Third Edition

COGNITIVE PSYCHOLOGY

CONNECTING MIND, RESEARCH, AND EVERYDAY EXPERIENCE

E. Bruce Goldstein

Cognitive Psychology

Cognitive Psychology

CONNECTING MIND, RESEARCH, AND EVERYDAY EXPERIENCE

THIRD EDITION

E. Bruce Goldstein
University of Pittsburgh
University of Arizona

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Cognitive Psychology: Connecting Mind, Research, and Everyday Experience, Third Edition
E. Bruce Goldstein

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Library of Congress Control Number: 2010923871

Student Edition:

ISBN-13: 9780840033550
ISBN-10: 0-8400-3355-9

Loose-leaf Edition:

ISBN-13: 978-0-495-91497-6
ISBN-10: 0-495-91497-5

Wadsworth
20 Davis Drive
Belmont, CA 94002-3098
USA

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Printed in Canada
1 2 3 4 5 6 7 14 13 12 11 10

To Barbara

About the Author

E. BRUCE GOLDSTEIN is Professor Emeritus of Psychology at the University of Pittsburgh and Adjunct Professor of Psychology at the University of Arizona. He has received the Chancellor's Distinguished Teaching Award from the University of Pittsburgh for his classroom teaching and textbook writing. He received his bachelor's degree in chemical engineering from Tufts University and his PhD in experimental psychology from Brown University. He was a post-doctoral fellow in the Biology Department at Harvard University before joining the faculty at the University of Pittsburgh. Bruce has published papers on a wide variety of topics, including retinal and cortical physiology, visual attention, and the perception of pictures. He is the author of *Sensation and Perception,* 8th edition (Wadsworth, 2010) and is the editor of the *Blackwell Handbook of Perception* (Blackwell, 2001) and the two-volume *Sage Encyclopedia of Perception* (Sage, 2010).

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Preface to Instructors

The Evolution of a Cognitive Psychology Textbook

This book is the culmination of a process that began in 2002, when I decided to write the first edition of this book. From a survey of more than 500 instructors and my conversations with colleagues, it became apparent that many teachers were looking for a text that not only covers the field of cognitive psychology but is also accessible to students. From my teaching of cognitive psychology, it also became apparent that many students perceive cognitive psychology as being too abstract and theoretical, and not connected to everyday experience. With this information in hand, I set out to write a book that would tell the story of cognitive psychology in a concrete way that would help students appreciate the connections between empirical research, the principles of cognitive psychology, and everyday experience.

I did a number of things to achieve this result. I started by including about a dozen **real-life examples** per chapter, and **neuropsychological case studies** where appropriate. To provide students with firsthand experience with the phenomena of cognitive psychology, I included more than 40 **Demonstrations**—easy-to-do mini-experiments that were contained within the narrative of the text—as well as 20 additional suggestions of things to try, throughout the chapters. The Demonstrations in this edition are listed on page xxii.

Students also received access to more than 45 online **CogLab experiments** that they could run themselves, and then compare their data to the class average and to the results of the original experiments from the literature. In order to ensure that students not only know the results of experiments but also appreciate how these results were obtained, I **described experiments in detail**, so students would understand what the experimenter and participants were doing. In addition, most of these descriptions were supported by illustrations such as pictures of stimuli, diagrams of the experimental design, or graphs of the results.

The first edition (2005) therefore combined many elements designed to achieve the goal of covering the basic principles of cognitive psychology in a way that students would find interesting and easy to understand. My goal was for students to come away feeling excited about the field of cognitive psychology.

The acceptance of the first edition was gratifying, but one thing I've learned from years of teaching and textbook writing is that there are always explanations that can be clarified, new pedagogical techniques to try, and new research and ideas to describe. With this in mind as I began preparing the second edition (2008), I elicited feedback from students in my classes and received more than 1,500 written responses indicating areas in the first edition that could be improved. In addition, I also received feedback from instructors who had used the first edition. This feedback was the starting point for the second edition, so in addition to updating the book, I revised many sections that students and instructors had flagged as needing clarification.

Retained Features

All of the features described above were well received by students and instructors, and so are continued in this new third edition. Additional pedagogical features that have been retained from previous editions include **Test Yourself** sections, which help students review the material, and **Think About It** questions, which ask students to consider questions that go beyond the material.

Method sections, which were introduced in the second edition, highlight the ingenious methods cognitive psychologists have devised to study the mind. The 27 Method sections, which are integrated into the text, describe methods such as brain imaging, lexical priming, and think-aloud protocols. This not only highlights the importance of the method, but makes it easier to return to its description when it is referred to later in the text. See page xxii for a list of Methods.

The end-of-chapter **Something to Consider** sections describe cutting-edge or controversial research. A few examples of topics covered in this section are "Attention in Social Situations—the Case of Autism," "Are Memories Ever 'Permanent'?" and "Culture, Language, and Cognition." **If You Want to Know More** includes brief descriptions of interesting topics that are related to the chapter but could not be discussed in detail in the text for space reasons. A few references are provided to help students begin exploring this additional material. **Chapter Summaries** provided succinct outlines of the chapters, without serving as a substitute for reading the chapters.

What Is the Same and What Is New in the Third Edition?

An obvious difference between the second edition and this one is that the third edition *looks* different. In response to comments that students didn't like having to refer to the separate "color plates" section when brain scans or other color plates were mentioned, plus my feeling that more color would enhance the book's accessibility and pedagogy, we took the major step of redoing the entire illustration program in full color. The results are obvious, and for me, reinforce the message in the text that cognitive psychology is an exciting and vibrant field.

But this edition is more than a color version of the last one. Material has been extensively updated throughout the text, and in a few cases chapters have been rewritten or reorganized to improve clarity and pedagogy. One significant organizational change was to divide coverage of long-term memory (Chapter 6 of the second edition, Long-Term Memory: Basic Principles) into two chapters of more manageable length (Chapter 6, Long-Term Memory: Structure, and Chapter 7, Long-Term Memory: Encoding and Retrieval). Following is a selective chapter-by-chapter list of a few of the key changes in this edition.

CHAPTER 1 INTRODUCTION TO COGNITIVE PSYCHOLOGY

- Expanded treatment of the nature of the mind to include coverage of different ways of defining "mind."
- Revised section on "Researching the Mind," using research on memory consolidation to illustrate psychophysical and physiological approaches.
- Revised section on "Models of the Mind," using Broadbent's filter model of attention as an example
- New *Something to Consider*: "Learning From This Book," to make students aware that the material is presented as a series of "mini-stories"—description of a phenomenon followed by experimental evidence.

CHAPTER 2 COGNITIVE NEUROSCIENCE

- Discussion of physiological details that do not appear later in the book has been eliminated.
- Chapter completely rewritten to help students appreciate the relationship between neural representation and cognition.

- Expanded sections on localization of function and the distributed representation in the brain.
- New *Something to Consider*: "'Mind Reading' by Measuring Brain Activity."

CHAPTER 3 PERCEPTION

- Completely rewritten to reflect contemporary research in perception. New topics include the role of context in perception, physical and semantic regularities in the environment, and parallel processing streams.
- Increased focus on top-down versus bottom-up processing.
- New section on the connection between perception and action.
- New *Demonstrations*: "Two Quarters" (size constancy); "Visualizing Scenes and Objects."
- New *Method*: "Brain Ablation."
- New *Something to Consider*: "Mirror Neurons."

CHAPTER 4 ATTENTION

- Material on inattentional blindness and change detection has been moved from the perception chapter to this chapter.
- Section on overt attention (eye movements) rewritten.
- New section on covert attention.
- New *Demonstrations*: "Detecting a Target" (divided attention); "Looking for a Face in the Crowd" (scanning).

CHAPTER 5 SHORT-TERM AND WORKING MEMORY

- Rewritten section on how information is coded in STM.
- New *Demonstrations*: "Remembering Letters" (chunking); "Recalling Visual Patterns" (visual coding).
- New *Something to Consider*: "The Advantages of Having a More Efficient Working Memory."
- New *Method*: "Reading Span."

CHAPTER 6 LONG-TERM MEMORY: STRUCTURE

- This is the first part of the old Chapter 6 in the second edition, which introduces the basic types and dimensions of long-term memory.
- Discussion of conditioning added to section on implicit memory.
- Rewritten section on priming, which distinguishes between repetition priming and conceptual priming.
- Distinction between explicit and implicit memory clarified.
- New *Methods*: "Recognition Memory"; "Avoiding Explicit Remembering in a Priming Experiment."
- New *Demonstration*: "Mirror Drawing."
- New *Something to Consider*: "Memory Loss in the Movies."

CHAPTER 7 LONG-TERM MEMORY: ENCODING AND RETRIEVAL

- This is the second part of Chapter 6 from the second edition, which focuses on the interrelationship between encoding and retrieval.
- New explanation of the circularity in the definition of depth of processing, to illustrate why LOP theory became less popular.

- New material on the testing effect in the section "Research Showing That Encoding Influences Retrieval."
- Expanded treatment of how memory principles can be applied to studying.
- "Memory and the Brain" section moved to the end of the chapter to avoid interrupting the narrative describing encoding and retrieval.
- New *Method*: "Cued Recall."

CHAPTER 8 EVERYDAY MEMORY AND MEMORY ERRORS

- Expanded section on the constructive nature of memory.
- Expanded treatment of source monitoring.
- New *Method*: "Testing for Source Monitoring."
- Updated material on memory errors and eyewitness testimony, including a description of the reverse testing effect.

CHAPTER 9 KNOWLEDGE

- Simplified treatment of the connectionist approach to knowledge representation.
- New material on category information in single neurons.
- New material on neuropsychological studies of category-specific knowledge impairment.
- New material discussing how the brain's representation of category knowledge includes activation of areas that respond to properties such as what an object is used for and how it moves.
- New *Demonstration*: "Activation of Property Units in a Connectionist Network."
- New *Something to Consider*: "Categorization in Infants."
- New *Method*: "Familiarization/Novelty Preference Procedure."

CHAPTER 10 VISUAL IMAGERY

- Minor changes were made in this chapter.
- New *Demonstration*: "Experiencing Imagery."

CHAPTER 11 LANGUAGE

- *Method*: "Word Superiority Effect" moved to this chapter.
- Section on understanding sentences rewritten, focusing on clarifying sections students found difficult. To accomplish this, the section on parsing has been rewritten.
- New *Demonstrations*: "Late Closure"; "Making Up a Story" (inference in story understanding).
- Situation models updated, with new material on mental representations as simulations, and the physiology of simulations.
- *Something to Consider* on the Whorf-Sapir hypothesis has been rewritten to consider research on how Russian names for "blue" affect color categorization and on the relation between brain lateralization and the effect of language on color perception.

CHAPTER 12 PROBLEM SOLVING

- Minor changes to this chapter focus on improving pedagogy.
- Newell-Simon approach and analogical problem solving sections rewritten and tables added for increased clarity.
- New *Something to Consider*: "Does Large Working Memory Capacity Result in Better Problem Solving? It Depends" (on the effect of stress on problem solving).

CHAPTER 13 REASONING AND DECISION MAKING

- Section on categorical and conditional syllogisms streamlined in response to feedback that the treatment in the second edition was too detailed.
- Section on decision making updated, with new material on how emotions affect decision making (using, as one example, the *Deal or No Deal* game show).

Ancillaries to Support Your Teaching

COGLAB 2.0 FOR GOLDSTEIN'S *COGNITIVE PSYCHOLOGY: CONNECTING MIND, RESEARCH, AND EVERYDAY EXPERIENCE*

Free with every new copy of this book, CogLab 2.0 lets your students do more than just think about cognition. CogLab 2.0 uses the power of the web to teach concepts using important classic and current experiments that demonstrate how the mind works. Nothing is more powerful for students than seeing for themselves the effects of these experiments! CogLab 2.0 includes features such as simplified student registration, a global database that combines data from students all around the world, between-subject designs that allow for new kinds of experiments, and a "quick display" of student summaries. Also included are trial-by-trial data, standard deviations, and improved instructions.

INSTRUCTOR MANUAL/TEST BANK (ISBN 0840033583)

This supplement contains chapter outlines, discussion questions, in-class demonstrations, term projects, and references to relevant websites. The test bank has approximately 65 multiple-choice questions and 5–7 essay questions per chapter. Each chapter has a section dedicated to CogLab online, providing discussion questions, experiments, and activities.

POWERLECTURE WITH EXAMVIEW (ISBN 0840034482)

PowerLecture instructor resources are a collection of book-specific lecture and class tools on either CD or DVD. The fastest and easiest way to build powerful, customized, media-rich lectures, PowerLecture assets include chapter-specific PowerPoint presentations, images, video, instructor manuals, test banks, and more. PowerLecture media teaching tools are an effective way to enhance the educational experience. Includes lecture outlines on PowerPoint.

BOOK COMPANION WEBSITE (WWW.CENGAGE.COM/PSYCHOLOGY/GOLDSTEIN)

When you adopt *Cognitive Psychology: Connecting Mind, Research, and Everyday Experience,* Third Edition, you and your students will have access to a rich array of teaching and learning resources that you won't find anywhere else. This outstanding site features multiple-choice questions, short essay questions, flashcards, crossword puzzles, web links, and a glossary.

Preface to Students

As you begin reading this book, you probably have some ideas about how the mind works from things you have read, from other media, and from your own experiences. In this book, you will learn what we actually do and do not know about the mind, as determined from the results of controlled scientific research. Thus, if you thought that there is a system called "short-term memory" that can hold information for short periods of time, then you are right; when you read the chapters on memory, you will learn more about this system and how it interacts with other parts of your memory system. If you thought that some people can accurately remember things that happened to them as very young infants, you will see that there is a good chance that these reports are inaccurate. In fact, you may be surprised to learn that even more recent memories that seem extremely clear and vivid may not be entirely accurate due to basic characteristics of the way the memory system works.

But what you will learn from this book goes much deeper than simply adding more accurate information to what you already know about the mind. You will learn that there is much more going on in your mind than you are conscious of. You are aware of experiences such as seeing something, remembering a past event, or thinking about how to solve a problem—but behind each of these experiences are a myriad of complex and largely invisible processes. Reading this book will help you appreciate some of the "behind the scenes" activity in your mind that is responsible for everyday experiences such as perceiving, remembering, and thinking.

Another thing you will become aware of as you read this book is that there are many practical connections between the results of cognitive psychology research and everyday life. You will see examples of these connections throughout the book. For now I want to focus on one especially important connection—what research in cognitive psychology can contribute to improving your studying. This discussion appears on pages 187–189 of Chapter 7, but you might want to look at this material now, rather than waiting until later in the course. I invite you to also consider the following two principles, which are designed to help you get more out of this book.

Principle 1: It is important to know what you know.

Professors often hear students lament, "I came to the lecture, read the chapters a number of times, and still didn't do well on the exam." Sometimes this statement is followed by ". . . and when I walked out of the exam, I thought I had done pretty well." If this is something that you have experienced, the problem may be that you didn't have a good awareness of what you knew about the material and what you didn't know. If you think you know the material but actually don't, you might stop studying or might continue studying in an ineffective way, with the net result being a poor understanding of the material and an inability to remember it accurately, come exam time. Thus, it is important to test yourself on the material you have read by writing or saying the answers to the Test Yourself questions in the chapter and also by taking advantage of the sample test questions that are available on the Book Companion Website. To access these questions and other valuable learning aids, go to www.cengage.com/psychology/goldstein.

Principle 2: Don't mistake ease and familiarity for knowing.

One of the main reasons that students may think they know the material, even when they don't, is that they mistake familiarity for understanding. Here is how it works: You read the chapter once, perhaps highlighting as you go. Then later, you read the chapter again, perhaps focusing on the highlighted material. As you read it over, the material is familiar because you remember it from before, and this familiarity might lead you to think, "Okay, I know that." The problem is that this feeling of familiarity is not necessarily equivalent to knowing the material and may be of no help when you have to come up with an answer on the exam. In fact, familiarity can often lead to errors on multiple-choice exams because you might pick a choice that looks familiar, only to find out later that although it was something you had read, it wasn't really the best answer to the question.

This brings us back again to the idea of testing yourself. One finding of cognitive psychology research is that the very act of *trying* to answer a question increases the chances that you will be able to answer it when you try again later. Another related finding is that testing yourself on the material is a more effective way of learning it than simply rereading the material. The reason testing yourself works is that *generating* material is a more effective way of getting information into memory than simply *reviewing* it. Thus, you may find it effective to test yourself before rereading the chapter or going over your highlighted text.

Whichever study tactic you find works best for you, keep in mind that an effective strategy is to rest (take a break or study something else) before studying more and then retesting yourself. Research has shown that memory is better when studying is spaced out over time, rather than being done all at once. Repeating this process a number of times—testing yourself, checking back to see whether you were right, waiting, testing yourself again, and so on—is a more effective way of learning the material than simply looking at it and getting that warm, fuzzy feeling of familiarity, which may not translate into actually knowing the material when you are faced with questions about it on the exam.

I hope you will find this book to be clear and interesting and that you will sometimes be fascinated or perhaps even surprised by some of the things you read. I also hope that your introduction to cognitive psychology extends beyond just "learning the material." Cognitive psychology is endlessly interesting because it is about one of the most fascinating of all topics—the human mind. Thus, once your course is over, I hope you will take away an appreciation for what cognitive psychologists have discovered about the mind and what still remains to be learned. I also hope that you will become a more critical consumer of information about the mind that you may encounter on the Internet or in movies, magazines, or other media. Finally, if you have any questions or comments about anything in the book, please feel free to contact me at bruceg@email.arizona.edu.

Acknowledgments

The starting point for a textbook like this one is an author who has an idea for a book, but other people soon become part of the process. Editors first provide guidance regarding the kind of book teachers want and, along with outside reviewers, provide feedback about chapters as they are written. When the manuscript is completed, the production process begins, and a new group of people take over to turn the manuscript into a book. This means that this book has been a group effort and that I had lots of help, both during the process of writing and after submitting the final manuscript. I would therefore like to thank the following people for their extraordinary efforts in support of this book.

- Jaime Perkins, my editor, for his continued support of this book, and particularly for doing what was necessary to make it possible to publish this book in full color.
- Kristin Makarewycz, my developmental editor, who read every word of every chapter and somehow, even after I had "perfected" the writing, found numerous ways to make it better. Also, thank you, Kristin, for the moral support along the way.
- Anne Draus of Scratchgravel Publishing Services, for dealing so expertly with the hundreds of details that have to be dealt with in the process of assembling a book. Thank you, Anne, for making the complex process of assembling all of the various components of this book seem easy, even though I know it wasn't. Also, thanks for your obsession with cats and dogs near the end of the process, which I completely enjoyed (pages 238–239, 263–264). And finally, thanks for the many ways that you supported the book and my efforts.
- Vernon Boes (a.k.a. Pablo), the art director, for directing the team responsible for the look and layout of this book and for being open to suggestions, even from the author!
- Cheryl Carrington, for yet another elegant and beautiful cover.
- Liz Harasymczuk, for the eye-catching and functional interior design.
- Lisa Torri, art editor, for yet again directing the art program for one of my books, this time as director of the illustrators at Precision Graphics, who carried out the daunting task of recreating more than 250 of the illustrations from the second edition in color, plus 80 new ones.
- Charlene Carpentier, content project manager, for making sure everything was done correctly and on time during the production process.
- Philip Hovanessian, editorial assistant extraordinaire, who really meant it when he said, "Let me know if there's anything else I can do for you." Thank you, Philip, for your support.
- Margaret Tropp, for her expert and extremely thorough copy editing that went beyond just "copy editing" to include pointing out places that needed further clarification.
- Martha Hall of Pre-Press PMG, for her photo research, for obtaining permissions, and for patiently waiting for my answers to her questions.
- Martha Ghent, for the essential task of proofreading.
- James Minkin, for creating the index.
- Paige Leeds, assistant editor, for coordinating the supplements for the book.
- Lauren Keyes, media editor, for her work on the media that accompanies the book.
- Carla and Steve Loper and the staff at Sertinos Café in Tucson, for providing the coffee and a writer-friendly environment that were essential for completing this book.

In addition to the help I received from the above people on the editorial and production side, I received a great deal of help from teachers and researchers who gave me feedback on what I wrote and made suggestions regarding new work in the field. I thank the following people for their help:

GENERAL REVIEWERS

Many of these reviewers read multiple chapters. They all provided invaluable input, based both on their expertise in specific areas and on their experience in teaching the course.

Pamela Ansburg
Metropolitan State College of Denver

Teresa A. Hutchens
University of Tennessee–Knoxville

Jerwen Jou
University of Texas–Pan American

Aarre Laakso
University of Michigan, Dearborn

Tracy Lennertz
Florida Atlantic University

Esin Esendal Provitera
Argosy University

Hildur Schilling
Fitchburg State College

Kenith V. Sobel
University of Central Arkansas

Lucy J. Troup
Colorado State University

Jennifer Zapf
University of Wisconsin–Green Bay

SPECIALIST REVIEWERS

A number of experts were commissioned to read one of the chapters from the second edition (indicated in parentheses) and provide suggestions on updating the content for the third edition to include cutting-edge research. What made many of these reviews especially helpful were suggestions that combined the reviewers' expertise with their experience of presenting the material in their classes.

Anne Cleary (Long-Term Memory)
Colorado State University

Nelson Cowan (Working Memory)
University of Missouri

Tim Curran (Long-Term Memory)
University of Colorado

Michael Dodd (Attention)
University of Nebraska

Jason Hicks (Everyday Memory and Memory Errors)
Louisiana State University

Marsha Lovett (Problem Solving)
Carnegie-Mellon University

Richard Marsh (Everyday Memory and Memory Errors)
University of Georgia

Akira Miyake (Working Memory)
University of Colorado

Paul Price (Reasoning and Decision Making)
California State University at Fresno

Michael Tanenhaus (Language)
University of Rochester

Matthew Traxler (Language)
University of California at Davis

In addition, the following reviewers read parts of chapters to check for accuracy in their areas of expertise.

Marlene Behrmann
Carnegie-Mellon University

Sian Beilock
University of Chicago

Alain Brunet
McGill University

Jason C. K. Chan
Iowa State University

Marci DeCaro
Vanderbilt University

David Freedman
University of Chicago

Wayne D. Gray
Rensselaer Polytechnic Institute

Tiago Maia
Columbia University

Jay McClelland
Stanford University

Paul Quinn
University of Delaware

Svetlana Shinkareva
University of South Carolina

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

Mary Bravo
Rutgers University

Linda Chao
University of California, San Francisco

David Freedman
University of Chicago

Olaf Hauk
Medical Research Council, Cambridge, UK

Mary Hayhoe
University of Texas

Brian Henderson
University of Edinburgh

Andrew Hollingworth
University of Iowa

Brian Levine
University of Toronto

Aude Oliva
Massachusetts Institute of Technology

Friedmann Pulvermuller
Medical Research Council, Cambridge, UK

Svetlana Shinkareva
University of South Carolina

Antonio Torralba
Massachusetts Institute of Technology

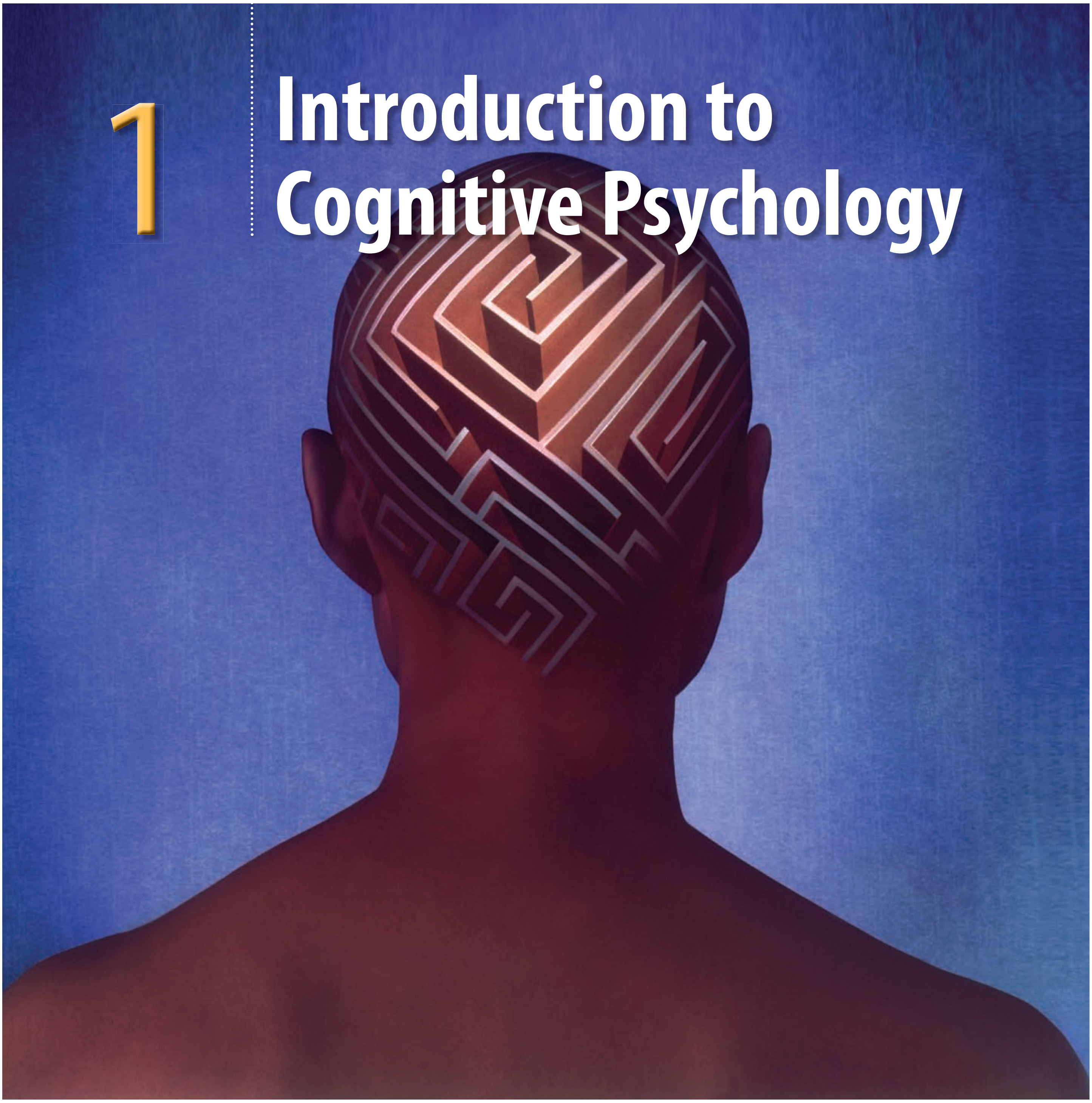
Melissa Võ
Harvard University

Jonathan Winawer
Stanford University

Jeffrey Zacks
Washington University

Cognitive Psychology

1 Introduction to Cognitive Psychology



Dianna Sarto/CORBIS

▸ How is cognitive psychology relevant to everyday experience? (4)

▸ Are there practical applications of cognitive psychology? (4)

▸ How is it possible to study the inner workings of the mind, when we can't really see the mind directly? (7)

▸ What is the connection between computers and the study of the mind? (13–14)

As Raphael is walking across campus, talking to Susan on his cell phone about meeting at the student union later this afternoon, he remembers that he left the book she had lent him at home (● Figure 1.1). "I can't believe it," he thinks, "I can see it sitting there on my desk, where I left it. I should have put it in my backpack last night when I was thinking about it."

As he finishes his call with Susan and makes a mental note to be on time for their appointment, his thoughts shift to how he is going to survive after Wednesday when his car is scheduled to go into the shop. Renting a car offers the most mobility, but is expensive. Bumming rides from his roommate is cheap, but limiting. "Perhaps I'll pick up a bus schedule at the student union," he thinks, as he puts his cell phone in his pocket.

Entering his anthropology class, he remembers that an exam is coming up soon. Unfortunately, he still has a lot of reading to do, so he decides that he won't be able to take Susan to the movies tonight, as they had planned, because he needs time to study. As the lecture begins, Raphael is anticipating, with some anxiety, his meeting with Susan.

This brief slice of Raphael's life is noteworthy because it is ordinary, while at the same time so much is happening. Within a short span of time, Raphael does the following things that are related to material covered in chapters in this book:

- *Perceives* his environment—seeing people on campus and hearing Susan talking on the phone (Chapter 3: Perception)
- *Pays attention* to one thing after another—the person approaching on his left, what Susan is saying, how much time he has to get to his class (Chapter 4: Attention)
- *Remembers* something from the past—that he had told Susan he was going to return her book today (Chapters 5–8: Memory)
- *Distinguishes items in a category*, when he thinks about different possible forms of transportation—rental car, roommate's car, bus (Chapter 9: Knowledge)
- *Visualizes* the book on his desk the night before (Chapter 10: Visual imagery)
- *Understands and produces language* as he talks to Susan (Chapter 11: Language)
- Works to *solve a problem*, as he thinks about how to get places while his car is in the shop (Chapter 12: Problem Solving)
- *Makes a decision*, when he decides to postpone going to the movies with Susan so he can study (Chapter 13: Reasoning and Decision Making)

● **FIGURE 1.1** What's happening in Raphael's mind as he walks across campus? Each of the "thought bubbles" corresponds to something in the story in the text.

The things Raphael is doing not only are covered in this book but also have something very important in common: They all involve the mind. **Cognitive psychology** is the branch of psychology concerned with the scientific study of the mind. As you read the story about the quest to understand the mind, you will learn what the mind is, how it has been studied, and what researchers have discovered about how the mind works. In this chapter we will first describe the mind in more detail, then consider some of the history behind the field of cognitive psychology, and finally introduce a few of the ways that modern cognitive psychologists have gone about studying the mind.

Cognitive Psychology: Studying the Mind

You may have noticed that we have been using the term **mind** without precisely defining it. As we will see, mind, like other concepts in psychology, such as intelligence or emotion, can be thought of in a number of different ways.

WHAT IS THE MIND?

One way to approach the question "What is the mind?" is to consider how "mind" is used in everyday conversation. Here are a few examples:

1. "He was able to call to mind what he was doing on the day of the accident." (The mind as involved in memory)
2. "If you put your mind to it, I'm sure you can solve that math problem." (The mind as problem-solver)
3. "I haven't made up my mind yet" or "I'm of two minds about this." (The mind as used to make decisions or consider possibilities)
4. "He is of sound mind and body" or "When he talks about his encounter with aliens, it sounds like he is out of his mind." (A healthy mind being associated with normal functioning, a nonfunctioning mind with abnormal functioning)
5. "A mind is a terrible thing to waste." (The mind as valuable, something that should be used)
6. "He has a beautiful mind." (From Sylvia Nasar's book *A Beautiful Mind*, about Nobel Prize winner John Nash, which was made into an Academy Award–winning movie staring Russell Crowe)

These statements tell us some important things about what the mind is. Statements 1, 2, and 3, which highlight the mind's role in memory, problem solving, and making decisions, are related to the following definition of the mind: *The **mind** creates and controls mental functions such as perception, attention, memory, emotions, language, deciding, thinking, and reasoning*. This definition reflects the mind's central role in determining our various mental abilities, which are reflected in the titles of the chapters in this book.

Statement 4 is related to another definition of the mind: *The mind is a system that creates representations of the world so that we can act within it to achieve our goals*. This definition reflects the mind's importance for functioning and survival, and also provides the beginnings of a description of how the mind achieves these ends. The idea of creating representations is something we will return to throughout this book.

These two definitions of the mind are not incompatible. The first one indicates different types of **cognition**—the mental processes such as perception attention, memory, and so on, that are what the mind does. The second definition indicates something about how the mind operates (it creates representations) and its function (it enables us to act and to achieve goals). It is no coincidence that all of the cognitions in the first definition play important roles in acting to achieve goals.

The final two everyday statements about the mind emphasize the importance and beauty of the mind. The mind is something to be used, and the products of some people's minds are considered extraordinary. But one of the messages of this book is that the "beauty" of the mind is not reserved for "extraordinary" minds, because even the most "routine" things—recognizing a person, having a conversation, or deciding what courses to take next semester—become amazing in themselves when we consider the properties of the mind that enable us to achieve these familiar activities.

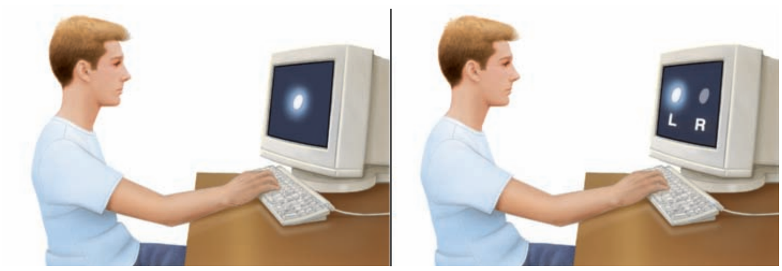
What exactly are the properties of the mind? What are its characteristics? How does it operate? Saying that the mind creates cognition and is important for functioning and survival tells us *what the mind does* but not *how it achieves what it does*. Determining the properties and mechanisms of the mind is what cognitive psychology is about. Our goal in the rest of this chapter is to describe how the field of cognitive psychology evolved from its early beginnings to where it is today, and to begin describing how cognitive psychologists approach the scientific study of the mind.

STUDYING THE MIND: EARLY WORK IN COGNITIVE PSYCHOLOGY

The idea that the mind can be studied scientifically is a modern one. In the 1800s, ideas about the mind were dominated by the belief that it is not possible to study the mind. One reason given was that it is not possible for the mind to study itself, but there were other reasons as well, including the idea that the properties of the mind simply cannot be measured. Nonetheless, some researchers defied the common wisdom and decided to study the mind anyway. One of these people was the Dutch physiologist Franciscus Donders, who in 1868, eleven years before the founding of the first laboratory of scientific psychology, did one of the first experiments that today would be called a cognitive psychology experiment. (It is important to note that the term "cognitive psychology" was not coined until 1967, but the early experiments we are going to describe qualify as cognitive psychology experiments.)

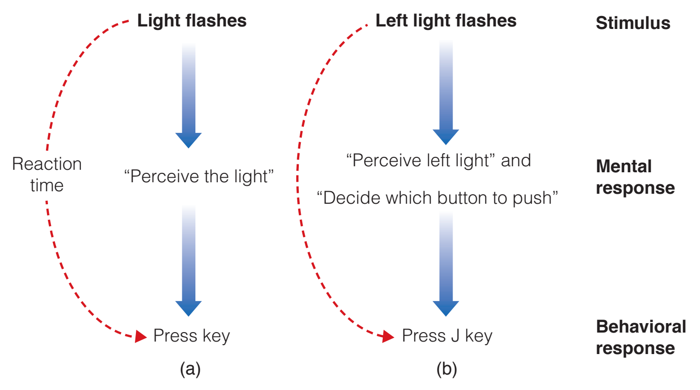
Donders' Pioneering Experiment: How Long Does It Take to Make a Decision?

Donders was interested in determining how long it takes for a person to make a decision. He determined this by measuring **reaction time**, how long it takes to respond to presentation of a stimulus. In the first part of his experiment, he asked his participants to press a button upon presentation of a light (● Figure 1.2a). This is called



(a) Press J when light goes on. (b) Press J for left light, K for right.

● **FIGURE 1.2** A modern version of Donders' (1868) reaction time experiment: (a) the simple reaction time task; and (b) the choice reaction time task. In the simple reaction time task, the participant pushes the J key when the light goes on. In the choice reaction time task, the participant pushes the J key if the left light goes on and the K key if the right light goes on. The purpose of Donders' experiment was to determine the time it took to decide which key to press for the choice reaction time task.



● **FIGURE 1.3** Sequence of events between presentation of the stimulus and the behavioral response in Donders' experiment. The dashed line indicates that Donders measured reaction time, the time between presentation of the light and the participant's response. (a) Simple reaction time task; (b) choice reaction time task.

a **simple reaction time** task. In the second part of the experiment, he made the task more difficult by presenting two lights, one on the left and one on the right. The participants' task in this part of the experiment was to push one button when the light on the left was illuminated and another button when the light on the right was illuminated (Figure 1.2b). This is called a **choice reaction time** task.

The rationale behind the simple reaction time task is shown in ● Figure 1.3a. Presenting the stimulus (the light) causes a mental response (perceiving the light), which leads to a behavioral response (pushing the button). The reaction time (dashed line) is the time between presentation of the stimulus and the behavioral response.

The diagram for the choice reaction time task in Figure 1.3b shows that the mental response includes not only perceiving the light but also deciding which button to push. Donders reasoned that choice reaction time would be longer than simple reaction time because of the additional time it takes to make the decision, and that the difference in reaction time between the simple and choice conditions would indicate how long it took to make the decision. Because the choice reaction time took one-tenth of a second longer than simple reaction time, Donders concluded that it took one-tenth of a second to decide which button to push.

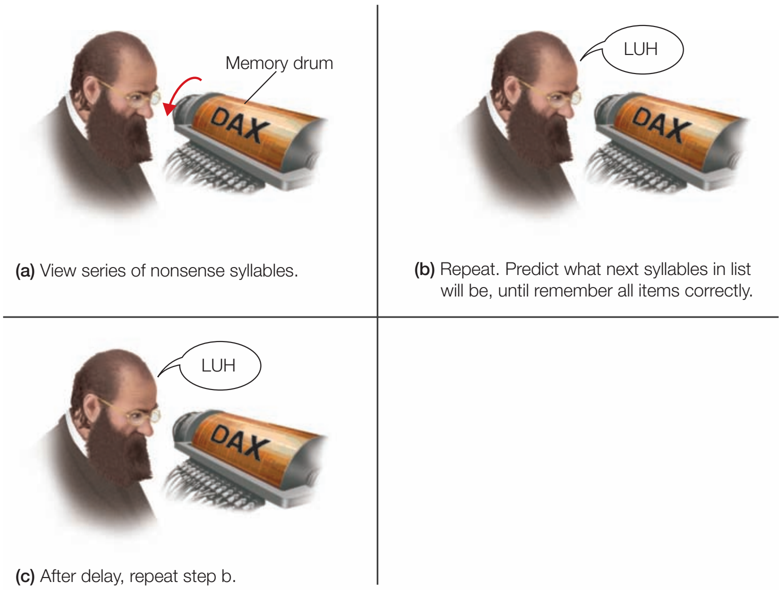
Donders' experiment is important, both because it was one of the first cognitive psychology experiments and because it illustrates something extremely significant about studying the mind: Mental responses (perceiving the light and deciding which button to push, in this example) cannot be measured directly, but must be *inferred* from behavior. We can see why this is so by noting the dashed lines in Figure 1.3. These lines indicate that when Donders measured the reaction time, he was measuring the relationship between the presentation of the stimulus and the participant's response. He did not measure the mental response directly, but *inferred* how long it took from the reaction times. The fact that mental responses can't be measured directly, but must be inferred from observing behavior, is a principle that holds not only for Donders' experiment but for all research in cognitive psychology.

Ebbinghaus's Memory Experiment: What Is the Time-Course of Forgetting? Another pioneering approach to measuring the properties of the mind was devised by Hermann Ebbinghaus (1885/1913). Ebbinghaus was interested in determining the nature of memory and forgetting—specifically, how information that is learned is lost over time. Ebbinghaus determined this by testing himself, using the procedure shown in ● Figure 1.4. He presented nonsense syllables such as DAX, QEH, LUH, and ZIF to himself one at a time, using a device called a memory drum (modern cognitive psychologists would use a computer). He used nonsense syllables so that his memory would not be influenced by the meaning of a particular word.

The first time through the list, he looked at each syllable one at a time and tried to learn them in order (Figure 1.4a). The second time through, his task was to begin by remembering the first syllable on the list, look at it in the memory drum to see if he was correct, then remember the second syllable, check to see if he was correct, and so on (Figure 1.4b). He repeated the procedure, going through the list and trying to remember each syllable in turn, until he was able to go through the list without making any errors. He noted the number of trials it took him to do this.

After learning a list, Ebbinghaus waited, for delays ranging from almost immediately after learning the list to 31 days. He then repeated the above procedure for each

● **FIGURE 1.4** Ebbinghaus's memory drum procedure for measuring memory and forgetting. (a) Initial viewing—going through the list of nonsense syllables for the first time. (b) Learning the list—going through the list a number of times until each syllable can be correctly predicted from the one before. The number of repetitions necessary to learn the list is noted. (c) After a delay, the list is relearned. The number of repetitions needed to relearn the list is noted.



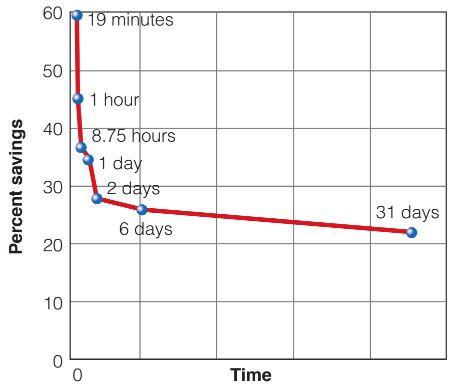
list and noted how many trials it took him to remember all of the syllables without any errors (Figure 1.4c). He used the **savings method** to analyze his results, calculating the savings by subtracting the number of trials needed to learn the list after a delay from the number of trials it took to learn the list the first time. He then calculated a *savings score* for each delay interval, using the following formula:

$$\text{Savings} = [(\text{Initial repetitions}) - (\text{Relearning repetitions})/\text{Initial repetitions}] \times 100$$

Ebbinghaus found that the savings were greater for short intervals than for long. For example, after a short interval it may have taken him 3 trials to relearn the list. If it had taken him 9 trials to learn the list the first time, then the savings score would be 67 percent ($[(9 - 3)/9] \times 100 = 67$ percent). If after a longer interval it took 6 trials to learn the list the second time, his savings score would be 33 percent.

Ebbinghaus's "savings curve" (● Figure 1.5) shows savings as a function of retention interval. The curve indicates that memory drops rapidly for the first 2 days after the initial learning and then levels off. This curve was important because it demonstrated that memory could be quantified and that functions like the forgetting curve could be used to describe a property of the mind—in this case, the ability to retain information. Notice that although Ebbinghaus's savings method was very different from Donders' reaction time method, both measured *behavior* to determine a property of the *mind*.

Wundt's Psychology Laboratory: Structuralism and Analytic Introspection In 1879, Wilhelm Wundt founded the first laboratory of scientific psychology at the University of Leipzig in Germany, with the goal of studying the mind scientifically. Wundt's approach, which dominated psychology in the late 1800s and early 1900s, was called **structuralism**. According to structuralism, our overall experience is determined by combining basic elements of experience the structuralists called *sensations*. Thus, just as chemistry had developed a periodic table of the elements, which organized elements on the basis of their molecular weights and chemical properties, Wundt wanted to create a "periodic table of the mind," which would include all of the basic sensations involved in creating experience. Wundt thought he could achieve this by using **analytic introspection**, a technique in which trained participants described their experiences and



● **FIGURE 1.5** Ebbinghaus's savings (or forgetting) curve. Taking the percent savings as a measure of the amount remembered, Ebbinghaus plotted this against the time interval between initial learning and testing. (Source: Based on data from Ebbinghaus, 1885/1913.)

thought processes in response to stimuli. For example, in one experiment, Wundt asked participants to describe their experience of hearing a five-note chord played on the piano. Wundt was interested in whether they heard the five notes as a single unit or if they were able to hear the individual notes.

Although Wundt never achieved his goal of explaining behavior in terms of sensations, he had a major impact on psychology by establishing the first laboratory of scientific psychology and training PhDs who established psychology departments at other universities, including many in the United States.

William James: *Principles of Psychology* William James, one of the early American psychologists (although not a student of Wundt's), taught Harvard's first psychology course and made significant observations about the mind in his textbook, *Principles of Psychology* (1890). James' observations were based not on the results of experiments, but on introspections about the operation of his own mind. His skill in doing this is reflected in the fact that many of his observations still ring true today, and his book is notable for the breadth of its coverage. In it, James covers a wide range of cognitive topics, including thinking, consciousness, attention, memory, perception, imagination, and reasoning.

The work of Donders, Ebbinghaus, Wundt, James, and others provided what seemed to be a promising start to the study of the mind. However, research on the mind was to soon to be curtailed, largely because of events early in the 20th century that shifted the focus of psychology away from the study of the mind and mental processes. One of the major forces that caused psychology to reject the study of mental processes was a negative reaction to the technique of analytic introspection.

Abandoning the Study of the Mind

Research in many early departments of psychology was conducted in the tradition of Wundt's laboratory, using analytic introspection to reveal hidden mental processes. This emphasis on studying the mind was to change, however, because of the efforts of John Watson, who received his PhD in psychology in 1904 from the University of Chicago.

WATSON FOUNDS BEHAVIORISM

The story of how John Watson founded an approach to psychology called behaviorism is well known to introductory psychology students. We will briefly review it here because of its importance to the history of cognitive psychology.

As a graduate student at the University of Chicago, Watson became dissatisfied with the method of analytic introspection. His problems with this method were (1) it produced extremely variable results from person to person, and (2) these results were difficult to verify because they were interpreted in terms of invisible inner mental processes. In response to what he perceived to be deficiencies in analytic introspection, Watson proposed a new approach called **behaviorism**. One of Watson's papers, "Psychology As the Behaviorist Views It," set forth the goals of this approach to psychology in this famous quote:

> Psychology as the Behaviorist sees it is a purely objective, experimental branch of natural science. Its theoretical goal is the prediction and control of behavior. *Introspection forms no essential part of its methods*, nor is the scientific value of its data dependent upon the readiness with which they lend themselves to interpretation in terms of consciousness. . . . What we need to do is start work upon psychology *making behavior, not consciousness, the objective point of our attack*. (Watson, 1913, pp. 158, 176; emphasis added)

● **FIGURE 1.6** In Pavlov's famous experiment, he paired ringing a bell with presentation of food. Initially, only presentation of the food caused the dog to salivate, but after a number of pairings of bell and food, the bell alone caused salivation. This principle of learning by pairing, which came to be called classical conditioning, was the basis of Watson's "Little Albert" experiment.

This passage makes two key points: (1) Watson rejects introspection as a method, and (2) observable behavior, not consciousness (which would involve unobservable processes such as thinking, emotions, and reasoning), is the main topic of study. In another part of this paper, Watson also proclaims that "psychology . . . need no longer delude itself into thinking that it is making mental states the object of observation" (p. 163). Watson's goal was to eliminate the mind as a topic of study in psychology and replace it with the study of directly observable behavior.

As behaviorism became the dominant force in American psychology, psychologists' attention shifted from asking "What does behavior tell us about the mind?" to "What is the relation between stimuli in the environment and behavior?" Thus, the focus shifted from the mind as the topic of study to behavior (with no reference to the mind) as the topic.

Watson's most famous experiment was the "Little Albert experiment," in which Watson and Rosalie Rayner (1920) subjected Albert, a 9-month-old-boy, to a loud noise every time a rat (which Albert had originally liked) came close to the child. After a few pairings of the noise with the rat, Albert reacted to the rat by crawling away as rapidly as possible.

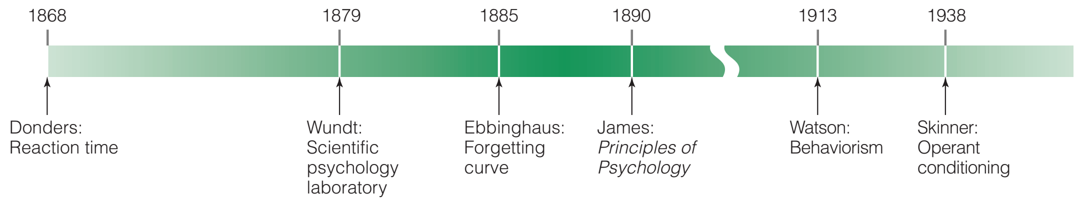
Watson's ideas are associated with **classical conditioning**—how pairing one stimulus (such as the loud noise presented to Albert) with another, previously neutral stimulus (such as the rat) causes changes in the response to the neutral stimulus. Watson's inspiration for his experiment was Ivan Pavlov's research, begun in the 1890s, that demonstrated classical conditioning in dogs. In these experiments (● Figure 1.6), Pavlov's pairing of food (which made the dog salivate) with a bell (the initially neutral stimulus) caused the dog to salivate to the sound of the bell (Pavlov, 1927).

Watson used classical conditioning to argue that behavior can be analyzed without any reference to the mind. For Watson, what was going on inside Albert's head, either physiologically or mentally, was irrelevant. He only cared about how pairing one stimulus with another affected Albert's behavior.

SKINNER'S OPERANT CONDITIONING

In the midst of behaviorism's dominance of American psychology, B. F. Skinner, a young graduate student at Harvard, provided another tool for behaviorism, which insured this approach would dominate psychology for decades to come. Skinner introduced **operant conditioning**, which focused on how behavior is strengthened by the presentation of positive reinforcers, such as food or social approval (or withdrawal of negative reinforcers, such as a shock or social rejection). For example, Skinner showed that reinforcing a rat with food for pressing a bar maintained or increased the rat's rate of bar pressing. Like Watson, Skinner was not interested in what was happening in the mind, but focused solely on determining the relationship between stimuli and responses (Skinner, 1938).

The idea that behavior can be understood by studying stimulus-response relationships influenced an entire generation of psychologists and dominated psychology in the United States from the 1940s through the 1960s. Psychologists applied the techniques of classical and operant conditioning to things like classroom teaching, treating psychological disorders, and testing the effects of drugs on animals. ● Figure 1.7 is a timeline showing the initial studies of the mind and the rise of behaviorism. We now move beyond this timeline to the 1950s, when changes began to occur in psychology that eventually led to a decline in the influence of behaviorism.

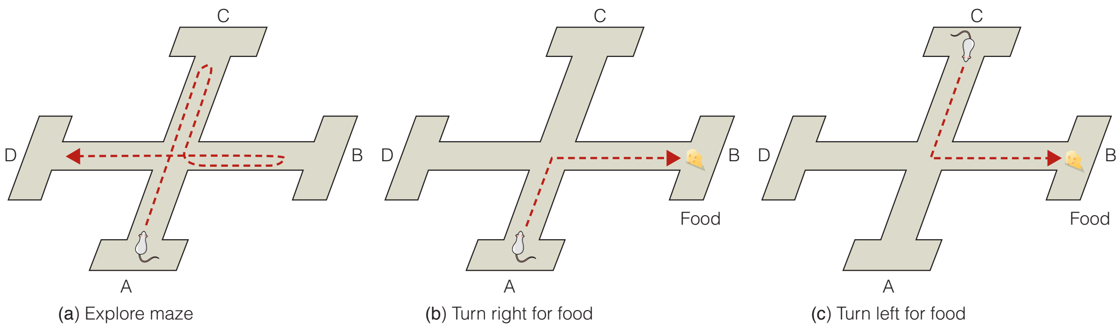


● **FIGURE 1.7** Timeline showing early experiments studying the mind in the 1800s and events associated with the rise of behaviorism in the 1900s.

SETTING THE STAGE FOR THE REEMERGENCE OF THE MIND IN PSYCHOLOGY

Although behaviorism dominated American psychology for many decades, there were some researchers who were not toeing the strict behaviorist line. One of these researchers was Edward Chance Tolman. Tolman, who, from 1918 to 1954 was at the University of California at Berkeley, called himself a behaviorist because his focus was on measuring behavior. But in reality he was one of the early cognitive psychologists, because he used behavior to infer mental processes.

In one of his experiments, Tolman (1938) placed a rat in a maze like the one in ● Figure 1.8. Initially the rat explored the maze, running up and down each of the alleys (Figure 1.8a). After this initial period of exploration, the rat was placed at A and food was placed at B, and the rat quickly learned to turn right at the intersection to obtain the food. This is exactly what the behaviorists would predict, because turning right was rewarded with food (Figure 1.8b). However, when Tolman then placed the rat at C, something interesting happened. At the intersection, the rat turned *left* to reach the food at B (Figure 1.8c). Tolman's explanation of this result was that when the rat initially experienced the maze it was developing a **cognitive map**, a conception of the maze's layout (Tolman, 1948). Thus, even though the rat had previously learned to turn right, when the rat was placed at C, it used its map to turn left at the intersection to reach the food at B. Tolman's use of the word *cognitive*, and the idea that something other than stimulus-response



● **FIGURE 1.8** Maze used by Tolman. (a) Rat initially explores the maze; (b) the rat learns to turn right to obtain food at B when it starts at A; (c) when placed at C the rat turns left to reach the food at B. In this experiment, precautions are taken to prevent the rat from knowing where the food is based on cues such as smell.

connections might be occurring in the rat's mind, placed Tolman outside of mainstream behaviorism.

Other researchers were aware of Tolman's work, but for most American psychologists in the 1940s, the use of the term *cognitive* was difficult to accept because it violated the behaviorists' idea that internal processes, such as thinking or maps in the head, were not acceptable topics to study. It wasn't until about a decade after Tolman introduced the idea of cognitive maps that developments occurred that were to lead to a resurgence of the mind in psychology. Ironically, one of these developments was the publication, in 1957, of a book by B. F. Skinner titled *Verbal Behavior*. In this book, Skinner argued that children learn language through operant conditioning. According to this idea, children imitate speech that they hear and repeat correct speech because it is rewarded. But in 1959 Noam Chomsky, a linguist from the Massachusetts Institute of Technology, published a scathing review of Skinner's book, in which he pointed out that children say many sentences that have never been rewarded by parents ("I hate you, Mommy," for example), and that during the normal course of language development, they go through a stage in which they use incorrect grammar, such as "the boy hitted the ball," even though this incorrect grammar may never have been reinforced.

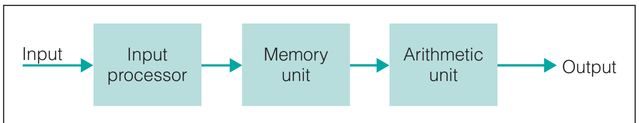
Chomsky saw language development as being determined not by imitation or reinforcement, but by an inborn biological program that holds across cultures. Chomsky's idea that language is a product of the way the mind is constructed, as opposed to being caused by reinforcement, led psychologists to reconsider the idea that language and other complex behaviors, such as problem solving and reasoning, can be explained by operant conditioning. Instead, they began to realize that to understand complex cognitive behaviors, it is necessary not only to measure observable behavior, but also to consider what this behavior tells us about how the mind works.

The Rebirth of the Study of the Mind

The decade of the 1950s is generally recognized as the beginning of the **cognitive revolution**—a shift in psychology from the behaviorist's stimulus-response relationships to an approach whose main thrust was to understand the operation of the mind. Chomsky's critique of Skinner's book was only one of many events in the 1950s that reintroduced the mind to psychology. These events provided a new way to study the mind, called the **information-processing approach**—an approach that traces the sequence of mental operations involved in cognition. One of the events that inspired psychologists to think of the mind in terms of information processing was a newly introduced device called the digital computer.

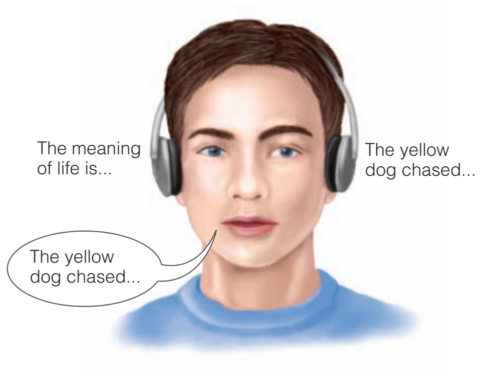
INTRODUCTION OF THE DIGITAL COMPUTER

The first digital computers, developed in the late 1940s, were huge machines that took up entire buildings, but in 1954 IBM introduced a computer that was available to the general public. These computers were still extremely large compared to the laptops of today, but they found their way into university research laboratories, where they were used both to analyze data and, most important for our purposes, to suggest a new way of thinking about the mind.



● **FIGURE 1.9** Flow diagram for an early computer.

Flow Diagrams for Digital Computers One of the characteristics of computers that captured the attention of psychologists in the 1950s was that they processed information in stages. For example, the diagram in ● Figure 1.9 shows the layout of a computer in which information is received by an "input processor" and is then stored in a "memory unit" before it is processed



● **FIGURE 1.10** This person in Colin Cherry's (1953) selective attention experiment is listening to the message being presented to his left ear (the attended message) and not to the message presented to his right ear (the unattended message). He repeats the attended message out loud to indicate that he is paying attention to it. The results of experiments such as this were used by Broadbent to create his filter model of attention.

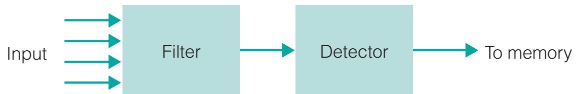
by an "arithmetic unit," which then creates the computer's output. Using this stage approach as their inspiration, some psychologists proposed the then-revolutionary idea that the operation of the mind could also be described as occurring in a number of stages. Applying this stage approach to the mind led psychologists to ask new questions and to frame their answers to these questions in new ways. One of the first experiments influenced by this new way of thinking about the mind involved studying how well people are able to pay attention to only some information when a lot of information is being presented at the same time.

Flow Diagrams for the Mind Beginning in the 1950s, a number of researchers became interested in describing how well the mind can deal with incoming information. One question they were interested in answering was: When a number of auditory messages are presented at once (as might occur at a noisy party, for example), can a person focus on just one of these messages (as when you are having a conversation with one of the people at the party)? In one experiment, by British psychologist Colin Cherry (1953), participants were presented with two messages simultaneously, one to the left ear and one to the right (● Figure 1.10), and were told to focus their attention on one of the messages (called the *attended message*) and to ignore the other one (called the *unattended message*).

The results of this experiment, which we will describe in detail when we discuss attention in Chapter 4, is that people could focus their attention on the message presented to one ear, and when they did, they were aware of little of the message being presented to the other, unattended ear. This result led another British psychologist, Donald Broadbent (1958), to propose the first flow diagram of the mind (● Figure 1.11). This diagram represented what happens in a person's mind as he or she directs attention to one stimulus in the environment. This flow diagram, which we will describe in more detail in Chapter 4, is notable because it was the first to depict the mind as processing information in a sequence of stages. Applied to the attention experiments, "input" would be the sounds entering the person's ears; the "filter" lets through only the part of the input to which the person is attending; and the "detector" records the information that gets through the filter.

Applied to your experience when talking to a friend at a noisy party, the filter lets in your friend's conversation and filters out all of the other conversations and noise. Thus, although you might be aware that there are other people talking, you would not be aware of detailed information, such as what the other people were talking about.

Broadbent's flow diagram provided a way to analyze the operation of the mind in terms of a sequence of processing stages and proposed a **model** that could be tested by further experiments. You will see many more flow diagrams like this throughout this book because they have become one of the standard ways of depicting the operation of the mind.



● **FIGURE 1.11** Flow diagram for Broadbent's filter model of attention. This diagram shows that many messages enter a "filter" that selects the message to which the person is attending for further processing by a detector and then storage in memory. We will describe this diagram more fully in Chapter 4.

CONFERENCES ON ARTIFICIAL INTELLIGENCE AND INFORMATION THEORY

In the early 1950s John McCarthy, a young professor of mathematics at Dartmouth College, had an idea. Would it be possible, McCarthy wondered, to program computers to mimic the operation of the human mind? Rather than simply asking the question, McCarthy decided to do something about it by organizing a conference at Dartmouth in the summer of 1956 to provide a forum for researchers to discuss ways that computers could be programmed to carry out intelligent behavior. The title of the conference, Summer

Research Project on Artificial Intelligence, was the first use of the term **artificial intelligence**. McCarthy defined the artificial intelligence approach as "making a machine behave in ways that would be called intelligent if a human were so behaving" (McCarthy et al., 1955).

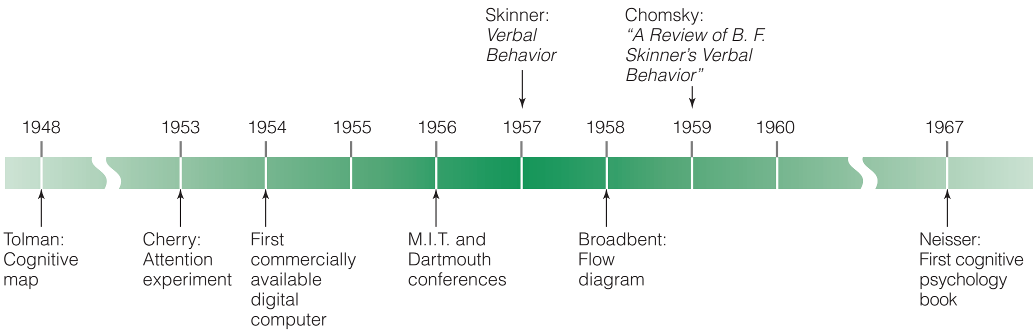
Researchers from a number of different disciplines—psychologists, mathematicians, computer scientists, linguists, and experts in information theory—attended the conference, which spanned 10 weeks. A number of people attended most of the conference, others dropped in and out, but perhaps the two most important participants of all—Herb Simon and Alan Newell from Carnegie Institute of Technology—were hardly there at all (Boden, 2006). The reason they weren't there is that they were busy trying to create the artificial intelligence machine that McCarthy had envisioned. Simon and Newell's goal was to create a computer program that could create proofs for problems in logic—something that up until then had only been achieved by humans.

Newell and Simon succeeded in creating the program, which they called the **logic theorist**, in time to demonstrate it at the conference. What they demonstrated was revolutionary, because the logic theorist program was able to create proofs of mathematical theorems that involve principles of logic too complex to describe here. This program, although primitive compared to modern artificial intelligence programs, was a real "thinking machine" because it did more than simply process numbers—it used human-like reasoning processes to solve problems.

Shortly after the Dartmouth conference, in September of the same year, another pivotal conference was held, the Massachusetts Institute of Technology Symposium on Information Theory. This conference provided another opportunity for Newell and Simon to demonstrate their logic theorist program, and the attendees also heard George Miller, a Harvard psychologist, present a version of his paper "The Magical Number 7 Plus or Minus 2," which had just been published (Miller, 1956). In that paper, Miller presented the idea that there are limits to the human's ability to process information—that the information processing of the human mind is limited to about 7 items (for example, the length of a telephone number). As we will see when we discuss this idea in Chapter 5, there are ways to increase our ability to take in and remember information (for example, we have little trouble adding an area code to the 7 digits of many telephone numbers). Nonetheless, Miller's basic principle that there are limits to the amount of information we can take in and remember was an important idea, which, you might notice, was similar to the point being made by Broadbent's filter model at about the same time.

The events we have described, Broadbent's filter model and the two conferences in 1956, represented the beginning of a shift in psychology from behaviorism to the study of the mind. This shift has been called the cognitive revolution, but the word *revolution* should not be interpreted as meaning that the shift from behaviorism to the cognitive approach occurred quickly. The scientists attending the conferences in 1956 had no idea that these conferences would, years later, be seen as historic events in the birth of a new way of thinking about the mind or that scientific historians would someday call 1956 "the birthday of cognitive science" (Bechtel et al., 1998; Miller, 2003; Neisser, 1988). In fact, even years after these meetings, a textbook on the history of psychology made no mention of the cognitive approach (Misiak & Sexton, 1966), and it wasn't until 1967 that Ulrich Neisser published a textbook with the title *Cognitive Psychology* (Neisser, 1967).

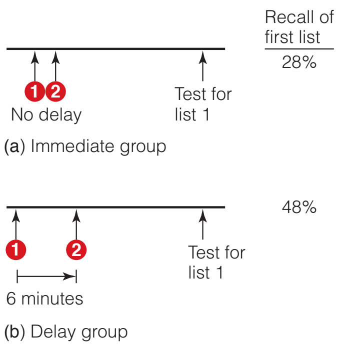
Neisser's textbook, which coined the term *cognitive psychology* and emphasized the information-processing approach to studying the mind is, in a sense, the grandfather of the book you are now reading. As often happens, each successive generation creates new ways of approaching problems, and cognitive psychology has been no exception. Since the 1956 conferences and the 1967 textbook, many experiments have been carried out, new theories proposed, and new techniques developed; as a result, cognitive psychology, and the information-processing approach to studying the mind, has become one of the dominant approaches in psychology. ● Figure 1.12 shows a timeline illustrating the events that led to the establishment of the field of cognitive psychology.



● **FIGURE 1.12** Timeline showing events associated with the decline of the influence of behaviorism (above the line) and events that led to the development of the information-processing approach to cognitive psychology (below the line).

Researching the Mind

How is the mind studied? The basic principle of using behavior to infer mental processes, as Donders did, still guides present-day research. In addition, new technologies have enabled psychologists to expand their research to also study the relation between mental processes and the brain. To illustrate how cognitive psychologists have used both **behavioral** and **physiological approaches** to studying the operation of the mind, we will now describe a few experiments designed to study a phenomenon called *memory consolidation*.



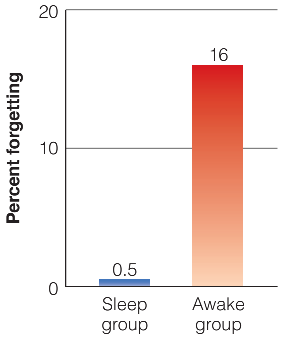
● **FIGURE 1.13** Procedure for Muller and Pilzecker's experiment. (a) In the immediate condition, participants learned the first list (1) and then immediately learned the second list (2). (b) In the delay condition, the second list was learned after a 6-minute delay. Numbers on the right indicate the percentage of items from the first list recalled when memory for that list was tested later.

MEMORY CONSOLIDATION FROM A BEHAVIORAL PERSPECTIVE

A football player is running downfield, the ball tucked securely under his arm. Suddenly, his run is unexpectedly cut short by a vicious tackle. His helmet hits the ground, and he lies still for a few moments before slowly getting up and making his way back to the bench. Later, sitting on the bench, he can't remember getting hit, or even taking the handoff from the quarterback at the beginning of the play.

The football player's lack of memory for the events that occurred just before he got hit illustrate that our memory for recent events is fragile. Normally, he would have had no trouble remembering the handoff and run, but the hit he took wiped out his memory for these events. More accurately, the hit prevented the information about the handoff and run from undergoing a process called **memory consolidation**, during which the information about the handoff and run, which was in a fragile state, could become strengthened and transformed into a strong memory that is more resistant to interference by events such as taking a hit to the head.

Research on the phenomenon of memory consolidation dates back to the beginnings of the study of cognition, when the German psychologists Georg Muller and Alfons Pilzecker (1900; also see Deware et al., 2007) had two groups of participants each learn two lists of nonsense syllables. The "immediate" group learned one list and were then asked to immediately learn a second list. The "delay" group learned the first list and then waited for 6 minutes before learning the second list (● Figure 1.13). When recall for the first list was then measured, participants in the delay group remembered 48 percent of the syllables, but participants in the immediate group remembered only 28 percent of the syllables. Apparently, immediately presenting the second list to the immediate group interrupted the forming of a stable memory for the first list—the process that came to be called consolidation.



● **FIGURE 1.14** Results of the Gais et al. (2007) experiment in which memory for word pairs was tested for two groups. The sleep group went to sleep shortly after learning a list of word pairs. The awake group stayed awake for quite a while after learning the word pairs. Both groups did get to sleep before testing, so they were equally rested before being tested, but the performance of the sleep group was better.

Many experiments investigating this consolidation process have been done in the more than 100 years since Muller and Pilzecker's experiment. One question that is a topic of current investigation is "How does going to sleep right after learning affect consolidation?" To investigate this question, Steffan Gais and coworkers (2006) had high school students learn a list of 24 pairs of English-German vocabulary words. The "sleep group" studied the words and then went to sleep within 3 hours. The "awake group" studied the words and remained awake for 10 hours before getting a night's sleep. Both groups were tested within 24 to 36 hours after studying the vocabulary lists (The actual experiment involved a number of different sleep and awake groups to control for time of day and other factors we aren't going to consider here.) The results of the experiment, shown in ● Figure 1.14, indicate that students in the sleep group forgot much less material than the students in the awake group.

This result, like Muller and Pilzecker's 100 years earlier, raises its own questions. What is it about going to sleep right away that improves memory? Is sleeping just a way to avoid being exposed to interfering stimuli, or is something special happening during the sleep process that helps strengthen memory? This question is being researched in a number of laboratories. Some results indicate that sleep may just be a way of avoiding interference (Sheth et al., 2009), but research is continuing on this question.

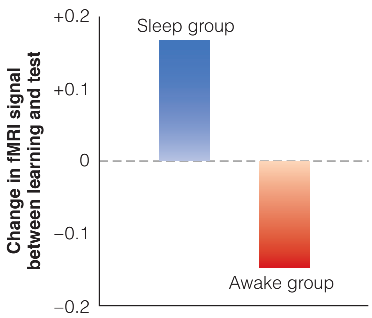
MEMORY CONSOLIDATION FROM A PHYSIOLOGICAL PERSPECTIVE

The two experiments we have just described studied consolidation by measuring behavior. But what brain processes are involved in consolidation? Although early researchers knew that consolidation involved processes in the brain, they had no way of determining what those processes might be. Modern researchers, armed with techniques for measuring physiological processes, have begun to determine these processes. For example Louis Flexner and coworkers (1963) did an experiment in which they showed that injecting a chemical that inhibits the synthesis of proteins in rats eliminates formation of memories. This suggests that interference, such as that experienced by the football player, may disrupt chemical reactions that are necessary for consolidation.

Flexner's study provides information about how consolidation might operate at the molecular level involved in protein synthesis. Cognitive psychologists are also interested in determining which structures in the brain are involved in consolidation. One way to determine this is to use a technique called brain scanning (which we will describe in Chapter 2), which makes it possible to measure the response of different areas of the human brain.

In an extension of the experiment described previously, in which Gais and coworkers (2006) showed that participants in the sleep group had better memory for word pairs than participants in the awake group, Gais and coworkers (2007) carried out another experiment, in which participants learned word pairs and then were tested two days later. As in the previous experiment, participants in the sleep group remembered more word pairs than participants in the awake group. This time, however, in addition to measuring memory, Gais measured brain activity, using a brain imaging technique called fMRI (which we will describe in the next chapter). He measured this activity first as participants were learning the word pairs and again as they were tested two days later.

● Figure 1.15 shows that the activity of the hypothalamus, a structure deep in the brain that is known to be involved in the storage of new memories, increased from learning to test for the sleep group but decreased from learning to test for the awake group. Gais concluded from this result that immediate sleep helps strengthen the memory trace in the hypothalamus.



● **FIGURE 1.15** Results of the Gais et al. (2007) experiment in which the brain activity of participants' in the sleep and awake groups was measured as they were initially learning a list of word pairs and as they were remembering the list two days later. Activity in the hippocampus increased for participants in the sleep group, but decreased for participants in the awake group. Also, in data not shown here, the overall level of activity in the hippocampus was greater during testing in the sleep group.

The purpose of these examples of behavioral and physiological experiments is not to provide an explanation of how consolidation works (we will discuss consolidation further in Chapter 7), but to illustrate how cognitive psychologists use both behavioral and physiological measurements to search for answers. The basic premise of much research in cognitive psychology, and of the approach taken in this book, is that only by studying cognition both behaviorally and physiologically can we completely understand the mechanisms underlying cognition.

Another point that our example of consolidation illustrates is how results of basic research can have practical applications. Even without knowing the mechanisms responsible for consolidation, we can conclude that when studying for an exam it might make sense to go to sleep soon after studying, rather than doing something that might keep all that knowledge from being consolidated (thereby eliminating the "I-knew-it-last-night-but-it-wasn't-there-for-the-exam" phenomenon!). We will be considering how the findings of cognitive psychology research can be applied to real-life situations throughout this book. (See Chapter 7, page 187, for some more "study hints" based on principles of cognitive psychology.)

MODELS OF THE MIND

As you read about cognitive psychology in this book, you will encounter many models of the mind. A model can be a representation of something, as a model car or airplane represents the appearance of a real car or airplane. Similarly, plastic models of the brain are often used to illustrate the locations of different structures of the brain. But models can also illustrate how something works, and in cognitive psychology models are generally used to represent how information is processed by the mind. These models often take the form of flow diagrams, which represent how information flows through various components of the mind. For example, Broadbent's flow diagram in Figure 1.11 is a model of how a person processes information to selectively attend to one message out of many.

One advantage of models is that they often make a complicated system easier to understand. Although the process of selective attention is certainly more complex than the two processing steps in Broadbent's model, this simple model provides a good starting point for seeking further details of how selective attention operates.

One of the ways that models provide this "starting point" is by helping suggest questions to ask. For example, a researcher studying attention might want to ask questions about how the filter in Broadbent's model works. According to Broadbent, the filter lets through attended information (such as the contents of the conversation you are having with a friend at a party) and filters out the unattended information (such as all of the other conversations and noise at the party). But what about the situation that occurs when you hear someone across the room call out your name? Hearing your name means that your name somehow got through the filter, even though you were focusing your attention on the conversation you were having.

Could this mean that perhaps there isn't a filter? Or perhaps there is a filter, but its operation is more complicated than Broadbent's initial proposal. Good models such as Broadbent's are usually stated in a way that suggests further questions, which can be answered by doing further experiments, and the results of these experiments often lead to the proposal of a new, updated model.

Students often wonder whether the boxes in models such as Broadbent's stand for specific areas in the brain. Although in some models each box corresponds to a specific place in the brain, the boxes in most of the models we will be describing do not correspond to one brain area. We will see that a basic principle of the operation of the mind is that activity is distributed across many areas of the brain. Thus, although a model might represent the attentional filter by a single box, the actual filtering may be accomplished by a number of different structures that are located in different parts of the brain.

➔ Something to Consider

Learning From This Book

Congratulations! You now know how some researchers began doing cognitive psychology experiments in the 19th century, how the study of the mind was suppressed in the middle of the 20th century, how the study of the mind made a glorious comeback in the 1950s, and that present-day psychologists use both behavioral and physiological techniques to study the mind. One of the purposes of this chapter—to provide you with some background to orient you to the field of cognitive psychology—has been accomplished.

Another purpose of this chapter is to help you get the most out of this book. After all, cognitive psychology is the study of the mind. As you will see as you get further into the book, especially in the chapters on memory, there are things that have been discovered about cognitive psychology that can help you get as much as possible from this book and from the course you are taking. One way to appreciate how cognitive psychology can be applied to studying is to look at pages 187–189 in Chapter 7. It would make sense to skim this material now, rather than waiting. There will be some terms that you may not be familiar with, but these aren't crucial for what you want to accomplish—picking up some hints that will make your studying more efficient and effective. Two terms worth knowing, though, are *encoding*—which is what is happening as you are learning the material—and *retrieval*—what is happening when you are remembering the material. The trick is to encode the material during your studying in a way that will make it easier to retrieve it later. (Also see page xxix in the preface.)

Something else that might help as you learn from this book is to be aware of how it is constructed. As you read the book, you will see that often a basic idea or theory is presented and then it is supported by examples or experiments. Consider our discussion of memory consolidation in this chapter. First the phenomenon was described (memory is initially fragile and so can be disrupted), and then experiments were presented to illustrate it (Muller and Pilzecker: memory is interrupted if a second list is learned immediately; Gais and coworkers: memory is better if sleep occurs shortly after learning).

This way of presenting information breaks the discussion of a particular topic into a series of "mini-stories." Each story begins with an idea or phenomenon and is followed by demonstrations of the phenomenon and usually evidence to support it. Often there is also a connection between one story and the next. For example, once consolidation is described behaviorally, the next story is about how it can be studied physiologically.

What's important about this is that realizing how the story of cognitive psychology is presented can help you remember what you have read. It is easier to remember a number of facts if they are presented as part of a story than if they are presented as separate, unrelated facts. So as you read this book, keep in mind that your main job is to understand the stories, each of which is a basic premise followed by supporting evidence. Thinking about the material in this way will make it more meaningful and therefore easier to remember.

One more thing: Just as specific topics can be described as a number of small stories that are linked together, the field of cognitive psychology as a whole consists of many themes that are related to each other, even if they appear in different chapters. Perception, attention, memory, and other cognitive processes all involve the same nervous system and therefore share many of the same properties. The principles shared by many cognitive processes are part of the larger story of cognition that will unfold as you progress through this book.

TEST YOURSELF 1.1

1. Why could we say that Donders and Ebbinghaus were cognitive psychologists, even though in the 19th century there was no field called cognitive psychology? Describe Donders' experiment and the rationale behind it, and Ebbinghaus's memory experiments. What do Donders' and Ebbinghaus's experiments have in common?
2. When was the first laboratory of scientific psychology founded? How important was the study of mental functioning in psychology at the end of the 19th century and beginning of the 20th?
3. Describe the rise of behaviorism, especially the influence of Watson and Skinner. How did behaviorism affect research on the mind?
4. Describe the events that helped lead to the decline in importance of behaviorism in psychology and the events that led to the "cognitive revolution." Be sure you understand what the information-processing approach is.

5. Describe the behavioral and physiological approaches to the study of cognition. How are they different, and what do they have in common? Give some examples of how both approaches have been used to study the phenomenon of memory consolidation.
6. Why are models important in cognitive psychology? Do the boxes in models like Broadbent's model of memory correspond to structures in the brain?
7. What are two suggestions for improving your ability to learn from this book?

CHAPTER SUMMARY

1. Cognitive psychology is the branch of psychology concerned with the scientific study of the mind.
2. The mind creates and controls mental capacities such as perception, attention, and memory, and creates representations of the world that enable us to function.
3. The work of Donders (simple vs. choice reaction time) and Ebbinghaus (the forgetting curve for nonsense syllables) are examples of early experimental research on the mind.
4. Because the operation of the mind cannot be observed directly, its operation must be inferred from what we can measure, such as behavior or physiological responding. This is one of the basic principles of cognitive psychology.
5. The first laboratory of scientific psychology, founded by Wundt in 1879, was concerned largely with studying the mind. Structuralism was the dominant theoretical approach of this laboratory, and analytic introspection was one of the major methods used to collect data.
6. William James, in the United States, used observations of his own behavior as the basis of his textbook, *Principles of Psychology*.
7. In the first decades of the 20th century, John Watson founded behaviorism, partly in reaction to structuralism and the method of analytic introspection. His procedures were based on classical conditioning. Behaviorism's central tenet was that psychology was properly studied by measuring observable behavior, and that invisible mental processes were not valid topics for the study of psychology.
8. Beginning in the 1930s and '40s, B. F. Skinner's work on operant conditioning assured that behaviorism would be the dominant force in psychology through the 1950s.
9. In the 1950s, a number of events occurred that led to what has been called the cognitive revolution—a decline in the influence of behaviorism and the reemergence of the study of the mind. These events included the following: (a) Chomsky's critique of Skinner's book *Verbal Behavior*; (b) the introduction of the digital computer and the idea that the mind processes information in stages, like computers; (c) Cherry's attention experiments and Broadbent's introduction of flow diagrams to depict the processes involved in attention; and (d) interdisciplinary conferences at Dartmouth and the Massachusetts Institute of Technology.
10. The phenomenon of memory consolidation was used to illustrate how answering one question can lead to many additional questions, and how cognitive psychologists study the mind by using both behavioral and physiological approaches. Using these two approaches together results in a more complete understanding of how the mind operates than using either one alone.
11. Models play an essential role in cognitive psychology, by helping organize data from many experiments. Broadbent's model of attention is an example of one of the early models in cognitive psychology. It is important to realize that models such as this one are constantly being revised in response to new data, and also that the boxes in these models often do not correspond to areas in the brain.
12. Two things that may help in learning the material in this book are to read the study hints in Chapter 7, which are based on some of the things we know about memory research, and to realize that the book is constructed like a story, with basic ideas or principles followed by supporting evidence.

Think ABOUT IT

1. What do you think the "hot topics" of cognitive psychology are, based on what you have seen or heard in the media? Hint: Look for stories such as the following: "Scientists Race to Find Memory Loss Cure"; "Defendant Says He Can't Remember What Happened."
2. The idea that we have something called "the mind" that is responsible for our thoughts and behavior is reflected in the many ways that the word *mind* can be used. A few examples of the use of *mind* in everyday language were cited at the beginning of the chapter. See how many more examples you can think of that illustrate

different uses of the word *mind*, and decide how relevant each is to what you will be studying in cognitive psychology (as indicated by the table of contents of this book).

3. The idea that the operation of the mind can be described as occurring in a number of stages was the central principle of the information-processing approach that was one of the outcomes of the cognitive revolution that began in the 1950s. How can Donders' reaction time experiment from the 1800s be conceptualized in terms of the information-processing approach?
4. Donders compared the results of his simple and choice reaction time experiments to infer how long it took to make the decision as to which button to push, when given a choice. But what about other kinds of decisions? Design an experiment to determine the time it takes to make a more complex decision. Then relate this experiment to the diagram in Figure 1.3.

If You WANT TO KNOW MORE

1. **The birth of cognitive psychology.** To get a feel for the kinds of things cognitive psychologists were concerned with near the beginning of the "cognitive revolution," look at Ulrich Neisser's book, *Cognitive Psychology*. This was the first modern textbook on the subject. Try comparing it to what's in this book. One thing you will notice is that the field of cognitive psychology is far more concerned with physiological processes now than it was at the beginning.

   Neisser, U. (1967). *Cognitive psychology*. New York: Appleton-Century-Crofts.

2. **How the mind works.** An engaging book for the general reader, *How The Mind Works*, is worth checking out for a well-known cognitive psychologist's perspective on the mind. Pinker describes the mind as a natural computer and presents his ideas regarding how the mind has been shaped by the process of natural selection and how its operation is influenced by our modern environment.

   Pinker, S. (1997). *How the mind works*. New York: Norton.

Key TERMS

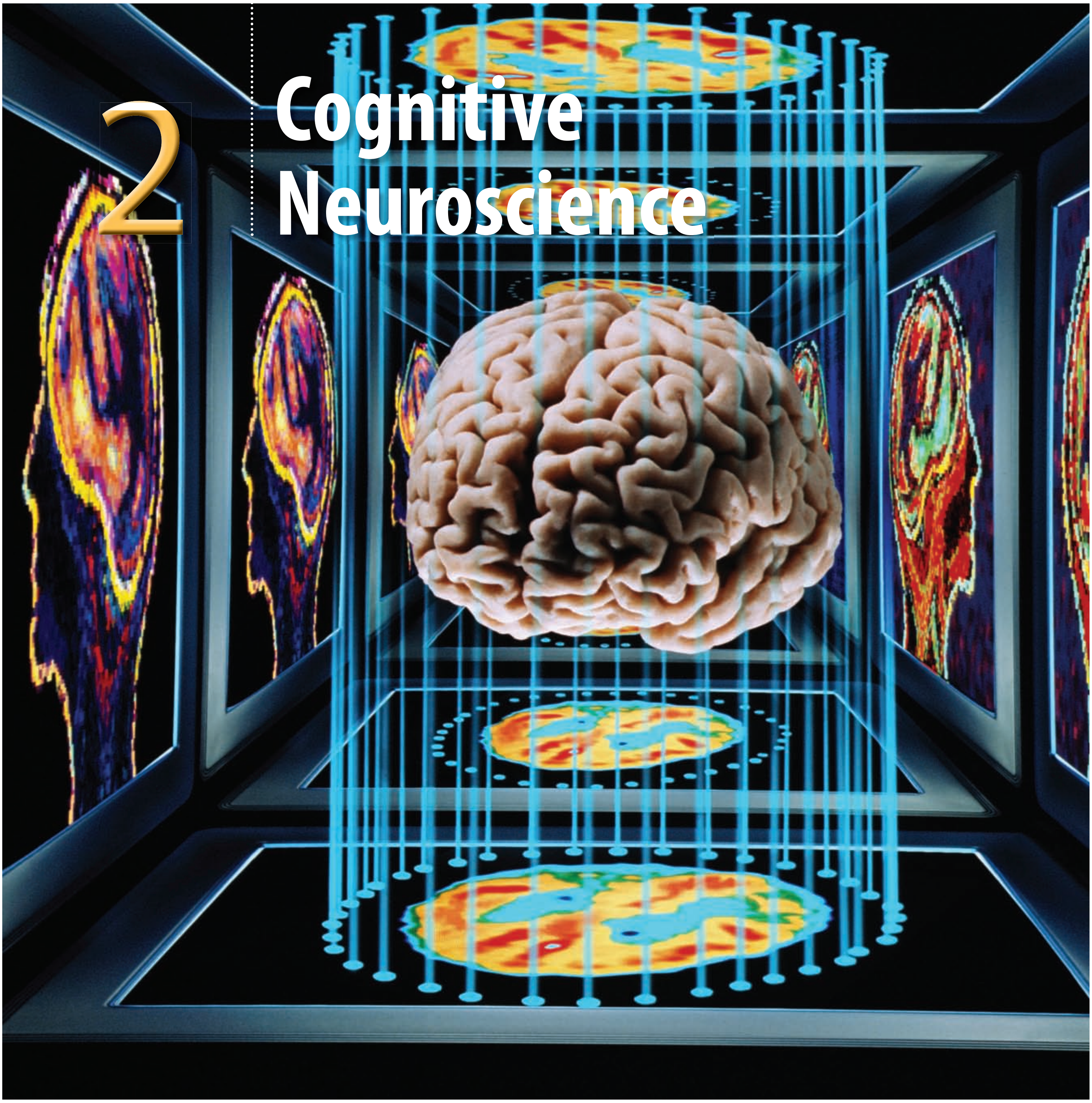
Media RESOURCES

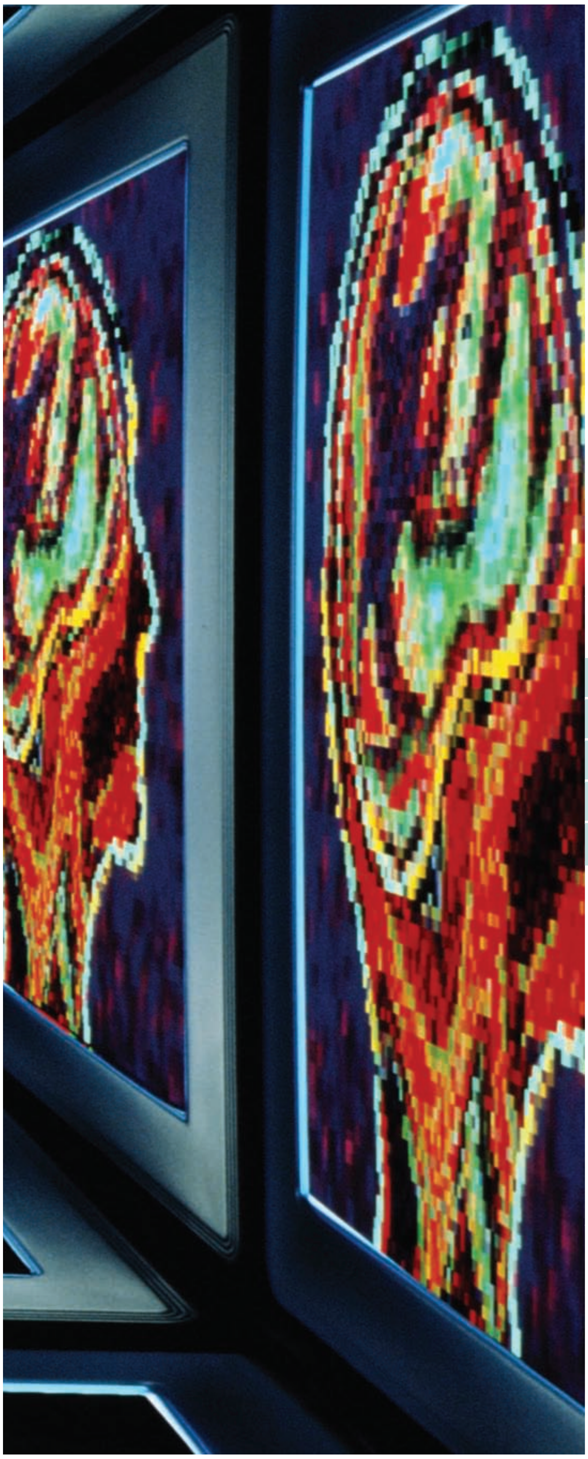
The *Cognitive Psychology* Book Companion Website

www.cengage.com/psychology/goldstein

Prepare for quizzes and exams with online resources—including a glossary, flashcards, tutorial quizzes, crossword puzzles, and more.

2 Cognitive Neuroscience





Barry Blackman/Getty Images

- What is cognitive neuroscience, and why is it necessary? (24)
- How is information transmitted from one place to another in the nervous system? (26)
- How are things in the environment, such as faces and trees, represented in the brain? (38)
- Is it possible to read a person's mind by measuring the activity of the person's brain? (41)

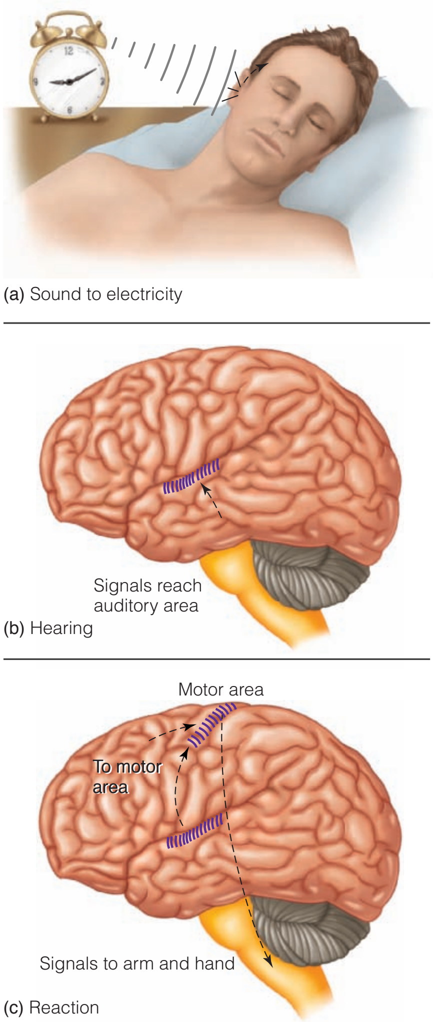
At 7:00 a.m., in response to hearing the familiar but irritating sound of his alarm clock, Juan swings his arm in a well-practiced arc, feels the contact of his hand with the snooze button, and in the silence he has created, turns over for 10 more minutes of sleep. How can we explain Juan's behavior in terms of physiology? What is happening inside Juan's brain that makes it possible for him to hear the alarm, take appropriate action to turn it off, and know that he can sleep a little longer and still get to his early morning class on time?

We can give a general answer to this question by considering some of the steps involved in Juan's action of turning off the alarm. The first step in hearing the alarm occurs when sound waves from the alarm enter Juan's ears and stimulate receptors that change the sound energy into electrical signals (● Figure 2.1a). These signals then reach the auditory area of Juan's brain, which causes him to hear the ringing of the bell (Figure 2.1b). Then signals are sent from a number of places in the brain to the motor area, which controls movement. The motor area sends signals to the muscles of Juan's hand and arm (Figure 2.1c), which carry out the movement that turns off the alarm.

But there is more to the story than this sequence of events. For one thing, Juan's decision to hit the snooze button of his alarm is based on his knowledge that this will silence the alarm temporarily, and that the alarm will sound again in 10 minutes. He also knows that if he stays in bed for 10 more minutes, he will still have time to get to his class. A more complete picture of what's happening in Juan's brain when the alarm rings would, therefore, have to include processes involved in retrieving knowledge from memory and making decisions based on that knowledge. Thus, a seemingly simple behavior such as turning off an alarm in the morning involves a complex series of physiological events.

Students often wonder why they need to know about principles of nervous system functioning for a course in cognitive psychology. One answer to this question is that the development of brain scanning technology over the last few decades has placed the brain at the center of much present-day research in cognitive psychology. The study of cognitive psychology today consists of both purely behavioral experiments and experiments that consider links between behavior and the brain.

The purpose of this chapter is to introduce **cognitive neuroscience**, the study of the physiological basis of cognition. This chapter provides the basic background you will need to understand the physiological material on perception, attention, memory, language, decision making, and problem solving that we will be covering in the chapters that follow. We will describe some basic principles of nervous system functioning by first considering the structure and functioning of cells called **neurons**, which are the building blocks and transmission lines of the nervous system. We then focus on the collection of 180 billion of these neurons that form the brain. As we do this, you will see that to understand the brain we need to understand how its neurons are organized and how they signal information about the environment and our actions within the environment.



● **FIGURE 2.1** Some of the physiological processes that occur as Juan turns off his alarm. (a) Sound waves are changed to electrical signals in the ear and are sent to the brain. (b) Signals reaching the auditory areas of the brain—which are located inside the brain, under the hatched area—cause Juan to hear the alarm. (c) After Juan hears the alarm, signals are sent to the motor area. The two arrows pointing up symbolize the fact that these signals reach the motor area along a number of different pathways. Signals are then sent from the motor area to muscles in Juan's arm and hand so he can turn off the alarm.

Neurons: The Building Blocks of the Nervous System

How is it possible that the 3.5-pound structure called the brain could be the seat of the mind? It is, after all, just static tissue. It has no moving parts (like the heart). It doesn't expand or contract (like the lungs), and when observed with the naked eye it looks almost solid. As it turns out, to understand the relation between the brain and the mind it is necessary to look within the brain and observe the small units that make up its structure and the electrical signals that travel in these units.

THE MICROSTRUCTURE OF THE BRAIN: NEURONS

For many years, the nature of the brain's tissue was a mystery. Looking at the interior of the brain with the unaided eye gave no indication that it is made up of billions of smaller units. The nature of electrical signals in the brain and the pathways over which they traveled were just beginning to be discovered in the 19th century.

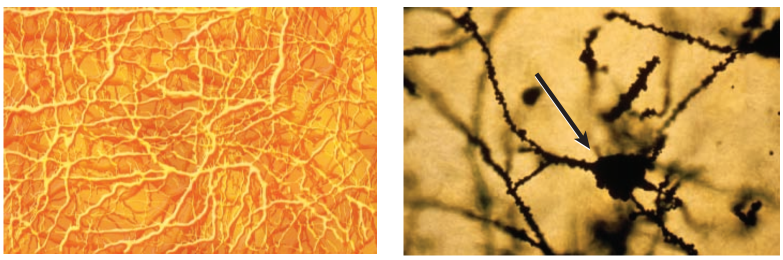
To observe the structure of the brain, 19th-century anatomists applied special stains to the brain tissue, which increased the contrast between different types of tissue within the brain. When they viewed this stained tissue under a microscope, they saw a network they called a **nerve net**. This network was believed to be continuous, like a highway system in which one street connects directly to another, but without stop signs or traffic lights. When visualized in this way, the nerve net provided a complex pathway for conducting signals uninterrupted through the network (● Figure 2.2a).

One reason for describing the microstructure of the brain as a continuously interconnected network was that the staining techniques and microscopes of the time could not resolve small details, and without these details, the nerve net appeared to be continuous. However, in the 1870s, the Italian anatomist Camillo Golgi developed a staining technique that involved immersing a thin slice of brain tissue in a solution of silver nitrate. This technique created pictures like the one in Figure 2.2b, in which individual cells were randomly stained. What made this technique useful was that fewer than 1 percent of the cells were stained, so they stood out from the rest of the tissue. (If all of the cells had been stained, it would be difficult to distinguish one cell from another because the cells are so tightly packed). Also, the cells that were stained were stained completely, so it was possible to see their structure.

This brings us to Ramon y Cajal, a Spanish physiologist who was interested in investigating the nature of the nerve net. Cajal cleverly used two techniques to achieve his goal. First he used the Golgi stain, which stained only some of the cells in a slice of brain tissue. Second, he decided to study tissue from the brains of newborn animals, because the density of cells in the newborn brain is small compared to the density in the adult brain. This property of the newborn brain, combined with the fact that the Golgi stain affects less than 1 percent of the neurons, made it possible for Cajal to clearly see that the Golgi-stained cells were individual units (Kandel, 2006). Cajal's discovery that individual units called neurons were the basic building blocks of the brain was the centerpiece of **neuron doctrine**—the idea that individual cells transmit signals in the nervous system, and that these cells are not continuous with other cells as proposed by nerve net theory.

● Figure 2.3a shows the basic parts of a neuron. The **cell body** contains mechanisms to keep the cell alive. **Dendrites** branch out from the cell body to receive signals from other neurons, and the **axon** or **nerve fiber** transmits signals to other neurons. Thus, the neuron has a receiving end and a transmitting end, and its role, as visualized by Cajal, was to transmit signals.

Cajal also came to some other conclusions about neurons: (1) In addition to neurons in the brain, there are also neurons that pick up information from the environment, such as the neurons in the skin, eye, and ear. These neurons, called **receptors** (Figure 2.3b), are similar to brain neurons in that they have a cell body and axon, but they have specialized



(a) (b)

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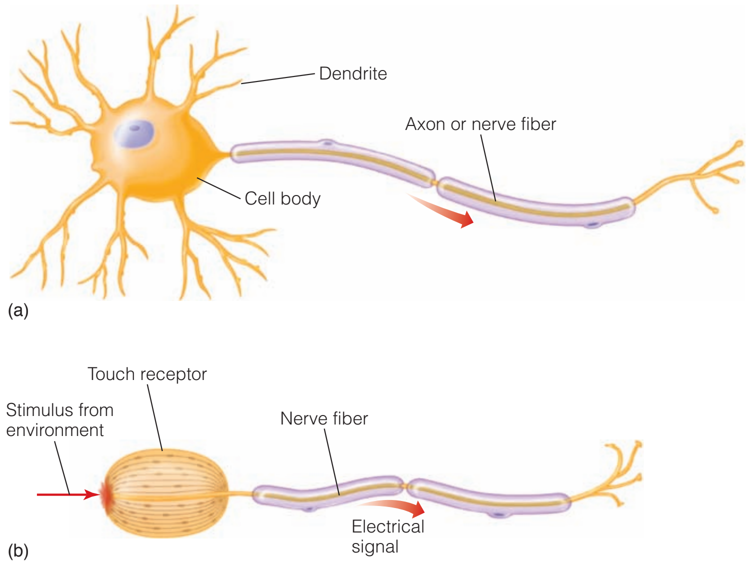
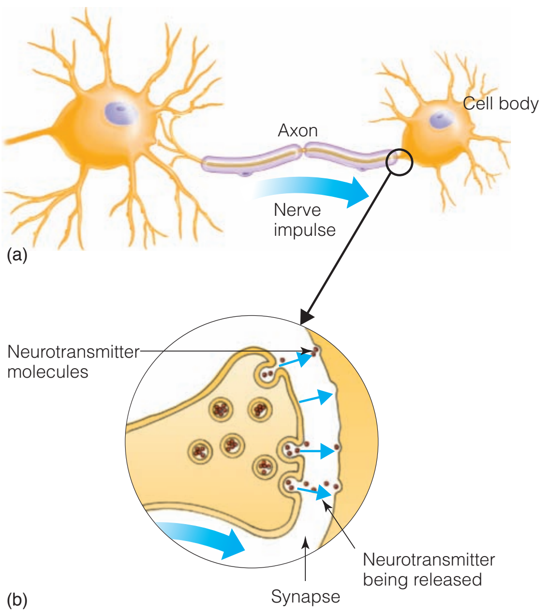
● **FIGURE 2.2** (a) Nerve net theory proposed that signals could be transmitted throughout the net in all directions. (b) A portion of the brain that has been treated with Golgi stain shows the shapes of a few neurons. The arrow points to a neuron's cell body. The thin lines are dendrites or axons (see Figure 2.3).



● **FIGURE 2.3** (a) Basic components of a neuron in the cortex. (b) A neuron with a specialized receptor in place of the cell body. This receptor responds to pressure on the skin.



● **FIGURE 2.4** (a) Neuron synapsing on the cell body of another neuron; (b) close-up of the synapse showing the space between the end of one neuron and the cell body of the next neuron, and neurotransmitter being released.

receptors that pick up information from the environment. (2) For all neurons, there is a small gap between the end of the neuron's axon and the dendrites or cell body of another neuron. This gap is called a **synapse** (● Figure 2.4). (3) Neurons are not connected indiscriminately to other neurons, but form connections only to specific neurons. Usually many neurons are connected together to form **neural circuits**.

Cajal's idea of individual neurons that communicate with other neurons to form neural circuits was an enormous leap forward in the understanding of how the nervous system operates. All of the concepts introduced by Cajal—individual neurons, synapses, and neural circuits—are basic principles that today are used to explain how the brain creates cognitions. These discoveries earned Cajal the Nobel Prize in 1906, and today he is recognized as "the person who made this cellular study of mental life possible" (Kandel, 2006, p. 61).

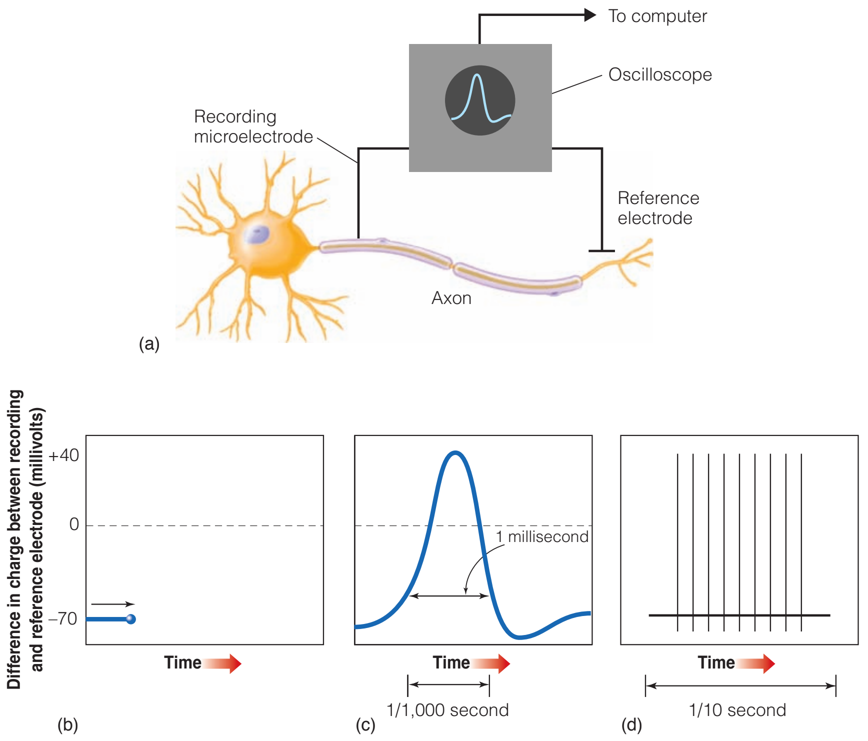
THE SIGNALS THAT TRAVEL IN NEURONS

Cajal succeeded in describing the structure of individual neurons and how they are related to other neurons, and he knew that these neurons transmitted signals. However, determining the exact nature of these signals had to await the development of electronic amplifiers that were powerful enough to make the extremely small electrical signals generated by the neuron visible. In the 1920s, Edgar Adrian was able to record electrical signals from single sensory neurons, an achievement for which he was awarded the Nobel Prize in 1932 (Adrian, 1928, 1932).

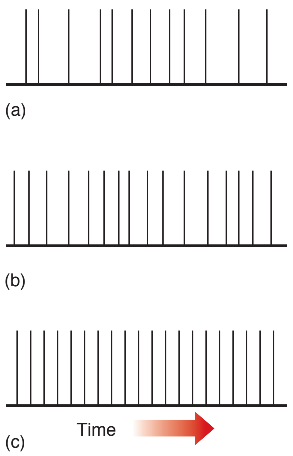
METHOD Recording From a Neuron

Adrian recorded electrical signals from single neurons using **microelectrodes**—small shafts of hollow glass filled with a conductive salt solution that can pick up electrical signals at the electrode tip and conduct these signals back to a recording device. Modern physiologists use metal microelectrodes. The electrode is lowered into tissue until the tip of the electrode is positioned near a neuron. This electrode, called the **recording electrode**, is connected to a recording device and to another electrode, called the **reference electrode**, which is located outside of the tissue (● Figure 2.5a).

The key principle for understanding how electrical signals are recorded from neurons is that we are always measuring the *difference in charge* between the recording and reference electrodes. The difference in charge between these two electrodes is displayed on an oscilloscope, which indicates the difference in charge by the vertical position of a small dot that creates a line as it moves across the screen. For example, the record in Figure 2.5b indicates that the difference in charge between the recording and reference electrode is −70 mV (mV = millivolt = 1/1,000 volt) and the dot continues to move along this −70 mV line as long as no electrical signals are being transmitted in the neuron. However, when an electrical signal, called a **nerve impulse** or **action potential**, is transmitted down the axon, the dot is deflected up (as the neuron becomes more positive) and then back down (as the charge returns to its original level), all within 1 millisecond (1/1,000 second), as shown in Figure 2.5c. Figure 2.5d shows action potentials on a compressed time scale, so an action potential like the one in Figure 2.5c appears to be a vertical line. Each line in this record is an action potential, so the series of lines indicates that a number of action potentials are traveling past this electrode. There are other electrical signals in the nervous system, but we will focus here on the action potential, because it is the mechanism by which information is transmitted throughout the nervous system.



● **FIGURE 2.5** Recording from a single neuron. (a) The difference in charge between the recording and reference electrodes is displayed on the oscilloscope screen. (b) A small dot moves across the screen, which briefly leaves a trail. In this situation, electrical signals are not being transmitted by the axon, so the difference in charge remains at –70 millivolts. (c) When an action potential travels down the axon, it causes a brief positive pulse, like the one shown here, as the potential passes the recording electrode. (d) A number of action potentials are displayed on an expanded time scale, so a single action potential appears as a "spike."



● **FIGURE 2.6** Action potentials recorded from an axon in response to three levels of pressure stimulation on the skin: (a) light; (b) medium; (c) strong. Increasing stimulus intensity causes an increase in the rate of nerve firing.

In addition to recording action potentials from single neurons, Adrian made other discoveries as well. He also found that each action potential travels all the way down the axon without changing its size. This property makes action potentials ideal for sending signals over a distance, because it means that once an action potential is started at one end of an axon, the signal is still the same size when it reaches the other end.

At about the same time Adrian was recording from single neurons, other researchers were showing that when the signals reach the end of the axon, a chemical called a **neurotransmitter** is released that makes it possible for the signal to be transmitted across the synaptic gap that separates the end of the axon from the dendrite or cell body of another neuron (see Figure 2.4).

Although all of these discoveries about the nature of neurons and the signals that travel in them were extremely important (and garnered a number of Nobel prizes for their discoverers), our main interest is not in how axons transmit signals, but in how these signals contribute to the operation of the mind. So far our description of how signals are transmitted is analogous to describing how the Internet transmits electrical signals without describing how the signals are transformed into words and pictures that people can understand. Adrian was acutely aware that it was important to go beyond simply describing nerve signals, so he did a series of experiments to relate nerve signals to stimuli in the environment and therefore to people's experience.

Adrian studied the relation between nerve firing and sensory experience by measuring how the firing of a neuron from a receptor in the skin changed as he applied more pressure to the skin. What he found was that the shape and height of the action potential remained the same as he increased the pressure, but the *rate* of nerve firing—that is, the number of action potentials that travel down the axon per second—increased (● Figure 2.6).

What this means in terms of cognition is that the intensity of a stimulus can be represented by the *rate* of nerve firing. So, for example, increasing the pressure to the skin causes neurons in the touch system to fire more rapidly, and this causes an experience of increased pressure. Or increasing the intensity of light presented to visual receptors in the retina causes more rapid firing of neurons in the visual system and an increased perception of brightness. Thus, the rate of neural firing is related to the intensity of stimulation which, in turn, is related to the magnitude of an experience such as feeling pressure on the skin or experiencing the brightness of a light.

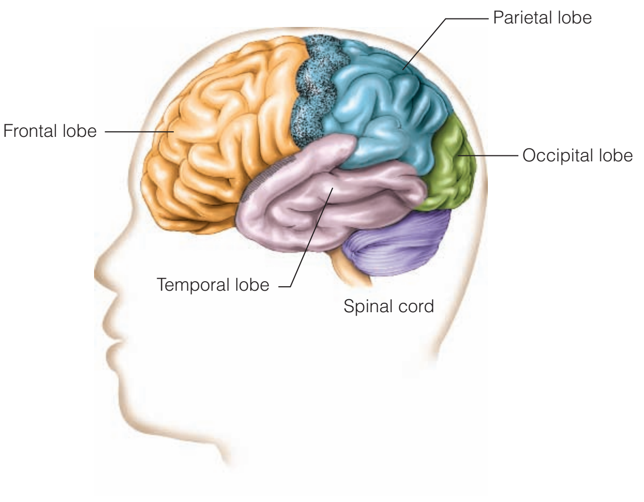
If the *amplitude* of experience—our perception of a 100-watt light as brighter than a 40-watt bulb—is related to the rate of nerve firing, what about the *quality* of experience? For the senses, quality refers to the different experience associated with each of the senses—perceiving light for vision, sound for hearing, smells for olfaction, and so on. We can also ask about quality *within* a particular sense. How do we perceive different shapes, different colors, and various directions of movement, for example?

One way to answer the question of how action potentials determine different qualities is to propose that the action potentials for each quality might look different. However, Adrian ruled out that possibility by determining that all action potentials are basically the same.

If all nerve impulses are basically the same whether they are caused by seeing a red fire engine or remembering what you did last week, how can these impulses stand for different qualities? The answer to this question is that neurons serving different cognitive functions transmit signals to different areas of the brain, a principle called *localization of function*.

Localization of Function

One of the basic principles of brain organization is **localization of function**—specific functions are served by specific areas of the brain. Most of the cognitive functions are served by the **cerebral cortex**, which is a layer of tissue about 3 mm thick that



● **FIGURE 2.7** The human brain, showing the locations of the primary receiving areas for the senses: vision = occipital lobe; skin senses = parietal lobe (dotted area); hearing = temporal lobe (located within the temporal lobe, approximately under the hatched area). Areas for taste and smell are not visible. The frontal lobe responds to all of the senses and is involved in higher cognitive functioning.

covers the brain (Fischl & Dale, 2000). The cortex is the wrinkled covering you see when you look at an intact brain (● Figure 2.7). Localization of function has been demonstrated for many different cognitive functions. We first consider perception.

LOCALIZATION FOR PERCEPTION

One of the most basic demonstrations of localization of function is the **primary receiving areas** for the senses, shown in Figure 2.7. These are the first areas of the cerebral cortex to receive signals from each of the senses. For example, when sound stimulates receptors in the ear, the resulting electrical signals reach the auditory receiving area in the **temporal lobe**.

The primary receiving area for vision occupies most of the **occipital lobe**, and the area for the skin senses—touch, temperature, and pain—is located in the **parietal lobe**. The areas for taste and smell are located on the underside of the temporal lobe (smell) and in a small area within the frontal lobe (taste). The **frontal lobe** receives signals from all of the senses and plays an important role in perceptions that involve the coordination of information received through two or more senses.

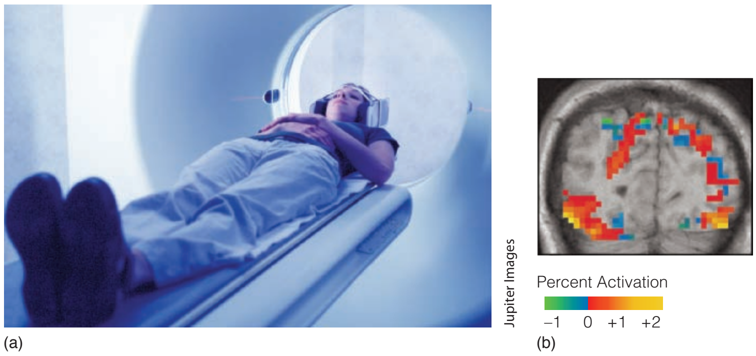
The primary receiving areas were initially identified by noting the effects of brain damage. For example, it was noted that damage to the occipital lobe caused by battlefield injuries caused blindness. Another source of brain damage is stroke—disruption of the blood supply to the brain, usually due to a blood clot. As with battlefield injuries, the perceptual effects of strokes are linked to each of the sensory receiving areas.

In addition to the primary receiving areas, other areas also serve specific sensory functions. People who have suffered damage to a certain area in the temporal lobe on the lower right side of the brain (not the auditory area, which is higher up in the temporal lobe) have a condition called **prosopagnosia**—an inability to recognize faces. People with prosopagnosia can tell that a face is a face, but can't recognize whose face it is, even for people they know well such as friends and family members. In some cases, people with prosopagnosia look into a mirror and, seeing their own image, wonder who the stranger is looking back at them! What is special about this condition is that the problem is restricted to using the sense of vision to recognize faces. The person can recognize other objects, can recognize people based on their voices or mannerisms, and have normal memory and general cognitive functioning (Burton et al., 1991; Hecaen & Angelergues, 1962; Parkin, 1996).

Localization of function has also been demonstrated by recording from neurons in different areas of the brains of animals (mainly monkeys). Neurons in the occipital lobe respond to stimulation of the eye with light, neurons in the temporal lobe to sound, neurons in another area in the temporal lobe to faces, and so on. In addition, a technique called brain imaging has been used to demonstrate localization of function in the human cortex.

METHOD Brain Imaging

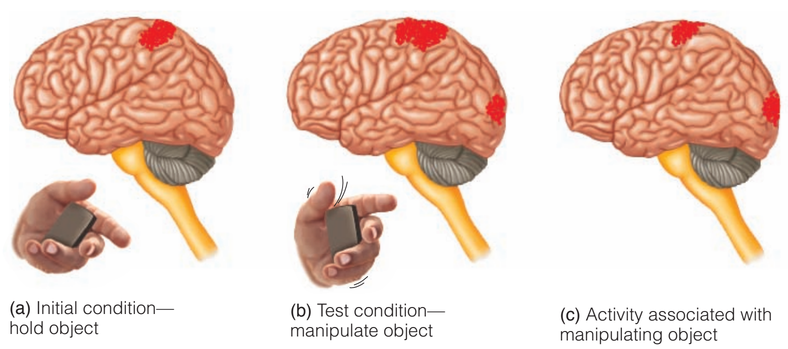
A widely used technique for measuring brain activity in humans is **brain imaging**, which allows researchers to create images that show which areas of the brain are activated as awake humans carry out various cognitive tasks. One of these techniques, **positron emission tomography (PET)**, was introduced in the 1970s (Hoffman et al., 1976; Ter-Pogossian et al., 1975). PET takes advantage of the fact that blood flow increases in areas of the brain that are activated by a cognitive task. To measure blood flow, a low dose of a radioactive tracer is injected into a person's bloodstream.



● **FIGURE 2.8** (a) Person in a brain scanner. (b) In this cross section of the brain, areas of the brain that are activated are indicated by the colors. Increases in activation are indicated by red and yellow, decreases by blue and green. (Source: Part b from Alumit Ishai, Leslie G. Ungerleider, Alex Martin, James V. Haxby, "The Representation of Objects in the Human Occipital and Temporal Cortex," *Journal of Cognitive Neuroscience, 12*:2, 2000, pp. 35–51. © 2000 by the Massachusetts Institute of Technology.)

(The dose is low enough that it is not harmful to the person.) The person's brain is then scanned by the PET apparatus, which measures the signal from the tracer at each location in the brain. Higher signals indicate higher levels of brain activity (● Figure 2.8).

PET enabled researchers to track changes in blood flow, and thus to determine which brain areas were being activated. To use this tool, researchers developed the **subtraction technique**. Brain activity is measured first in a "control state," before stimulation is presented, and again while the stimulus is presented. For example, in a study designed to determine which areas of the brain are activated when a person manipulates an object, activity generated by simply placing the object in the hand would be measured first. This is the control state (● Figure 2.9a). Then activity is measured as the person manipulates the object. This is the stimulation state (Figure 2.9b). Finally, the activity due to manipulation is determined by subtracting the control activity from the stimulation activity (Figure 2.9c).



● **FIGURE 2.9** The subtraction technique used to interpret the results of brain imaging experiments. (a) Colored area indicates activation when a person is holding a small object. (b) Colored areas indicate activation when the person begins manipulating the object. (c) Subtracting the activation in (a) from the activation in (b) indicates the activation due to manipulation of the object. (Source: B. Goldstein, *Sensation and Perception*, 8th ed., Fig. 4.16, p. 83. Copyright © 2010, Wadsworth, a part of Cengage Learning. Reproduced with permission. www.cengage .com/permissions.)

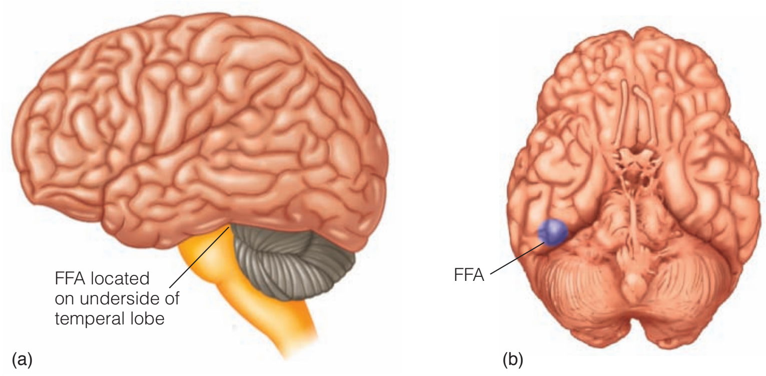
Following the introduction of PET, another neuroimaging technique, called **functional magnetic resonance imaging (fMRI)**, was introduced. Like PET, fMRI is based on the measurement of blood flow. An advantage of fMRI is that blood flow can be measured without radioactive tracers. fMRI takes advantage of the fact that hemoglobin, which carries oxygen in the blood, contains a ferrous (iron) molecule and therefore has magnetic properties. If a magnetic field is presented to the brain, the hemoglobin molecules line up, like tiny magnets.

fMRI indicates the presence of brain activity because the hemoglobin molecules in areas of high brain activity lose some of the oxygen they are transporting. This makes the hemoglobin more magnetic, so these molecules respond more strongly to the magnetic field. The fMRI apparatus determines the relative activity of various areas of the brain by detecting changes in the magnetic response of the hemoglobin. The subtraction technique described above for PET is also used for fMRI. Because fMRI doesn't require radioactive tracers and is more accurate, this technique has become the main method for determining which areas of the brain are activated by different cognitive functions.

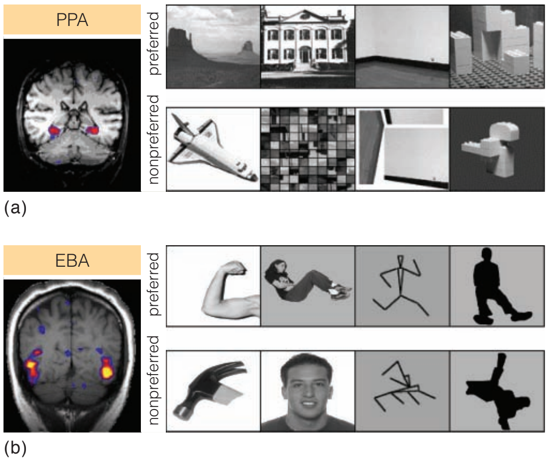
● Figure 2.10 shows the location of the area in the human brain that responds to faces, as determined by fMRI. This area, which is called the **fusiform face area (FFA)** because it is in the fusiform gyrus on the underside of the temporal lobe, corresponds to the area usually damaged in patients with prosopagnosia (Kanwisher et al., 1997).

In addition to the FFA, two other specialized areas in the temporal cortex have been identified. The **parahippocampal place area (PPA)** is activated by pictures representing indoor and outdoor scenes like those shown in ● Figure 2.11a (Aguirre et al., 1998; R. Epstein et al., 1999). Apparently what is important for this area is information about spatial layout, because increased activation occurs when viewing pictures both of empty rooms and of rooms that are completely furnished (Kanwisher, 2003). The other specialized area, the **extrastriate body area (EBA)**, is activated by pictures of bodies and parts of bodies (but not by faces), as shown in Figure 2.11b (Downing et al., 2001).

As we will see throughout this book, the technique of brain imaging has also identified many other connections between cognitive functioning and specific areas of the brain. In fact, this idea has become so prominent that a new term, *modularity*, is often used to refer to localization. A **module** is an area specialized for a specific function. Using this terminology, we would say that the fusiform face area, extrastriate body area, and parahippocampal place area are modules for perceiving faces, bodies, and places, respectively.



● **FIGURE 2.10** (a) Side view of the brain. The fusiform face area (FFA) is not visible in this view because it is located on the underside of the brain. (b) Underside of the brain, showing location of the FFA. (Source: B. Goldstein, *Sensation and Perception,* 8th ed., Fig. 13.14, p. 323. Copyright © 2010 Wadsworth, a part of Cengage Learning. Reproduced with permission. www.cengage.com/permissions.)



● **FIGURE 2.11** (a) The parahippocampal place area is activated by places (top row) but not by other stimuli (bottom row). (b) The extrastriate body area is activated by bodies (top), but not by other stimuli (bottom). (Source: L. M. Chalupa & J. S. Werner, eds., *The Visual Neurosciences,* 2-vol. set, figure from pages 1179–1189, © 2003 Massachusetts Institute of Technology, by permission of The MIT Press.)

LOCALIZATION FOR LANGUAGE

Early evidence for localization of function was provided by Paul Broca's and Carl Wernicke's studies of patients whose difficulty in producing and understanding language could be traced to damage in different areas of the brain.

In 1861, the French neurologist Paul Broca proposed that there is an area in the frontal lobe that is specialized for producing language. Broca based this idea on his study of patients who had suffered strokes and who produced speech that was slow and labored, often with jumbled sentence structure. Following is an example of the speech of a modern patient with similar symptoms. This person is attempting to describe when he had his stroke, which occurred when he was in a hot tub.

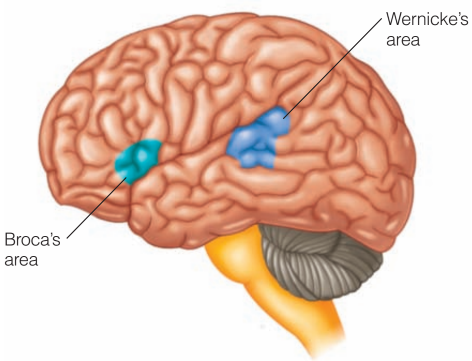
> Alright...Uh...stroke and un...I...huh tawanna guy...H...h...hot tub and...And the...Two days when uh...Hos...uh...Huh hospital and uh...amet...am...ambulance. (From Dick et al., 2001, p. 760)

Although Broca's patients had difficulty expressing themselves, they had no trouble understanding what other people were saying. When patients died, Broca performed autopsies and determined that one specific area in the brain was damaged (● Figure 2.12). This area, in the frontal lobe, came to be called **Broca's area**, and the condition he described was called **Broca's aphasia**.

In 1879, Carl Wernicke studied another group of patients, who had damage in an area of the temporal lobe now called **Wernicke's area**. Their speech was fluent and grammatically correct, but tended to be incoherent. The following is a modern example of the speech of a patient similar to those Wernicke studied:

> It just suddenly had a feffort and all the feffort had gone with it. It even stepped my horn. They took them from earth you know. They make my favorite nine to severed and now I'm a been habed by the uh stam of fortment of my annulment which is now forever. (From Dick et al., 2001, p. 761)

Patients such as this not only produced meaningless speech, but were unable to understand speech and writing. This condition was called **Wernicke's aphasia**.



● **FIGURE 2.12** Broca's and Wernicke's areas were identified in early research as being specialized for language production and comprehension. (Source: L. M. Chalupa & J. S. Werner, eds., *The Visual Neurosciences,* 2-vol. set, Fig. 13.14, p. 323. © 2003 Massachusetts Institute of Technology, by permission of The MIT Press.)

The straightforward link between language production and Broca's area and language understanding and Wernicke's area was for many years the accepted model of language processing. But as we described in our introduction of models in Chapter 1 (see page 17), models are often revised in response to new data, and the Broca/Wernicke model is no exception.

Beginning in the 1970s, researchers began providing new evidence about language processing and the brain. One line of evidence shows how important it is to pay close attention to how the behavior of brain-damaged patients is tested. Broca's idea that patients with Broca's aphasia could understand language but had a problem producing it has been challenged by research showing that these patients do, in fact, have problems understanding language. Consider, for example, the following two sentences:

(1) The apple was eaten by the girl.

(2) The boy was pushed by the girl.

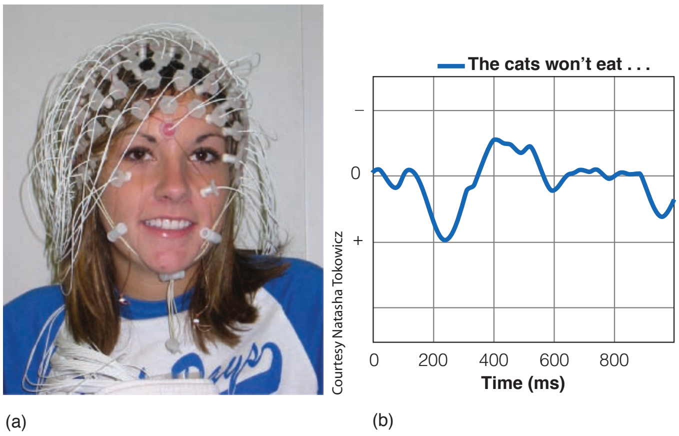
Patients with Broca's aphasia have no trouble understanding the first sentence, but have difficulty with the second one. The problem they have with the second sentence is deciding who was doing the pushing and who got pushed. Did the girl push the boy, or did the boy push the girl? While you may think it is obvious that the girl pushed the boy, patients with Broca's aphasia have difficulty processing connecting words such as "was" and "by," and this makes it difficult to determine who was pushed (notice what happens to the sentence when these two words are omitted). In contrast, the first sentence cannot be interpreted in two ways. It is clear that the girl ate the apple, because it is not possible, outside of an unlikely science fiction scenario, for the apple to eat the girl (Dick et al., 2001; Novick et al., 2005).

The fact that Broca's patients do have a problem understanding language indicates that Broca's aphasia is not simply a problem with producing language. The results of many behavioral and physiological experiments have caused some researchers to distinguish not between problems of *production* and *understanding*, but between problems of *form* and *meaning*. Form problems involve difficulties in determining the relation between words in a sentence (like the Broca's aphasia patients' problem with sentence 2, above). Meaning problems involve wider differences in understanding like those experienced by Wernicke's aphasia patients, who would also have difficulty with sentence 1.

A method of recording rapid electrical responses of the human brain, called the *event-related potential (ERP)*, has provided additional evidence for distinguishing between form and meaning in language.

METHOD Event-Related Potential

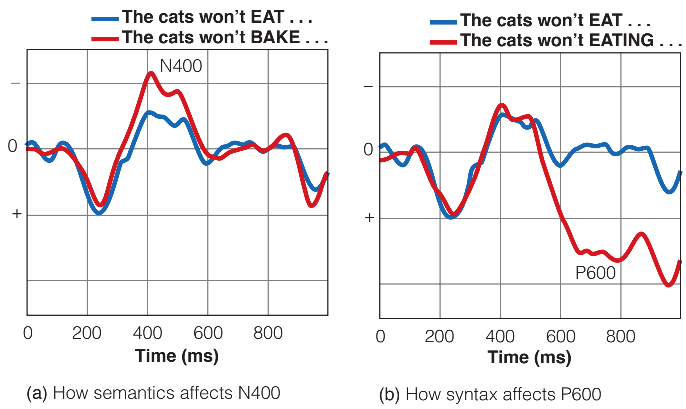
The **event-related potential (ERP)** is recorded with small disc electrodes placed on a person's scalp, as shown in ● Figure 2.13a. Each electrode picks up signals from groups of neurons that fire together. Figure 2.13b shows an event-related potential recorded as a person listens to the phrase "The cats won't eat." Notice that the signals are very rapid, occurring on a time scale of fractions of a second. This makes the ERP ideal for investigating a process such as understanding a conversation, in which speakers say three words per second, on the average (Levelt, 1999). The rapid response of the ERP contrasts with the slow response of brain imaging techniques such as fMRI, which take seconds to develop. A disadvantage of the ERP is that it is difficult to pinpoint where the response is originating in the brain. There are ways to estimate where an ERP is originating, but it isn't as straightforward as the fMRI, which highlights specific structures that are activated. However, the ability of the ERP to provide a nearly continuous record of what is happening in the brain from moment to moment makes it particularly well suited for studying dynamic processes such as language (Kim & Osterhout, 2005; Osterhout et al., in press).



● **FIGURE 2.13** (a) Person wearing electrodes for recording the event-related potential (ERP). (b) An ERP to the phrase "The cats won't eat."

The ERP is useful in distinguishing between form and meaning because the ERP consists of a number of waves that occur at different delays after a stimulus is presented and that can be linked to different functions. Two components that respond to different aspects of language are the N400 component and the P600 component, where N stands for "negative" (note that negative is up in ERP records) and P for "positive." The numbers 400 and 600 stand for the time at which the response peaks, in milliseconds.

● Figure 2.14 shows the response to "The cats won't eat" plus the response to two modified versions of this phrase. In Figure 2.14a, the phrase "The cats won't bake" results in a larger N400 response. This component of the response is sensitive to the meaning of words in a sentence, and is larger when words don't fit the sentence. In Figure 2.14b, the phrase "The cats won't eating" results in a larger P600 response. This response is sensitive to the form of a sentence, and is larger when the form is incorrect.



● **FIGURE 2.14** (a) The N400 wave of the ERP is affected by the meaning of the word. It becomes larger (red line) when the meaning of a word does not fit the rest of the sentence. (b) The P600 wave of the ERP is affected by grammar. It becomes larger (red line) when a grammatically incorrect form is used. (Source: From Osterhout et al., "Event-Related Potentials and Language," in *Trends in Cognitive Sciences,* Volume 1, Issue 6. Copyright © 1997 Elsevier Ltd. Reproduced with permission.)

What is important about these results is that they illustrate different physiological responses to two different aspects of language: form and meaning. Other experiments have shown that the N400 response is associated with structures in the temporal lobe. For example, damage to areas in the temporal lobes reduces the larger N400 response that occurs when meanings don't fit in a sentence. The P600 response is associated with structures in the frontal lobe, more toward the front of the brain. Damage to areas in the frontal lobe reduces the larger P600 response that occurs when the form of a sentence is incorrect (Osterhout et al., in press; Van Petten & Luka, 2006).

The studies of the effects of brain damage and ERP results we have described as examples of modern research related to Broca and Wernicke are only two results out of many. Hundreds of experiments have shown that the physiology of language processing is more complex than proposed by Broca and Wernicke, both because the idea of a strict separation of "production" and "comprehension" is too simple and because many areas in addition to Broca's and Wernicke's areas are involved in language processing (Binder et al., 1997; Dick et al., 2001; Dronkers et al., 2004; Friederici, 2002, 2009; Friederici et al., 2006).

The picture that is emerging from all of this research is that (1) specific language functions are localized in specific brain areas, so that localization of function is an important part of language processing; and (2) language processing is distributed over a large area of the brain. In the next section we will see that this widespread processing across the brain is an important principle that holds not only for language, but for other cognitive functions as well.

TEST YOURSELF 2.1

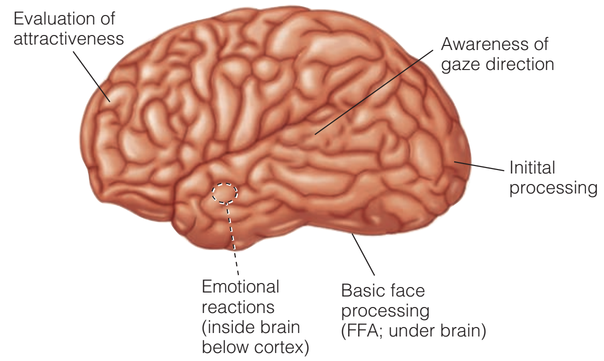
1. How did early brain researchers describe the brain in terms of a nerve net? How does the idea of individual neurons differ from the idea of a nerve net?
2. Describe the research that led Cajal to propose the neuron doctrine.
3. Describe the structure of a neuron. Describe the synapse and neural circuits.
4. How are action potentials recorded from a neuron? What do these signals look like, and what is the relation between action potentials and stimulus intensity?
5. How has the question of how action potentials indicate different qualities been answered?
6. Describe evidence for localization of function for perception, including the primary receiving areas of the brain and evidence from brain damage and brain imaging. Be sure you understand the principle behind brain imaging.
7. How did Broca and Wernicke use the behavior of patients with brain damage to provide evidence for localization of function?
8. What behavioral evidence caused a modification of the idea of two areas, one for language production and one for language understanding? What is the ERP, and how has it been used to demonstrate different aspects of language functioning? What basic conclusions about localization of function have emerged from research on the physiology of language?

Distributed Processing in the Brain

The idea of **distributed processing** is that specific functions are processed by many different areas in the brain. Although this might at first seem to contradict the ideas of localization of function and modules described above, we will see that these two ideas actually complement each other.

We can describe distributed processing by starting with localization of face perception in the brain. We saw that brain imaging experiments have identified an area called the FFA that is strongly activated by faces and responds more weakly to other types of stimuli. But just because there is an area that is specialized to respond to faces doesn't mean that faces activate *only* that area. Faces strongly activate the FFA, *plus* other areas as well.

What is particularly significant about faces is that while a number of areas of the brain participate in *perception* of a face, other areas also respond to various *reactions* to a face. For example, when you see someone walking down the street, looking at the person's face activates many neurons in your FFA plus neurons in other areas that are responding to the face's form. But your response to that person's face may go beyond simply "That's a person's face." You may also be affected by whether the person is looking at you, how attractive you think the person is, any emotions the face may elicit, and your reactions to the person's facial expression. As it turns out, different areas in the brain are activated by each of these responses to the face (see ● Figure 2.15). Looking at a face thus



● **FIGURE 2.15** Areas of the brain that are activated by different aspects of faces. (Source: B. Goldstein, *Sensation and Perception,* 8th ed., Fig. 5.45, p. 121. Copyright © 2010 Wadsworth, a part of Cengage Learning. Reproduced with permission. www.cengage.com/permissions.)

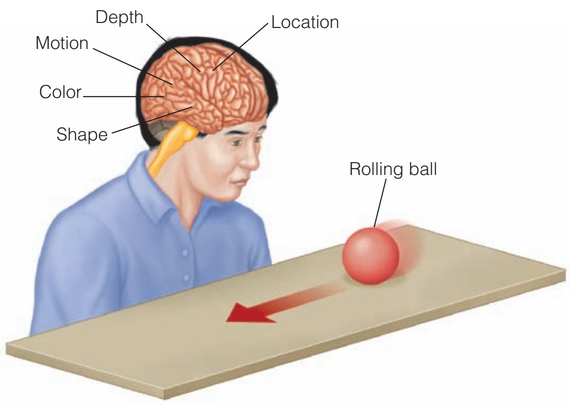
activates areas involved in perceiving the face plus areas associated with reactions elicited by the face.

But what about an encounter with a much simpler stimulus—one that doesn't look (or not look) at you, have emotional expressions, or elicit emotional responses? How about perceiving a rolling red ball, as the person is doing in ● Figure 2.16? Even this simple, neutral stimulus causes a wide distribution of activity in the brain, because each of the ball's qualities—color (red), movement (to the right), shape (round), depth, location—is processed in a different area of the brain.

There is an important message in the way that these qualities, which are processed in separate areas of the brain, come together to result in the perception of the rolling red ball. The message is that even simple everyday experiences result in activation of widespread areas of the brain, but that our experience contains little or no evidence of this widely distributed activity. We just see the object! The importance of this observation extends beyond perceiving a rolling red ball to other cognitive functions, such as memory, language, making decisions, and solving problems, all of which involve distributed activity in the brain.

For example, research on the physiology of memory, which we will consider in detail in Chapters 5 and 7, has revealed that multiple areas in every lobe of the brain are involved in storing memories for facts and events and then remembering them later. Recalling a fact or remembering an event not only elicits associations with other facts or events but can also elicit visual, auditory, smell, or taste perceptions associated with the memory, emotions elicited by the memory, and other thought processes as well. Additionally, there are different types of memory—short-term memory, long-term memory, memories about events in a person's life, memories for facts, and so on—all of which activate different, and sometimes partially overlapping, areas of the brain.

The idea that the principle of distributed processing holds for perception, memory, and other cognitive processes reflects the generality of the mechanisms responsible for cognition. Even though this book contains separate chapters on various types of cognitions, this separation does not always occur in the mind or the brain. The mind is, after all, not a textbook; it does not necessarily subdivide our experiences or cognitions into neat categories. Instead, the mind creates cognitive processes that can involve a number of different functions. Just as a symphony is created by many different instruments, all working together in an orchestra to create the harmonies and melodies of a particular composition, cognitive processes are created by many specialized brain areas, all working together to create a distributed pattern of activity that creates all of the different components of that particular cognition.



● **FIGURE 2.16** As this person watches the red ball roll by, different properties of the ball activate different areas of his cortex. These areas are in separate locations, although there is communication between them. (Source: B. Goldstein, *Sensation and Perception,* 8th ed., Fig. 6.18, p. 144. Copyright © 2010 Wadsworth, a part of Cengage Learning. Reproduced with permission. www.cengage.com/permissions.)

Representation in the Brain

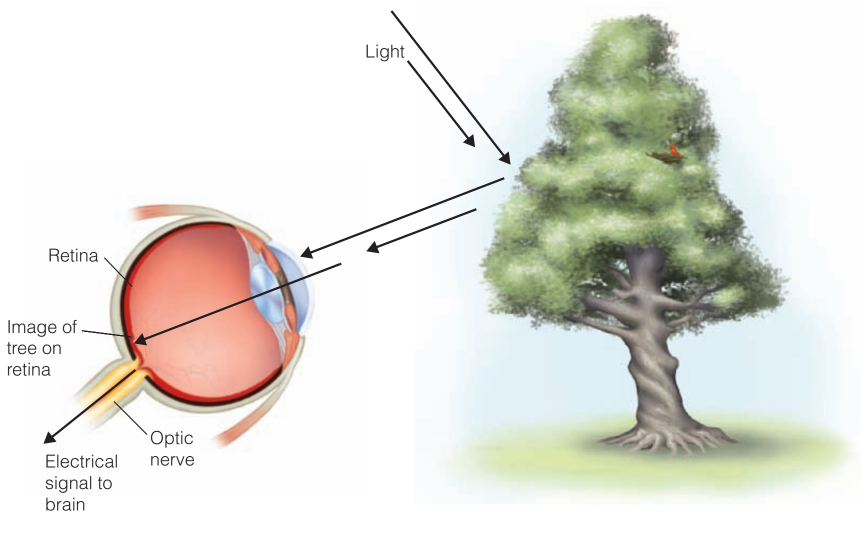
So far we have explained the connection between physiology and cognition in terms of (1) action potentials, (2) specialized areas of the brain, and (3) distributed activity in the brain. We can describe what happens when you see someone you know as involving activation of your fusiform face area plus other areas, which enables you to recognize and perhaps react to the person. But this description, while correct, is too general. We want to know how you are able to respond "That's Bill," as opposed to identifying the person as Roger or Sally. What is it about the electrical activity in your brain that goes beyond "That's a face" to actually representing a specific face such as Bill's? This is the question of *representation*, and to begin answering it, we will consider what happens when you perceive another stimulus—a tree.

REPRESENTING A TREE: FEATURE DETECTORS

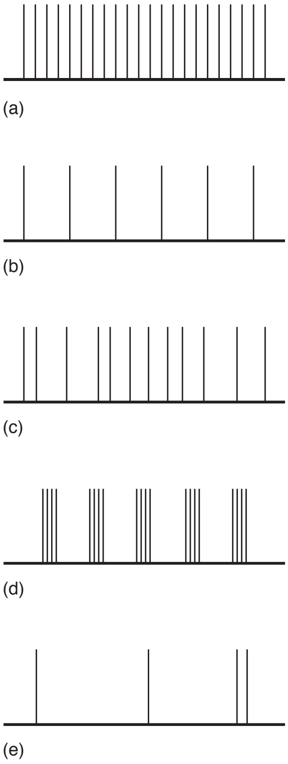
Considering how a tree is represented in the nervous system brings us back to one of the definitions of mind presented in Chapter 1, which stated that *the mind is a system that creates representations of the world, so we can act within it to achieve our goals*. Applied to the brain, the major idea behind this statement is that a tree, and everything else we perceive, is *represented* in the brain. We can appreciate what this means by considering what happens as we look at a tree.

We see the tree because light reflected from the tree enters the eye and an image of the tree is focused onto the **retina**, the layer of neurons that lines the back of the eye (● Figure 2.17). The important word here is *image*, because it is the image created by light reflected by the tree that gets into the eye, not the tree itself. The idea of the tree not getting into the eye may seem silly because it is so obvious, but the point is an important one: What enters the eye is a *representation* of the tree—something that stands for the tree.

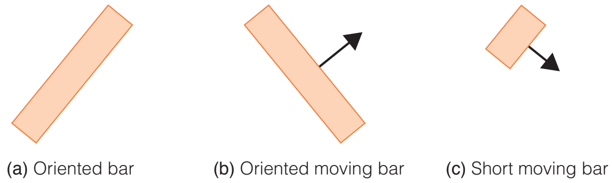
One property of this representation is that although it may look like the tree, it is also different from the tree. It is not only smaller, but may be distorted or blurred because of the optics of the eye. This difference between the actual tree and its representation becomes more dramatic about a few thousandths of a seconds later when receptors in the retina transform the tree's image into electrical signals, which then travel through the retina, leave the eye via the optic nerve, and eventually reach the primary visual receiving area of the brain. Our perception of the tree is therefore based not on direct contact with the tree, but on the way the tree is represented by action potentials in the brain. Early research on the nature of this representation led to the proposal that this representation could involve neurons called **feature detectors** that respond to features that make up objects.



● **FIGURE 2.17** Light reflected from the tree enters the eye and forms an image of the tree on the retina. This image is transformed into electrical signals that travel out the back of the eye along the optic nerve and eventually reach the brain. Our perception of the tree is based on the information contained in these neural signals.



● **FIGURE 2.19** The types of nerve firing patterns that would be recorded from a few of the feature detectors that respond to the tree: (a) rapid, evenly spaced firing; (b) slower, evenly spaced firing; (c) irregular firing; (d) bursts of firing; (e) little or no firing. The overall pattern of firing of these neurons, and the many other neurons that respond to the tree, are the neural representation of the tree.



● **FIGURE 2.18** Three types of stimuli that Hubel and Wiesel (1959, 1965) found caused neurons in the cat cortex to respond. They found neurons that responded to bars with a specific orientation, to bars with a specific orientation that were moving in a particular direction, and bars of a particular length that were moving in a particular direction. Neurons that responded to these specific types of stimuli were called feature detectors.

Two researchers who played an important role in describing feature detectors are David Hubel and Thorsten Wiesel, who began their careers at Johns Hopkins University and then established a laboratory at Harvard, where they carried out research on the visual system that earned them a Nobel Prize in 1981. Their tactic was to monitor the signals generated by neurons in the cortex of cats and monkeys (see Method: Recording From a Neuron, p. 28) and determine which visual stimuli caused each neuron to fire. Hubel and Wiesel found that each neuron fired only to a specific type of stimulation presented to a small area of the retina. ● Figure 2.18 shows some of the stimuli that caused neurons in and near the visual receiving area to fire (Hubel, 1982; Hubel & Wiesel, 1959, 1961, 1965).

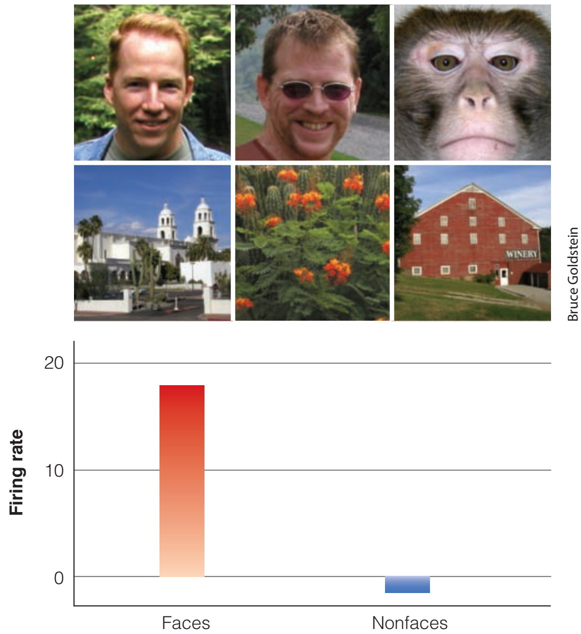
This knowledge that neurons in the visual system fire to specific types of stimuli led researchers to propose that each of the thousands of neurons that fire when we look at a tree fire to different features of the tree. Some neurons fire to the vertically oriented trunk, others to the variously oriented branches, and some to more complex combinations of a number of features. We could, in fact, describe the firing of all of these neurons together as creating a "chorus" of neural signals, with some neurons firing vigorously (● Figure 2.19a), some slowly (Figure 2.19b), some steadily (Figures 2.19a and b), some irregularly (Figure 2.19c), some in bursts (Figure 2.19d), and some little or not at all (Figure 2.19e). What is important about this "neural chorus" is that it stands for—or represents—the tree. Other objects in the environment create their own, unique choruses of firing. Thus, we can describe the tree we are looking at or other stimuli in the environment, such as the sound of a bird's chirping or the smell of pine needles, as each being represented by a particular pattern of firing in a number of neurons. The way these patterns of neural firing represent environmental stimuli is called the **neural code**.

The discovery of feature detectors in the primary visual receiving area was the first step in determining the neural code. Further research in areas beyond the primary receiving area revealed neurons that respond to stimuli that are more complex than oriented lines. Many researchers, recording from neurons in the temporal lobe, found neurons that responded to complex geometrical objects and some to that now familiar stimulus—the face (● Figure 2.20). Because faces are such a common stimulus, and because of the discovery of neurons sensitive to faces, we will now consider some ideas about the neural code for faces.

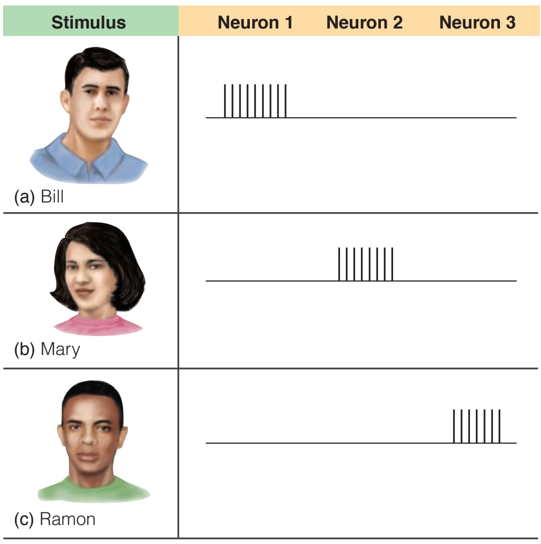
CogLab
Receptive Fields

THE NEURAL CODE FOR FACES

How can a particular face be represented by the firing of neurons in the temporal cortex? Although we will use faces as an example, our answer applies to all experiences, not just to seeing faces. One possible way that faces could be represented is by **specificity coding**—the representation of a specific stimulus, such as a particular person's face, by the firing of very specifically tuned neurons that are specialized to respond just to that face. This



● **FIGURE 2.20** Firing rate, in nerve impulses per second, of a neuron in the monkey's temporal cortex that responds to face stimuli but not to nonface stimuli. (Source: Based on data from Rolls & Tovee, 1995.)



● **FIGURE 2.21** How faces could be coded by specificity coding. Each faces causes one specialized neuron to respond. (Source: B. Goldstein, *Sensation and Perception* 8th ed., Fig. 2.21, p. 36. Copyright © 2010 Wadsworth, a part of Cengage Learning. Reproduced with permission. www.cengage.com/permissions.)

is illustrated in ● Figure 2.21, which shows that Bill's face would be signaled by the firing of neuron 1, which responds only to his face; Mary's face is signaled by the firing of neuron 2; and Ramon's face by the firing of neuron 3. Thus, specificity coding proposes that there are neurons that are tuned to respond just to one specific stimulus.

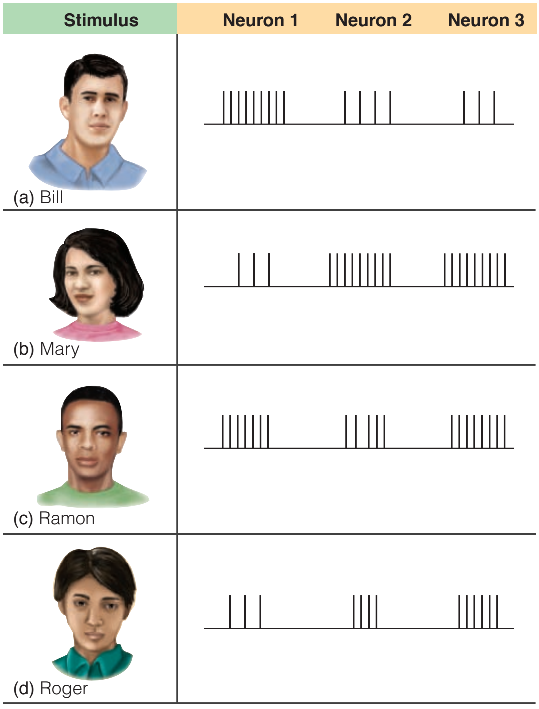
The idea that there might be single neurons that respond only to specific stimuli was proposed in the 1960s by Jerzy Konorski (1967) and Jerry Lettvin (see Barlow, 1995; Gross, 2002; Rose, 1996). Lettvin coined the term *grandmother cell* to describe this highly specific type of cell. A **grandmother cell**, according to Lettvin, is a neuron that responds only to a specific stimulus. This stimulus could be a specific image, such as a picture of your grandmother; a concept, such as the idea of grandmothers in general; or your real-life grandmother (Gross, 2002).

But there are problems with this idea: (1) There are just too many different faces and other objects in the environment to assign specific neurons to each one; and (2) although there are neurons that respond only to specific types of stimuli, such as faces, even these neurons respond to a number of different faces. Thus, a neuron that responds to Bill's face would also respond to Roger's and Samantha's faces. Because of these problems, the idea of a highly specific grandmother-type neuron has not been accepted by researchers.

The generally accepted solution to the problem of neural coding is that a particular face is represented not by the firing of a single neuron, but by the firing of *groups* of neurons. For example, let's consider how the three neurons in ● Figure 2.22 fire to a number of different faces. Bill's face causes all three neurons to fire, with neuron 1 responding the most and neuron 3 responding the least. Mary's face also causes firing in all three neurons, but the pattern is different, with neuron 3 responding the most and neuron 1 the least. All three neurons also fire to Ramon's and Roger's faces, but with their own individual patterns.

Thus, each face is represented by a pattern of firing across a number of neurons. This solution to the problem of neural coding is basically the same thing as the idea of a "chorus" of neural firing that we described when considering how feature detectors could represent a tree. This is called **distributed coding** because the code that indicates a specific face is *distributed* across a number of neurons. One of the advantages of distributed coding is that the firing of just a few neurons can signal a large number of stimuli. In our example, the firing of three neurons signals four faces, but these three neurons could also signal other faces, which would have their own pattern of firing. (The similarity of the terms *distributed coding* and *distributed processing* might cause some confusion. For our purposes, distributed coding refers to the pattern of firing of a number of individual neurons, and distributed processing refers to the activation of a number of different areas of the brain.)

What all of this means is that our ability to identify and recognize the huge number of different objects in our environment is the end result of distributed cooperation



● **FIGURE 2.22** How faces could be coded by distributed coding. Each face causes all the neurons to fire, but the pattern of firing is different for each face. One advantage of this method of coding is that many faces could be represented by the firing of the three neurons. (Source: B. Goldstein, *Sensation and Perception*, 8th ed., Fig. 2.23, p. 38. Copyright © 2010 Wadsworth, a part of Cengage Learning. Reproduced with permission. www.cengage.com/permissions.)

among many neurons. This occurs even for stimuli like faces that are served by specialized neurons that respond just to faces. It may not take many neurons to let you know that you are seeing a face, but it takes a number of neurons working together to signal the presence of one particular face.

THE NEURAL CODE FOR MEMORY

Memories are also represented in the brain, and the same principles hold for memory as for perception—experiences are represented by nerve firing, with different experiences represented by different patterns of firing. Thus, if a few weeks after you look at the tree you remember seeing it, perhaps even visualizing what it looked like, this memory is elicited by a particular pattern of the firing of many neurons in the brain. There is, however, an important difference between the neural firing caused by perception and the neural firing caused by memory.

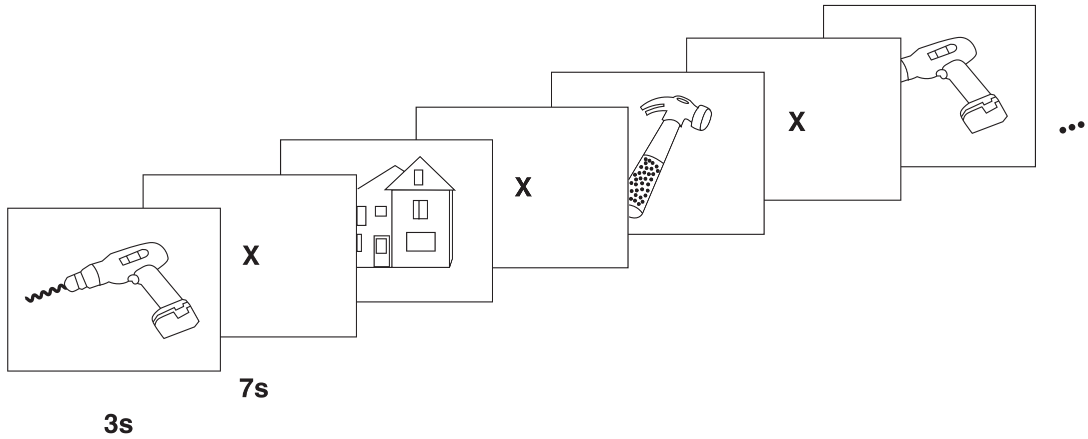
The neural firing associated with experiencing a perception is caused by stimulation of the sensory receptors. In contrast, the neural firing associated with experiencing a memory is caused by firing in structures that contain information about what happened in the past. Thus, while the firing associated with perception is associated with what is happening as you are looking at the tree, firing associated with memory is associated with information that has been stored in the brain. We know less about the actual form of this stored information for memory, but it is likely that the basic principle of distributed coding also operates for memory, with specific memories being represented by particular patterns of stored information that result in a particular pattern of nerve firing when we experience the memory. We will discuss the physiological processes involved in memory in Chapters 5 and 7.

Something to Consider

"Mind Reading" by Measuring Brain Activity

The idea that cognitions are represented by distributed activity in the brain raises an interesting question: Is it possible to determine what a person is seeing, thinking, or remembering by measuring the activity of the brain? To achieve this, we would have to know exactly what pattern of activity was associated with every possible object, thought, or memory, and we are far from being able to do this. However, recent research using computer programs that can be trained to recognize the patterns of brain activity associated with seeing and thinking about an object has brought us closer to this goal. Computer programs have recently been developed that can, with a surprising degree of accuracy, identify from a group of objects the specific object a person is seeing.

We will describe an experiment by Svetlana Shinkareva and coworkers (2008). In the first part of the experiment, a computer learned the patterns of neural activity that were associated with different objects. The first step was to have participants look at a series of pictures like the one in ● Figure 2.23. These pictures are line drawings of tools and dwellings. The participants' saw pictures of five different tools and five different dwellings while in a brain scanner, which measured the fMRI response to each



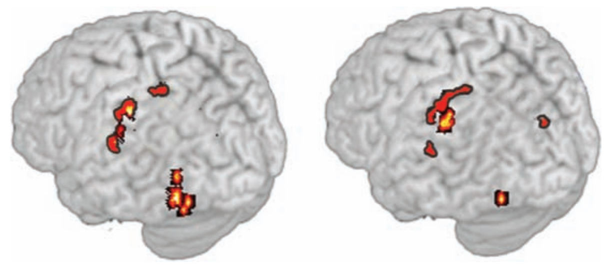
● **FIGURE 2.23** Stimuli for the Shinkareva et al. (2008) experiment. Participants viewed a series of pictures for 3 seconds each, with 7 seconds between pictures, while their brain activity was being measured in an fMRI scanner. (Source: S. V. Shinkareva et al., "Using fMRI Brain Activation to Identify Cognitive States Associated with Perception of Tools and Dwellings," *PLoS One*, Figure 1, p. 2, 2008.)

picture. Participants were asked to think of properties of the object as they looked at the picture. For example, when looking at the drill they might think about drilling holes in a board. Each picture was presented for 3 seconds, followed by a 7-second rest interval. While the participants viewed the pictures, the activity of their cortex was being recorded by the fMRI scanner.

The key to the success of this experiment was the computer program, which analyzed the responses of the brain voxel by voxel, where a voxel is a small cube-shaped area of the brain about 2 or 3 mm on a side. (The size of the voxel depends on the resolution of the fMRI scanner. Scanners are being developed that will be able to resolve volumes smaller than 2 or 3 mm on a side.) By determining which voxels were activated by each picture and how strongly they were activated, the computer created a response profile, or "neural signature," for each object, which included many areas of the brain. Eventually, after collecting patterns from a dozen participants, the computer determined the neural pattern associated with each class of objects (tool vs. dwelling) and with each individual object (hammer, apartment, or screwdriver, for example).

The computer was then tested by having it analyze a person's brain activity as he or she was viewing an object. Based on the pattern, the computer predicted what the person was seeing. When the computer's task was simply to indicate whether the person was looking at a tool or a dwelling, the accuracy for 4 of the 12 participants was 97 percent; for the entire group of 12 participants, it was 87 percent (chance performance being 50 percent because there were two possible answers). The average accuracy for identifying specific objects was 78 percent (chance being 10 percent, because there were 10 different objects).

This is impressive performance, but what is even more impressive is that the computer made accurate predictions even for people whose data had not been previously analyzed. Imagine what this means. You walk into the brain imaging facility for the first time, are placed in the scanner, and view a picture of an apartment building. The computer analyzes your brain activity and concludes that you are looking at a "dwelling," and also predicts "apartment building." Average accuracy for determining the category ("dwelling") is 82 percent. This ability to determine what a particular person is seeing based on the data from other people is possible because patterns of brain activation are similar for different people. In other words, different people have similar neural signatures for specific types of objects. This commonality among people is illustrated in ● Figure 2.24, which shows the



● **FIGURE 2.24** The red areas indicate the location of voxels for two of Shinkareva's participants, which provided information that they were viewing "tools."

location of the voxels that provided information the computer used to determine that two different participants were looking at "tools."

Do these results mean that a computer could determine what you are thinking by analyzing your brain's pattern of activation? At this point, being able to determine whether someone is looking at an apartment or an igloo is far from being able to tell that you are thinking about what you did on your summer vacation. Nonetheless being able to make predictions about what category of object a person is looking at is a huge advance, especially when we consider that just 50 years earlier the state-of-the-art discovery was neurons that respond most vigorously to oriented bars (Figure 2.18).

TEST YOURSELF 2.2

1. What is distributed processing? How was it described in the text, beginning with how information about faces is localized in the brain? What is "particularly significant" about faces?
2. How was distributed processing illustrated by the example of the rolling red ball? The physiology of memory?
3. What does it mean to say that a tree, or other object, is *represented* in the brain? How did early researchers describe this representation in terms of feature detectors?
4. How do current researchers describe the neural code for faces? Be sure you understand specificity coding, grandmother cells, and distributed coding. What is the distinction between distributed coding, as described in this section, and distributed processing that was described earlier?
5. Describe recent experiments that have been able to demonstrate a form of "mind reading" by monitoring brain activity.

CHAPTER SUMMARY

1. Cognitive neuroscience is the study of the physiological basis of cognition.
2. Ramon y Cajal's research resulted in the abandonment of the neural net theory in favor of the neuron doctrine, which states that individual cells called neurons transmit signals in the nervous system.
3. Signals can be recorded from neurons using microelectrodes. Adrian, who recorded the first signals from single neurons, determined that action potentials remain the same size as they travel down an axon and that increasing stimulus intensity increases the rate of nerve firing.
4. The idea of localization of function in perception is supported by the existence of a separate primary receiving area for each sense, by the effects of brain damage on perception (for example, prospoganosia), and by the results of brain imaging experiments.
5. Brain imaging measures brain activation by measuring blood flow in the brain. Functional magnetic resonance imaging (fMRI) is widely used to determine brain activation during cognitive functioning. One result of brain imaging experiments has been the identification of areas in the human brain that respond best to faces, places, and bodies.
6. Research on brain-damaged patients by Broca and Wernicke provided evidence for localization of function for language. Based on the patients' symptoms, they identified two different conditions, Broca's aphasia and Wernicke's aphasia, as involving problems in language production and language understanding, respectively. These two conditions were associated with damage to different areas of the brain.
7. Recent research has resulted in modification of the Broca/Wernicke model. Behavioral research has shown

that patients with Broca's aphasia can, under certain conditions, have difficulty understanding language. Physiological research, involving both studying brain-damaged patients and recording the event-related potential, suggests two processes for language processing, one involving the form of language and the other involving meaning.

8. The idea of distributed processing is that specific functions are processed by many different areas in the brain. This principle is illustrated by the finding that faces activate many areas of the brain and by the simpler example of the rolling red ball, which also activates a number of areas.
9. Distributed processing also occurs for other cognitive functions, such as memory, decision making, and problem solving. A basic principle of cognition is that different cognitive functions often involve similar mechanisms.
10. Objects and properties of the environment are represented by electrical signals in the nervous system.
11. Research indicating that individual neurons in the visual system fire to specific simple stimuli, such as oriented bars, led to the idea of feature detectors. This research suggests that a particular object is represented by the firing of many neurons, creating a unique "chorus" of electrical signals for that object. The pattern of neural firing that represents an environmental stimulus is called the neural code.
12. Among proposals regarding the nature of the neural code are specificity theory, which includes the idea of grandmother cells, and distributed coding. Current evidence favors the idea of distributed coding. Thus, a particular face would be represented by the pattern of firing across a number of neurons. This is similar to the idea of a neural chorus.
13. The idea of a distributed neural code also applies to memory and other cognitive functions. The code for memory involves stored information.
14. Computer programs have recently been developed that can, with a surprising degree of accuracy, use data from brain imaging, collected as a person is observing pictures of different objects, to identify from a group of objects the specific object that a person is seeing.

Think ABOUT IT

1. Some cognitive psychologists have called the brain the mind's computer. What are computers good at, that the brain is not? How do you think the brain and the mind compare in terms of complexity? What advantage does the brain have over a computer?
2. People generally feel that they are experiencing their environment directly, especially when it comes to sensory experiences such as seeing, hearing, or feeling the texture of a surface. However, our knowledge of how the nervous system operates indicates that this is not the case. Why would a physiologist say that all of our experiences are indirect?
3. When brain activity is being measured in an fMRI scanner, the person's head is surrounded by an array of magnets and must be kept perfectly still. In addition, the operation of the machine is very noisy. How do these characteristics of brain scanners limit the types of behaviors that can be studied using brain scanning?
4. It has been argued that we will never be able to fully understand how the brain operates because doing this involves using the brain to study itself. What do you think of this argument?

If You WANT TO KNOW MORE

Brain damage and behavior. There are numerous books that describe fascinating case studies of people whose behavior has been affected by brain damage.

Farah, M. J., & Feinberg, T. E. (2003). *Behavioral neurology and neuropsychology* (2nd ed.). New York: McGraw-Hill.

Ramachandran, V. S., & Blakeslee, S. (1998). *Phantoms of the mind: Probing the mysteries of the human mind.* New York: HarperCollins.

Sacks, O. (1985). *The man who mistook his wife for a hat.* New York: Touchstone.

Key TERMS

Action potential, 28
Axon, 26
Brain imaging, 30
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Neuron doctrine, 26
Neurotransmitter, 29
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Parietal lobe, 30
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Reference electrode, 28
Retina, 38
Specificity coding, 39
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Wernicke's area, 33

Media RESOURCES

The *Cognitive Psychology* Book Companion Website

www.cengage.com/psychology/goldstein

Prepare for quizzes and exams with online resources—including a glossary, flashcards, tutorial quizzes, crossword puzzles, and more.

CogLab

To experience these experiments for yourself, go to coglab.wadsworth.com. Be sure to read each experiment's setup instructions before you go to the experiment itself.Otherwise, you won't know which keys to press.

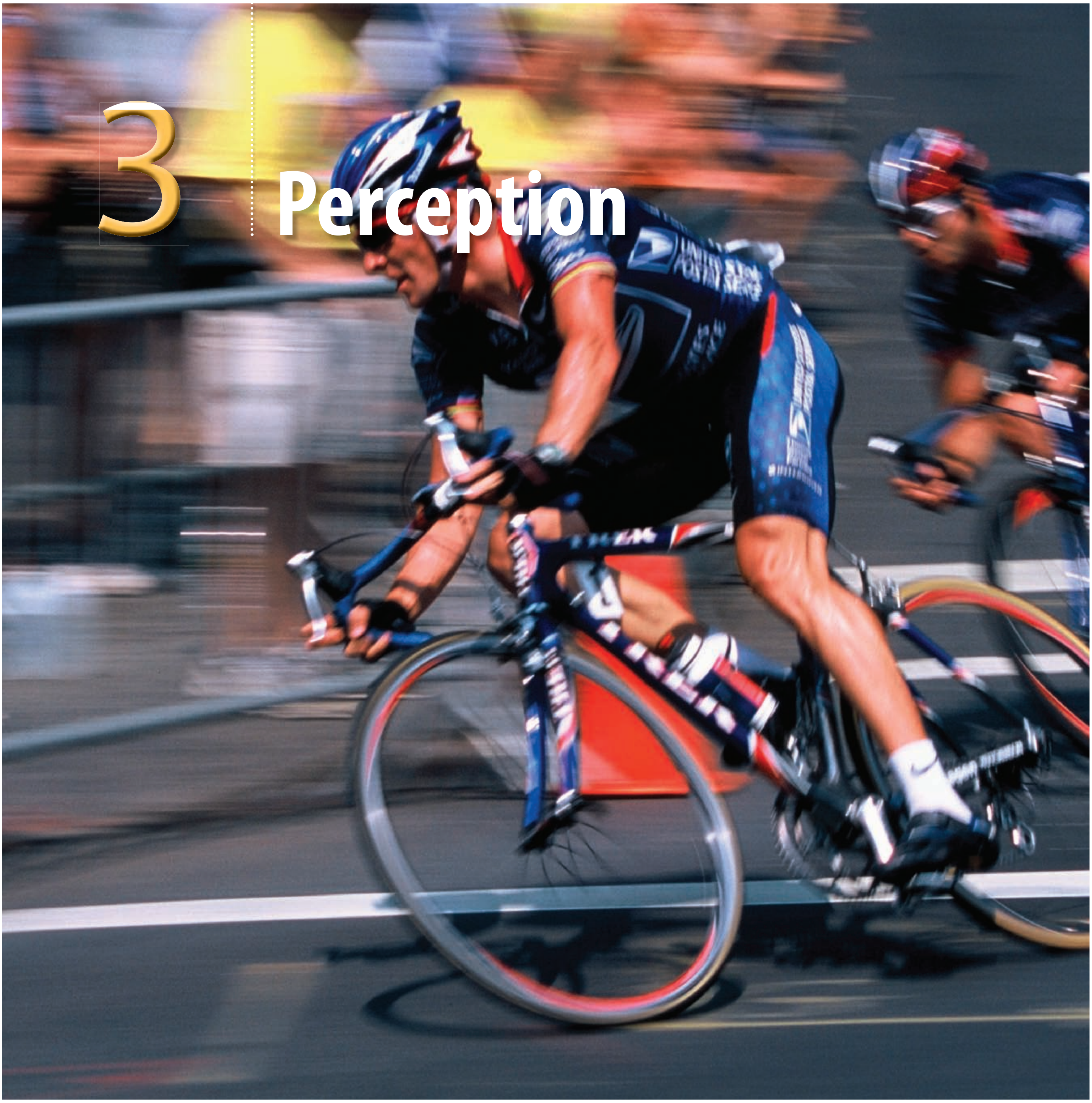
Primary Lab

Receptive fields A receptive field of a visual neuron is the area on the retina that influences the activity of that neuron. In this lab, you can map the receptive fields of some neurons. (p. 39)

Related Lab

Brain asymmetry How speed of processing for shapes and words may be different in the left and right hemispheres.

3 Perception

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- Why can two different people experience different perceptions in response to exactly the same stimulus? (57)
- How does perception depend on a person's knowledge about characteristics of the environment? (63)
- How does the brain become tuned to respond best to things that are likely to appear in the environment? (66)
- Are there neurons in the visual system that might help us understand other people's actions? (75)

Crystal begins her run along the beach just as the sun is rising over the ocean. She loves this time of day, both because it is cool and because the mist rising from the sand creates a mystical effect. As she looks down the beach, she notices something about 100 yards away that wasn't there yesterday. "What an interesting piece of driftwood," she thinks, although it is difficult to see because of the mist and dim lighting (● Figure 3.1a). As she approaches the object, she begins to doubt her initial perception, and just as she is wondering whether it might not be driftwood, she realizes that it is, in fact, the old beach umbrella that was lying under the lifeguard stand yesterday (Figure 3.1b). When she realizes this, she is amazed at what has happened. "Driftwood transformed into an umbrella, right before my eyes," she thinks.

Continuing down the beach, she passes some tangled rope that appears to be abandoned (Figure 3.1c). She stops to check it out. Grabbing one end, she flips the rope and sees that, as she suspected, it is one continuous strand. But she needs to keep running,

(a) (b) (c)

● **FIGURE 3.1** (a) Initially Crystal thinks she sees a large piece of driftwood far down the beach. (b) Eventually she realizes she is looking at an umbrella. (c) On her way down the beach, she passes a piece of rope.

because she is supposed to meet a friend at Beach Java, a coffeehouse far down the beach at the end of her run. Later, sitting in the coffeehouse, she tells her friend about the piece of magic driftwood that was transformed into an umbrella.

The Nature of Perception

Crystal's experiences illustrate a number of things about **perception**, which we define as experiences resulting from stimulation of the senses. Her experience illustrates how perceptions can change, based on added information (Crystal's view became better as she got closer to the umbrella), and how perception can involve a process similar to reasoning or problem solving (Crystal figured out what the object was based partially on remembering having seen that umbrella the day before). (Another example of an initially erroneous perception followed by a correction is the tag line "It's a bird. It's a plane. It's Superman!")

Crystal's experience also demonstrates how arriving at a perception can involve a *process*. It took some time for Crystal to realize that what she thought was driftwood was actually an umbrella, so it is possible to describe her perception as involving a "reasoning" process. However, in most cases perception occurs so rapidly and effortlessly that it appears to be automatic. But as we will see in this chapter, perception is far from automatic. It involves complex, and usually invisible, processes that do resemble reasoning, although they occur much more rapidly than Crystal's realization that the driftwood was actually an umbrella.

Finally, Crystal's experience also illustrates how perception occurs in conjunction with action. Crystal is running and perceiving at the same time; later, she easily reaches for her cup of coffee, a process that involves a coordination between seeing the coffee cup, determining its location, physically reaching for it, and grasping its handle. This aspect of Crystal's experiences is just like what happens in everyday perception. We are usually moving, and even when we are just sitting in one place watching TV, a movie, or a sporting event, our eyes are constantly moving as we shift our attention from one thing to another to perceive what is happening. We also grasp and pick up things many times a day, whether it is a cup of coffee, a pen or pencil, or this book. As we will see in this chapter, perception involves dynamic processes that accompany and support our actions.

Before describing these processes, it is important to note that the importance of perception extends beyond identifying objects or helping us take action within our environment. We can appreciate this by remembering that cognitive psychology is about acquiring knowledge, storing this knowledge in memory, and retrieving it later to accomplish various tasks such as remembering events from the past, solving problems, communicating with other people, recognizing someone you met last week, and answering questions on a cognitive psychology exam. Without perception, it is unlikely that these feats of cognition would be possible.

Think about this for a moment. How aware could you be of things that are happening right now, and how well could you accomplish the cognitive skills mentioned above, if you had lost all of your senses and, therefore, your ability to perceive? Considered in this way, perception is the gateway to all of the other cognitions that we will be describing in the other chapters in this book.

The goal of this chapter is to explain the mechanisms responsible for perception. We will do this by first describing how perception begins when receptors are activated by stimuli in the environment. We will then show that other factors, in addition to stimulation of the receptors, are also involved in creating perceptions. As we do this, you will see that although perception appears to occur automatically, it is actually the outcome of complex processes that resemble, to some extent, processes involved in solving problems. Finally, we will describe how perception occurs in conjunction with action, as when Crystal perceives an object as she runs down the beach and as she combines perception and action in reaching for her cup of coffee.

Perception Starts at the Receptors: Bottom-Up Processing

The first step in perception is the stimulation of receptors by stimuli from the environment. Let's first consider the signals generated in Crystal's visual receptors. Crystal sees the umbrella because light reflected from the umbrella enters her eyes, stimulates receptors, and starts electrical signals traveling toward the visual receiving area of the cortex. Processing that begins with stimulation of the receptors is called **bottom-up processing**. All of our sensory experiences, with the exception of situations in which we might imagine something or "see stars" from getting hit on the head, begins with bottom-up processing. We can describe bottom-up processing both physiologically and behaviorally.

BOTTOM-UP PROCESSING: PHYSIOLOGICAL

We can describe the physiological approach to bottom-up processing briefly, because we have already described, in Chapter 2, the sequence of events that occur after light reflected from a tree stimulates the visual receptors in the eye (see page 38). We saw that stimulation of the receptors triggers a series of events in which electrical signals are transmitted from the receptors toward the brain. Perceiving the tree or a bird chirping occurs after electrical signals that start in the receptors reach the brain.

The initial effect of these signals in the cortex has been determined by recording electrical signals from individual neurons. As we described in Chapter 2, neurons in the cortex that respond best to simple shapes like lines or bars with specific orientations are called feature detectors because they respond to simple features.

Perceiving a tree, or any other object, depends on activity beyond the visual cortex, but the feature detectors' response is the first step in the brain's response to objects. Thus, when you look at an object such as a tree, neurons in the visual cortex that respond to specific orientations fire to features of the tree, such as the trunk and branches, as shown in ● Figure 3.2.

(a) (b)

Bruce Goldstein

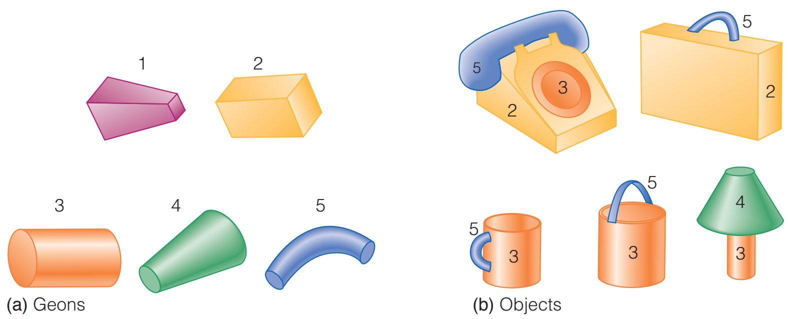
● **FIGURE 3.2** A tree such as this one can be created from a number of simple features, such as oriented bars (a few of which are highlighted on the right). When a person looks at the tree, each feature can activate feature detectors in the cortex that respond best to specific orientations. This occurs at an early stage of cortical processing.

BOTTOM-UP PROCESSING: BEHAVIORAL

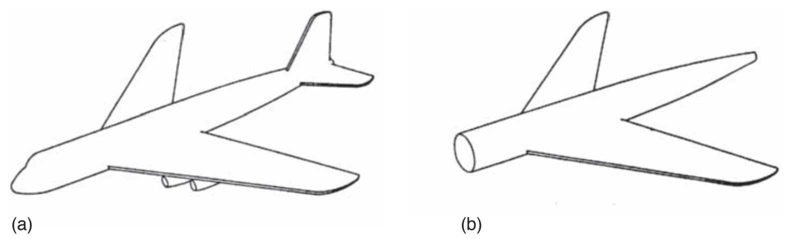
The idea that neurons fire to individual features of a tree suggests that perhaps our perception of the tree is created by combining the information provided by the firing of many feature detectors. A behavioral approach to this idea that perception can be created by combinations of individual features has been proposed by Irving Biederman (1987). His idea, called **recognition-by-components (RBC)** theory, proposes that we perceive objects by perceiving elementary features like those in ● Figure 3.3a, called **geons**. Geons are perceptual building blocks that can be combined to create objects, as shown in Figure 3.3b.

One of the characteristics of object perception, according to RBC, is that we can recognize an object if we are able to perceive just a few of its geons. For example, Biederman showed that an airplane that has a total of nine geons (● Figure 3.4a) was recognized correctly about 78 percent of the time even if only three geons were present (Figure 3.4b), and 96 percent of the time if six geons were present.

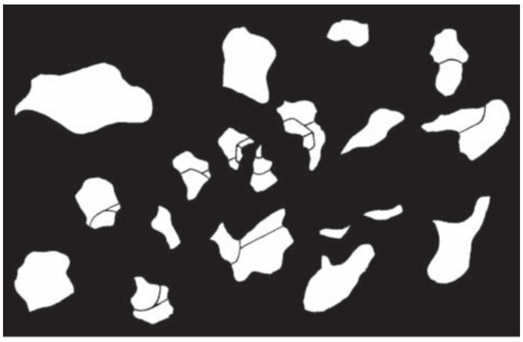
We can also perceive objects even if portions of the geons are obscured, as shown in ● Figure 3.5a. The reason you can tell this is a flashlight, according to RBC, is that you are able to make out its geons. This is an example of the **principle of componential recovery**—if we can recover (see) an object's geons, we can identify the object.



● **FIGURE 3.3** *Left*: Some geons. *Right*: Some objects created from the geons on the left. The numbers on the objects indicate which geons are present. Note that recognizable objects can be formed by combining just two or three geons. Also note that the relations between the geons matter, as illustrated by the cup and the pail. (Source: Adapted from I. Biederman, "Recognition-by-Components: A Theory of Human Image Understanding," *Psychological Review, 24*, 2, 115–147, Figures 3, 6, 7, and 11, Copyright © 1987 by the American Psychological Association. Reprinted by permission.)



● **FIGURE 3.4** An airplane represented (a) by nine geons and (b) by three geons. (Source: From I. Biederman, *Computer Vision, Graphics and Image Processing*, p. 73. Copyright © 1985 by Irving Biederman. Academic Press, 1985. All rights reserved. Reproduced by permission of Elsevier, Ltd.)



(a)

(b)

● **FIGURE 3.5** (a) It is possible to identify this object as a flashlight, even though it is partially obscured, because it is possible to perceive its geons. (b) When the shading is arranged so the geons can't be perceived, it is not possible to recognize the flashlight. (Source: From I. Biederman, *Computer Vision, Graphics and Image Processing*, pp. 29 and 32. Copyright © 1985 by Irving Biederman. Academic Press, 1985. All rights reserved. Reproduced by permission of Elsevier, Ltd.)

Figure 3.5b shows an example in which the corners and intersections of the flashlight's geons are covered, so the geons can't be identified. This is the flip side of the principle of componential recovery—if we *can't* see an object's individual geons, we *can't* recognize the object.

RBC provides an example of bottom-up processing because its basic unit—the geon—is simple and because perceiving simple geometric objects like the ones in Figure 3.3 can be related to patterns of stimulation on the retina. This is similar to how the cortical neurons in Figure 3.2 can be related to stimuli that are presented to the retina. But although perceiving objects begins with stimulation of receptors that leads to the activation of physiologically or behaviorally determined features, there is more to perceiving objects than this.

Beyond Bottom-Up Processing

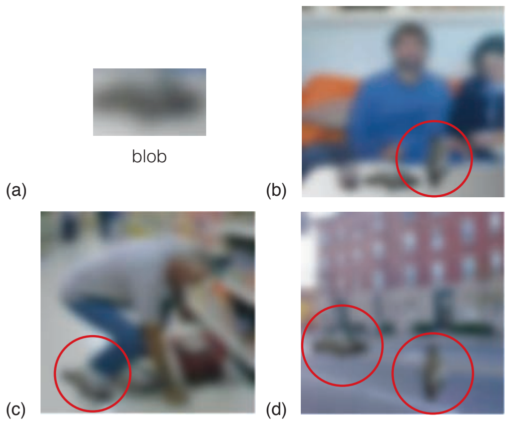
If perception were determined solely by bottom-up processing, then we could understand perception by considering only the information presented to the receptors. But perception depends on information in addition to that falling on the receptors, including knowledge that a person brings to the situation.

PERCEPTION DEPENDS ON ADDITIONAL INFORMATION

Consider the objects in Figure 3.3b. Although the individual geons that make up these objects may be determined by bottom-up processing, additional processing is involved when the geons are combined to create objects. In fact, the same geons can be combined to create different objects, such as the pail and the cup. We are able to recognize these different objects based on the arrangement of their geons, and to give these objects names like "pail" or "cup," because of knowledge we bring to the situation. Processing that begins with a person's prior knowledge or expectations is called **top-down processing**. Top-down processing is also involved in our ability to recognize objects based on just a few geons, as in Figure 3.4, or when large portions of the object are obscured, as in Figure 3.5. In both of these cases, prior knowledge about airplanes and flashlights probably helps a person perceive these objects.

Another example of how top-down processing is involved in perceiving objects is illustrated in ● Figure 3.6, which is called "the multiple personalities of a blob" (Oliva & Torralba, 2007). The blob shown in (a) is perceived as different objects depending on its orientation and the context within which it is seen. It appears to be an object on a table in (b), a shoe on a person bending down in (c), and a car and a person crossing the street in (d). Even though the blob has the same geons in all of the pictures, we perceive it as different objects because of our knowledge of the kinds of objects that are likely to be found in different types of scenes.

The idea that perception involves more than bottom-up processing also becomes apparent when we return to our discussion of physiology. We saw that signals traveling from the receptors to the brain provide information about an object's basic features. However, as these signals travel to the brain, other signals in addition to those generated by the object's features become involved as well. Some signals provide information about other parts of the scene. For example, signals from the tree (green arrows in ● Figure 3.7) are accompanied by signals from the grass surrounding the tree and from the sky in



● **FIGURE 3.6** "Multiple personalities of a blob." What we expect to see in different contexts influences our interpretation of the identity of the "blob" inside the circles. (Source: Adapted from A. Oliva & A. Torralba, "The Role of Context in Object Recognition," *Trends in Cognitive Sciences, 11*, Figure 2, 520–527. Copyright © 2007, with permission from Elsevier. Photographs courtesy of Antonio Torralba.)

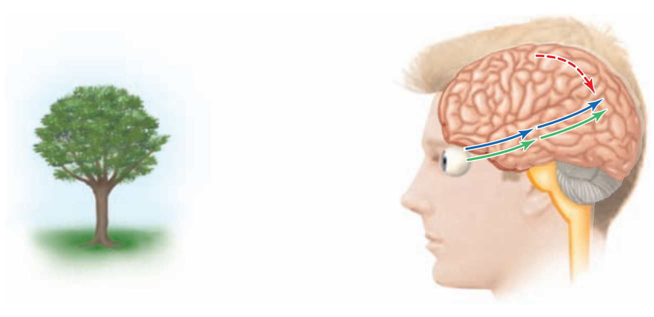
the background (blue arrows). In addition, other signals, which are associated with a person's knowledge and expectations, are being transmitted down from higher levels in the brain (dashed arrow). Signals such as this, that travel down from higher centers to influence incoming signals, are called **feedback signals** (Di Lollo, 2010).

From the physiological point of view, therefore, perception of an object is based on signals representing the object plus signals representing other aspects of the environment and feedback signals representing prior knowledge or expectations (Figure 3.7). Looking at perception in this way, we can draw an analogy between perception and baking a loaf of bread. The basic ingredients for bread are flour and water, plus extra ingredients such as poppy seeds or salt, depending on the recipe. But if you just mix these ingredients together, the bread doesn't rise. A little yeast is also necessary to make the bread rise. Add the yeast to these other ingredients, bake, and you get a loaf of bread. (Without the yeast, unleavened bread such as matzo, flatbread, or communion wafers results.)

Just as creating a loaf of bread requires the basic ingredients plus yeast, perception depends on information provided by stimulation of receptors plus additional information such as information about the environment and a person's prior knowledge. This information is carried in the additional physiological signals we have described, but we can also use perceptual examples to demonstrate how the perceptual system takes additional information into account. We will do this by describing two different kinds of perceptions: perception of the size of an object and perception of the intensity of an odor.

PERCEIVING SIZE: TAKING DISTANCE INTO ACCOUNT

Imagine that you are walking down some railroad tracks when you suddenly come upon the scene in ● Figure 3.8. The small creature near you seems harmless, but you're a little worried about the larger one! You perceive the two creatures to be very different in size, yet they both cover the same distance across your field of view and therefore have the same-sized image on your retina (● Figure 3.9). (Check this out by measuring them!) This means that something in addition to the size of the creature's image on the retina determines your perception of its size.

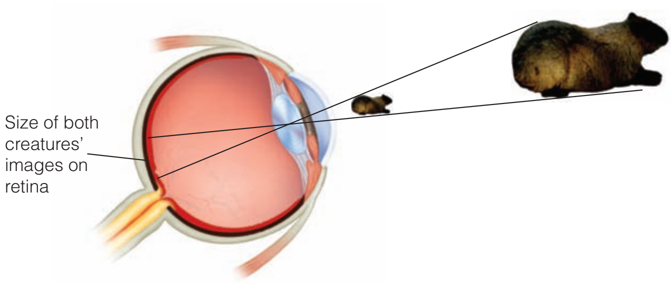


● **FIGURE 3.7** Perception is determined by three sources of information: (1) information originating from stimulation of the receptors (bottom-up = green arrows); (2) additional information such as the context in which an object appears (blue arrows); (3) knowledge or expectations of the perceiver (top-down = dashed arrow). The dashed red arrow represents feedback signals.

What other information is available? Perhaps the most obvious is that the creatures are at different distances. A large amount of research has shown that if two objects are perceived to be at different distances but cast the same-sized image on the retina, the perceptual system takes the distance of the farther object into account, so it is perceived as its true, larger size. This makes sense, because in our everyday experience a distant object can result in the same-sized image on the retina as a much smaller object that is closer (see ● Figure 3.10), so the way the perceptual system takes depth into account helps us more accurately perceive the size of the faraway object.

In addition to depth, the perceptual system could also be taking into account the size of the object relative to other objects in the environment. Returning to our creatures on the railroad tracks, we can see that the near creature fits within the two tracks with space to spare, while the far one

● **FIGURE 3.8** These two creatures are at different distances, but the farther one is larger. Both creatures cover the same amount of the observer's field of view (measure them!). (Source: William Vann/www.edupic.net.)



● **FIGURE 3.9** The two creatures on the railroad tracks cover the same area in the field of view and cast the same-sized images on the retina because one is small but close and the other is larger but farther away.

overlaps the tracks. Thus, the relationship of the creatures to the railroad tracks provides information about their relative sizes. The perceptual system's use of information about the creatures' distance and their size relative to the tracks illustrates how information in addition to the size of the image on the retina helps determine the perception of their size.

Here's a demonstration that shows how information provided by the retinal image does not necessarily correspond to what we perceive.

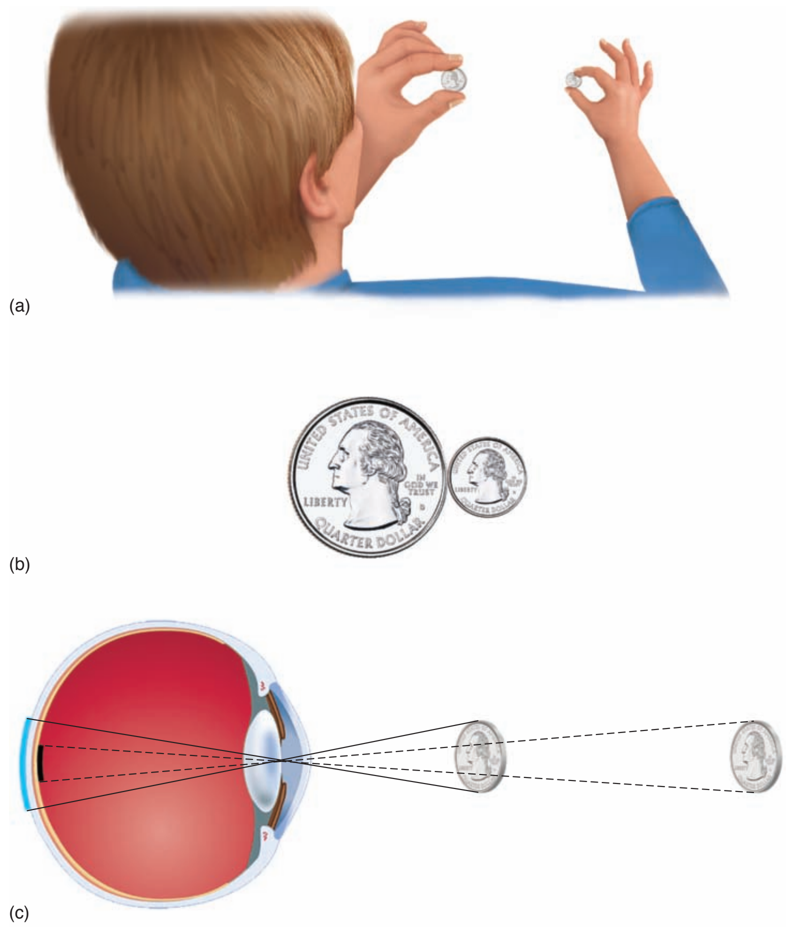
DEMONSTRATION Two Quarters

Hold two quarters as shown in ● Figure 3.11a, with one far away and one closer (at about half the distance). Then close one eye and view the two quarters, keeping them at the same distances and positioning them so their edges appear to be touching (Figure 3.11b). Notice how you perceive the sizes of the two quarters under these conditions. Then open your other eye and view the quarters with both eyes so they no longer appear to be right next to each other. How does that affect your perception of the sizes of the two quarters?

● **FIGURE 3.10** Like the two creatures on the railroad tracks, the top part of the nearby planter and the faraway building are the same size in the observer's field of view.

It is likely that in the first part of the demonstration, when you viewed the quarters next to each other with one eye, the farther quarter appeared smaller. This perception corresponds to the fact that the farther quarter creates a smaller image on the retina (Figure 3.11c). It is also likely that in the second part of the demonstration, with both eyes open, the quarters appeared more similar in size. This occurs because opening both eyes increases your ability to perceive depth, or the relative distance of the two quarters. The perceptual system can then take into account the quarters' distance, and this added information enables you to perceive their sizes more accurately.

Taking distance into account occurs all the time in real life. For example, as a person who is standing near you begins to walk away, he doesn't appear to shrink as his distance increases. A person who appears to be 6 feet tall when he is nearby also appears to be 6 feet tall when he is standing across the room, even though the size of his image on your retinas (as with the far quarter in the demonstration) is much smaller when he is farther away. This phenomenon is called **size constancy**—we tend to perceive objects as remaining the same size even when they move to different distances. All of the examples above, which are summarized in Table 3.1, lead to the same conclusion: Perception of the size of an object does not depend solely on the size of the object's image on the receptors.



● **FIGURE 3.11** (a) Viewing two quarters held at different distances. (b) Positioning the two quarters so, when viewed with one eye, their edges appear to be touching. (c) The far quarter causes a smaller image on the observer's retina than does the near quarter.

TABLE 3.1 Perception Is Not Completely Determined by the Size of the Image on the Retina

Example	Size of Image on Receptors	Perception
Two creatures on railroad tracks	Image size is the same.	Far creature appears larger.
Two quarters at different distances	Far quarter has smaller image on the receptors.	Two quarters appear about the same size when viewed with two eyes.
Person walking to the other side of the room	Person's image on observer's retina becomes smaller as he walks away.	Person appears the same size when near and farther away.

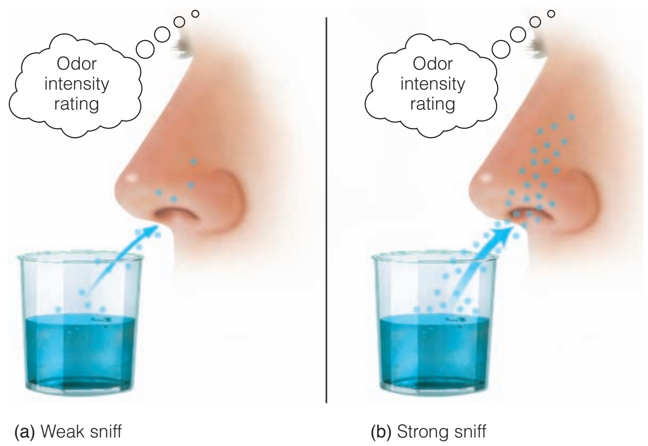


FIGURE 3.12 (a) A weak sniff causes few molecules to stimulate receptors inside the nose; (b) a stronger sniff increases the number of molecules reaching the receptors. Even though the receptors are stimulated differently in the two cases, the person's rating of odor intensity does not change.

PERCEIVING ODOR INTENSITY: TAKING SNIFFING INTO ACCOUNT

Imagine that you are given the following instructions: "Your task is to smell this flower and rate the intensity of its odor on a scale of 1 to 10. Flowers with very strong odors, with a fragrance you can smell from a distance, would receive a rating near the high end of the scale. Flowers with more subtle odors, which can be smelled only from very close up, would receive a rating nearer the low end of the scale. The odor of the flower you are going to smell is somewhere between these two extremes." Following these instructions, you bring the flower to your nose and sniff. You begin with a weak sniff, and then sniff more strongly. The question is, Would you rate the flower's odor intensity differently following these two different sniffs?

In a classic experiment, Robert Teghtsoonian and coworkers (1978) asked participants in a laboratory situation to rate the odor intensity of different odorants (chemical solutions with odors) and found that their participants gave almost identical ratings for weak sniffs and for strong sniffs. Think about what this means. Even though stronger sniffing causes more odor molecules to stimulate the receptors, this did not influence the participants' odor intensity ratings (● Figure 3.12). Teghtsoonian and coworkers concluded from this result that their participants were taking the strength of their sniff into account in making their ratings. Does this sound familiar? Just as the perceptual system takes distance and perhaps other factors into account when a person is perceiving size, the perceptual system takes sniff intensity into account when a person is perceiving odor intensity.

It is clear from these two very different examples that while perception may start at the receptors, it depends on additional sources of information as well. The goal of the perceptual system, after all, is to provide accurate information about what is out there in the environment. This is obviously important for survival. For example, we will know to take care when we see a large creature, even if it is far away and so casts a small image on our retinas, and to sniff only very weakly when we might be dealing with a potentially dangerous chemical.

TEST YOURSELF 3.1

1. What does Crystal's run down the beach illustrate about perception? List at least three different characteristics of perception. Why does the importance of perception extend beyond identifying objects?
2. What is bottom-up processing? How can it be described physiologically? Behaviorally? Be sure you understand the basic idea behind recognition-by-components theory, including the role of geons and the principle of componential recovery.
3. Describe how the following indicate that perception involves more than bottom-up processing: (1) naming objects created by geons; (2) multiple personalities of a blob; (3) physiological feedback signals. Following up on this, what is top-down processing, and how can we draw an analogy between perception and baking bread?
4. Describe how the following examples show that perception involves taking into account information in addition to what is on the receptors: (1) perceiving size, including the examples of the creatures on the railroad tracks, the two-quarters demonstration, and perceiving a person at two different distances; (2) perceiving the intensity of smell stimuli with weak and strong sniffs.

Using Knowledge: Top-Down Processing

We will now consider some further examples of how perception depends on more than just stimulation of the receptors. In this section we consider the role of top-down processing, processing that depends on a person's prior knowledge or expectations. We have already described two examples of top-down processing: the naming of objects created by different arrangements of geons, and the blob with the multiple personalities.

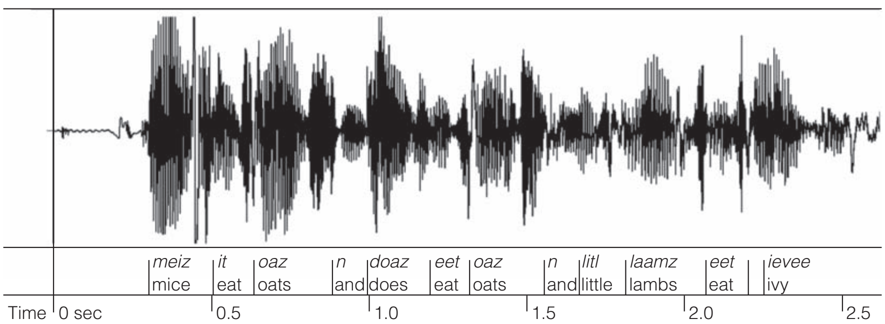
Another example of top-down processing is illustrated by something that happens when, as I channel-surf on TV, I stop at Telemundo, a channel that often has dramatic programs in which the action seems extremely interesting. My problem, however, is that Telemundo is a Spanish-language station and I don't understand Spanish. So while the people on the program understand each other, to me the dialogue often sounds like an unbroken string of sound, except occasionally when a familiar word like *gracias* pops out. My perception reflects the fact that the sound signal for speech is generally continuous, and when there are breaks in the sound, they do not necessarily occur between words. You can see this in ● Figure 3.13 by comparing the place where each word in the sentence begins with the pattern of the sound signal.

But when my Spanish-speaking acquaintances watch Telemundo, they perceive this unbroken string of sound as individual, meaningful words. Because of their knowledge of the language, they are able to tell when one word ends and the next one begins, a phenomenon called **speech segmentation**. The fact that a listener familiar only with English and another listener familiar with Spanish can receive *identical sound stimuli* but experience *different perceptions* means that each listener's experience with language (or lack of it!) is influencing his or her perception.

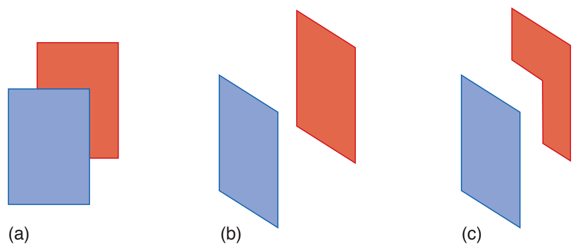
This example illustrates how knowledge that a person brings to the situation can influence perception. In our example, this knowledge is prior knowledge of Spanish, which makes it possible to perceive the individual words and therefore identify where one word ends and the other begins. The idea that perception depends on knowledge is not a new one. The 19th-century physicist and physiologist Hermann von Helmholtz (1866/1911) proposed a theory based on this idea.

HELMHOLTZ'S THEORY OF UNCONSCIOUS INFERENCE

Helmholtz proposed a principle called the **theory of unconscious inference**, which states that some of our perceptions are the result of unconscious assumptions that we



● **FIGURE 3.13** Sound energy for the sentence "Mice eat oats and does eat oats and little lambs eat ivy." The italicized words just below the sound record indicate how this sentence was pronounced by the speaker. The vertical lines next to the words indicate where each word begins. Note that it is difficult or impossible to tell from the sound record where one word ends and the other begins. (Source: Speech signal courtesy of Peter Howell.)



● **FIGURE 3.14** The display in (a) is usually interpreted as being (b) a blue rectangle in front of a red rectangle. It could, however, be (c) a blue rectangle and an appropriately positioned six-sided red figure.

make about the environment. This theory was proposed to account for our ability to create perceptions from stimulus information that can be seen in more than one way. For example, what do you see in the display in ● Figure 3.14a? Most people perceive a blue rectangle in front of a red rectangle, as shown in Figure 3.14b. But as Figure 3.14c indicates, this display could have been caused by a six-sided red shape positioned either in front of or behind the blue rectangle.

The theory of unconscious inference includes the **likelihood principle**, which states that we perceive the object that is *most likely* to have caused the pattern of stimuli we have received. Thus, we infer that it is likely that Figure 3.14a is a rectangle covering another rectangle because of experiences we have had with similar situations in the past. Helmholtz therefore described the process of perception as being similar to the process involved in solving a problem. For perception, the problem is to determine which object has caused a particular pattern of stimulation, and this problem is solved by a process in which the observer applies his or her knowledge of the environment in order to infer what the object might be. In cases such as the overlapping shapes in Figure 3.14, this process is unconscious, hence the term *unconscious inference*. (See Rock, 1983, for a modern version of this idea.)

We can apply this idea that perception involves a process similar to solving a problem to Crystal's attempts to identify the faraway shape on the beach. Based on what she saw at first, she hypothesized "driftwood" based on the image on her receptors and her knowledge of which objects are often found on the beach. But as she got closer, she decided it was more likely that the image was caused by the umbrella she had seen the day before. Although in this example Crystal used a conscious reasoning process that was much slower than Helmholtz's unconscious inference, the basic principle is similar to his proposal that perception involves an inferential process that resembles the process involved in solving a problem.

THE GESTALT LAWS OF ORGANIZATION

About 30 years after Helmholtz proposed his theory of unconscious inference, a group called the **Gestalt psychologists** proposed another approach. The goal of this approach was the same as Helmholtz's—to explain how we perceive objects—but the emphasis was different. The Gestalt psychologists were concerned with **perceptual organization**, the way elements are grouped together to create larger objects. For example, in ● Figure 3.15, some of the black areas become grouped to form a Dalmatian and others are seen as shadows in the background. The Gestalt psychologists proposed a number of **laws of perceptual organization** that indicate how elements in the environment are organized, or grouped together.

The starting points for the Gestalt laws are things that usually occur in the environment. Consider, for example, the rope in ● Figure 3.16a that Crystal saw as she was running down the beach (Figure 3.1c). Remember that when she grabbed one end of the rope and flipped it, it didn't surprise her that it was one continuous strand (page 48). The reason this didn't surprise her is that even though there were many places where one part of the rope overlapped another part, she didn't perceive the rope as consisting of a number of separate pieces, but perceived the rope as continuous. She perceived it this way because when one object overlaps another in the environment, the overlapped (underneath) object usually continues unbroken beneath the object on top. This is illustrated by the highlighted segment of the rope in Figure 3.16b.

Observations such as this led the Gestalt psychologists to propose the **law of good continuation**, which states: *Points that, when connected, result in straight or smoothly curving lines are seen as belonging together, and the lines tend to be seen in such a way*

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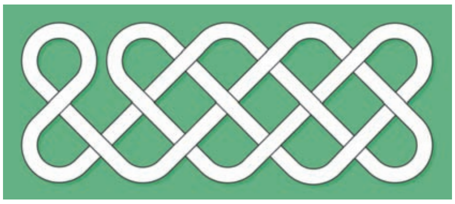
(a) (b)

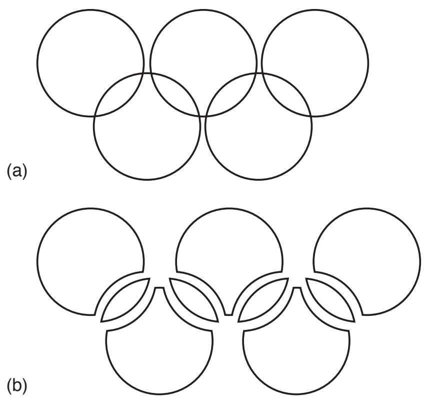
● **FIGURE 3.16** (a) Rope on the beach. (b) Good continuation helps us perceive the rope as a single strand.

as to follow the smoothest path. Also, objects that are overlapped by other objects are perceived as continuing behind the overlapping object. The Celtic knot pattern in ● Figure 3.17 illustrates this overlap effect, in which good continuation assures that we see a continuous interwoven pattern that does not appear to be broken into little pieces every time one strand overlaps another.

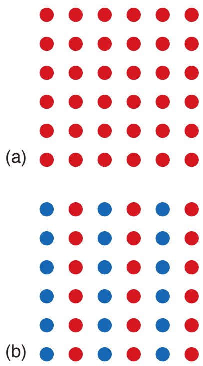
The rationale behind the law of good continuation bears repeating: It predicts that what we perceive is based on what usually happens in the environment. This means that if perception follows the Gestalt laws, it is likely that the resulting perception will



● **FIGURE 3.17** Because of good continuation, we perceive this pattern as a continuous interwoven strand.



● **FIGURE 3.18** The Olympic symbol is perceived as five circles (a), not as the nine shapes in (b).



● **FIGURE 3.19** (a) This pattern of dots is perceived as horizontal rows, vertical columns, or both. (b) This pattern of dots is perceived as vertical columns. (Source: From E. B. Goldstein, *Sensation and Perception*, 8th ed., Fig. 5.14, p. 106. Copyright © 2010 Wadsworth, a part of Cengage Learning. Reproduced with permission. www.cengage.com/permissions.)

accurately reflect what is happening in the environment. This is similar to Helmholtz's likelihood principle: Our perception corresponds to the object that is most likely to have caused the pattern of stimulation we have received. Here are some other Gestalt laws that make additional predictions about our perception based on what usually happens in the environment.

Pragnanz *Pragnanz*, roughly translated from the German, means "good figure." The **law of pragnanz**, also called the **law of good figure** or the **law of simplicity**, states: *Every stimulus pattern is seen in such a way that the resulting structure is as simple as possible.* The familiar Olympic symbol in ● Figure 3.18a is an example of the law of simplicity at work. We see this display as five circles and not as a larger number of more complicated shapes such as the ones in Figure 3.18b. (The law of good continuation also contributes to perceiving the five circles. Can you see why this is so?)

Similarity Most people perceive ● Figure 3.19a as either horizontal rows of circles, vertical columns of circles, or both. But when we change the color of some of the columns, as in Figure 3.19b, most people perceive vertical columns of circles. This perception illustrates the **law of similarity**: *Similar things appear to be grouped together.* The law of similarity causes us to perceive a number in ● Figure 3.20, and in environmental scenes helps define individual objects.

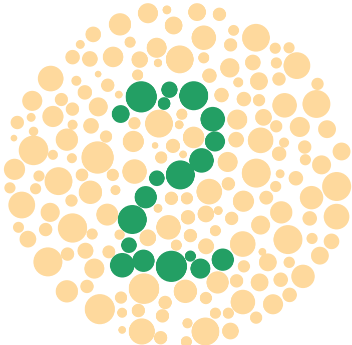
To understand how similarity helps define objects, look at the environmental scene in ● Figure 3.21. Pick a point on the scene (such as A), then move slightly away from that point to B. If the color at this second point is the same as the color at A, then it is likely that these two points are on the same object. If, however, you move to a point that is a different color, like point C, then it is likely that you have crossed over a contour to another object. While you are looking at this scene, see if you can also find examples of good continuation and good figure.

Meaningfulness or Familiarity According to the **law of familiarity**, *things that form patterns that are familiar or meaningful are likely to be grouped together* (Helson, 1933; Hochberg, 1971). This is illustrated by the Dalmatian picture in Figure 3.15 and by the following demonstration.

DEMONSTRATION Finding Faces in a Landscape

Consider the picture in ● Figure 3.22. At first glance this scene appears to contain mainly trees, rocks, and water. On closer inspection, however, you can see some faces in the trees in the background, and if you look more closely, you can see that a number of faces are formed by various groups of rocks. See if you can find all 13 faces hidden in this picture.

Some people find it difficult to perceive the faces at first, but then suddenly they succeed. The change in perception from "rocks in a stream" or "trees in a forest" to "faces" is a change in the perceptual organization of the rocks and the trees. The two shapes that you at first perceive as two separate rocks in the stream become perceptually grouped together when they become the left and right eyes of a face. In fact, once you perceive a particular grouping of rocks as a face, it is often difficult *not* to perceive them in this way—they have become permanently organized into a face. This is similar to the process we observed for the Dalmatian. Once we see the Dalmatian, it is difficult not to perceive it. Although it is unlikely that elements in an actual scene would be arranged to create so many faces, arrangements do occur in the environment that



● **FIGURE 3.20** Perception of a number reflects the law of similarity, because dots of the same color are grouped together.

Bruce Goldstein

● **FIGURE 3.21** This scene illustrates a number of Gestalt principles. See text for details.

become perceptually organized into "objects." Consider, for example, the pattern in ● Figure 3.23. When the blue area just over the mountain is perceived as a bird's head facing to the right, the small white cloud becomes the bird's eye and so becomes perceptually grouped with the head.

● **FIGURE 3.22** *The Forest Has Eyes* by Bev Doolittle (1984). Can you find 13 faces in this picture? E-mail the author at bruceg@email.arizona.edu for the solution. (Source: "The Forest Has Eyes" © 1984 Bev Doolittle, courtesy of The Greenwich Workshop, Inc.)

● **FIGURE 3.23** Clouds over a mountain. Can you see a bird?

THE GESTALT "LAWS" ARE "HEURISTICS"

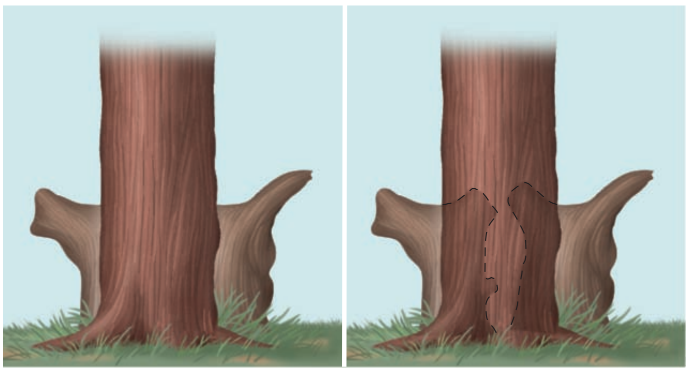
Although the Gestalt psychologists called their principles *laws* of perceptual organization, they fall short of being laws because they don't always accurately predict what is in the environment. For example, consider the following situation in which the Gestalt laws might cause an incorrect perception: As you are hiking in the woods, you stop cold in your tracks because not too far ahead you see what appears to be an animal lurking behind a tree (● Figure 3.24a). The Gestalt laws of organization play a role in creating this perception. You see the two shapes to the left and right of the tree as a single object because of the Gestalt law of similarity (because both shapes are the same color, it is likely that they are part of the same object). Also, good continuation links these two parts into one because the line along the top of the object extends smoothly from one side of the tree to another. Finally, the image resembles animals you've seen before. For all of these reasons, it is not surprising that you perceive the two objects as part of one animal.

Because you fear that the animal might be dangerous, you take a different path. As your detour takes you around the tree, you notice that the dark shapes aren't an animal after all, but are two oddly shaped tree stumps (Figure 3.24b). In this case, the Gestalt laws have misled you. Notice, however, that the reason the Gestalt laws didn't "work" was because of an unusual arrangement of objects that would normally occur only rarely in the environment.

The fact that the Gestalt laws can sometimes lead to incorrect perceptions means that it is more accurate to call them **heuristics**—rules of thumb that provide a best-guess solution to a problem. We can understand what heuristics are by comparing them to another way of solving a problem, called algorithms.

An **algorithm** is a procedure that is *guaranteed* to solve a problem. An example of an algorithm is the procedures we learn for addition, subtraction, and long division. If we apply these procedures correctly, we get the right answer every time. In contrast, a heuristic may not result in a correct solution every time. For example, suppose that you want to find your keys that you have misplaced somewhere in the house. An algorithm for doing this would be to systematically search every room in the house. If you do this, looking everywhere in each room, you will eventually find the keys, although it may take a while. A heuristic for finding the keys would be to first look in the places where you usually leave your keys and in the places you went right after you used the keys to unlock the front door. This may not always lead to finding the keys, but if it does, it has the advantage of usually being faster than the algorithm.

We say the Gestalt principles are heuristics because they are best-guess rules, based on how the environment is organized, that work *most* of the time, but not necessarily all of the time. The fact that heuristics are usually faster than algorithms helps explain why the perceptual system is designed to operate in a way that sometimes produces errors. Consider, for example, what the algorithm would be for determining what the shape in Figure 3.24a really is. It would involve walking around the tree so you can see it from different angles and perhaps taking a closer look at the objects behind the tree. Although this may result in an



(a) (b)

● **FIGURE 3.24** (a) What lurks behind the tree? (b) It is two strangely shaped tree stumps, not an animal!

accurate perception, it is potentially slow and therefore risky (what if the object actually *is* a dangerous animal?).

The idea of describing the operation of Gestalt principles as heuristics surprises some people, because heuristics are most often associated with reasoning, solving problems, and making decisions. In fact, many books don't discuss heuristics until the chapter on problem solving. But doing that would miss a chance to introduce one of the main messages of this book, which is that different types of cognition, such as perception, attention, memory, language, reasoning, problem solving, and decision making, involve similar mechanisms.

Because all of these cognitions share the same nervous system and are outcomes of the operation of the same mind, it shouldn't be surprising that they have some operating principles in common. We will see, for example, when we discuss long-term memory in Chapter 8, that knowledge gained from past experiences can influence memory. Thus, when a person is asked to remember a written passage describing a familiar situation, such as visiting a dentist's office, the memory report is often influenced by earlier experiences the person has had in visiting the dentist. Sometimes these experiences aid memory, and sometimes they result in errors, just as occurred in our perceptual example when the forms in Figure 3.24 were mistaken for a creature.

In Chapters 7 and 8 we will have more to say about how our prior knowledge affects memory. To continue our discussion of the role of knowledge in perception, we now consider the idea that perception is influenced by *regularities in the environment*.

TAKING REGULARITIES IN THE ENVIRONMENT INTO ACCOUNT

Modern perceptual psychologists have introduced the idea that perception is influenced by our knowledge of **regularities in the environment**—characteristics of the environment that occur frequently. For example, blue is associated with open sky, landscapes are often green and smooth, and verticals and horizontals are often associated with buildings. We can distinguish two types of regularities, *physical regularities* and *semantic regularities*.

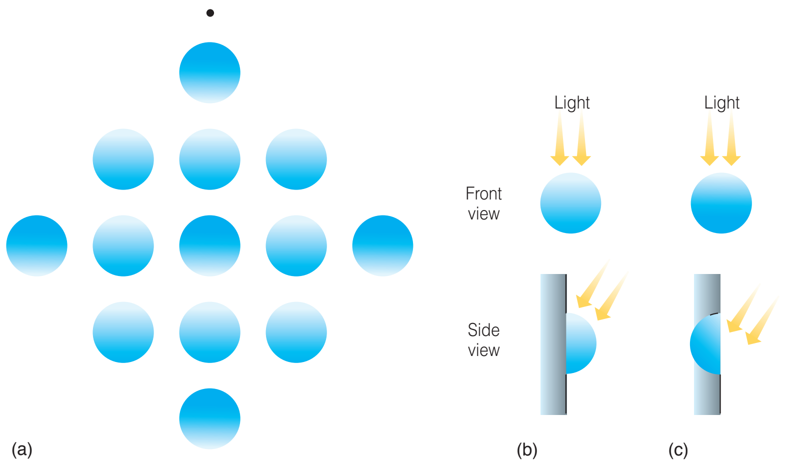
Physical Regularities **Physical regularities** are regularly occurring physical properties of the environment. For example, there are more vertical and horizontal orientations in the environment than oblique (angled) orientations. This occurs in human-made environments (for example, buildings contain lots of horizontals and verticals) and also in natural environments (trees and plants are more likely to be vertical or horizontal than slanted) (Coppola et al., 1998). It is therefore no coincidence that people can perceive horizontals and verticals more easily than other orientations, an effect called the **oblique effect** (Appelle, 1972; Campbell et al., 1966; Orban et al., 1984). Another example of a physical regularity is that when one object partially covers another one, the contour of the partially covered object "comes out the other side," as occurs for the rope in Figure 3.16 and the Celtic knot in Figure 3.17.

Another physical regularity is illustrated by the following demonstration.

DEMONSTRATION Shape From Shading

What do you perceive in ● Figure 3.25a? Do some of the discs look as though they are sticking out, like parts of three-dimensional spheres, and others appear to be indentations? If you do see the discs in this way, notice that the ones that appear to be sticking out are arranged in a square. After observing this, rotate the page so the small dot is below the discs. Does this change your perception?

Figures 3.25b and c show that if we assume that light is coming from above (which is usually the case in the environment), then patterns like the circles that are light-colored on the top would be created by an object that bulges out, as illustrated in Figure 3.25b,



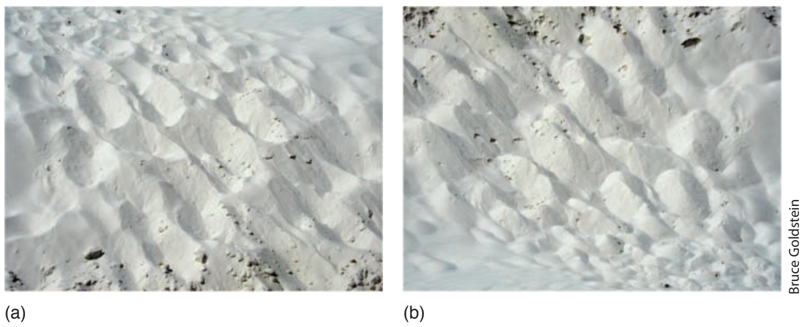
● **FIGURE 3.25** a) Some of these discs are perceived as jutting out, and some are perceived as indentations. The explanation for this perception is that light coming from above will illuminate (b) the top of a shape that is jutting out and (c) the bottom of an indentation.

but a pattern like the circles that are light on the bottom would be created by an indentation in a surface (see Figure 3.25c). The assumption that light is coming from above has been called the **light-from-above heuristic** (Kleffner & Ramachandran, 1992). Apparently, people make the light-from-above assumption because most light in our environment comes from above. This is true of the sun, as well as most artificial light sources.

Another example of the light-from-above heuristic at work is provided by the two pictures in ● Figure 3.26. Figure 3.26a shows indentations created by people walking in the sand. But when we turn this picture upside down, as shown in Figure 3.26b, the indentations in the sand become rounded mounds.

Thus, one reason we are able to perceive and recognize objects and scenes is because of our knowledge of physical characteristics of our environment. We also have knowledge about regularities of the environment that indicate what types of objects typically occur in specific types of scenes.

Semantic Regularities In language, *semantics* refers to the meanings of words or sentences. Applied to perceiving scenes, *semantics* refers to the meaning of a scene. This



● **FIGURE 3.26** Why does (a) look like indentations in the sand and (b) look like mounds of sand? Note that these are the same images, but (b) is upside down.

meaning is often related to what happens within a scene. For example, food preparation, cooking, and perhaps eating occur in a kitchen; waiting around, buying tickets, checking luggage, and going through security checkpoints happen in airports. **Semantic regularities** are the characteristics associated with the functions carried out in different types of scenes.

One way to demonstrate that people are aware of semantic regularities is simply to ask them to imagine a particular type of scene or object, as in the following demonstration.

DEMONSTRATION Visualizing Scenes and Objects

Your task in this demonstration is simple. Close your eyes and then visualize or simply think about the following scenes and objects:

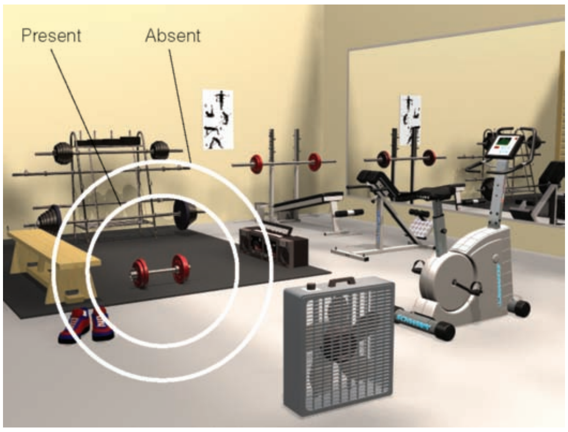
1. An office
2. The clothing section of a department store
3. A microscope
4. A lion

Most people who have grown up in modern society have little trouble visualizing an office or the clothing section of a department store. What is important about this ability, for our purposes, is that part of this visualization involves details within these scenes. Most people see an office as having a desk with a computer on it, bookshelves, and a chair. The department store scene contains racks of clothes, a changing room, and perhaps a cash register.

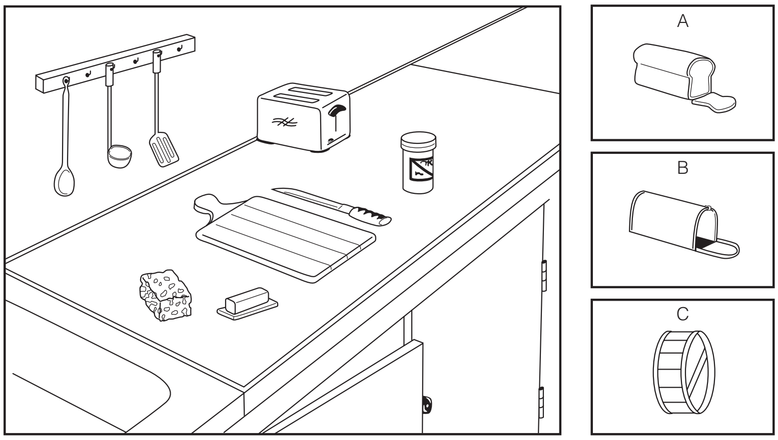
What did you see when you visualized the microscope or the lion? Many people report seeing not just a single object, but an object within a setting. Perhaps you perceived the microscope sitting on a lab bench or in a laboratory and the lion in a forest, on a savannah, or in a zoo. Knowledge of semantic regularities were probably at work when Crystal used her knowledge of the things that are usually found on beaches when she first perceived "driftwood" and then "beach umbrella."

An example of the knowledge we have of things that typically belong in certain scenes is provided by an experiment in which Andrew Hollingworth (2005) had observers study for 20 seconds a scene, such as the picture of the gym in ● Figure 3.27, that contained a target object, such as the barbell on the mat, or the same scene but without the target object. Observers then saw a picture of the target object alone in the center of the screen followed by a blank screen, and were asked to move a cursor on the blank screen to the place where the target object was in the scene they had just seen (if they had seen the picture of the scene containing the target object) or where they would *expect* to see the target object in the scene (if they had seen the picture of the scene but without the target object).

The results, which included the averaged data for many different objects and scenes, indicated that observers who saw the target objects located their positions accurately in the scene (small circle), but observers who had not seen the target objects were still able to predict where they would be (larger circle). What this means for the gym scene is that observers were apparently able to predict where the barbell would appear based on their prior experience in seeing objects in gyms.



● **FIGURE 3.27** Hollingworth's (2005) observers saw scenes like this one (without the circles). In this scene, the target object is the barbell, although observers do not know this when they are viewing the scene. "Non-target" scenes are the same but do not include the target. The circles indicate the average error of observers' judgments of the position of the target object for trials in which they had seen the object in the scene (small circle) and trials in which the object had not appeared in the scene (larger circle). (Source: A. Hollingworth, "Memory for Object Position in Natural Scenes," *Visual Cognition, 12,* 1003–1016, 2005. Reprinted by permission of the publisher, Taylor & Francis Ltd, http://www.tandf.co.uk/journals.)



● **FIGURE 3.28** Stimuli used in Palmer's (1975) experiment. The scene at the left is presented first, and the observer is then asked to identify one of the objects on the right. (Source: S. E. Palmer, "The Effects of Contextual Scenes on the Identification of Objects," *Memory and Cognition, 3*, 519–526, 1975. Reprinted by permission of the Psychonomic Society, Inc.)

This effect of semantic knowledge on our ability to perceive was illustrated in an experiment by Stephen Palmer (1975), using stimuli like the picture in ● Figure 3.28. Palmer first presented a context scene such as the one on the left and then briefly flashed one of the target pictures on the right. When Palmer asked observers to identify the object in the target picture, they correctly identified an object like the loaf of bread (which is appropriate to the kitchen scene) 80 percent of the time, but correctly identified the mailbox or the drum (two objects that don't fit into the scene) only 40 percent of the time. Apparently Palmer's observers were using their knowledge about kitchens to help them perceive the briefly flashed loaf of bread. The effect of semantic regularities is also illustrated by the "multiple personalities of a blob" illustration in Figure 3.6, because our perception of the blob depends on our knowledge of what is usually found in different types of scenes.

TEST YOURSELF 3.2

1. What is speech segmentation? How does the author's description of his Telemundo experience illustrate how perception is influenced by knowledge?
2. Describe Helmholtz's theory of unconscious inference. What does it say about the role of knowledge in determining perception?
3. Describe the Gestalt laws of perceptual organization. Why do we say that these laws are based on what usually occurs in the environment? What is the relation between these laws and Helmholtz's likelihood principle? Why can the Gestalt laws be called "heuristics"?
4. What are regularities in the environment? Describe physical regularities and semantic regularities. Be sure you understand the following concepts and experiments: oblique effect; light-from-above heuristic; Hollingworth gym experiment; Palmer kitchen experiment; multiple personalities of a blob.

Neurons and Knowledge About the Environment

Our discussion of how perception is linked to the perceiver's knowledge of the environment has so far focused on behavioral examples. But there is neural activity behind every behavior, and research has demonstrated connections between neural activity, the nature of the environment, and perception by showing that there are neurons that are tuned to respond best to things that occur regularly in the environment. We can understand why this is important by considering the problem of designing a machine that can perceive.

DESIGNING A PERCEIVING MACHINE

Imagine that you are given the assignment of designing a computer-based system that could scan a room and determine its layout. Luckily, you have at your disposal a powerful computer, an expert computer programmer, and an array of high-technology sensing devices.

One approach to this problem would be to have the sensors scan the environment, determining the patterns of light and dark within a room, and have the computer analyze this information to determine the layout of the room. But since we know that it helps to have some knowledge of the environment, it would make sense to design your computer program to be able to recognize elements that frequently appear inside rooms. One of the first things to do would be to be sure the program was designed to pick up verticals and horizontals. These are features that are usually found in rooms; they are associated with the borders between the walls, ceilings, and the floor. It would also make sense to program the computer to be able to sense flat surfaces, such as floors, ceilings, and walls. In other words, your computer-based seeing system would operate more efficiently if it were programmed to be especially sensitive to features that occur frequently in rooms. This principle for designing a perceiving machine is the same principle used by the "computer" for the human "perceiving machine"—the brain.

THE HUMAN "PERCEIVING MACHINE"

One of the basic operating principles of the human brain is that it contains some neurons that respond best to things that occur regularly in the environment. When we described physical regularities in the environment, we mentioned that horizontals and verticals are common features of the environment, and behavioral experiments have shown that people are more sensitive to these orientations than to other orientations that are not as common (the *oblique effect*, see page 63). It is not a coincidence, therefore, that when researchers have recorded the activity of single neurons in the visual cortex of monkeys and ferrets, they have found more neurons that respond best to horizontals and verticals compared to neurons that respond best to other orientations, such as slants (Coppola et al., 1998; DeValois et al., 1992). There is evidence from brain scanning experiments that this occurs in humans as well (Furmanski & Engel, 2000).

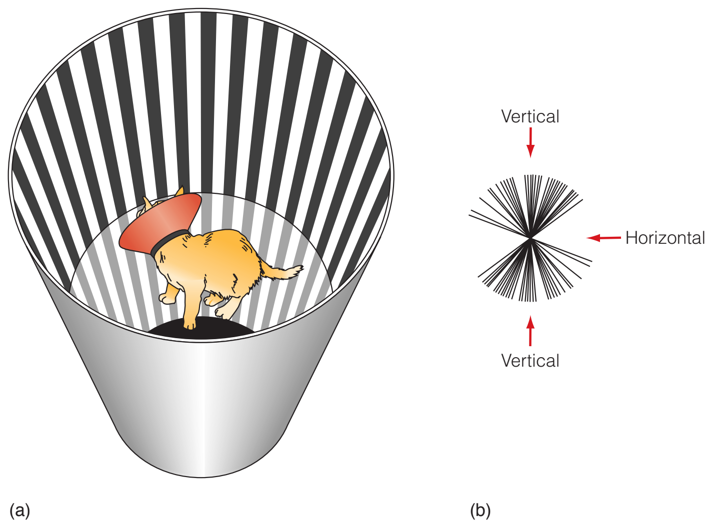
Why are there more neurons that respond to horizontals and verticals? One possible answer is that through the process of evolution the brain has evolved to respond best to situations or stimuli that are commonly found in the environment. According to the **theory of natural selection**, genetically based characteristics that enhance an animal's ability to survive, and therefore reproduce, will be passed on to future generations. A person whose visual system contains neurons that fire to important things in the environment (such as verticals and horizontals, which would occur frequently in the forest, for example) will be more likely to survive and pass on his or her characteristics than will a person whose visual system does not contain these specialized neurons. Through this evolutionary process, the visual system may have been shaped to contain neurons that respond to things that are found frequently in the environment.

Although there is no question that perceptual functioning has been shaped by evolution, it is difficult to prove whether a particular capacity is, in fact, "built in" by evolution or acquired by learning (Kanwisher, 2003). There is, however, a great deal of evidence that learning can shape the response properties of neurons through a process called *experience-dependent plasticity*.

EXPERIENCE-DEPENDENT PLASTICITY

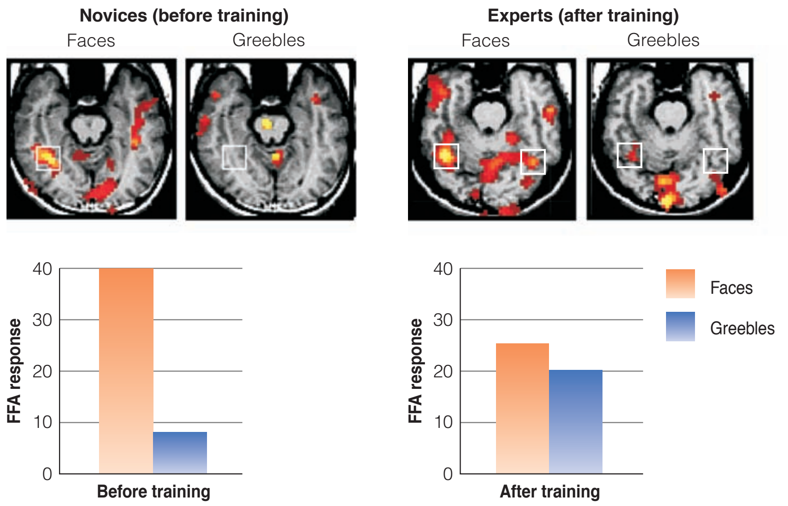
The brain is changed, or "shaped," by its exposure to the environment so it can perceive the environment more efficiently. The mechanism through which the structure of the brain is changed by experience, called **experience-dependent plasticity**, has been demonstrated in many experiments on animals. These experiments have shown that if an animal is reared in a particular environment, neurons in the animal's brain change so they become tuned to respond more strongly to specific aspects of that environment. For example, when a kitten is born, its visual cortex contains orientation-selective neurons that fire to oriented bars like the ones in Figure 3.2b. Normally the kitten's brain contains neurons that respond to all orientations, ranging from horizontal to slanted to vertical, but Colin Blakemore and Graham Cooper (1970) found that rearing a kitten in an environment consisting only of verticals (● Figure 3.29a) reshaped the kitten's visual cortex so it eventually contained neurons that responded mainly to verticals (Figure 3.29b). Similarly, kittens reared in an environment consisting only of horizontals ended up with a visual cortex that contained neurons that responded mainly to horizontals. Thus, the kitten's brain had been shaped to respond best to the environment to which the kitten had been exposed.

Experience-dependent plasticity has also been demonstrated in humans, using the brain imaging technique of fMRI (see Method: Brain Imaging, page 30). The starting point for this research is the finding that there is an area in the temporal lobe called the fusiform face area (FFA) that contains many neurons that respond best to faces (see Chapter 2, page 32). Isabel Gauthier and coworkers (1999) determined whether this response to faces might be due to experience-dependent plasticity by measuring the level of activity in the FFA in response to faces and to objects called Greebles (● Figure 3.30). Greebles are families of computer-generated "beings" that all have the same basic configuration but differ in the shapes of their parts (just like faces). The bars and the brain scans in ● Figure 3.31a show that for "Greeble novices" (people who have had little experience in perceiving Greebles), the faces cause more activity than the Greebles in the FFA. This is also evident in the brain cross section, in which the white areas indicate higher activity.



● **FIGURE 3.29** (a) Striped tube used in Blakemore and Cooper's (1970) selective rearing experiments. (b) Distribution of optimal orientations for 72 cells from a cat reared in an environment of vertical stripes. (Source: From C. Blakemore & G. F. Cooper, "Development of the Brain Depends on the Visual Environment," *Nature*, London, *228*, 477–478. Copyright © 1970. Used with permission of Nature Publishing Group.)

● **FIGURE 3.30** Greeble stimuli used by Gauthier. Participants were trained to name each different Greeble. (Source: Reprinted with permissions from I. Gauthier, M. J. Tarr, A. W. Anderson, P. Skudlarski, & J. C. Gore, "Activation of the Middle Fusiform 'Face Area' Increases With Experience in Recognizing Novel Objects," *Nature Neuroscience*, *2*, 568–573, 1999.)



● **FIGURE 3.31** Magnitude of brain responses to faces and Greebles (a) before and (b) after Greeble training. The colored areas in the brain records indicate brain activity. The FFA is located within the white squares. (Source: Reprinted with permissions from I. Gauthier, M. J. Tarr, A. W. Anderson, P. Skudlarski, & J. C. Gore, "Activation of the Middle Fusiform 'Face Area' Increases With Experience in Recognizing Novel Objects," *Nature Neuroscience, 2,* 568–573, 1999.)

Gauthier then gave her participants extensive training over a 4-day period in "Greeble recognition." These training sessions, which required that each configuration of Greeble be labeled with a specific name, turned the participants into "Greeble experts." The bars and brain pictures in Figure 3.31b show that after the training, the FFA responded almost as well to Greebles as to faces. Apparently, the FFA contains neurons that respond not just to faces, but to other complex objects as well. The particular objects to which the neurons respond best are established by experience with the objects. In fact, Gauthier has also shown that neurons in the FFA of people who are experts in recognizing cars and birds respond well not only to human faces, but to cars (for the car experts) and to birds (for the bird experts) (Gauthier et al., 2000).

These demonstrations of experience-dependent plasticity in kittens and humans show that the brain's functioning can be "tuned" to operate best within a specific environment. Thus, continued exposure to things that occur regularly in the environment can cause neurons to become adapted to respond best to these regularities. Looked at in this way, it is not unreasonable to say that neurons can reflect knowledge about properties of the environment.

Reaching for a Cup: The Interaction Between Perceiving and Taking Action

Our discussion so far has considered the relationship between stimuli and what we perceive. This approach has yielded valuable information about how perception works, but it could be called the "sitting in a chair" way of studying perception—all of the situations we have described could occur as a person sits in a chair viewing various stimuli. In fact, that is probably what you are doing as you read this book—reading words, looking at pictures, doing "demonstrations," all while sitting still. We will now

● **FIGURE 3.32** Three views of a "horse." Moving around an object can reveal its true shape.

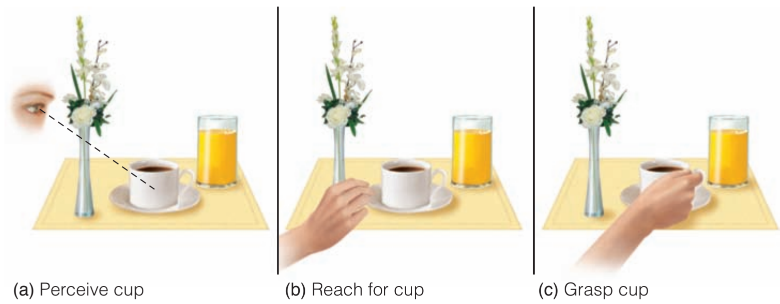
consider how movement helps us perceive, and how movement and perception interact with one another.

MOVEMENT FACILITATES PERCEPTION

Although movement adds a complexity to perception that isn't there when we are sitting in one place, movement also helps us perceive objects in the environment more accurately. One reason this occurs is that moving reveals aspects of objects that are not apparent from a single viewpoint. For example, consider the "horse" in ● Figure 3.32. From one viewpoint this object looks like a metal sculpture of a fairly normal horse (Figure 3.32a). However, it walking around the horse reveals that it isn't as normal as it first appeared (Figures 3.32b and c). Thus, seeing an object from different viewpoints provides added information that results in more accurate perception, especially for objects that are out of the ordinary, such as the distorted horse.

THE INTERACTION OF PERCEPTION AND ACTION

Our concern with movement extends beyond noting that it helps us perceive objects by revealing additional information about them. Movement is also important because of the coordination that is continually occurring between perceiving stimuli and taking action toward these stimuli. Consider, for example, what happens when Crystal reaches out and picks up her coffee cup (● Figure 3.33). She first identifies the coffee cup among



● **FIGURE 3.33** Picking up a cup of coffee: (a) perceiving and recognizing the cup; (b) reaching for it; (c) grasping and picking it up. This action involves coordination between perceiving and action that is carried out by two separate streams in the brain, as described in the text.

the flowers and other objects on the table (Figure 3.33a). Once the coffee cup is perceived, she reaches for it, taking into account its location on the table (Figure 3.33b). As she reaches, avoiding the flowers, she positions her fingers to grasp the cup, taking into account her perception of the cup's handle (Figure 3.33c); then she lifts the cup with just the right amount of force, taking into account her estimate of how heavy it is based on her perception of its fullness. This simple action requires continually perceiving the position of the cup, and her hand and fingers relative to the cup, while calibrating her actions in order to accurately grasp the cup and then pick it up without spilling any coffee (Goodale, 2010). All this just to pick up a cup of coffee!! What's amazing about this sequence is that it happens almost automatically, without much effort at all. But as with everything else about perception, this ease and apparent simplicity are achieved with the aid of complex underlying mechanisms. We will now describe the physiology behind these mechanisms.

THE PHYSIOLOGY OF PERCEPTION AND ACTION

Psychologists have long realized the close connection between perceiving objects and interacting with them, but the details of this link between perception and action have become clearer as a result of physiological research that began in the 1980s. This research has shown that there are two processing streams in the brain—one involved with perceiving objects, and the other involved with locating and taking action toward these objects. In describing this physiological research, we will introduce two methods: *brain ablation*—the study of the effect of removing parts of the brain in animals, and *neuropsychology*—the study of the behavior of people with brain damage. Both of these methods demonstrate how studying the functioning of animals and humans with brain damage can reveal important principles about the functioning of the normal (intact) brain. Later in the book we will see that both brain ablation and neuropsychology have also been applied to the study of other cognitive processes—notably, memory and language.

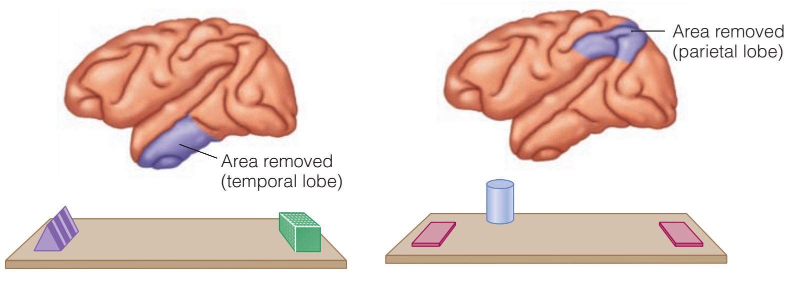
What and _Where_ Streams In a classic experiment, Leslie Ungerleider and Mortimer Mishkin (1982) studied how removing part of a monkey's brain affected its ability to identify an object and to determine the object's location. This experiment used a technique called **brain ablation**—removing part of the brain.

METHOD Brain Ablation

The goal of a brain ablation experiment is to determine the function of a particular area of the brain. This is accomplished by first determining an animal's capacity by testing it behaviorally. Most ablation experiments studying perception have used monkeys because of the similarity of its visual system to that of humans and because monkeys can be trained to determine perceptual capacities such as acuity, color vision, depth perception, and object perception.

Once the animal's perception has been measured, a particular area of the brain is ablated (removed or destroyed), either by surgery or by injecting a chemical in the area to be removed. Ideally, one particular area is removed and the rest of the brain remains intact. After ablation, the monkey is tested to determine which perceptual capacities remain and which have been affected by the ablation.[1]

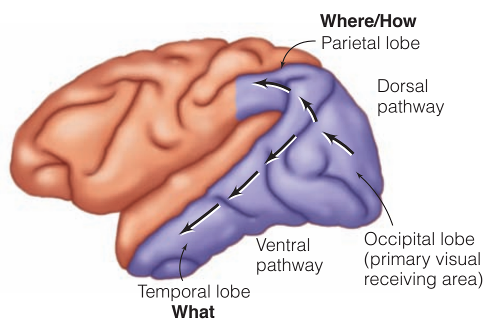
[1]Because a great deal of physiological research has been done on cats and monkeys, students often express concerns about how these animals are treated. All animal research in the United States follows strict guidelines for the care of animals established by organizations such as the American Psychological Association and the Society for Neuroscience. The central tenet of these guidelines is that every effort should be made to ensure that animals are not subjected to pain or distress. Research on animals has provided essential information for developing aids to help people with sensory disabilities such as blindness and deafness, for helping develop techniques to ease severe pain, and for improving our understanding of deficits such as amnesia and blindness that are caused by damage to the brain.



● **FIGURE 3.34** The two types of discrimination tasks used by Ungerleider and Mishkin. (a) Object discrimination: Pick the correct shape. Lesioning the temporal lobe (purple shaded area) makes this task difficult. (b) Landmark discrimination: Pick the food well closer to the cylinder. Lesioning the parietal lobe makes this task difficult. (Source: From M. Mishkin, L. G. Ungerleider, & K. A. Makco, "Object Vision and Spatial Vision: Two Central Pathways," Trends in *Neuroscience, 6,* 414-417, Figure 2. Copyright © 1983 Elsevier Science Publishers B.V. Reprinted by permission.)

Ungerleider and Mishkin presented monkeys with two tasks: (1) an object discrimination problem and (2) a landmark discrimination problem. In the **object discrimination problem**, a monkey was shown one object, such as a rectangular solid, and was then presented with a two-choice task like the one shown in ● Figure 3.34a, which included the "target" object (the rectangular solid) and another stimulus, such as the triangular solid. If the monkey pushed aside the target object, it received the food reward that was hidden in a well under the object. The **landmark discrimination problem** is shown in ● Figure 3.34b. Here, the monkey's task is to remove the food well cover that is closer to the tall cylinder.

In the ablation part of the experiment, part of the temporal lobe was removed in some monkeys. Behavioral testing showed that the object discrimination problem was very difficult for monkeys with their temporal lobes removed. This result indicates that the pathway that reaches the temporal lobes is responsible for determining an object's identity. Ungerleider and Mishkin therefore called the pathway leading from the striate cortex to the temporal lobe the ***what* pathway** (● Figure 3.35).



● **FIGURE 3.35** The monkey cortex, showing the *what* or *perception* pathway from the occipital lobe to the temporal lobe, and the *where* or *action* pathway from the occipital lobe to the parietal lobe. (Source: From E. B. Goldstein, *Sensation and Perception,* 8th ed., Fig. 4.27, p. 88. Copyright © 2010 Wadsworth, a part of Cengage Learning. Reproduced with permission. www.cengage.com/permissions. Adapted from Mishkin, Ungerleider, & Macko, 1983.)

Other monkeys, which had their parietal lobes removed, had difficulty solving the landmark discrimination problem. This result indicates that the pathway that leads to the parietal lobe is responsible for determining an object's location. Ungerleider and Mishkin therefore called the pathway leading from the striate cortex to the parietal lobe the ***where* pathway**.

Applying this idea of *what* and *where* pathways to our example of a person picking up a cup of coffee, the *what* pathway would be involved in the initial perception of the cup and the *where* pathway in determining its location—important information if we are going to carry out the action of reaching for the cup. In the next section we consider another physiological approach to studying perception and action, describing how the study of the behavior of a person with brain damage provides further insights into what is happening in the brain as a person reaches for an object.

Perception and Action Streams Another approach that has revealed two streams, one involving the temporal lobe and the other involving the parietal lobe, is **neuropsychology**—studying the behavior of people with brain damage. One of the central procedures in neuropsychology is determining *dissociations*.

	Name object	Accurately reach for object
(a) **Alice**	No	Yes
(b) **Bert**	Yes	No

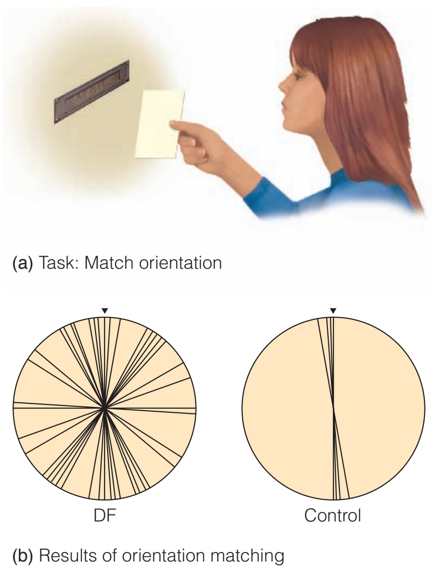
● **FIGURE 3.36** (a) Alice can't name objects but can accurately reach for them; (b) Bert can name objects, but has trouble accurately reaching for them. Alice and Bert together illustrate a double dissociation.

METHOD Dissociations in Neuropsychology

One of the basic principles of neuropsychology is that we can understand the effects of brain damage by studying **dissociations**—situations in which one function is absent while another function is present. There are two kinds of dissociations: **single dissociations**, which can be studied in one person, and **double dissociations**, which require two or more people.

To illustrate a single dissociation, let's consider a woman, Alice, who has suffered damage to her temporal lobe. She is shown an object, then asked to name the object and indicate where it is on the table by pointing to it. When given this task, Alice can't name the object, but she can reach to where it is located on the table (● Figure 3.36a). Alice demonstrates a single dissociation—one function is absent (naming objects) and another is present (locating objects). From a single dissociation such as this, in which one function is lost while another function remains, we can conclude that the two functions (in this example, naming and locating objects) involve different mechanisms, although they may not operate totally independently of one another.

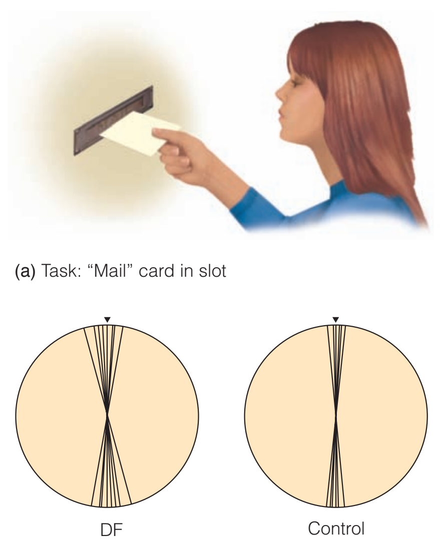
We can illustrate a double dissociation by finding another person who has one function present and another absent, but in a way opposite to Alice. For example, Bert, who has parietal lobe damage, can identify objects but can't tell exactly where they are located (Figure 3.36b). The key to understanding the cases of Alice and Bert is that they are both given the same two tasks, but Alice can do one task (reaching) and not the other (naming) while the opposite result occurs for Bert. The cases of Alice and Bert, taken together, represent a double dissociation. Establishing a double dissociation enables us to conclude that two functions are served by different mechanisms *and* that these mechanisms operate independently of one another.



● **FIGURE 3.37** (a) D.F.'s orientation task; (b) results for the orientation task.

The method of determining dissociations was used by Milner and Goodale (1995) to study D.F., a 34-year-old woman who suffered damage to her temporal lobe from carbon monoxide poisoning caused by a gas leak in her home. One result of the brain damage was revealed when D.F. was asked to match the orientation of a card held in her hand to different orientations of a slot (● Figure 3.37a). She was unable to do this, as shown in the left circle in Figure 3.37b. Each line in the circle indicates how D.F. adjusted the card's orientation. Perfect matching performance would be indicated by a vertical line for each trial, but D.F.'s responses are widely scattered. The right circle shows the accurate performance of the normal controls.

Because D.F. had trouble orienting a card to match the orientation of the slot, it would seem reasonable that she would also have trouble *placing* the card through the slot because to do this she would have to turn the card so that it was lined up with the slot. But when D.F. was asked to "mail" the card through the slot (● Figure 3.38a), she could do it, as indicated by the results in Figure 3.38b. Even though D.F. could not turn the card to match the slot's orientation, *once she started moving the card toward the slot*, she began rotating it to match the orientation of the slot. Thus, D.F. performed poorly in the static orientation-matching task but did well as soon as *action* was involved (Murphy, Racicot, & Goodale, 1996). Milner and Goodale interpreted D.F.'s behavior as showing that there is one mechanism for judging orientation and another for coordinating vision and action.



● **FIGURE 3.38** (a) D.F.'s "mailing" task; (b) results for the mailing task.

These results for D.F. demonstrate a single dissociation, which indicates that judging orientation and coordinating vision and action involve different mechanisms. To show that these two functions are not only served by different mechanisms but are also *independent* of one another, we have to demonstrate a double dissociation. As we saw in the example of Alice and Bert, this involves finding a person whose symptoms are the opposite of D.F.'s, and such people do, in fact, exist. These people can judge visual orientation, but they can't accomplish the task that combines vision and action. As we would expect, whereas D.F.'s temporal lobe is damaged, these other people have damage to their parietal lobe.

Based on these results, Milner and Goodale suggested that the pathway from the visual cortex to the temporal lobe (which was damaged in D.F.'s brain) be called the **perception pathway** and the pathway from the visual cortex to the parietal lobe (which was intact in D.F.'s brain) be called the **action pathway**. The perception pathway corresponds to the *what* pathway we described in conjunction with the monkey experiments, and the action pathway corresponds to the *where* pathway. Thus, some researchers refer to *what* and *where* pathways and some to perception and action pathways. But whatever the terminology, this research demonstrates that perception and action are processed in two separate pathways in the brain.

PICKING UP A COFFEE CUP AND OTHER BEHAVIORS

With our knowledge that perception and action involve two separate mechanisms, we can add physiological notations to our description of picking up the coffee cup, as follows:

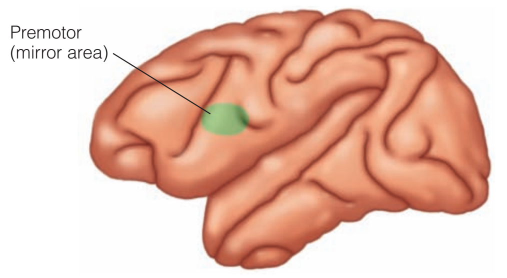
> The first step in the process of picking up the cup is to identify the coffee cup among the vase of flowers and the glass of orange juice on the table (*perception pathway*). Once the coffee cup is perceived, we reach for the cup (*action pathway*), taking into account its location on the table. As we reach, avoiding the flowers and orange juice, we position our fingers to grasp the cup (*action pathway*), taking into account our perception of the cup's handle (*perception pathway*), and we lift the cup with just the right amount of force (*action pathway*), taking into account our estimate of how heavy it is based on our perception of the fullness of the cup (*perception pathway*).

Thus, even a simple action like picking up a coffee cup involves a number of areas of the brain, which coordinate their activity to create perceptions and behaviors. A similar coordination between different areas of the brain also occurs for the sense of hearing. Thus, hearing someone call your name and then turning to see who it is activates two separate pathways in the auditory system—one that enables you to hear and identify the sound (the auditory *what* pathway) and another that helps you locate where the sound is coming from (the auditory *where* pathway) (Lomber & Malhotra, 2008).

The discovery of different pathways for perceiving, determining location, and taking action illustrates how studying the physiology of perception has helped broaden our conception far beyond the old "sitting in the chair" approach. These physiological findings, combined with behavioral experiments that have focused on active aspects of perception (Gibson, 1979), mean that we can call perception "dynamic" not only because it involves processes such as inference and taking knowledge into account, but also because of how closely perception is linked to action. In the next section we show how this idea has been carried even further, by describing neurons that fire not only when a person takes action, but also when a person watches someone else take action.

Something to Consider

Mirror Neurons



● **FIGURE 3.39** The green shaded area indicates the location of the premotor cortex, which is where mirror neurons are found. (Source: From E. B. Goldstein, *Sensation and Perception*, 8th ed., Fig. 7.8, p. 161. Copyright © 2010 Wadsworth, a part of Cengage Learning. Reproduced with permission. www.cengage.com/permissions.)

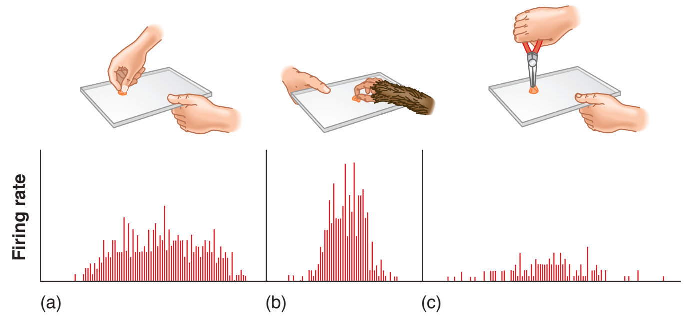
We not only take action ourselves, but we regularly watch other people take action. This "watching others act" is most obvious when we watch other people's actions on TV or in a movie, but it also occurs any time we are around someone else who is doing something. One of the most exciting outcomes of research studying the link between perception and action has been the discovery of neurons in the premotor cortex (● Figure 3.39) called *mirror neurons*.

In the early 1990s, Giacomo Rizzolatti and coworkers (2006; also see di Pellegrino et al., 1992; Gallese et al., 1996) were investigating how neurons in the monkey's premotor cortex fired as the monkey performed actions such as picking up a toy or a piece of food. Their goal was to determine how neurons fired as the monkey carried out specific actions, but they observed something they didn't expect. They found neurons in the monkey's premotor cortex that fired not only when the monkey picked up a piece of food, but also when the monkey observed the experimenter picking up a piece of food.

This initial observation, followed by many additional experiments, led to the discovery of **mirror neurons**—neurons that respond both when a monkey observes someone else (usually the experimenter) grasping an object, such as food on a tray (● Figure 3.40a), and when the monkey itself grasps the food (Figure 3.40b) (Rizzolatti et al., 1996). These neurons are called *mirror neurons* because the neuron's response to watching the experimenter grasp an object is similar to the response that would occur if the monkey were performing the action. Just looking at the food causes no response, and watching the experimenter grasp the food with a pair of pliers instead of his hands, as in Figure 3.40c, causes only a small response (Gallese et al., 1996; Rizzolatti et al., 2000).

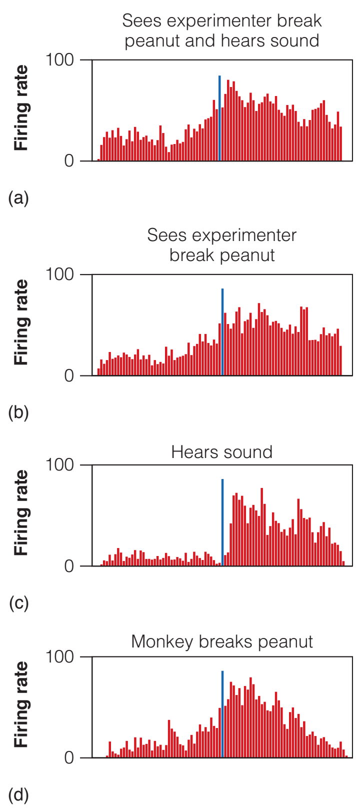
Most mirror neurons are specialized to respond to only one type of action, such as grasping or placing an object somewhere. Although you might think that perhaps the monkey was responding to the anticipation of receiving food, the type of object made little difference. The neurons responded just as well when the monkey observed the experimenter pick up an object that was not food.

Consider what is happening when a mirror neuron fires in response to seeing someone else perform an action. This firing provides information about the characteristics of the action, because the neuron's response to watching someone else perform the action is the same as the response that occurs when the observer performs the action. This means that one function of the mirror neurons might be to help understand another person's actions and react appropriately to them (Rizzolatti & Arbib, 1998; Rizzolatti et al., 2000, 2006).



● **FIGURE 3.40** Response of a mirror neuron when (a) the monkey watches the experimenter grasp food on the tray; (b) the monkey grasps the food; (c) the monkey watches the experimenter pick up food with a pair of pliers. (Source: Reprinted from G. Rizzolatti et al., "Premotor Cortex and the Recognition of Motor Actions," *Cognitive Brain Research, 3,* 131–141, Copyright © 2000, with permission from Elsevier.)

What is the evidence that these neurons are actually involved in helping "understand" an action? The fact that a strong response occurs when the experimenter picks up the food with his hand but not when the experimenter uses pliers argues that the neuron is not just responding to the pattern of motion. Other evidence that mirror neurons are doing more than just responding to a particular pattern of stimulation is that neurons have been discovered that



● **FIGURE 3.41** Response of an audiovisual mirror neuron to four different stimuli. (Source: Kohler et al., 2002.)

respond to sounds that are *associated with* actions. These neurons, also in the premotor cortex, called **audiovisual mirror neurons**, respond when a monkey performs a hand action *and* when it hears the sound associated with this action (Kohler et al., 2002). For example, the results in ● Figure 3.41 show the response of a neuron that fires (a) when the monkey sees and hears the experimenter break a peanut, (b) when the monkey just sees the experimenter break the peanut, (c) when the monkey just hears the sound of the breaking peanut, and (d) when the *monkey* breaks the peanut. What this means is that just *hearing* a peanut breaking or just *seeing* a peanut being broken causes activity that is also associated with the perceiver's *action* of breaking a peanut. These neurons are, therefore, responding to the characteristics of observed actions—in this case, what the action of breaking a peanut looks like and what it sounds like.

Since the first descriptions of mirror neurons in the 1990s, a great deal of research has confirmed the existence of these neurons in both monkeys and humans. Researchers have proposed other functions in addition to understanding another person's actions, including understanding language (Rizzolatti & Arbib, 1998), imitation (Iacoboni, 2009), deficits in autism (Dapretto et al., 2006), and determining another person's intentions (Iacoboni et al., 2005). Not all researchers agree with all of the functions that have been attributed to mirror neurons, but there is no question that mirror neurons provide an impressive example of the link between perception and action.

Although we have described many different principles and experiments in this chapter, we can summarize the chapter by noting that perception is the outcome of processes that are also involved in other cognitive functions. In common with memory, problem solving, and decision making, perception involves underlying "intelligent" processes such as inference, taking into account multiple factors, and making use of prior knowledge. Like memory, it is sometimes fallible, but often correct and highly adaptive. But sharing properties with other cognitive processes is only part of the story. The other part is that perception and all cognitive processes interact with each other. This interaction will be apparent in the next chapter, when we see that what we perceive is often determined by how we pay attention, and how we pay attention is influenced by perceptual qualities of the environment.

TEST YOURSELF 3.3

1. What is experience-dependent plasticity? Describe the kitten-in-the tube experiment and the Greeble experiment. What is behind the idea that neurons can reflect knowledge about properties of the environment?
2. Describe the link between perception and action in everyday perception, by giving a specific example and describing the interaction between perceiving and taking action.
3. Describe the Ungerleider and Mishkin experiment. How did they use the procedure of brain ablation to demonstrate *what* and *where* streams in the cortex?
4. Describe the dissociation procedure used in neuropsychology and how it was used to determine the presence of two processing streams in patient D.F. How do the results obtained from D.F. compare to the results of the Ungerleider and Mishkin monkey experiment?
5. Describe how the perception and action pathways both play a role in an action such as walking on a crowded sidewalk.
6. What is a mirror neuron? What are some potential functions of mirror neurons?

CHAPTER SUMMARY

1. The example of Crystal running on the beach and having coffee later illustrates how perception can change based on new information, that perception is a process, and how perception and action are connected.
2. Perception starts with bottom-up processing, which involves receptors. Signals from these receptors cause neurons in the cortex to respond to specific types of stimuli.
3. Recognition-by-components theory, which provides a behavioral example of bottom-up processing, proposes that recognizing objects is based on building blocks called geons.
4. Examples of situations in which perception can't be explained only in terms of the information on the receptors include (1) recognizing different arrangements of geons; (2) recognizing a "blob" shape in different contexts; (3) the effect of physiological feedback signals; (4) size constancy; and (5) perceiving odors following different intensities of sniffing.
5. An example of top-down processing is that knowledge of a language makes it possible to perceive individual words in a conversation even though the sound signal for speech is often continuous.
6. The idea that perception depends on knowledge was proposed by Helmholtz's theory of unconscious inference.
7. The Gestalt approach to perception proposed a number of laws of perceptual organization, which were based on how stimuli usually occur in the environment. These laws provide best-guess predictions of how we will perceive stimuli in the environment. The laws are therefore best described as "heuristics," because they are rules of thumb that are usually, but not always, correct.
8. Regularities in the environment are characteristics of the environment that occur frequently. We take both physical regularities and semantic regularities into account when perceiving.
9. One of the basic operating principles of the brain is that it contains some neurons that respond best to things that occur regularly in the environment.
10. Experience-dependent plasticity is one of the mechanisms responsible for creating neurons that are tuned to respond to specific things in the environment. The experiments in which kittens were reared in vertical or horizontal environments and in which people's brain activity was measured as they learned about Greebles support this idea.
11. Perceiving and taking action are linked. Movement of an observer relative to an object provides information about the object. Also, there is a constant coordination between perceiving an object (such as a cup) and taking action toward the object (such as picking up the cup).
12. Research involving brain ablation in monkeys and neuropsychological studies of the behavior of people with brain damage have revealed two processing pathways in the cortex: a pathway from the occipital lobe to the temporal lobe responsible for perceiving objects, and a pathway from the occipital lobe to the parietal lobe responsible for controlling actions toward objects. These pathways work together to coordinate perception and action.
13. Mirror neurons are neurons that respond both to carrying out an action and to observing someone else carry out the same action. Mirror neurons may help people understand other people's actions; other functions have also been proposed.

Think ABOUT IT

1. Describe a situation in which you initially thought you saw or heard something, but then realized that your initial perception was in error. (Two examples: misperceiving an object under low-visibility conditions; mishearing song lyrics.) What was the role of bottom-up and top-down processing in this process of first having an incorrect perception and then realizing what was actually there?
2. Look at the picture in ● Figure 3.42. Is this a huge giant's hand getting ready to pick up a horse, a normal-size hand picking up a tiny plastic horse, or something else? Explain, based on some of the things we take into account in addition to the image that this scene creates on the retina, why it is unlikely that this picture shows either a giant hand or a tiny horse. How does your answer relate to top-down processing?
3. In the section on experience-dependent plasticity, it was stated that neurons can reflect knowledge about properties of the environment. Would it be valid to suggest that the response of these neurons represents top-down processing? Why or why not?
4. Try observing the world as though there were no such thing as top-down processing. For example, without the aid of top-down processing, seeing a restaurant's restroom sign that says "Employees must wash hands" could be taken to mean that we should wait for an employee to wash our hands! If you try this exercise, be warned that it is extremely difficult because top-down processing is so pervasive in our environment that we usually take it for granted.

● **FIGURE 3.42** Is a giant hand about to pick up the horse?

If You WANT TO KNOW MORE

1. **"Top-down" processing in the visual cortex.** Some research has shown that the responding of neurons in the visual receiving area of the cortex can be affected by factors such as attention, which suggests that top-down processing can influence responding in this area of the cortex.

   Mehta, A. D., Ulbert, I., & Schroeder, C. E. (2000). Intermodal selective attention in monkeys: I. Distribution and timing of effects across visual areas. *Cerebral Cortex, 10*, 343–358.

2. **Gestalt psychology.** The ideas of the Gestalt psychologists dominated the field of perception in the mid-20th century and are still important today. Wolfgang Kohler was one of the founders of the Gestalt school.

   Kohler, W. (1929). *Gestalt psychology.* New York: Liveright.

3. **Organization in hearing.** The process of perceptual organization is usually illustrated using visual examples, but it occurs in hearing as well.

   Bregman, A. S. (1990). *Auditory scene analysis.* Cambridge, MA: MIT Press.

   Deutsch, D. (1996). The perception of auditory patterns. In W. Prinz & B. Bridgeman (Eds.), *Handbook of perception and action* (Vol. 1, pp. 253–296). San Diego, CA: Academic Press.

4. **Perception as problem solving.** A number of modern researchers have proposed that perceptual mechanisms are similar to the mechanisms involved in cognitive processes like thinking and problem solving.

   Ramachandran, V. S., & Anstis, S. M. (1986, May). The perception of apparent motion. *Scientific American*, pp. 102–109.

   Rock, I. (1983). *The logic of perception.* Cambridge, MA: MIT Press.

5. **Interactive activation model of word recognition.** A model of word recognition, proposed in the 1980s, proposed that recognizing words is based on activation of feature-detector-like units that are arranged in layers. Units that respond to simple features, such as line orientation or combinations of lines, are in lower layers, and units that respond to words are in the upper layer.

   Goldstein, E. B. (2008). *Cognitive psychology* (2nd ed., pp. 61–66). Belmont, CA: Wadsworth.

   McClelland, J. L., & Rumelhart, D. E. (1981). An interactive activation model of context effects in letter perception: Part 1. An account of basic findings. *Psychological Review, 88*, 375–405.

   Rumelhart, D. E., & McClelland, J. L. (1982). An interactive activation model of context effects in letter perception: Part 2. The contextual enhancement effect and some tests and extensions of the model. *Psychological Review, 89*, 60–94.

Key TERMS

Media RESOURCES

The *Cognitive Psychology* Book Companion Website

www.cengage.com/psychology/goldstein

Prepare for quizzes and exams with online resources—including a glossary, flashcards, tutorial quizzes, crossword puzzles, and more.

CogLab

To experience these experiments for yourself, go to coglab.wadsworth.com. Be sure to read each experiment's setup instructions before you go to the experiment itself. Otherwise, you won't know which keys to press.

Related Labs

Apparent motion How flashing two dots one after another can result in an illusion of motion.

Blind spot Map the blind spot in your visual field that is caused by the fact that there are no receptors where the optic nerve leaves the eye.

Metacontrast masking How presentation of one stimulus can impair perception of another stimulus.

Muller-Lyer illusion Measure the size of a visual illusion.

Signal detection Collect data that demonstrate the principle behind the theory of signal detection, which explains the processes behind detecting hard-to-detect stimuli.

Visual search Visual searching for targets that are accompanied by different numbers of distractors.

Garner interference An experiment about making perceptual judgments based on different dimensions of a stimulus.