch in Infants

The Chemical Senses (Chapter 16)

- Comparing human and animal perception of scent
- Music can influence flavor
- Color can influence flavor
- Odors can influence attention and performance
- Loss of smell in COVID-19 and Alzheimer's
- STC: Community of the Senses

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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 Laura and I are grateful to all of them.

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- Bethany Bourgeois, for the striking cover.
- Heather Mann, for her expert and creative copyediting.

In addition to the help received from people on the editorial and production side, Laura and 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 we have relied heavily on the advice of experts in specific areas to alert us to emerging new research and to check the content for accuracy. The following is a list of "expert reviewers," who checked the relevant chapter from the 10th edition for accuracy and completeness, and provided suggestions for updating.

<u>Chapter 5</u>

Joseph Brooks
Keele University

Bevil Conway
Wellesley College

<u>Chapter 6</u>

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New York University

John McDonald
Simon-Fraser University

<u>Chapter 7</u>

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Jonathan Marotta
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<u>Chapter 8</u>

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University of Rochester

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David Brainard
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<u>Chapter 10</u>

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<u>Chapter 11</u>

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University of Chicago

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Indiana University

A Note on the Writing of This Edition

Taking the 10th edition as our starting point, this edition was created by myself (B. G.) and Laura Cacciamani. Laura revised Chapters 1–5, and is therefore responsible for the greatly improved organization of Chapters 1–4, which introduce the field of perception and which set the stage for the discussion of the different aspects of perception in the chapters that follow. I revised Chapters 6–16. We read and commented on each other's chapters and made suggestions regarding both the writing and the content, so this was, in a very real sense, a collaborative project.

ELEVENTH EDITION

Sensation and Perception

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 is transformed into three-dimensional space that you can walk through. This book explains how this miracle happens.

Bruce Goldstein

Learning Objectives

After studying this chapter, you will be able to ...

- Explain the seven steps of the perceptual process.
- Differentiate between "top-down" and "bottom-up" processing.
- Describe how knowledge can influence perception.
- Understand how perception can be studied by determining the relationships between stimulus and behavior, stimulus and physiology, and physiology and behavior.
- Explain "absolute threshold" and "difference threshold" and the various methods that can be used to measure them.
- Describe how perception above threshold can be measured by considering five questions about the perceptual world.
- Understand the importance of the distinction between physical stimuli and perceptual responses.

CHAPTER 1

Introduction to Perception

CHAPTER CONTENTS

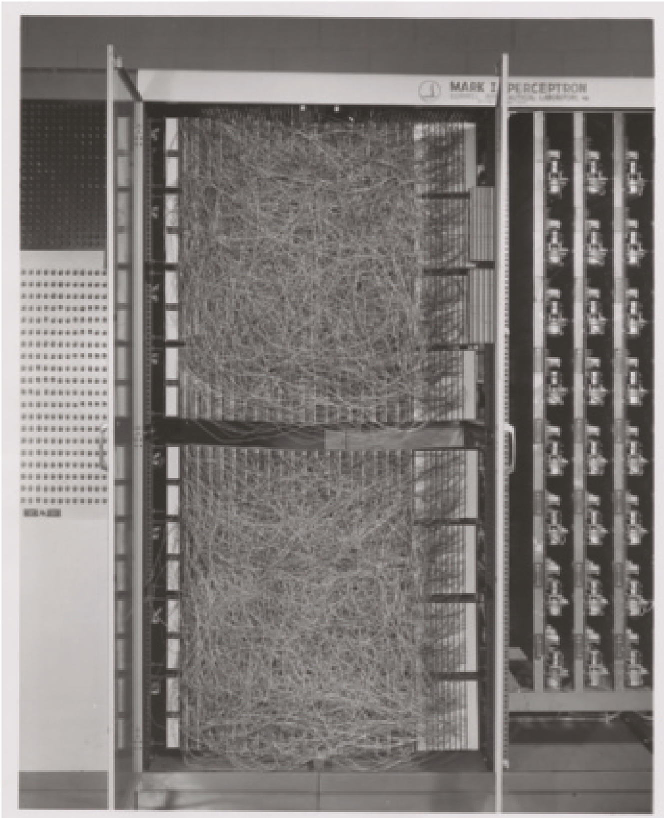
Some Questions We Will Consider:

- Why should you read this book? (p. 5)
- What is the sequence of steps from looking at a stimulus like a tree to perceiving the tree? (p. 6)
- What is the difference between perceiving something and recognizing it? (p. 9)
- How do perceptual psychologists go about measuring the varied ways that we perceive the environment? (p. 11)

In July of 1958, the *New York Times* published an intriguing article entitled, "Electronic 'Brain' Teaches Itself." The article described a new, potentially revolutionary technological advancement: "… an electronic computer named the Perceptron which, when completed in about a year, is expected to be the first non-living mechanism able to perceive, recognize, and identify its surroundings without human training or control."

The first Perceptron, created by psychologist Frank Rosenblatt (1958), was a room-sized five-ton computer (**Figure 1.1**) that could teach itself to distinguish between basic images, such as cards with markings on the left versus on the right. Rosenblatt claimed that this device could "… learn to recognize similarities or identities between patterns of optical, electrical, or tonal information, in a manner which may be closely analogous to the perceptual processes of a biological brain" (Rosenblatt, 1957). A truly astounding claim! And, in fact, Rosenblatt and other computer scientists in the 1950s and 1960s proposed that it would take only about a decade or so to create a "perceiving machine," like the Perceptron, that could understand and navigate the environment with humanlike ease.

So how did Rosenblatt's Perceptron do in its attempt to duplicate human perception? Not very well, since it took 50 trials to learn the simple task of telling whether a card had a mark on the left or on the right, and it was unable to carry out more complex tasks. It turns out that perception is much more complex than Rosenblatt or his Perceptron could comprehend. This invention therefore received mixed feedback from the field, and ultimately this line of research was dropped for many years. However, Rosenblatt's idea that a computer could be trained to learn perceptual patterns laid the groundwork for a resurgence of interest in this area in the 1980s, and many now consider Rosenblatt's work to be a key precursor to modern artificial intelligence (Mitchell, 2019; Perez et al., 2017).



Division of Rare and Manuscript Collections, Cornell University Library

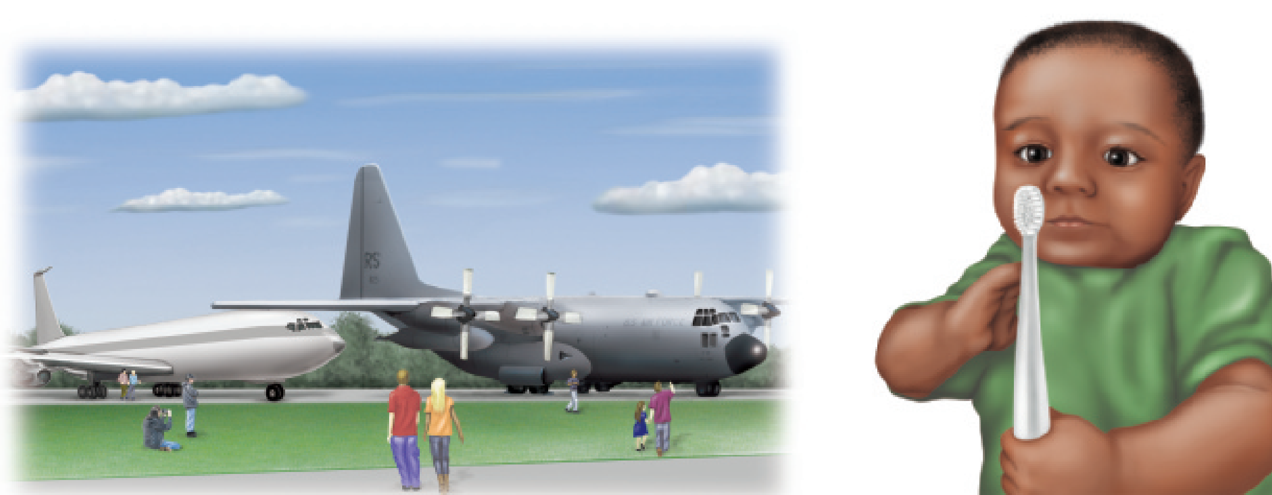
Figure 1.1 Frank Rosenblatt's original "Perceptron" machine.

Now over 60 years later, although great strides have been made in computer vision, computers still can't perceive as well as humans (Liu et al., 2019). Consider **Figure 1.2**, which shows pictures similar to those that were provided to a computer, which then created descriptions for each image (Fei-Fei, 2015). For example, the computer identified a scene similar to the one in **Figure 1.2a** as "a large plane sitting on a runway." But mistakes occur, as when a picture similar to the one in **Figure 1.2b** was identified as "a young boy holding a baseball bat." The computer's problem is that it doesn't have the huge storehouse of information that humans begin accumulating as soon as they are born. If a computer has never seen a toothbrush, it identifies it as something with a similar shape. And, although the computer's response to the airplane picture is accurate, it is beyond the computer's capabilities to recognize that this is a picture of airplanes on display, perhaps at an air show, and that the people are not passengers but are visiting the air show. So on one hand, we have come a very long way from the first attempts in the 1950s to design computer-vision systems, but to date, humans still out-perceive computers.

Why did early computer scientists think they would be able to create a computer capable of human-like perception within a decade or so, when it has actually taken over 60 years, and we still aren't there yet? One answer to this question is that **perception**—the experiences that result from stimulation of the senses—is something we usually accomplish so easily that we often don't even give it a second thought. Perception seems to "just happen." We open our eyes and see a landscape, a campus building, or a group of people. But the reality, as you will appreciate after reading this book, is that the mechanisms responsible for perception are extremely complex.

Throughout this book, we'll see many more examples illustrating how complex and amazing perception is. Our goal is to understand how humans and animals perceive, starting with the detectors—located in the eyes, ears, skin, tongue, 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.

In this chapter, we will consider some practical reasons for studying perception, how perception occurs in a sequence of steps, and how perception can be measured.



(a) (b)

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Figure 1.2 Pictures similar to one that a computer vision program identified as (a) "a large plane sitting on a runway" and (b) "a young boy holding a baseball bat." (Adapted from Fei-Fei, 2015)

1.1 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 autonomous 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 creating or understanding 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 an autonomous 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 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.

1.2 Why Is This Book Titled *Sensation and Perception*?

You may have noticed that so far in our discussion we've used the word *perception* quite a lot, but haven't mentioned *sensation*, even though the title of this book is *Sensation and Perception*. Why has *sensation* been ignored? 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, such as when light reaches the eye, sound waves enter the ear, or your food touches your tongue. In contrast, *perception* is identified with complex processes that involve higher-order mechanisms such as interpretation and memory that involve activity in the brain—for instance, identifying the food you're eating

[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 10th edition.

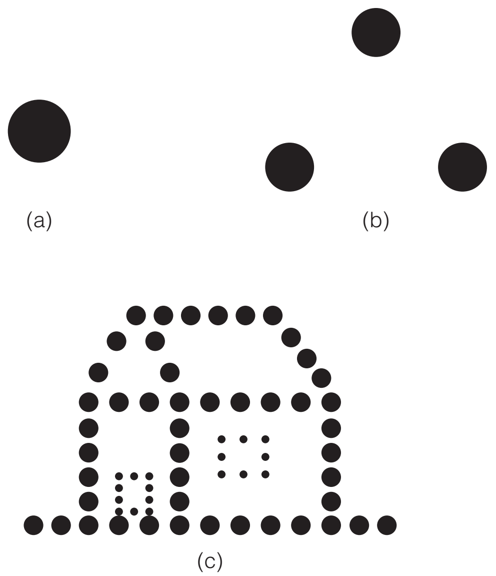

Figure 1.3 (a) One dot, (b) a triangle, (c) a house. What do these stimuli tell us about sensations and perceptions? See text for discussion.

and remembering the last time you had it. 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 an example from the sense of vision in **Figure 1.3. Figure 1.3a** 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 1.3b**, 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 1.3c**, 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 1.3a, which we called a dot. As it turns out, even a stimulus this simple can be seen in more than one 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 1.3a become *perception*?

This example illustrates that deciding what is *sensation* and what is *perception* is not always obvious, or even that useful. 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 (mainly in papers on the sense of taste, which refer to taste sensations, and touch which refer to touch sensations), whereas the term *perception* is extremely common. Despite the fact that introductory psychology books may distinguish between sensation and perception, most 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 describe perception as involving a number of steps, which we will call the perceptual process. These steps begin with a stimulus in the environment and end with perceiving the stimulus, recognizing it, and taking action relative to it.

1.3 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 1.4**, 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 (like walking up to take a closer look).

Although this example of perceiving a tree is from the sense of vision, keep in mind as we go through these steps that the same general process applies to the other senses as well. Furthermore, because this process is involved in everything we will be describing in this book, it is important to note that Figure 1.4 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 that our process 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; Peterson, 2019). 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 bidirectional arrows between perception, recognition, and action. In addition, there is an arrow from "action"

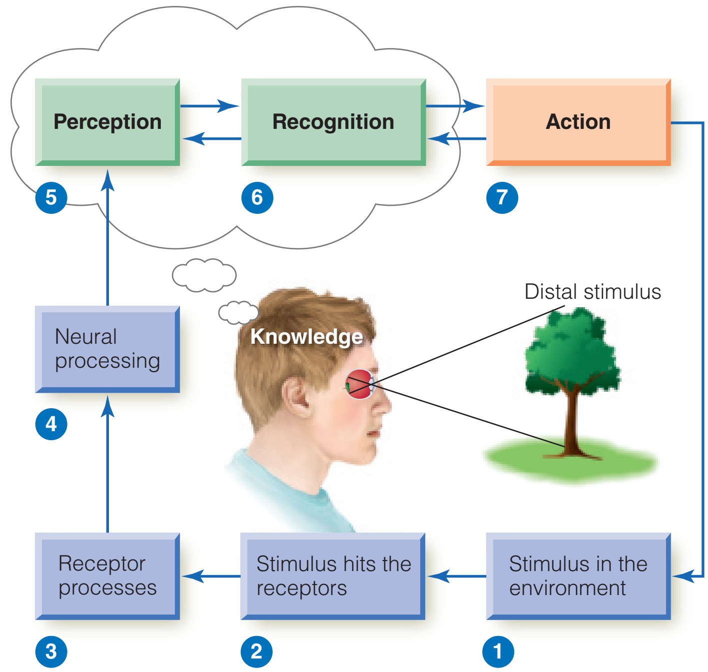

Figure 1.4 The perceptual process. These seven steps, plus "knowledge" inside the person's brain, summarize the major events that occur between the time a person looks at the stimulus in the environment (the tree in this example) and perceives the tree, recognizes it, and takes action toward it. Information about the stimulus in the environment (the *distal stimulus*; Step 1) hits the receptors, resulting in the *proximal stimulus* (Step 2), which is a representation of the stimulus on the retina. *Receptor processes* (Step 3) include transduction and the shaping of perception by the properties of the receptors. *Neural processing* (Step 4) involves interactions between the electrical signals traveling in networks of neurons. Finally, the behavioral responses—*perception*, *recognition*, and *action*—are generated (Steps 5–7).

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.

Even though the process is simplified and only depicts the perceptual process in one sense, Figure 1.4 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.

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, like a tree in the woods that you can see, hear, smell, and feel (and taste, if you wanted to be adventurous). Using this example, we will consider what happens in the first two steps of the perceptual process in which stimuli from the environment reach the sensory receptors.

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 or ear (ouch!), but on light reflected from the tree entering the eye and reaching the visual receptors, and the pressure changes in the air caused by the rustling leaves entering the ear and reaching the auditory receptors. This representation of the tree on the receptors is the **proximal stimulus** (Step 2), so called because it is "in proximity" to the receptors.

The light and pressure waves that stimulate the receptors introduce 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*.

For example, 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?). As this reflected light enters the eye, it is transformed again as it is focused by the eye's optical system (discussed further in Chapter 3) onto the retina, a 0.4-mm-thick network of nerve cells which contains the receptors for vision.

The fact that an image of the tree is focused on the receptors 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 receptors" is just the first in a series of transformations. We're only on Step 2 of the perceptual process, and we can already begin to understand the complexity of perception in these transformations! The next transformation occurs within the receptors themselves.

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. **Figure 1.5** shows examples of receptors from each of the senses. 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 sensory receptors receive the information from the environment, such as light reflected from the tree, they do two things: (1) They transform environmental

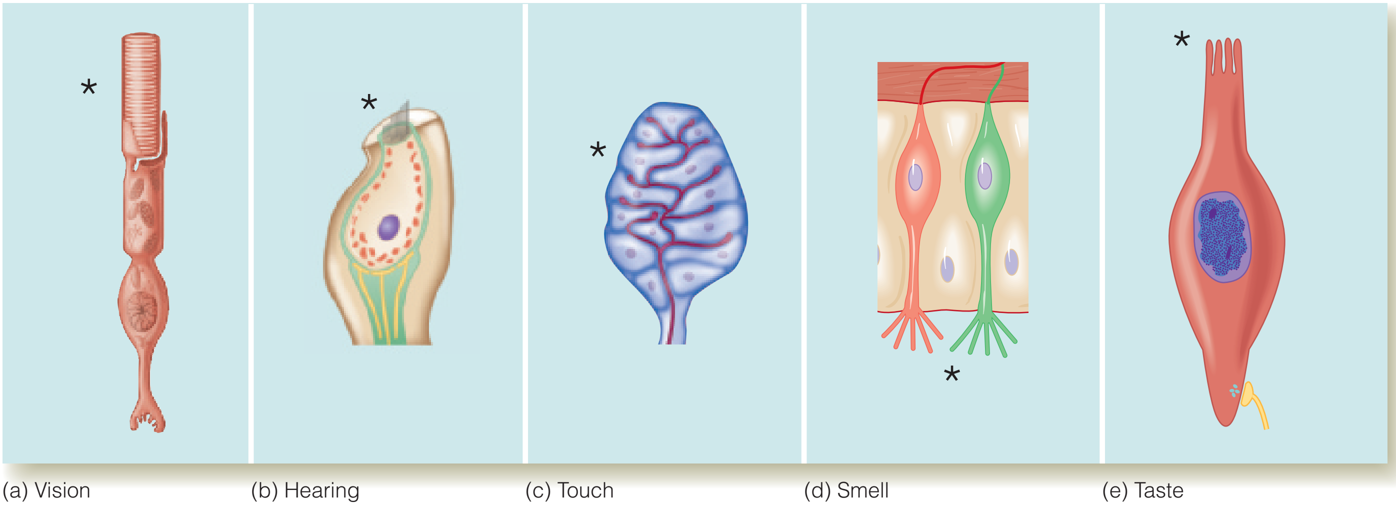

Figure 1.5 Receptors for (a) vision, (b) hearing, (c) touch, (d) smell, and (e) taste. Each of these receptors is specialized to transduce a specific type of environmental energy into electricity. Stars indicate the place on the receptor neuron where the stimulus acts to begin the process of transduction.

energy into electrical energy; and (2) they shape perception by the way they respond to different properties of the stimuli.

The transformation of environmental energy (such as light, sound, or thermal energy) to electrical energy is called **transduction**. For example, if you were to run your fingers over the bark of the tree, the stimulation of pressure receptors in your fingers would cause these receptors to produce electrical signals representing the texture of the bark. By transforming environmental energy into electrical energy, your sensory receptors are allowing the information that is "out there," like the texture of the tree, to be transformed into a form that can be understood by your brain. Transduction by the sensory receptors is, therefore, crucial for perception. Another way to think about transduction is that your sensory receptors are like a bridge between the external sensory world and your internal (neural) representation of that world. In the next step of the perceptual process, further processing of that neural representation takes place.

Neural Processing (Step 4)

Once transduction occurs, the tree becomes represented by electrical signals in thousands of sensory receptors (visual receptors if you're looking at the tree, auditory receptors if you're hearing the leaves rustling, and so on). 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 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 signals travel 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.

The changes in these signals that occur as they are transmitted through this maze of neurons is called **neural processing**. This processing will be discussed in much more detail in later chapters as we describe each sense individually. However, there are commonalities in neural processing between the senses.

For instance, the electrical signals created through transduction are often sent to a sense's **primary receiving area** in the cerebral cortex of the brain, as shown in **Figure 1.6**. 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, emotions, 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

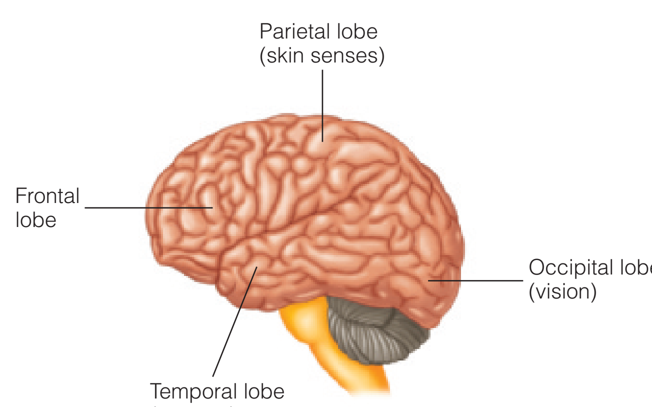

Figure 1.6 The four lobes of the brain, with the primary receiving areas for vision, hearing, and the skin senses (touch, temperature, and pain) indicated.

Figure 1.7 The behavioral responses of the perceptual process: *perception*, *recognition*, and *action*.

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 of that transformation, transduction, transmission, and processing, we reach the behavioral responses (**Figure 1.7**). This transformation is perhaps the most miraculous of all, because electrical signals have been transformed into the *conscious experience* of perception (Step 5), which then leads to *recognition* (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, as in **Figure 1.8**, 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 in response to the stimulus. For example, after having perceived and recognized the tree, the person might decide to walk toward the tree, touch 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.

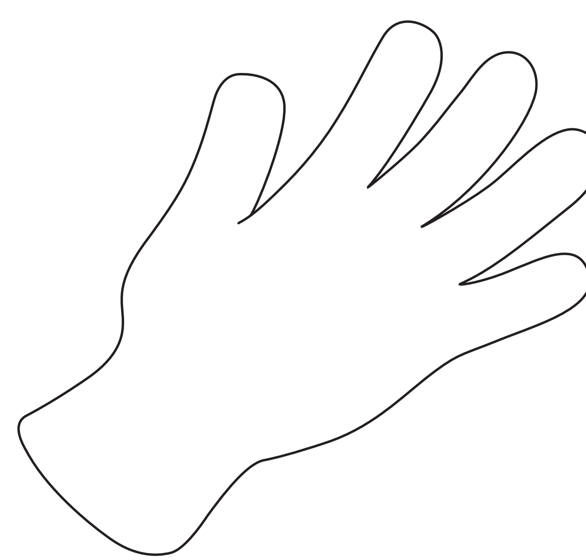

Figure 1.8 How Dr. P.—a patient with visual form agnosia—responded when his neurologist showed him a glove and asked him what it was.