Cognitive Psychology Goldstein 6th Edition PDF

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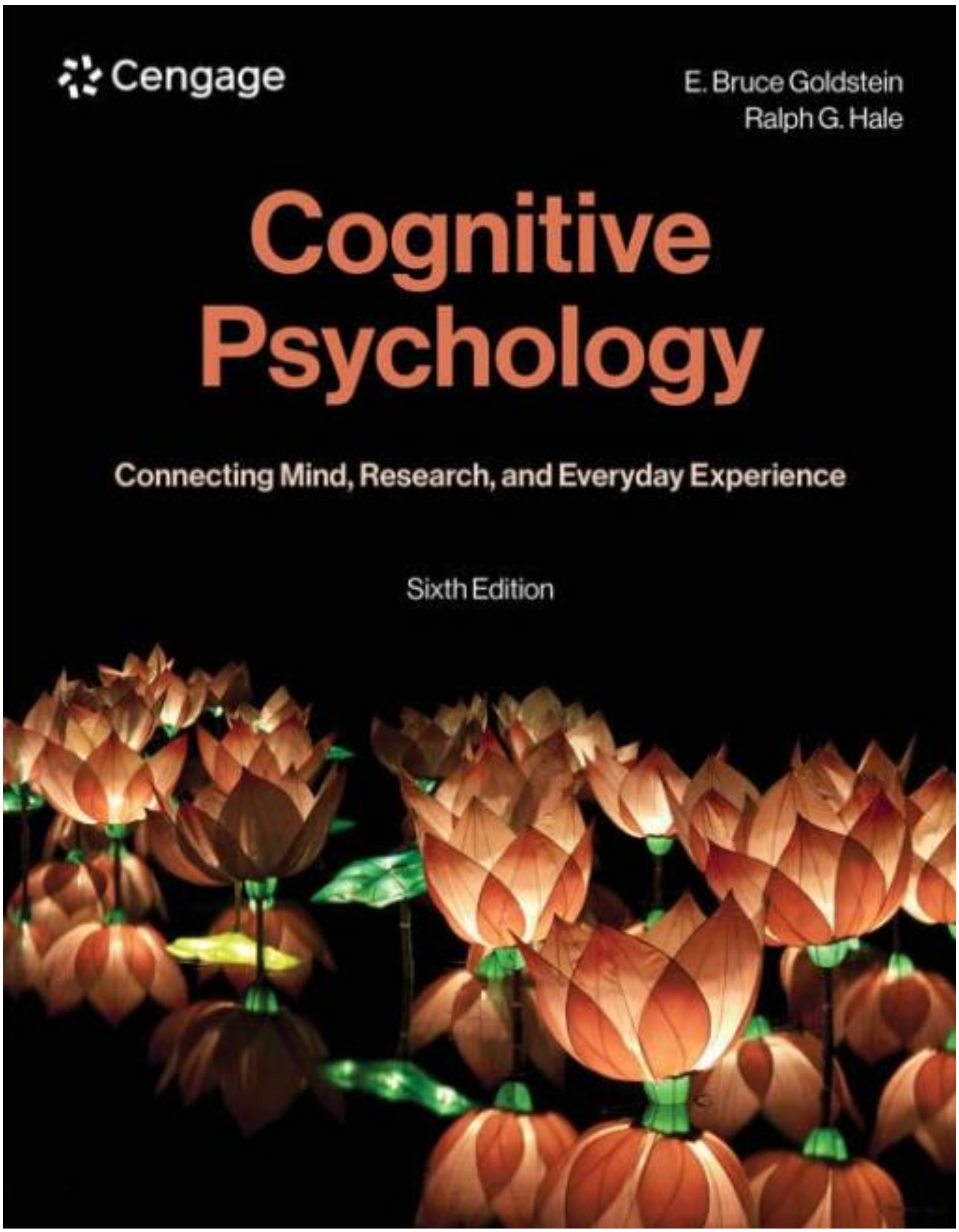


Preface to Instructors

By Ralph G. Hale

This text is the culmination of a process that began with the first edition in 2002 with the simple goal of being a text that not only covers the field of cognitive psychology but also is accessible to students. Many students perceive cognitive psychology as being too abstract, theoretical, and disconnected from everyday experience. This text aims to 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.

Many features of this text help accomplish this. Chapters include **real-world examples** and **neuropsychological case studies**, where appropriate. To provide students with firsthand experience with the phenomena of cognitive psychology, more than 40 **Demonstrations**—easy-to-do mini-experiments—appear in the text narrative. The Demonstrations in this edition are listed on page xxi.

This text also avoids simply presenting the results of experiments. Instead, whenever possible, detailed descriptions explain **how experiments were designed** and what participants were doing, so students would understand how results were obtained. 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.

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 the results of the original experiments from the literature. This text combines 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. The ultimate goal is for students to come away feeling excited about the field of cognitive psychology.

Much has been modified and updated since the first edition, but that goal remains the same. All the favorite features for students and faculty have been retained in this new sixth edition. In addition, much has been updated and modernized throughout the text. The result is a refreshing, approachable, cutting-edge cognitive psychology text.

Retained Features

All the features described above were well received by students and instructors, and so they are continued in this new sixth edition. Over 500 **bolded terms** and their definitions are included throughout the text and in the glossary. Additionally, over 1,000 reliable **sources** were cited throughout the text and included in the updated reference list. Additional pedagogical features that have been retained from previous editions include Test Yourself sections, which help students review the material, and end-of-chapter **Think About It** questions, which ask students to consider questions that go beyond the material.

Methods sections, which were introduced in the second edition, highlight the ingenious methods cognitive psychologists have devised to study the mind. Over two dozen Methods sections, which are integrated into the text, describe methods such as brain imaging, the lexical decision task, 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 xii for a list of Methods.

Chapter Summaries provide succinct outlines of the chapters, without serving as a substitute for reading the chapters.

What Is New in the Sixth Edition

- As with previous editions of this book, this edition features updates to material throughout, and in a few cases, chapters have been rewritten or reorganized to improve clarity and pedagogy. Cognitive psychology is a research-driven field, and the research in every chapter has been updated to reflect current findings, scientific consensus, and hot topics.
- **Learning objectives** have been added to the beginning of every chapter. These statements are clear, actionable goals that state what students will be able to do after completing that chapter. These learning objectives can help students focus their efforts and understand the relevance of the chapter content. Additionally, the learning objectives can serve as guidance for instruction and assessment. **Test Yourself** and **Think About It** items now include associated learning objectives to increase clarity of learning expectations.
- A primary goal of this text is to be approachable to students, and that means being inclusive to all students. Therefore, efforts were made to improve the inclusivity, equity, and diversity of content throughout this text. Updates include research findings from a more diverse range of researchers and participants from populations around the globe. Additionally, text language, examples, and figures are now more diverse, equitable, and inclusive.
- Since the last edition, the COVID-19 pandemic rocked the world. In this edition, the impact of the pandemic on cognitive psychology topics and students is discussed.

Below is a list that highlights a few of the new or updated topics in this edition.

Chapter 1 Introduction to Cognitive Psychology

- NEW: For the first time, cover art connects to an introductory example, providing continuity for the text overview!

- NEW: History of the term "computer" and transition from human to digital computers
- NEW: Virtual reality and augmented reality as tools for studying cognition and the mind

Chapter 2 Cognitive Neuroscience

- NEW: Grandmother cells and the Jennifer Aniston neuron
- NEW: Example of artist with prosopagnosia painting self-portrait
- NEW: Additional imaging technologies discussed, including EEG, MEG, NIRS, TMS, and DTI
- NEW: Evidence supporting the existence of the Default Mode Network

Chapter 3 Perception

- UPDATED: Sensation and perception
- UPDATED: History of computer vision, modern computer vision, and creating a "perceiving machine"
- NEW: Machine learning and deep learning, related to artificial intelligence and perception
- NEW: Real-world examples from art and nature

Chapter 4 Attention

- NEW: Endogenous versus exogenous attention
- UPDATED: Stroop and scanning demonstrations
- NEW: Divided attention, task switching, and multitasking
- NEW: Multitasking demonstration
- NEW: Cognitive "choking"
- UPDATED: Dangers of distracted driving
- NEW: Productivity illusion
- NEW: Impact of the pandemic on academic and technology-related attention
- UPDATED: Change blindness demonstration

Chapter 5 Short-Term and Working Memory

- UPDATED: Digit span and letter span demonstrations
- UPDATED: Articulatory suppression demonstration
- UPDATED: Working memory model
- NEW: Connections between working memory, SAT scores, and testing anxiety

Chapter 6 Long-Term Memory: Structure

- UPDATED: Case of Patient H.M.
- NEW: Prospective memory
- NEW: Mindfulness
- NEW: Operant conditioning

Chapter 7 Long-Term Memory: Encoding and Retrieval

- NEW: Mnemonics, verbal and visual
- UPDATED: Student habits related to notetaking and technology
- UPDATED: State-dependent learning
- NEW: Verbatim memory

Chapter 8 Everyday Memory and Memory Errors

- UPDATED: Chapter flow for clarity across all memory chapters
- NEW: False memories
- NEW: Amnesia, including anterograde, retrograde, and infantile
- NEW: Dementia
- UPDATED: Information processing model and connections to memory deficits
- UPDATED: Hyperthymesia (HSAM)

Chapter 9 Conceptual Learning

- NEW: Real-world examples of conceptual learning

Chapter 10 Visual Imagery

- NEW: Imagination
- UPDATED: Imagery debate, propositional versus depictive
- UPDATED: Neural accounts for visual imagery, perception
- NEW: Aphantasia
- NEW: Why we should care about mental imagery
  - Using imagery to improve memory
  - Motor training

Chapter 11 Language

- NEW: Communication versus language
- UPDATE: Animal communication
- NEW: Alphabets and written language, sign language, and Braille
- NEW: Revisiting the imagery debate: vision and language
- NEW: Lexical ambiguity demonstration
- NEW: Semantic satiation
- NEW: Bilingualism and multilingualism, including advantages and costs
- NEW: Speech disfluencies

Chapter 12 Problem Solving and Creativity

- NEW: Logic, creativity, and emotion
- NEW: Crossword puzzle with solutions
- NEW: Circle problem demonstration
- NEW: Candle problem demonstration
- NEW: Two-string problem demonstration
- UPDATE: Empirical aesthetics and creativity
- NEW: Inventions that utilize analogical thinking
- UPDATE: Mindfulness versus mind wandering, creativity

Chapter 13 Judgment, Decisions, and Reasoning

- UPDATE: Availability heuristic
- NEW: Spurious correlation
- UPDATE: Stereotypes

- UPDATE: Description of a person demonstration
- UPDATE: Confirmation bias
- NEW: Deepfakes
- NEW: The bias bias (or the bias blind spot)
- UPDATE: "What would you do?" demonstration
- UPDATE: The dual systems approach to thinking

Ancillaries to Support Your Teaching

Instructor Ancillaries

Online Instructor's Manual: The manual includes key terms, a detailed chapter outline, lesson plans, discussion topics, student activities, video links, and an expanded test bank.

Online PowerPoints: Helping you make your lectures more engaging while effectively reaching your visually oriented students, these handy Microsoft PowerPoint® slides outline the chapters of the main text in a classroom-ready presentation. The PowerPoint slides are updated to reflect the content and organization of the new edition of the text.

Cengage Learning Testing, powered by Cognero®: Cengage Learning Testing, Powered by Cognero®, is a flexible online system that allows you to author, edit, and manage test bank content. You can create multiple test versions in an instant and deliver tests from your LMS in your classroom.

CogLab

CogLab Online is a series of virtual lab demonstrations designed to help students understand cognition through interactive participation in cognitive experiments. Students with instructors who adopt CogLab also receive access to more than 50 online CogLab experiments that they can run themselves, then compare their data to the class average and the results of the original experiments from the literature. To view a demo, visit coglab.cengage.com.

MindTap

MindTap® Psychology: *MindTap® for Cognitive Psychology*, 6th edition, is the digital learning solution that helps instructors engage and transform today's students into critical thinkers. Through paths of dynamic assignments and applications that you can personalize, real-time course analytics, and an accessible reader, MindTap helps you turn cookie cutter into cutting-edge, apathy into engagement, and memorizers into higher-level thinkers. As an instructor using MindTap, you have at your fingertips the right content and a unique set of tools curated specifically for your course, all in an interface designed to improve workflow and save time when planning lessons and course structure. The control to build and personalize your course is all yours, focusing on the most relevant material while also lowering costs for your students. Stay connected and informed in your course through real-time student tracking that provides the opportunity to adjust the course as needed based on analytics of interactivity in the course.

Animated and experiential demonstrations are available in the MindTap. The purpose of these activities is to extend the students' experience beyond simply reading a description of an experiment, a principle, or a phenomenon, by allowing them to experience these things more fully and actively. This is achieved in several ways. Students may observe something unfolding on the screen or respond in some way, such as participating in a mini-experiment.

Preface to Students

By Ralph G. Hale

As you begin reading this text, you probably have some ideas about how the mind works from things you have read, other media, and your own experiences. In this text, you will learn what we actually do and do not know about the mind, as determined by the results of controlled scientific research. Thus, if you thought that a system called "short-term memory" can hold information for short periods, 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.

However, what you will learn from this text 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 just the aspects of which you are consciously aware. 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 seemingly automatic processes. Reading this text 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 text 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 text. 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 207—209 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 text.

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 did not have a good awareness of what you knew about the material versus what you did not know. If you think you know the material but actually do not, you might stop studying or might continue studying ineffectively, with the net result being a poor understanding of the material and an inability to remember it accurately during the exam. 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.

Principle 2: Do not mistake ease and familiarity for knowing.

One of the main reasons that students may think they know the material, even when they do not, 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 must 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 was not really the best answer to the question.

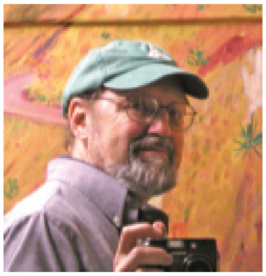
This brings us back again to the idea of testing yourself. One finding of cognitive psychology research is that the very act of *trying* to answer a question increases the chances that you will be able to answer it when you try again later. Another related finding is that testing yourself on the material 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 an exam.

I hope you will find this text 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, whether encountered on social media, in movies, or elsewhere. The study of cognitive psychology speaks to who we are as humans, both individually and collectively. I hope you enjoy studying it as much as I do.

About the Authors

E. Bruce Goldstein



E. Bruce Goldstein is Associate Professor Emeritus of Psychology at the University of Pittsburgh and Adjunct Professor of Psychology at the University of Arizona. He received the Chancellor's Distinguished Teaching Award from the University of Pittsburgh for his classroom teaching and textbook writing. After receiving his bachelor's degree in chemical engineering from Tufts University, he had a revelation that he wanted to go to graduate school in psychology, rather than engineering, so received his PhD in psychology, specializing in visual physiology, from Brown University. He continued his research in vision as a postdoctoral fellow in the Biology Department at Harvard University and then joined the faculty at the University of Pittsburgh. He continued his research at Pitt, publishing papers on retinal and cortical physiology, visual attention, and the perception of pictures, before focusing exclusively on teaching (Sensation & Perception, Cognitive Psychology, Psychology of Art, Introductory Psychology) and writing textbooks. He is the author of *Sensation and Perception*, 10th edition (Cengage, 2017), and edited the *Blackwell Handbook of Perception* (Blackwell, 2001) and the two-volume *Sage Encyclopedia of Perception* (SAGE, 2010). In 2016, he won "The Flame Challenge" competition, sponsored by the Alan Alda Center for Communicating Science, for his essay, written for 11-year-olds, on *What Is Sound?*

Ralph G. Hale

Ralph G. Hale is Associate Professor of Psychological Science at the University of North Georgia. He earned his PhD in psychology from the University of Georgia in 2018, specializing in visual perception. He also earned two certifications in interdisciplinary university teaching, one from the University of Georgia in 2018 and another from the Association of College and University Educators in 2024. He is dedicated to undergraduate education and teaches a wide variety of psychology courses, including cognitive psychology, memory, biopsychology, psychology of visual art, research methods, behavioral statistics, and senior psychology seminar. He has been recognized by his university for his commitment to quality education, winning the Teaching Excellence Award for Tenured Faculty in 2020 and the Ann Matthews Purdy Outstanding Teacher of the Year Award in 2023. He is also dedicated to scholarship, with an emphasis on undergraduate research. His areas of expertise are visual perception and memory with interests in visual aesthetics, errors in visual memory, and visual illusions. As principal investigator of the Hale Vision Lab, he mentors students through projects leading to conference presentations and publications. He recently has published papers related to color-spreading illusions, social gaze, and various cognitive effects. In 2023, he won his university's Excellence in Undergraduate Research Award in recognition of his scholarly mentorship. He asserts that undergraduate mentorship is the focal point of his academic career, from which all other aspects radiate. His venture into book writing is an extension of this commitment to mentorship, as quality textbooks and resources are fundamental to educational success.

Acknowledgments

By Ralph G. Hale

Embarking on this book project has been a challenging yet immensely rewarding journey. It feels like diving headfirst into the unknown. Taking on this new role as sole author for the revisions of the sixth edition of a successful, effective, and beloved text is terrifying and exhilarating in equal measure. The process has been humbling and transformative. This accomplishment would not have been possible without the unwavering support, patience, and encouragement of many remarkable individuals. To my family, whose love and belief in me have been my constant source of strength; to my colleagues, whose insights and guidance have been invaluable; and to all those working tirelessly behind the scenes, your contributions have been instrumental. I am deeply grateful for your education, your highest expectations, and your faith in my ability to bring this book to fruition. Thank you for being part of this incredible journey with me.

I would like to extend my appreciation to several key individuals whose contributions were especially impactful in the successful completion of this book:

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- **Suzie Walker**, copy editor. Thank you for your meticulous attention to detail and for ensuring the text was polished and precise. Your efforts significantly enhanced the quality of the book.
- **Deanna Ettinger**, our content acquisition analyst. Deanna, your work behind the scenes was crucial in gathering and organizing the content that forms the foundation of this book. Your dedication and efficiency are appreciated.

To everyone mentioned and the many others who contributed to this project, my heartfelt thanks. Your support, expertise, and hard work made this book possible.

Beautiful lotus flower lanterns, as shown here and on the cover of this text, symbolize many of the cognitive processes we will be describing in this text: Perception (Seeing colors and shapes); Attention (Where your eyes move when observing this scene); Memory (Seeing lanterns or lotus flowers might stimulate memories); Knowledge (You know these lanterns must be floating in water, and that we are seeing their reflection in that water); and Problem-Solving (Lotus flower lanterns! At what event might we see this beautiful scene?). What unfolds, as you read this text, is a fascinating story about how the mind works to create these cognitions and more. This chapter begins by describing the history of cognitive psychology.

1

Introduction to Cognitive Psychology

Learning Objectives

After reading this chapter, students will be able to:

1-1 Explain how cognitive psychology is relevant to everyday experience.
1-2 Describe the mind and cognition.
1-3 Understand early approaches to studying the mind, including structuralism and analytic introspection.
1-4 Explain why behaviorism was skeptical of the mind.
1-5 Explain how it is possible to study the inner workings of the mind when the mind is not directly observable.
1-6 Describe the history and relevance of the cognitive revolution.
1-7 Identify connections between digital computers and the human mind.
1-8 Apply concepts from the end of the chapter to improve study techniques.

It has been 16 years since the accident. Sam, lying in the long-term care facility, has been in a coma ever since. Observing Sam, who shows no signs of awareness or ability to communicate, it seems reasonable to conclude that Sam no longer has any conscious experiences. He may not even know he is alive. But is that true? Just because Sam has not moved or responded to stimulation—does that mean he does not have a "mind"? Is there any probability that his eyes, which appear to be vacantly staring into space, could be perceiving, and that these perceptions might be accompanied by thoughts? These are the questions Lorina Naci and colleagues (2014, 2015) were asking when they placed Sam in a brain scanner that measured increases and decreases in electrical activity throughout his brain.

While Sam was in the scanner, they played an 8-minute excerpt from an Alfred Hitchcock television program called "Bang, You're Dead" on a screen positioned in front of Sam's face. At the beginning of the video, a 5-year-old is playing with his toy gun. Then he discovers a real gun and some bullets in his uncle's suitcase. The boy loads one bullet into the gun, spins the chamber that contains the single bullet, and shoves the weapon into his toy-gun holster. As the child roams the neighborhood, pointing the gun at several different people, the tension mounts. He points the gun at someone! He pulls the trigger! The gun does not fire because the single bullet isn't in the firing chamber—but thoughts such as "Will the gun go off?" and "Will someone be killed?" are racing through the viewers' minds, knowing that the child's "play" could, at any moment, turn tragic. In the last scene, back at the boy's house, the boy's father, realizing that he is pointing a real gun, lunges toward the boy. The gun fires! A mirror shatters. Luckily, no one is hurt. The boy's father grabs the gun, and the audience breathes a sigh of relief.

When this film was shown to healthy participants in the scanner, brain activity increased and decreased at the same time for all of the participants, with changes in brain activity being linked to what was happening in the movie. Activity was highest at suspenseful moments in the film, such as when the child was loading the gun or pointing it at someone. So the viewers' brains were not just responding to the images on the screen; their brain activity was being driven both by the images *and* by the movie's plot. And—here is the important point—to understand the plot, it is necessary to understand things that weren't specifically presented in the movie, like "guns are dangerous when loaded," "guns can kill people," and "a 5-year-old child may not be aware that he could accidentally kill someone."

So, how did Sam's brain respond to the movie? Amazingly, his response was the same as the healthy participants' responses: brain activity increased during periods of tension and decreased when danger wasn't imminent. This indicates that Sam was not only seeing the images and hearing the soundtrack but that he was reacting to the movie's plot! His brain activity therefore indicated that Sam was consciously aware; that he still had a "mind" after all.

This story about Sam, who appeared to have a mental life despite appearances to the contrary, has an important message as we embark on the adventure of understanding the mind. Perhaps the most important message is that the mind is hidden from view. Sam is an extreme case because he could not move or talk, but you will learn that the "normal" mind also holds many secrets. Just as we cannot know exactly what Sam is experiencing, we do not know exactly what other people are experiencing, even though they can tell us about their thoughts and observations.

Although you may be aware of your own thoughts and observations, you are unaware of most of what is happening in your mind. Even though you understand what you are reading right now, there are many hidden processes operating within your mind, beneath your conscious awareness, that make this understanding possible.

As you read this text, you will learn how research has revealed many of these secret aspects of the mind's operation. This is no trivial thing because your mind not only makes it possible for you to read this text and understand the plots of movies, but it is responsible for who you are and what you do. It creates your thoughts, perceptions, desires, emotions, memories, language, and physical actions. It guides your decision making and problem-solving. And, perhaps most impressive of all, it creates your consciousness—the way in which you know what is "out there," what is going on in your body, and, simply, what it's like to be you.

In this text, we will be describing what the mind is, what the mind does, and how the mind does it. The first step in doing this is to explore some of the things the mind does. As we do this, we will learn that the mind is multifaceted, involving multiple functions and mechanisms. We begin this chapter by discussing the multifaceted nature of the mind and then describing some of the history behind the field of cognitive psychology.

1.1 Cognitive Psychology: Studying the Mind

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

Mind System that creates mental representations of the world and controls mental functions such as perception, attention, memory, emotions, language, deciding, thinking, and reasoning.

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. "They were able to call to mind what they were 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. "They are of sound mind and body" or "When they talks about their encounter with aliens, it sounds like they are out of their 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. "You have a brilliant mind." (Used to describe people who are particularly intelligent or creative)
7. "I should try to be more mindful." (The mind as a mental state in which one is focused on the present and self-awareness—**Figure 1.1**)

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 chapter titles in this text.

Another definition, which focuses on how the mind operates, is this: *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 text.

Figure 1.1 Students in a classroom sitting on their desks practicing being mindful during a meditation activity. The concept of mindfulness involves the mind, but it is just one of many ways we might discuss or use the word "mind."

wavebreakmedia/Shutterstock.com

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

Cognition The mental processes involved in perception, attention, memory, language, problem-solving, reasoning, and decision making.

Statements 4, 5, 6, and 7 emphasize the mind's importance for normal functioning and the amazing abilities of the mind. Though we may consider the minds of some individuals to be particularly extraordinary (such as Albert Einstein or Leonardo da Vinci), an important idea for this text is the fact that all minds are actually quite amazing. Even the most "routine" things—recognizing a person, having a conversation, or deciding what courses to take next semester—become extraordinary in themselves when we consider the properties of the mind that enable us to achieve these familiar activities.

Cognitive psychology is the study of mental processes, which includes determining the characteristics and properties of the mind and how it operates. Our goals in the rest of this chapter are 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.

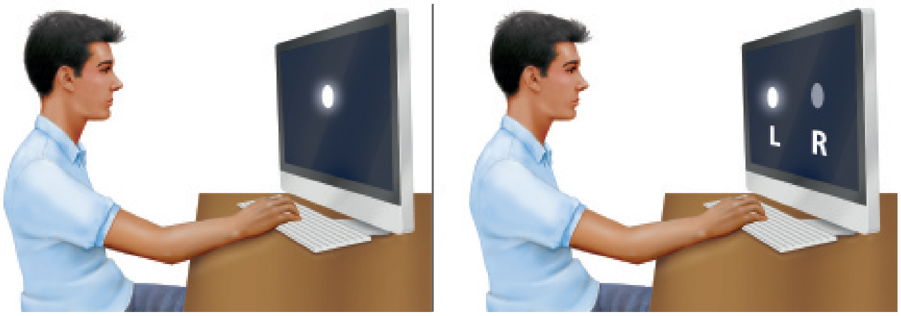
Cognitive psychology The branch of psychology concerned with the scientific study of the mental processes involved in perception, attention, memory, language, problem-solving, reasoning, and decision making. In short, cognitive psychology is concerned with the scientific study of the mind and mental processes.

1.2 Studying the Mind: Early Work in Cognitive Psychology

In the 1800s, many believed it was not possible to study the mind for a variety of reasons. Some said the mind could not study itself. Others said the properties of the mind simply could not 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, 11 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 using today's definitions.)

Donders's 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

Figure 1.2 **A modern version of Donders's (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's experiment was to determine how much time it took to decide which key to press in the choice reaction time task.**



(a) Press J when light goes on.

(b) Press J for left light, K for right.

Reaction time The time it takes to react to a stimulus. This is usually determined by measuring the time between presentation of a stimulus and the response to the stimulus. Examples of responses are pushing a button, saying a word, moving the eyes, and the appearance of a particular brain wave.

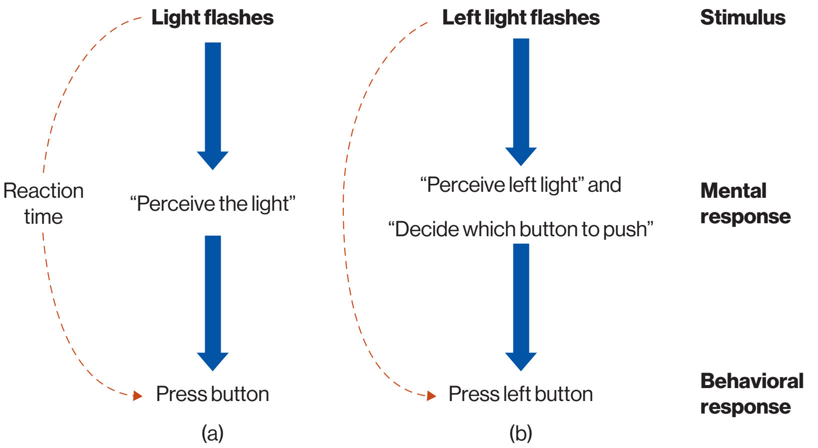
Simple reaction time Reacting to the presence or absence of a single stimulus (as opposed to having to choose between a number of stimuli before making a response). See also **Choice reaction time**.

this by measuring **reaction time**—how long it takes to respond to the presentation of a stimulus. He used two measures of reaction time. He measured **simple reaction time** by asking his participants to push a button as rapidly as possible when they saw a light go on (**Figure 1.2a**). He measured **choice reaction time** by using two lights and asking his participants to push the left button when they saw the left light go on and the right button when they saw the right light go on (**Figure 1.2b**).

The steps that occur in the simple reaction time task are shown in **Figure 1.3a**. Presenting the stimulus (the light flashes) 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 the presentation of the stimulus and the behavioral response.

But remember that Donders was interested in determining how long it took for a person to make a decision. The choice reaction time task added decisions by requiring participants to first decide whether the left or right light was illuminated and then which button to push. The diagram for this task, shown in **Figure 1.3b**, changes the mental response to "perceive

Figure 1.3 **Sequence of events between the presentation of the stimulus and the behavioral response in Donders's experiments: (a) simple reaction time task and (b) choice reaction time task. The dashed line indicates that Donders measured reaction time—the time between the presentation of the light and the participant's response.**



left light" and "decide which button to push." Donders reasoned that the difference in reaction time between the simple and choice conditions would indicate how long it took to make the decision that led to pushing the correct button. Because the choice reaction time took one-tenth of a second longer than simple reaction time, Donders concluded that the decision-making process took one-tenth of a second.

Choice reaction time Time to respond to one of two or more stimuli. For example, in the Donders experiment, subjects had to make one response to one stimulus and a different response to another stimulus.

Donders's 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 (in this example, perceiving the light and deciding which button to push) cannot be measured directly, but must be inferred from behavior. We can understand why this is so by noting the dashed lines in **Figure 1.3**. These lines indicate that when Donders measured reaction time, he was measuring the relationship between the presentation of the stimulus and the participant's response. He did not measure mental responses directly but inferred how long they took from the reaction times. The fact that mental responses cannot be measured directly, but must be inferred from observing behavior, is a principle that holds not only for Donders's experiment but for all research in cognitive psychology.

Wundt's Psychology Laboratory: Structuralism and Analytic Introspection In 1879, 11 years after Donders's reaction time experiment, Wilhelm Wundt founded the first laboratory of scientific psychology at the University of Leipzig in Germany. 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 developed a periodic table of the elements, which combine to create molecules, Wundt wanted to create a "periodic table of the mind," which would include all of the basic sensations involved in creating our experiences.

Structuralism An approach to psychology that explained perception as the adding up of small elementary units called sensations.

Wundt thought he could achieve this scientific description of the components of experience by using **analytic introspection**, a technique in which trained participants described their experiences and thought processes in response to stimuli. Analytic introspection required extensive training because the participants' goal was to describe their experience in terms of elementary mental elements. For example, in one experiment, Wundt asked participants to describe their experience of hearing a 5-note chord played on the piano. One of the questions Wundt hoped to answer was whether his participants were able to hear each of the individual notes that made up the chord. As we will determine when we consider perception in Chapter 3, structuralism was not a fruitful approach and so was abandoned in the early 1900s. Nonetheless, Wundt, considered by many today to be the "father of experimental psychology," made a substantial contribution to psychology by his commitment to studying behavior and the mind under controlled conditions. Wundt dedicated his life to expanding this blossoming field, training many doctoral graduate students who went on to establish psychology departments at universities all over the world, including many in the United States.

Analytic introspection A procedure used by early psychologists in which trained participants described their experiences and thought processes in response to stimuli.

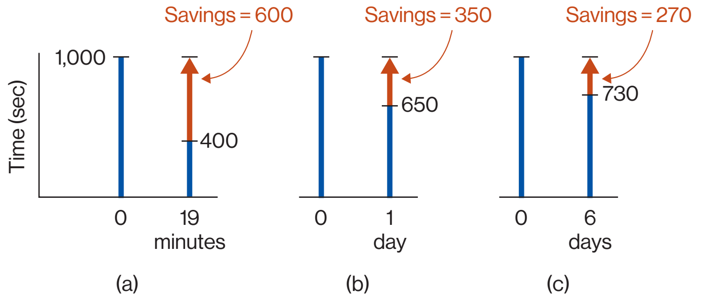
Ebbinghaus's Memory Experiment: What Is the Time Course of Forgetting? Meanwhile, 120 miles from Leipzig, at the University of Berlin, German psychologist Hermann Ebbinghaus (1885/1913) was using another approach to measuring the properties of the mind. Ebbinghaus was interested in determining the nature of memory and forgetting—specifically, how rapidly information that is learned is lost over time. Rather than using Wundt's method of analytic introspection, Ebbinghaus used a quantitative method for measuring memory. Using himself as the participant, he repeated lists of 13 nonsense syllables such as DAX, QEH, LUH, and ZIF to himself one at a time at a constant rate. He used nonsense syllables so that his memory would not be influenced by the meaning of a particular word.

Ebbinghaus determined how long it took to learn a list for the first time. He then waited for a specific amount of time (the delay) and then determined how long it took to relearn the list. Because forgetting had occurred during the delay, Ebbinghaus made errors when he first tried to remember the list. But because he had retained something from his original learning, he relearned the list more rapidly than when he had learned it for the first time.

Ebbinghaus used a measure called **savings**, calculated as follows, to determine how much was forgotten after a particular delay: Savings = (Original time to learn the list) − (Time to relearn the list after the delay). Thus, if it took 1,000 seconds to learn the list the first time

Savings Measure used by Ebbinghaus to determine the magnitude of memory left from initial learning. Higher savings indicate greater memory.

Figure 1.4 Calculating the savings score in Ebbinghaus's experiment. In this example, it took 1,000 seconds to learn the list of nonsense syllables for the first time. This is indicated by the bars at 0. The time needed to relearn the list at delays of (a) 19 minutes, (b) 1 day, and (c) 6 days are indicated by the bars to the right of each 0 bar. The red arrows indicate the savings score for each delay. Notice that savings decrease for longer delays. This decrease in savings provides a measure of forgetting.



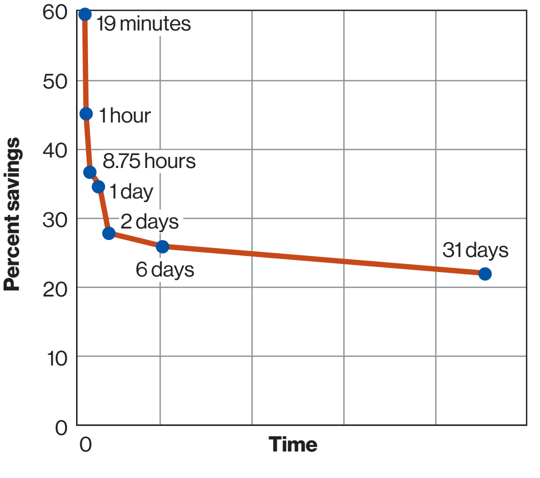
and 400 seconds to relearn the list after the delay, the savings would be 1,000 − 400 = 600 seconds. **Figure 1.4**, which represents original learning and relearning after three different delays, shows that longer delays result in smaller savings.

Savings curve Plot of savings versus time after original learning.

According to Ebbinghaus, this reduction in savings provided a measure of forgetting, with smaller savings meaning more forgetting. Thus, the plot of percent savings versus time in **Figure 1.5**, called a **savings curve**, shows 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 savings 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's reaction time method, both measured behavior to determine a property of the mind.

William James's *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).

Figure 1.5 Ebbinghaus's savings curve. Ebbinghaus considered the percent savings to be a measure of the amount remembered, so he plotted this versus the time between initial learning and testing. The decrease in savings (remembering) with increasing delays indicates that forgetting occurs rapidly over the first 2 days and then occurs more slowly after that.



(Source: Based on data from Ebbinghaus, 1885/1913.)

Table 1.1 Early Pioneers in Cognitive Psychology

Person	Procedure	Results and Conclusions	Contribution
Donders (1868)	Simple reaction time versus choice reaction time	Choice reaction time takes 1/10 seconds longer; therefore, it takes 1/10 second to make a decision	First cognitive psychology experiment
Wundt (1879)	Analytic introspection	No reliable results	Established the first laboratory of scientific psychology
Ebbinghaus (1885)	Savings method to measure forgetting	Forgetting occurs rapidly in the first 1 to 2 days after original learning	Quantitative measurement of mental processes
James (1890)	No experiments; reported observations of his own experience	Descriptions of a wide range of experiences	First psychology textbook; some of his observations are still valid today

James's observations were based on observations about the operation of his own mind rather than on results from experiments. One of James's best-known observations is the following, on the nature of attention:

> Millions of items . . . are present to my senses which never properly enter my experience. Why? Because they have no interest for me. My experience is what I agree to attend to. . . . Everyone knows what attention is. It is the taking possession by the mind, in clear and vivid form, of one out of what seem several simultaneously possible objects or trains of thought. Focalization, concentration of consciousness are of its essence. It implies withdrawal from some things in order to deal effectively with others.

The observation that paying attention to one thing involves withdrawing from other things still rings true today and has been the topic of many modern studies of attention. As impressive as the accuracy of James's observations, so too was the range of cognitive topics he considered, which included thinking, consciousness, attention, memory, perception, imagination, and reasoning.

The founding of the first laboratory of psychology by Wundt, the quantitative experiments of Donders and Ebbinghaus, and the perceptive observations of James provided what seemed to be a promising start to the study of the mind (**Table 1.1**). However, research on the mind was 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 Wundt's technique of analytic introspection.

1.3 Abandoning the Study of the Mind

Many early departments of psychology conducted research in the tradition of Wundt's laboratory, using analytic introspection to analyze mental processes. This emphasis on studying the mind was to change, however, because of the efforts of psychologist John Watson.

Watson Founds Behaviorism

The story of how American psychologist John B. Watson founded an approach to psychology called **behaviorism** is of great importance to the history of cognitive psychology. As a graduate student at the University of Chicago at the turn of the 20th century, 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.

Behaviorism The approach to psychology, founded by John B. Watson, which states that observable behavior provides the only valid data for psychology. A consequence of this idea is that consciousness and unobservable mental processes are not considered worthy of study by psychologists.

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 his new approach:

> 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, J. B. (1913). Psychology as the behaviorist views it. Psychological Review, 20, 158–177.

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 other words, Watson wanted to restrict psychology to behavioral data (such as Donders's reaction times) and rejected the idea of going beyond those data to draw conclusions about unobservable mental events. Watson eliminated the mind as a topic for investigation by proclaiming 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 replace the mind as a topic of study in psychology 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?"

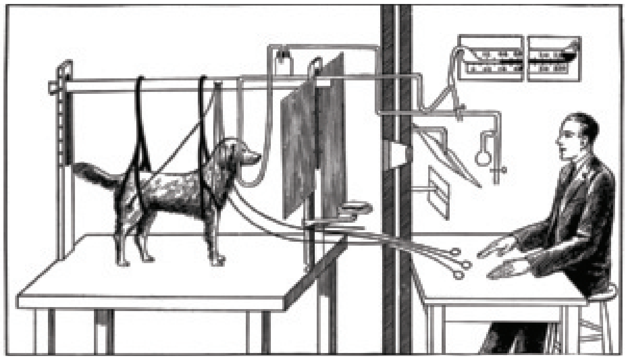
Watson's most famous experiment was the "Little Albert" experiment, in which Watson and Rosalie Rayner (1920) subjected Albert, a 9-month-old boy, to a loud noise every time a rat (which Albert had originally liked) came close to the child. After a few pairings of the noise with the rat, Albert reacted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

Classical conditioning A procedure in which pairing a neutral stimulus with a stimulus that elicits a response causes the neutral stimulus to elicit that response.

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 (or inside Pavlov's

Figure 1.6 In Pavlov's famous experiment, he paired ringing a bell with presentation of food. Initially, presentation of the food caused the dog to salivate, but after several 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.



Science History Images/Alamy Stock Photo dog's head), either physiologically or mentally, was irrelevant. He cared only about how pairing one stimulus with another affected behavior.

Skinner's Operant Conditioning

Amid behaviorism's dominance of American psychology, B. F. Skinner provided another tool for studying the relationship between stimulus and response, which ensured that 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 how behavior was controlled by stimuli (Skinner, 1938).

Operant conditioning A learning process by which behaviors are made more likely to recur by the inclusion of reinforcers or less likely to recur by the inclusions of punishments. Operant conditioning can be used to shape behavior toward a more desired outcome.

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 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. But even as behaviorism was dominating psychology, events occurred that would lead to the rebirth of the study of the mind.

Setting the Stage for the Reemergence of the Mind in Psychology

Although behaviorism dominated American psychology for many decades, not all researchers were on board. Edward Tolman, professor of psychology at the University of California at Berkeley from 1918 to 1954, considered himself a behaviorist because his focus was on measuring behavior;– in reality, he was one of the first 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 point A and food was placed at point 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 (after taking precautions to be sure the rat couldn't determine the location of the food based on smell) placed the rat at point C, something interesting happened. The rat turned left at the intersection to reach the food at point 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 within the rat's mind of the maze's layout (Tolman, 1948). Thus, even though the rat had previously been rewarded for turning right, its mental map indicated that when starting from the new location it needed to turn left to reach the food. Tolman's use of the word *cognitive*, and the idea that something other than stimulus–response connections might be occurring in the rat's mind, placed Tolman outside of mainstream behaviorism.

Cognitive map Mental conception of a spatial layout.

Figure 1.7 Timeline showing early experiments studying the mind in the 1800s and the rise of behaviorism in the 1900s.

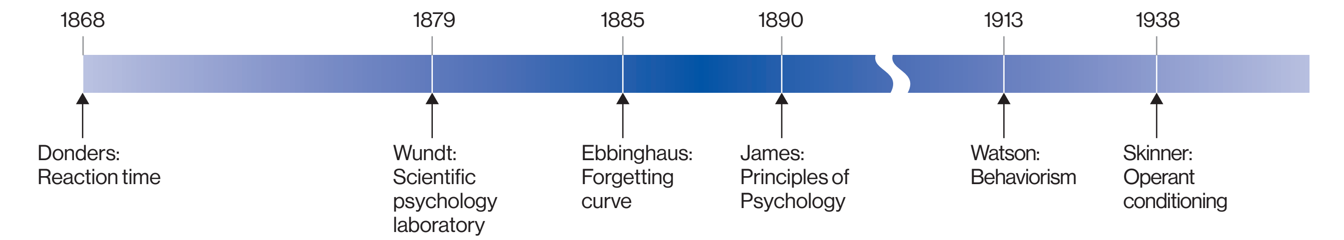
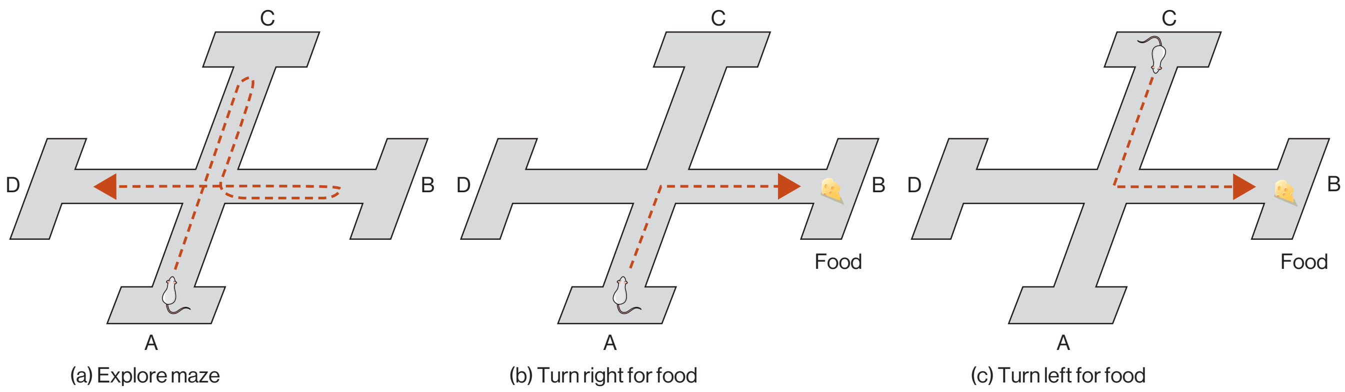


Figure 1.8 **Maze used by Tolman. (a) The rat initially explores the maze. (b) The rat learns to turn right to obtain food at B when it starts at A. (c) When placed at C, the rat turns left to reach the food at B. In this experiment, precautions are taken to prevent the rat from knowing where the food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



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 a resurgence began regarding the study of the mind in psychology.

Ironically, part of this resurgence in the study of the mind included the publication of a book titled *Verbal Behavior* by none other than behaviorist B. F. Skinner (1957). In his 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 (MIT), 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, rather than a result of 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.

1.4 The Rebirth of the Study of the Mind

Cognitive revolution A shift in psychology, beginning in the 1950s, from the behaviorist approach to an approach in which the main thrust was to explain behavior in terms of the mind. One of the outcomes of the cognitive revolution was the introduction of the information-processing approach to studying the mind.

In the 1950s, a **cognitive revolution** began. This "revolution" was a shift in psychology from the behaviorists' focus on stimulus–response relationships to an approach whose main thrust was to understand the operation of the mind. Even before Chomsky's critique of Skinner's book, other events signaled a shift from a singular focus on behavior toward studies of how the mind operates.

Before we describe the events that began the cognitive revolution, let's consider the following question: What is a revolution—and specifically a scientific revolution? One answer to this question can be found in philosopher Thomas Kuhn's (1962) book *The Structure of Scientific Revolutions*.

Paradigms and Paradigm Shifts

Kuhn defined a **scientific revolution** as a shift from one paradigm to another, where a **paradigm** is a system of ideas that dominates science at a particular time (Dyson, 2012). A scientific revolution, therefore, involves a **paradigm shift**.

Scientific revolution Occurs when there is a shift in thinking from one scientific paradigm to another.

Paradigm A system of ideas, which guide thinking in a particular field.

Paradigm shift A shift in thinking from one paradigm to another.

Here's one example of a paradigm shift in science. In the beginning of the 20th century, physicists introduced the theory of relativity and quantum theory. Before then, classical physics, founded by Isaac Newton (1642–1727), had made great progress in describing things like how objects are affected by forces (Newton's laws of motion) and the nature of electrical fields (Maxwell's laws, which described electromagnetism). The principles of classical physics did not, however, adequately describe subatomic phenomena and the relation between time and motion. For example, classical physics conceived of the flow of time as an absolute constant, which was the same for everyone. But in 1905, Albert Einstein, a young clerk in the Bern, Switzerland patent office, published his theory of relativity, which proposed that the measurement of space and time are affected by an observer's motion; so clocks should run slower when approaching the speed of light. He also proposed that mass and energy are equivalent, as expressed in his famous equation $E = mc^2$ (energy equals mass times the speed of light squared). Einstein's relativity theory, along with the newly introduced quantum theory, which explained the behavior of subatomic particles, marked the beginning of modern physics. This was revolutionary!

Just as the paradigm shift from classical physics to modern physics provided a new way of looking at the physical world, the paradigm shift from behaviorism to the cognitive approach provided a new way to look at behavior. During the reign of behaviorism, behavior was considered an end in itself. Psychology was dominated by experiments studying how behavior is affected by rewards and punishments. Some valuable discoveries resulted from this research, including psychological therapies called "behavioral therapies," which are still in use today. But the behaviorist paradigm did not allow any consideration of the mind's role in creating behavior. Therefore, in the 1950s, the new cognitive paradigm began to emerge. We cannot mark the beginning of this new paradigm by the publication of a single paper, like Einstein's (1905) proposal of relativity theory, but rather we can point to a series of events, which together culminated in a new way of studying and thinking about psychology. One of these events was the introduction of a new technology that suggested a novel way of describing the operation of the mind. That new technology was the digital computer.

Introduction of the Digital Computer

While we typically associate the term "computer" with a machine, the first computers were actually people (Grier, 2005). Someone who was a computer, as the name implies, would "compute" complex mathematical problems. Being a computer was an important career from the 15th century to the 19th century, used heavily in fields like astronomy and sea navigation. In the 19th and 20th centuries, human computers aided in technological breakthroughs such as mechanical engineering, weather forecasting, physics, and the space program. However, computing is a difficult and slow job that is prone to human error. As technology advanced into the 20th century, automation of this career began.

The first digital computers, developed in the late 1940s, were huge machines that took up entire buildings, like the one shown in **Figure 1.9**. However, in 1954 IBM introduced a computer that was available to the general public. These computers were still extremely large compared to the laptops, tablets, and smartphones of today, but they found their way into university research laboratories, where they were used both to analyze data and, most importantly for our purposes, to suggest a new way of thinking about the mind.

Flow Diagrams for Computers One of the characteristics of computers that captured the attention of psychologists in the 1950s was that they processed information in stages, as illustrated in **Figure 1.10a**. In this diagram, information is first received by an "input processor." It is then stored in a "memory unit" before it is processed by an "arithmetic unit," which then creates the computer's output. In other words, digital computers were designed to first receive information, then store it, and finally use it. This staged approach inspired

Figure 1.9 **Here is an example of an early digital computer. Built in 1944, this was the Harvard Mark 1, also called the IBM Automatic Sequence Controlled Calculator (ASCC). Notice the size of the three people in the picture to get a sense of how large some of these early digital computers were.**

Universal Images/Superstock

Information-processing approach The approach to psychology, developed beginning in the 1950s, in which the mind is described as processing information through a sequence of stages.

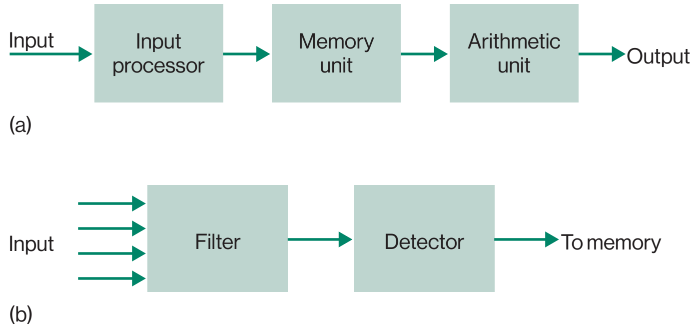
psychologists to propose the **information-processing approach** to studying the mind—an approach that traces sequences of mental operations involved in cognition. According to the information-processing approach, the operation of the mind can be described as occurring in several stages. Just as a computer can be designed to receive, store, and use information, so too might the human mind. Remember, digital computers were designed to replace human computers; therefore, it makes sense that early digital computers would attempt to replicate the same cognitive processes that humans use to complete similar computations. 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 can focus their attention on some information when other information is being presented at the same time.

Flow Diagrams for the Mind Beginning in the 1950s, several researchers became interested in describing how well the mind can deal with incoming information. One area of inquiry that interested them stemmed from an observation by William James: when we decide to attend to one thing, we often must withdraw from other things. Taking this idea as a starting point, British psychologist Colin Cherry (1953) presented participants with two auditory messages, one to the left ear and one to the right ear. They were told to focus their attention on one of the messages (the attended message) and to ignore the other one (the unattended message). For example, the participant might be told to attend to the left-ear message that began "As Leila drove down the road in her new car . . ." while simultaneously receiving, but not attending to, the right-ear message "Cognitive psychology, which is the study of mental processes . . ."

The result of this experiment, which we will describe in detail when we discuss attention in Chapter 4, was that when people focused on the attended message, they could hear the sounds of the unattended message but were unaware of the contents of that message. This result led another British psychologist, Donald Broadbent (1958), to propose the first flow diagram of the mind (**Figure 1.10b**). This diagram represents what Broadbent believed happens in a person's mind when directing attention to one stimulus in the environment. Applied to Cherry's attention experiment, "input" would be the sounds of both the attended and unattended messages; the "filter" lets through the attended message and filters out the unattended message; 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 the other conversations and noise. Thus, although you might be aware that there are other people talking, you are not aware of detailed information

Figure 1.10 **(a) Flow diagram for an early computer. (b) Flow diagram for Broadbent's filter model of attention. This diagram shows many messages entering a "filter," which selects the message to which the person is attending for further processing by a detector and then transfer to short-term memory. We will describe this diagram in more detail in Chapter 4.**



such as what the other people are talking about. The ability to focus on some information while filtering out other information has been called the **cocktail party effect** because, at noisy parties, people can focus on what one person is saying even when many conversations are happening at the same time.

Cocktail party effect The ability to focus on one stimulus while filtering out other stimuli, especially at a party where there are a lot of simultaneous conversations.

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 observe many more flow diagrams like this throughout this text because they have become one of the standard ways of depicting the operation of the mind. But the British psychologists Cherry and Broadbent weren't the only researchers finding new ways of studying the mind. At about the same time in the United States, researchers organized two conferences that, taking their cue from computers, conceived of the mind as a processor of information.

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 organize 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 (AI)**. 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).

Artificial intelligence (AI) The ability of a computer to perform tasks usually associated with human intelligence.

Researchers from several different disciplines—psychologists, mathematicians, computer scientists, linguists, and experts in information theory—attended the conference. Many people attended most of the conference, others dropped in and out, but perhaps the two most important participants—Herb Simon and Alan Newell from the Carnegie Institute of Technology—were hardly there at all (Boden, 2006); they were busy back in Pittsburgh trying to create the artificial intelligence machine that McCarthy had envisioned. Simon and Newell's goal was to develop a computer program that could create proofs for problems in logic—something that up until then could only be 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. 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 humanlike 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 Seven Plus or Minus Two," which had just been published (Miller, 1956). In that paper, Miller presented the idea that there are limits to a human's ability to process information—that the capacity of the human mind is limited to about seven items (for example, the length of a telephone number).

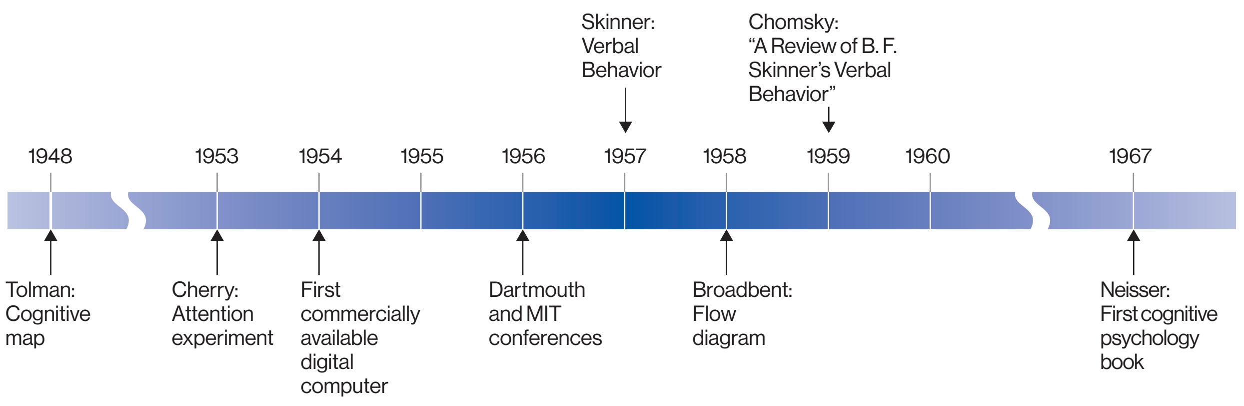
There are ways to increase our ability to take in and remember information (for example, we have little trouble adding an area code to the seven digits of many telephone numbers—especially if we use *chunking* to help break the numbers into groups. We will return to these ideas, including the concept of chunking, in Chapter 5). 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 Cognitive "Revolution" Took a While

The events we have described—Cherry's experiment, 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. Although we have called this shift the *cognitive revolution*, it is worth noting that the shift from Skinner's behaviorism to the cognitive approach, which was indeed revolutionary, occurred over time. 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). **Figure 1.11** shows a timeline of some of the events that led to the establishment of the field of cognitive psychology.

Neisser's textbook, which coined the term *cognitive psychology* and emphasized the information-processing approach to studying the mind, is, in a sense, the predecessor of the text you are now using. 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 1.11 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).



1.5 The Evolution of Cognitive Psychology

We have been describing the events in the 1950s and 1960s as the cognitive revolution. But it is important to realize that although the revolution made it acceptable to study the mind, the field of cognitive psychology continued to evolve in the decades that followed. One way to appreciate how cognitive psychology has evolved from the 1950s and 1960s to today is to look at the contents of Neisser's book.

What Neisser Wrote

Neisser stated that the purpose of his cognitive psychology book was "to provide a useful and current assessment of the existing state of the art" (p. 9). Given this purpose, it is instructive to consider the book's Table of Contents.

Most of the book is devoted to vision and hearing. There are descriptions of how information is taken in by vision and held in memory for short periods, and how people search for and use visual information to see simple patterns. Most of the discussion is about the intake of information and holding information in the mind for brief periods, such as how long people can remember sounds like strings of numbers. But it isn't until the end of the book that Neisser considers "higher mental processes" such as thinking, problem-solving, and long-term remembering. The reason Neisser gives for this scant treatment is that in 1967, we just didn't know much about higher mental processes yet.

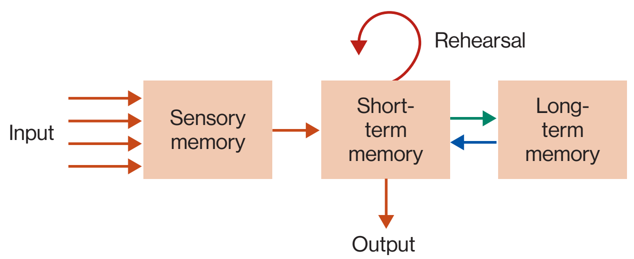
Another coverage gap is the almost complete absence of physiology. Neisser says that "I do not doubt that human behavior and consciousness depends entirely on the activity of the brain and related processes" (p. 5), but then he goes on to argue that he is interested in how the mind operates, but not in the physiological mechanisms behind this operation.

These two gaps in Neisser's book, the study of higher mental processes and the study of the physiology of mental processes, are now central topics in present-day cognitive psychology.

Studying Higher Mental Processes

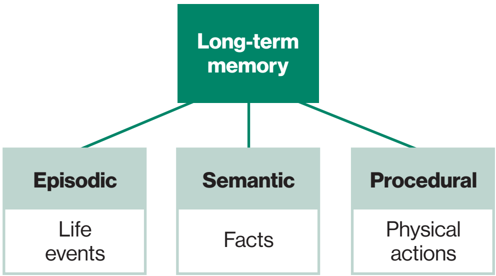
A big step toward the study of higher mental processes was Richard Atkinson and Richard Shiffrin's (1968) model of memory, which was introduced a year after the publication of Neisser's book. This model, shown in **Figure 1.12**, pictures the flow of information in the memory system as progressing through three distinctly separate stages. *Sensory memory* holds incoming information for a fraction of a second. Most of this information is quickly passed to *short-term memory*, which has limited capacity and holds information for seconds (like the name of someone who just introduced themselves to you). The curved arrow represents the process of rehearsal, which occurs when we repeat something, like the name of a person we just met, to keep from forgetting it. The blue arrow indicates that some information in short-term memory can be transferred to *long-term memory*, a high-capacity system that can hold information for long periods (like your memory of what you did last weekend, or the capitals of states). The green arrow indicates that some of the information in long-term memory can

Figure 1.12 **Atkinson and Shiffrin's (1968) model of memory.**



(Source: Based on R. C. Atkinson & R. M. Shiffrin, Human memory: A proposed system and its control processes, in K. W. Spence & J. T. Spence, Eds., The psychology of learning and motivation, Vol. 2, pp. 89–195, New York: Academic Press, 1968.)

Figure 1.13 **Endel Tulving (1972) divided long-term memory into three components.**



(Source: Based on E. Tulving, How many memory systems are there? American Psychologist, 40, 385–398, 1985.)

be returned to short-term memory. The green arrow, which represents what happens when we remember something that was stored in long-term memory, is based on the idea that remembering something involves bringing it back into short-term memory.

By distinguishing between different components of the memory process, this model opened the way for studying each part separately. Once researchers discovered more details about what was going on inside each of the model's boxes, they were able to subdivide these boxes into smaller units, which then could be studied in more depth. For example, Endel Tulving (1972, 1985), a prominent early memory researcher, proposed that long-term memory is subdivided into three distinct components (**Figure 1.13**). *Episodic memory* is memory for events (like what you did last weekend). Think of these memories as the "episodes" of your life, similar to episodes on a television show. *Semantic memory* is memory for facts (such as the capitals of the states). *Procedural memory* is memory for physical actions (such as how to ride a bike or play the piano). Subdividing the long-term memory box into types of long-term memory added detail to the model that provided the basis for research into how each of these components operates. As you will learn in every chapter of this text, the study of higher mental processes has extended to areas beyond memory. As you use this text, you will discover how researchers have often subdivided cognitive processes into smaller units to create a more detailed picture of how these processes operate.

Studying the Physiology of Cognition

While researchers were working to understand memory and other cognitive functions by conducting behavioral experiments, something else was happening. Physiological research, which we will learn in Chapter 2 had been making advances since the 1800s, was providing important insights into the "behind the scenes" activity of the nervous system that creates the mind.

Two techniques dominated early physiological research on the mind:

Neuropsychology The study of the behavioral effects of brain damage in humans.

Electrophysiology Techniques used to measure electrical responses of the nervous system.

Brain imaging Technique such as functional magnetic resonance imaging (fMRI) that results in images of the brain that represent brain activity. In cognitive psychology, activity is measured in response to specific cognitive tasks.

(1) **Neuropsychology**, the study of the behavior of people whose brains had been damaged by traumatic injury, had been providing insights into the functioning of different parts of the brain since the 1800s.

(2) **Electrophysiology**, measuring electrical responses of the nervous system, made it possible to observe and measure the activity of specific neurons. Most electrophysiology research was conducted on non-human animals.

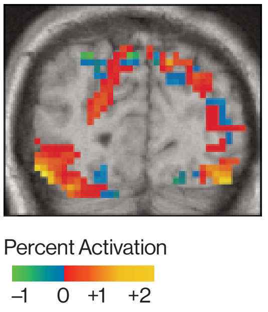
As we will explore in Chapter 2, both neuropsychology and electrophysiology have provided important insights into the physiological basis of the mind.

Perhaps the most significant physiological advance came a decade after Neisser's book when one of the first **brain imaging** techniques was invented. A procedure called *positron emission tomography* (PET), introduced in 1976, made it possible to see which areas of the human brain are active during certain cognitive activities (Hoffman et al., 1976; Ter-Pogossian et al., 1975). PET had disadvantages: it was expensive and involved injecting radioactive tracers into the bloodstream. PET was therefore replaced by another brain imaging technique called *functional magnetic resonance imaging* (fMRI), which did not involve radioactive tracers and which was capable of higher spatial resolution, meaning it could more precisely identify the specific locations of brain activity (Ogawa et al., 1990). fMRI also typically has a higher temporal resolution than PET. Temporal resolution refers to the ability to determine precisely when certain brain activity takes place. **Figure 1.14** shows the results of an fMRI experiment.

The introduction of fMRI brings us back to the idea of revolutions. According to Thomas Kuhn's views on paradigm shifts, a scientific revolution involves a shift in the way people think about a particular subject. This was clearly the case in the shift from the behavioral paradigm to the cognitive paradigm. However, science can also undergo a shift in how people *conduct* research (Dyson, 2012; Galison, 1997). This shift, which depends on new developments in technology, is what happened with the introduction of fMRI. *The Journal of Neuroscience* produced its first issue in 1981 but would not have included fMRI until its development in 1990. *Neuroimage*, a journal devoted solely to reporting neuroimaging research, was founded in 1992 (Toga, 1992), followed by *Human Brain Mapping* in 1993 (Fox, 1993). From its starting point in the early 1990s, the number of fMRI papers published in all journals has steadily increased, with an estimated 60,000 fMRI papers published as of 2024.

Both PET and fMRI research have limitations, and many other brain scanning techniques have been developed. However, there is no question that the trend started by the introduction of fMRI in 1990 caused its own revolution within cognitive psychology, which, as we will consider in Chapter 2, has led to a vast increase in our knowledge of how the brain functions.

Figure 1.14 Record of brain activation determined using fMRI. The colors red and yellow indicate increases in activity, caused here by perceiving pictures of faces. Blue and green indicate decreases in activity. Details of this procedure will be described in Chapter 2.



Source: From Ishai et al., 2000

New Perspectives on Behavior

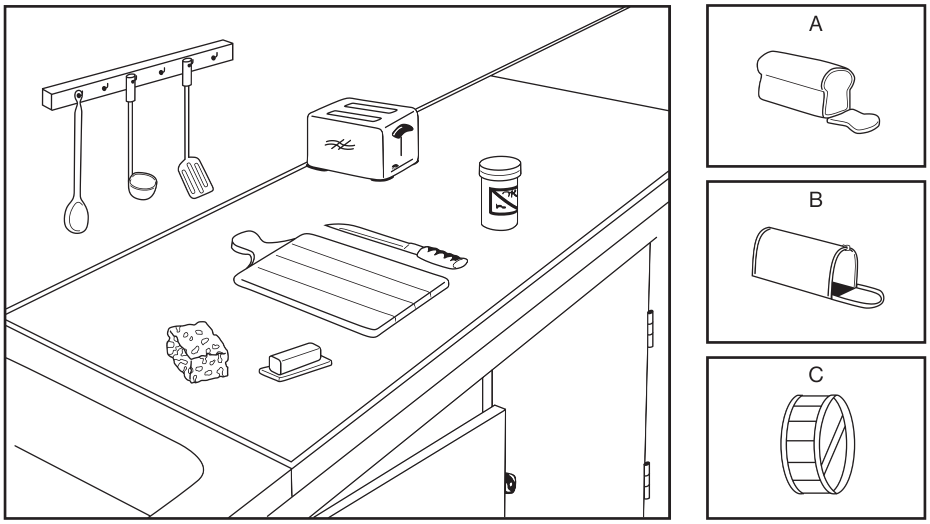
So how has cognitive psychology evolved since Neisser's 1967 "progress report"? As we have already mentioned, current cognitive psychology involves more sophisticated flow diagrams of the mind, a consideration of higher mental processes, and a large amount of physiological research.

Beyond developing more research on higher-level processes and physiology that we knew little about in 1967, researchers began taking research out of the laboratory. Most early research was conducted in laboratories, with participants sitting in one place looking at briefly presented stimuli, as in Donders's reaction time experiment. Later, it became clear that to fully understand the mind, we must also study what happens when a person is moving through the environment and interacting with it. Modern cognitive psychology therefore features an increasing amount of research on cognition in "real-world" situations. An important advance in this area is the use of virtual reality (VR) and augmented reality (AR) technology to simulate the real world in a controlled environment. VR often includes a headset that covers the eyes, completely replacing real-world visual information with whatever is displayed inside of it. However, technology like Apple's Vision Pro headset released in 2024, contains a mixed-reality environment where virtual information can "augment" (cover or replace) parts of the visual world. An example of this technology is displayed in **Figure 1.15**, where two architects observe virtual city plans while also being able to see the

Figure 1.15 Two architects look at a virtual representation of a city, viewed through mixed-reality (VR and AR) headsets. This technology can be used in cognitive research to ensure participants have an experience that can be generalized to real-world scenarios.

Gorodenkoff/Shutterstock.com

Figure 1.16 **Stimuli used in Palmer's (1975) experiment. The scene on the left is presented first, and then one of the objects on the right is briefly flashed. Participants in this experiment were more accurate in identifying the bread. This outcome indicates that knowledge of what is usually found in kitchens influences performance.**



(Source: From S. E. Palmer, The effects of contextual scenes on the identification of objects, Memory and Cognition, 3 , 519–526, 1975.)

physically real table, the room around them, and each other! Through VR and AR technologies, cognitive researchers can immerse participants in lifelike scenarios that can still be carefully controlled—ensuring cognition can be studied in ways that are both reliable and generalizable to the real world.

Modern perspectives on behavior also acknowledge that humans are not "blank slates" that just accept and store information. Instead, there is an emphasis on the importance of knowledge for cognition. For example, consider the picture in **Figure 1.16**, which was used by Stephen Palmer (1975) to illustrate how our knowledge about the environment can influence our perception. Palmer first presented a context scene such as the kitchen scene 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 do not fit into the scene) only 40 percent of the time. Observers were using knowledge of objects that are likely to be found in kitchens to help perceive the briefly flashed loaf of bread. Of course, knowledge is more than just an interesting effect to be demonstrated in a perception experiment; it is central to most cognitive processing. You will accumulate evidence for the importance of such knowledge in cognition because it appears in every chapter!

As you use this text, you will encounter a wide range of perspectives and approaches. You will learn how physiological research adds another dimension to our understanding of the mind; how cognitive psychology is studied in the laboratory and real-world environments; and how the knowledge a person brings to a situation plays a central role in cognition.

Something to Consider

Learning from This Text

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 how present-day cognitive psychologists approach the study of the mind. One of the purposes of this chapter—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 course. After all, cognitive psychology is the study of the mind, and some things have been discovered about memory that can help you improve your study techniques so you can get as much as possible from this text and from the course you are taking. One way to appreciate how cognitive psychology can be applied to studying is to look at pages 200–206 in Chapter 7. It makes sense to skim this material now, rather than waiting. There will be some terms that you may not be familiar with, but these are not crucial for what you want to accomplish, which is picking up some hints that will make your studying more efficient and effective. Two terms worth knowing as you review this text 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.

Something else that might help you learn from this text is to be aware of how it is constructed. As you read the text, you will notice that often a basic idea or theory is presented and then it is supported by examples or experiments. 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. The reason topics are presented as mini-stories is that it is easier to remember several facts if they are presented as part of a story than if they are presented as separate, unrelated facts. So, as you progress through this text, 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 last thing: Just as specific topics can be described as many 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 text.

Test Yourself

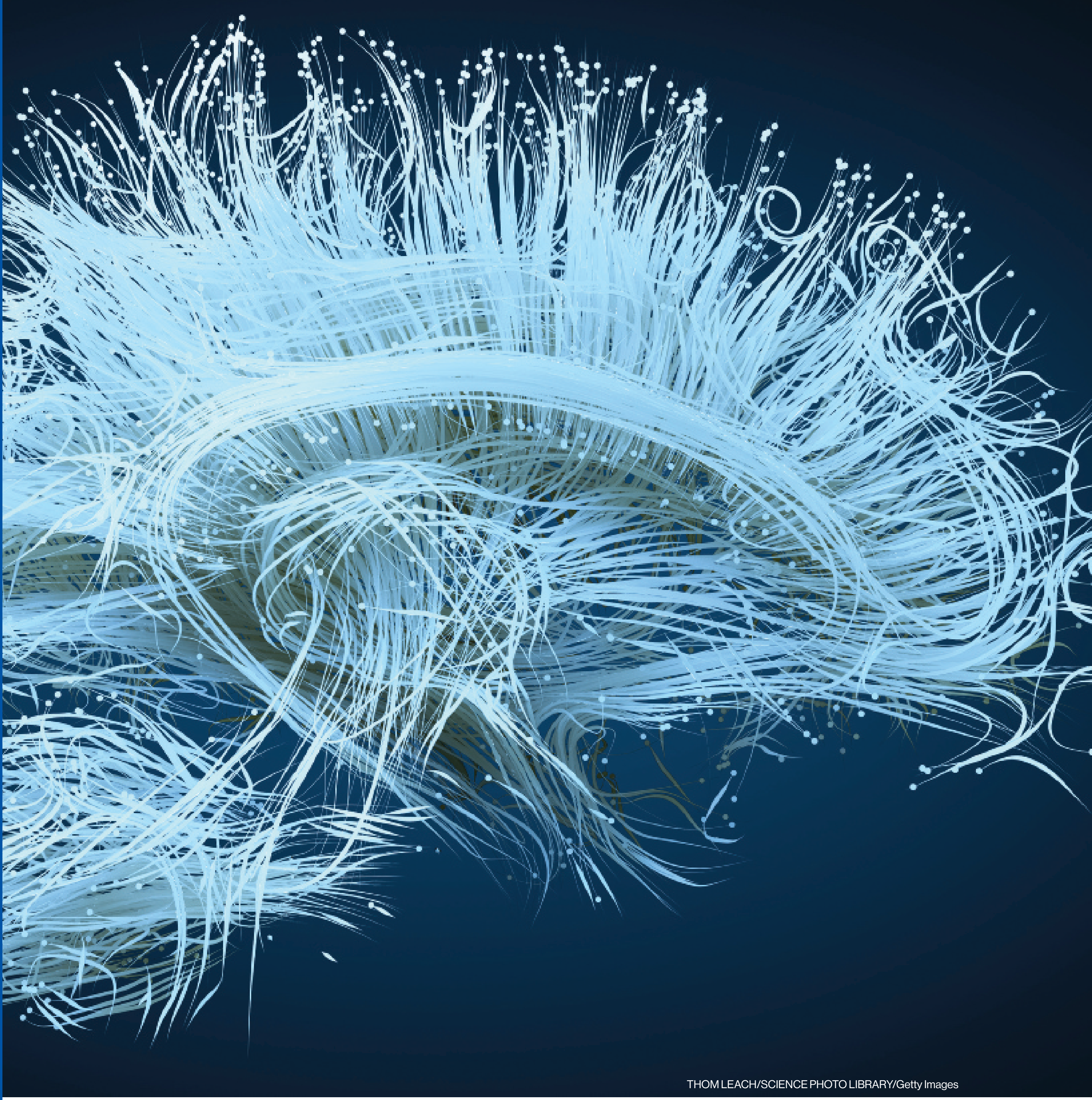
1. What was the takeaway of the opening story about Sam?
2. What are two ways of defining the mind?
3. Why might we say that Donders and Ebbinghaus were cognitive psychologists, even though in the 19th century there was no field called cognitive psychology?
4. Describe Donders's experiment and the rationale behind it, and Ebbinghaus's memory experiments. What do Donders's and Ebbinghaus's experiments have in common?
5. Who founded the first laboratory of scientific psychology? Describe the method of analytic introspection that was used in this laboratory.
6. What method did William James use to study the mind? How did it differ from previous methods?
7. Describe the rise of behaviorism, especially the influence of Watson and Skinner. How did behaviorism affect research on the mind?
8. How did Edward Tolman deviate from strict behaviorism?
9. What did Noam Chomsky say about Skinner's book *Verbal Behavior*, and what impact did that have on behaviorism?
10. What is a scientific revolution according to Thomas Kuhn? How is the cognitive revolution similar to the revolution that occurred in physics at the beginning of the 20th century?
11. Describe the events that led to the cognitive revolution. What role did digital computers and the information-processing approach play in moving psychology toward the study of the mind?
12. What was the state of cognitive psychology in 1967, according to Neisser's (1967) book?
13. What are neuropsychology, electrophysiology, and brain imaging?
14. What new perspectives on behavior emerged as cognitive psychology developed?
15. What are two suggestions for improving your ability to learn from this text?

Chapter 1 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 versus 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 mind 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 1940s, B. F. Skinner's work on operant conditioning ensured that behaviorism would be the dominant force in psychology through the 1950s.
9. Edward Tolman called himself a behaviorist but studied cognitive processes that were out of the mainstream of behaviorism.
10. The cognitive revolution involved a paradigm shift in how scientists thought about psychology, and specifically the mind.
11. In the 1950s, several events led to a decline in the influence of behaviorism and a reemergence of the study of the mind, known as the cognitive revolution. 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 a computer; (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.
12. Even after the shift in psychology that made studying the mind acceptable, our understanding of the mind was limited, as indicated by the contents of Neisser's (1967) book. Notable developments in cognitive psychology in the decades following Neisser's book were (1) development of more-sophisticated models; (2) research focusing on the physiological basis of cognition; (3) concern with cognition in the real world; and (4) the role of knowledge in cognition.
13. Two strategies that may help in learning the material in this text 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 text 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 with titles like: "Scientists Race to Find Memory Loss Cure" or "Defendant Says He Cannot 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 text).
3. The idea that the operation of the mind can be described as occurring in several stages was the central principle of the information-processing approach, which was one of the outcomes of the cognitive revolution that began in the 1950s. How can Donders's 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, when given a choice, to decide which button to push. 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**.



THOM LEACH/SCIENCE PHOTO LIBRARY/Getty Images

To fully understand cognition, we need to understand the brain. As we will learn in this chapter, the brain has been studied at levels ranging from single neurons to complex networks that interconnect various brain regions. This picture represents the complexity of the interconnections between different places in the brain, using technology like functional magnetic resonance imaging (fMRI) mentioned in Chapter 1. These interconnections are determined both by physical connections created by neurons and by the specific functions that the brain is carrying out at a particular time. The brain, therefore, is not only extremely complex, but its functioning is changeable and dynamic, in keeping with the dynamic nature of the cognitions it creates.

2

Cognitive Neuroscience

Learning Objectives

After reading this chapter, students will be able to:

2-1 Explain what cognitive neuroscience is and what its study can teach us.
2-2 Describe how information is transmitted from one place to another in the nervous system.
2-3 Describe how items in the environment, such as faces and places, are represented in the brain.
2-4 Explain neural networks and their role in cognition.
2-5 Describe the default mode network and how it differs from other neural networks.

As discussed in Chapter 1, research on the mind has been on a roller-coaster ride that began with a promising start in the 1800s with the early research of Donders and Ebbinghaus, only to be derailed by Watson's behaviorism in the early 1900s and Skinner's operant conditioning in the 1930s. However, in the 1950s and 1960s, there was a "cognitive revolution" with the mind at its forefront; researchers conducted experiments based on the information-processing model.

Coincidentally, at the same time as this cognitive revolution, several research papers were published that involved recording nerve impulses from single neurons Mountcastle, 1957; Strumwasser, 1958; Nakahama et al., 1968). As we will explore, research studying the relationship between neural responses and cognition began long before the 1950s, but technological advances led to a large increase in physiological research that began during the cognitive revolution.

In this chapter, we take up the story of **cognitive neuroscience**—the study of the physiological basis of cognition. We begin by discussing the idea of "levels of analysis," which is our rationale behind studying the physiology of the mind. We then go back in time to the 19th and early 20th centuries to look at the early research that set the stage for amazing discoveries that were going to be made, beginning in the 1950s.

2.1 Levels of Analysis

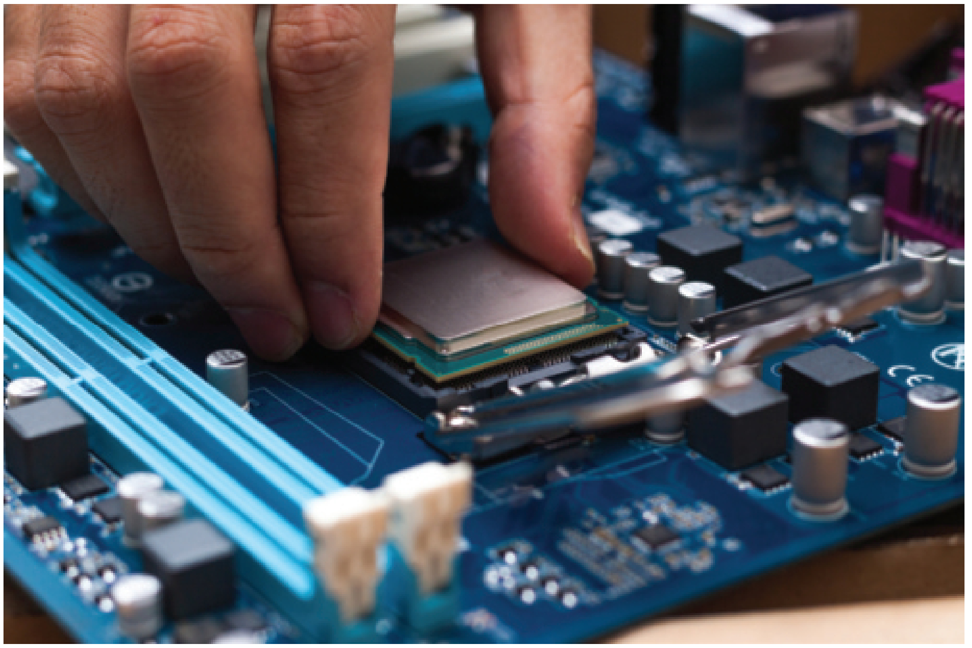
Levels of analysis refers to the idea that a topic can be studied in many different ways, with each approach contributing its own dimension to our understanding. To understand what this means, let's consider a topic outside the realm of cognitive psychology: understanding how a computer works (**Figure 2.1**).

Our starting point for this problem might be to visit a computer store and play around with various computers. We could determine how easy or difficult a computer is to use, what features it has, how fast it performs basic actions like starting up and opening programs, and how much it weighs (an important factor if it's a laptop you plan to carry around). Just by measuring many of these basic factors, we will already know a lot about the particular computer we are testing. However, to learn more, we can consider another level of analysis: how does this computer actually work? This investigation would involve looking at the hardware (the CPU, storage, RAM, motherboard, and graphics card) and software (operating system, productivity software, and security software) that are responsible for the computer's performance. For example, as of 2024, the standard 13" MacBook Air has an 8-core CPU running an Apple M1 chip, 256 GB solid-state drive storage, 8 GB of RAM, and runs macOS Sonoma operating system.

But we can look even deeper into the operation of the computer by considering another level of analysis designed to help us understand how the computer's fundamental hardware works. One approach would be to examine what happens inside a computer chip. When we do this, we observe that a chip receives instructions from the computer's memory. The chip decodes this information and determines what actions to perform, including "fetching" data from memory. Once the chip has the information it needs, it executes a specific action as requested by the initial instructions. Then it writes the results back to memory, and the process starts again. Clearly, considering a computer from the different levels— (1) operating a computer, (2) describing the components of a computer, and (3) learning how vital computer components function—provides more information about how computers work than could be gained by simply using a computer.

Applying this idea of levels of analysis to cognition, we can consider measuring behavior to be analogous to measuring the computer's performance and measuring the physiological processes behind the behavior as analogous to what we learned by looking at specific components of a computer's hardware and software. Just as we can study what is happening inside a

Figure 2.1 **A person assembling a computer by inserting a central processing unit (CPU) into a motherboard socket. The CPU is like the brain of a computer while the motherboard is like the extended nervous system.**



Shahril KHMD/Shutterstock.com

Cognitive neuroscience Field concerned with studying the neural basis of cognition.

Levels of analysis A topic can be understood by studying it at a number of different levels of a system.

computer at different levels, we can study the physiology of cognition at levels ranging from the whole brain, to structures within the brain, to chemicals that create electrical signals within these structures.

Consider, for example, a situation in which Gil is talking with Mariella in the park (**Figure 2.2a**), and then a few days later he passes the park and remembers what she was wearing and what they talked about (**Figure 2.2b**). This is a simple behavioral description of having an experience and later having a memory of that experience.

But what is going on at the physiological level? During the initial experience, in which Gil perceives Mariella as he is talking with her, chemical processes occur in Gil's eyes and ears, which create electrical signals in neurons (which we will describe shortly); individual brain structures are activated, and then multiple brain structures are activated, all leading to Gil's perception of Mariella and what is happening as they talk (Figure 2.2a).

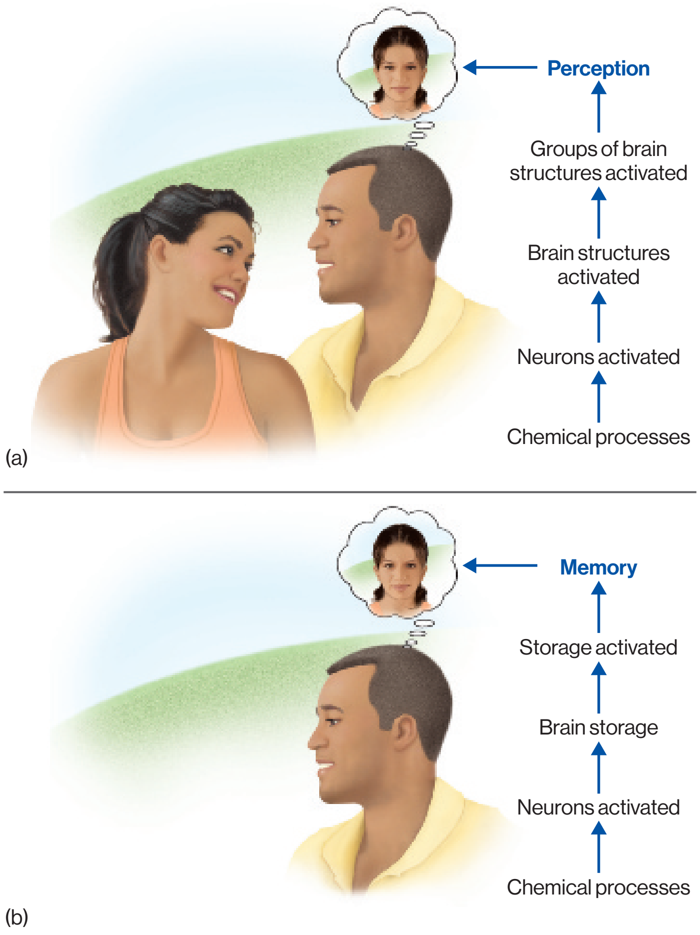
Meanwhile, other things are happening, both during Gil's conversation with Mariella and afterward. The electrical signals generated as Gil is talking with Mariella trigger chemical and electrical processes that result in the storage of Gil's experiences in his brain. Then, when Gil passes the park a few days later, another sequence of physiological events is triggered that retrieves the information that was stored earlier, which enables him to remember his conversation with Mariella (Figure 2.3b).

We have gone a long way to make a point, but it is an important one. To fully understand any phenomenon, whether it is how a computer operates or how people remember past experiences, it needs to be studied at different levels of analysis. In this text, we will be describing research in cognition at both the behavioral and physiological levels. We begin our description of physiology by considering one of the basic building blocks of the nervous system: the neuron.

2.2 Neurons: Basic Principles

How is it possible that the brain, a relatively small structure weighing only three pounds, could be home to the mind? If you were able to observe a healthy brain in a living person, it would appear to be rather unremarkable, static tissue. Unlike the heart, it has no moving parts. Unlike the lungs, it does not expand or contract. The brain simply looks still and solid.

Figure 2.2 **Physiological levels of analysis. (a) Gil perceives Mariella and their surroundings as he talks with her. The physiological processes involved in Gil's perception can be described at levels ranging from chemical reactions to single neurons, to structures in the brain, to groups of structures in the brain. (b) Later, Gil remembers his meeting with Mariella. The physiological processes involved in remembering can also be described at different levels of analysis.**



So how does that generate a mind? The brain generates an immense amount of activity, but it is not visible to the naked eye. To understand the relationship between the brain and the mind—and specifically to understand the physiological basis for everything we perceive, remember, and think—it is necessary to look within the brain and observe the small units called **neurons** that create and transmit information about what we experience and know.

Neuron Cell that is specialized to receive and transmit information in the nervous system.

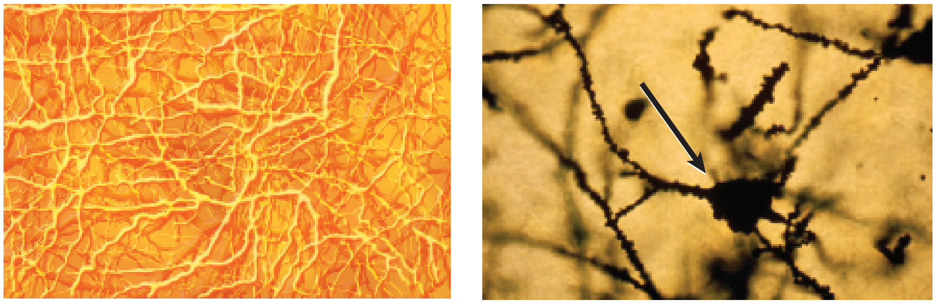
Early Conceptions of Neurons

For many years, the nature of the brain's tissue was a mystery. Looking at the interior of the brain with the unaided eye does not indicate that it is made up of billions of smaller units. However, in the 19th century, anatomists applied special stains to brain tissue, which increased the contrast between different types of tissue within the brain. When they viewed this stained tissue under a microscope, they observed a network they called a **nerve net** (**Figure 2.3a**). 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.

Nerve net A network of continuously interconnected nerve fibers (as contrasted with neural networks, in which fibers are connected by synapses).

One reason for describing the microstructure of the brain as a continuously interconnected network was that the staining techniques and microscopes used during that period 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 (1843–1926) developed a staining technique in which a thin slice of brain tissue was immersed in a solution of silver

Figure 2.3 (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 (review Figure 2.4).



(a) (b)

Clouds Hill Imaging Ltd./Corbis Documentary/Getty Images

nitrate. This technique created pictures like the one in **Figure 2.3b**, in which fewer than 1 percent of the cells were stained, so they stood out from the rest of the tissue. (If all 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.

Around the same time, the Spanish physiologist Ramon y Cajal (1852–1934) was using two techniques to investigate the nature of the nerve net. 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 with 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 observe that the nerve net was not continuous but rather interconnected individual units (Kandel, 2006). Cajal's discovery that individual units called neurons are 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 2.4a shows the basic parts of a neuron. The **cell body** is the metabolic center of the neuron; it contains mechanisms to keep the cell alive. The function of **dendrites** that branch out from the cell body is to receive signals from other neurons. **Axons** (also called **nerve fibers**) are usually long extensions from the cell body that transmit signals to other neurons. **Figure 2.4b** shows a neuron with a receptor that receives stimuli from the environment—pressure, in this example. 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) There is a small gap between the end of a neuron's axon and the dendrites or cell body of another neuron. This gap is called a **synapse** (**Figure 2.5**).

(2) Neurons are not connected indiscriminately to other neurons but form connections only to specific neurons. This forms groups of interconnected neurons, which together form **neural circuits**.

(3) In addition to neurons in the brain, some neurons are specialized to pick up information from the environment, such as the neurons in the eye, ear, and skin. These neurons, called **receptors** (Figure 2.4b), are similar to brain neurons in that they have an axon, but they have specialized receptors that receive information from the environment.

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. The concepts introduced by Cajal—individual neurons, synapses, and neural circuits—are basic principles used today to explain how the brain creates cognition. These discoveries earned Cajal the Nobel Prize in Physiology or Medicine in 1906, and today he is recognized as "the person who made this cellular study of mental life possible" (Kandel, 2006, p. 61).

Neuron doctrine The idea that individual cells called neurons transmit signals in the nervous system, and that these cells are not continuous with other cells as proposed by nerve net theory.

Cell body Part of a cell that contains mechanisms that keep the cell alive. In some neurons, the cell body and the dendrites associated with it receive information from other neurons.

Dendrites Structures that branch out from the cell body to receive electrical signals from other neurons.

Axon Part of the neuron that transmits signals from the cell body to the synapse at the end of the axon.

Nerve fiber Part of the neuron that transmits signals from the cell body to the synapse at the end of the axon.

Synapse Space between the end of an axon and the cell body or dendrite of the next axon.

Neural circuit Group of interconnected neurons that are responsible for neural processing.

Receptors Specialized neural structures that respond to environmental stimuli such as light, mechanical stimulation, or chemical stimuli.

Figure 2.4 **(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.**

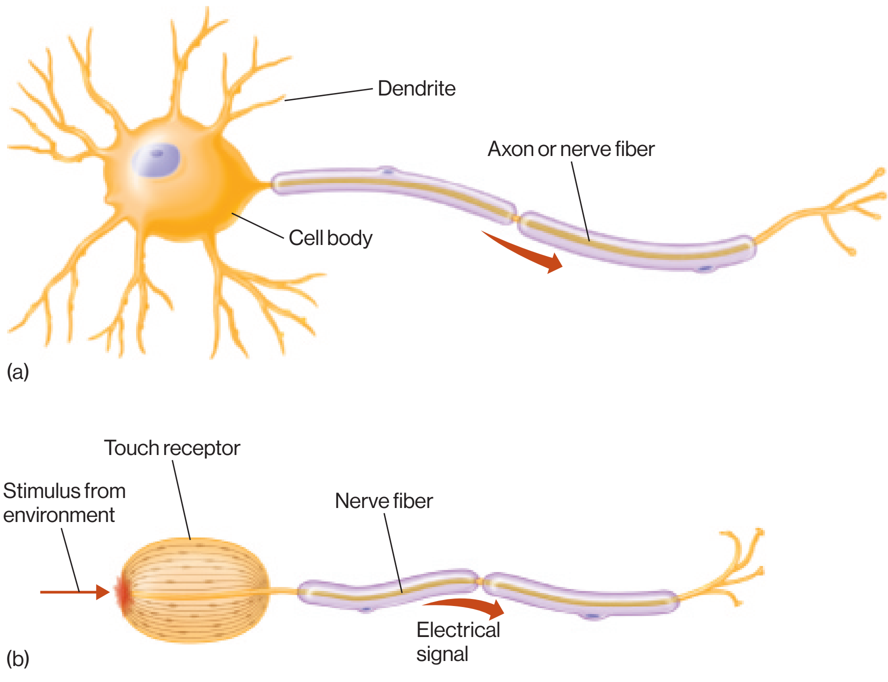
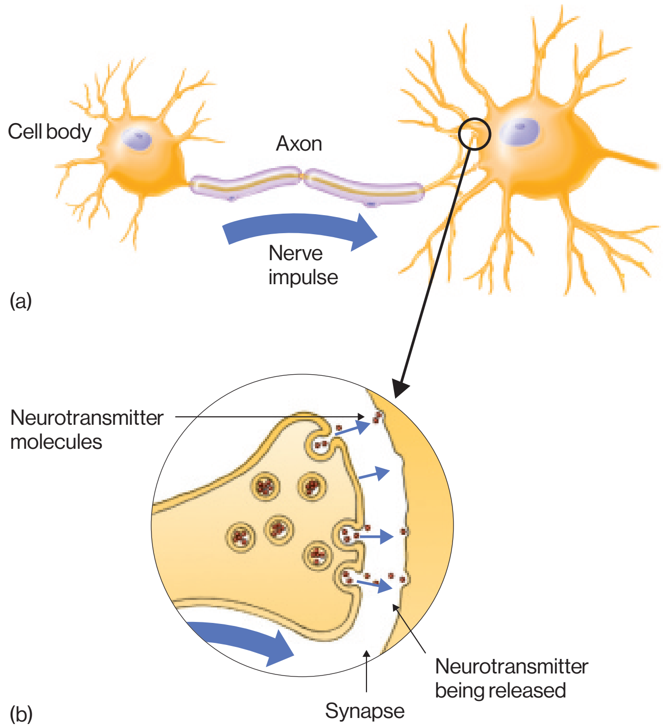


Figure 2.5 **(a) Neuron synapsing on the cell body of another neuron. (b) Close-up of the synapse showing the space between the end of one neuron and the cell body of the next neuron, and neurotransmitter being released.**



Resting potential Difference in charge between the inside and outside of a nerve fiber when the fiber is at rest (no other electrical signals are present).

Microelectrodes Small wires that are used to record electrical signals from single neurons.

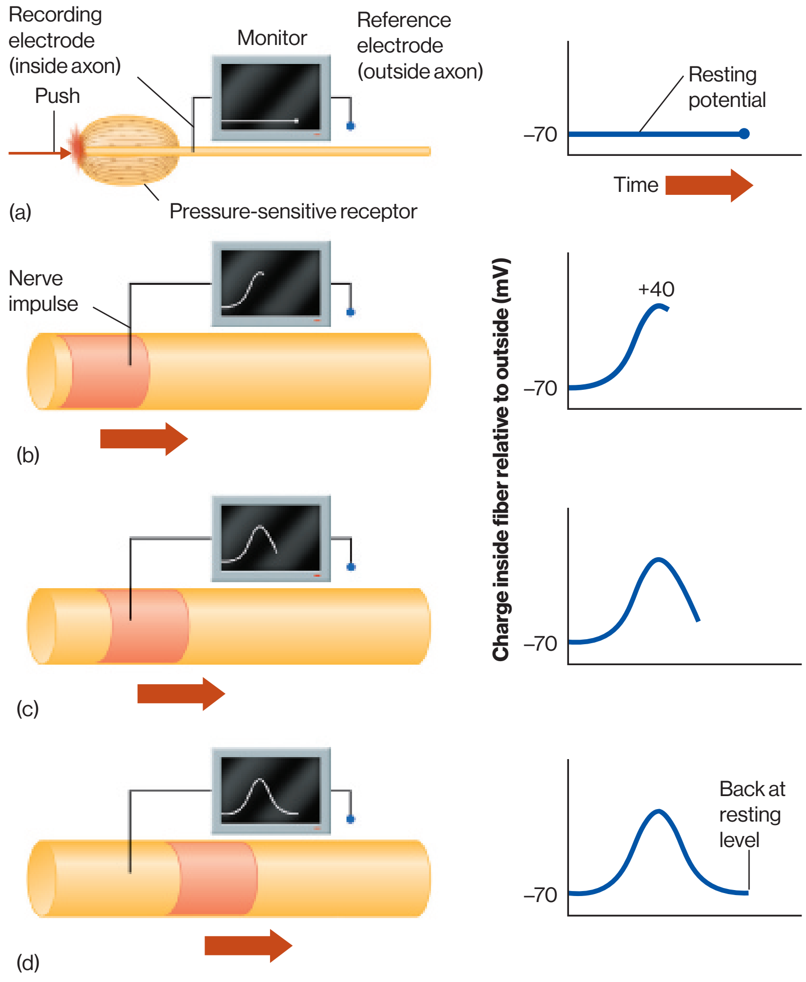
Recording electrode When used to study neural functioning, a very thin glass or metal probe that can pick up electrical signals from single neurons.

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 too was awarded the Nobel Prize in Physiology or Medicine in 1932 (Adrian, 1928, 1932).

When the axon, or nerve fiber, is at rest, the meter records a difference in potential between the tips of the two electrodes of −70 millivolts (a millivolt is 1/1000 of a volt), as shown on the right in **Figure 2.6a**. This value, which stays the same as long as there are no signals in the neuron, is called the **resting potential**. In other words, the inside of the neuron has a charge that is 70 mV more negative than the outside, and this difference continues as long as the neuron is resting.

Figure 2.6 **Recording an action potential as it travels down an axon. (a) When the nerve is at rest, there is a difference in charge, called the resting *potential*, of −70 millivolts (mV) between the inside and outside of the axon. The difference in charge between the recording and reference electrodes is fed into a computer and displayed on a computer monitor. This difference in charge is displayed on the right. (b) As the nerve impulse, indicated by the red band, passes the electrode, the inside of the fiber near the electrode becomes more positive. (c) As the nerve impulse moves past the electrode, the charge in the fiber becomes more negative. (d) Eventually, the neuron returns to its resting state.**



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. Physiologists today use metal microelectrodes instead of glass, but the mechanics are similar.

Figure 2.6 shows a typical setup used for recording from a single neuron. There are two electrodes: a **recording electrode**, shown with its recording tip inside (or very near) the neuron, and a **reference electrode**, located some distance away so it is not affected by the electrical signals. The difference in charge between the recording and reference electrodes is fed into a computer and displayed on the computer's screen.

Figure 2.6b shows what happens when the neuron's receptor is stimulated so that a **nerve impulse** is transmitted down the axon. As the impulse passes the recording electrode, the charge inside the axon rises to +40 millivolts, compared to the outside. As the impulse continues past the electrode, the charge inside the fiber reverses course and starts becoming negative again (**Figure 2.6c**), until it returns to the resting potential (**Figure 2.6d**). This impulse, which is called the **action potential**, lasts about 1 millisecond (1/1000 of a second).

Figure 2.7a shows action potentials on a compressed time scale. Each vertical line represents an action potential, and the series of lines indicates that several action potentials are traveling past the electrode. **Figure 2.7b** shows one of the action potentials on an expanded time scale, as shown in Figure 2.6. 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.

In addition to recording action potentials from single neurons, Adrian made other discoveries as well. He found that each action potential travels all the way down the axon without changing its height or shape. 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 will still be the same size when it reaches the other end.

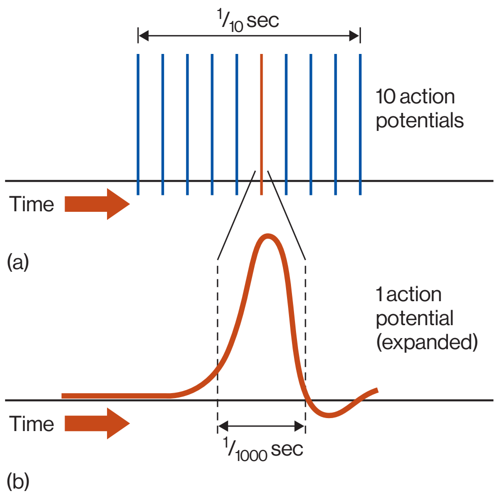
While Adrian was recording electrical signals from single neurons, other researchers were discovering that these electrical signals reaching the synapse at the end of the axon trigger

Reference electrode Used in conjunction with a recording electrode to measure the difference in charge between the two. Reference electrodes are generally placed where the electrical signal remains constant, so any change in charge between the recording and reference electrodes reflects events happening near the tip of the recording electrode.

Nerve impulse An electrical response that is propagated down the length of an axon (nerve fiber). Also called an **Action potential**.

Action potential Propagated electrical potential responsible for transmitting neural information and for communication between neurons. Action potentials typically travel down a neuron's axon.

Figure 2.7 **(a) A series of action potentials displayed on a time scale that makes each action potential appear as a thin line. (b) Changing the time scale reveals the shape of one of the action potentials.**



Neurotransmitter Chemical that is released at the synapse in response to incoming action potentials.

the release of chemicals called **neurotransmitters**. These chemicals make it possible for the signal to be transmitted across the gap that separates the end of the axon from the dendrite or cell body of another neuron (see Figure 2.4b).

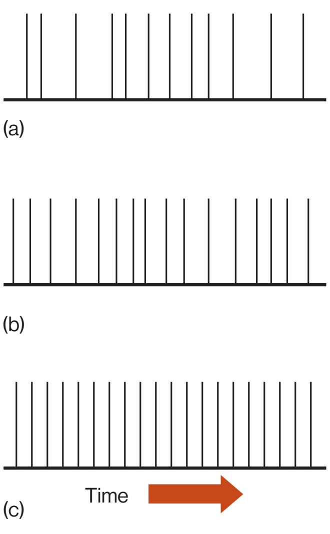
Although all these discoveries about the nature of neurons and the signals that travel in them were extremely important (and garnered several Nobel Prizes for their discoverers), our main interest is not in how axons transmit signals, but in how these signals contribute to the mind. So far, our description 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 experiences.

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. He found 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 traveled down the axon per second—increased (**Figure 2.8**). From this result, Adrian drew a connection between nerve firing and experience. He describes this connection in his book *The Basis of Sensation* (1928) by stating that if nerve impulses "are crowded closely together the sensation is intense, if they are separated by long intervals the sensation is correspondingly feeble" (p. 7).

Principle of neural representation Everything a person experiences is based on representations in the person's nervous system.

What Adrian is saying is that electrical signals are *representing* the intensity of the stimulus, so pressure that generates "crowded" electrical signals feels stronger than pressure that generates signals separated by long intervals. Later experiments demonstrated similar results for vision. Presenting high-intensity light generates a high rate of nerve firing and the light appears bright; presenting lower-intensity light generates a lower rate of nerve firing and the light appears dimmer. 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. Thus, the firing rate is consistent with the *quantity* of a stimulus.

Figure 2.8 Action potentials recorded from an axon in response to three levels of pressure stimulation on the skin: (a) light, (b) medium, and (c) strong. Increasing stimulus intensity causes an increase in the rate of nerve firing.



Now that we understand quantity, how is the *quality* of experience represented in neural firing? For the senses, quality *across the senses* refers to the different experiences 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*, such as for vision: color, movement, an object's shape, or the identity of a person's face.

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 have basically the same height and shape. 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 short answer to this question is that different qualities of stimuli, and also different aspects of experience, activate different neurons and different brain regions. We begin the long answer to this question in the next section by taking up the idea of representation, which we introduced in Chapter 1.

2.3 Representation by Neural Firing

In Chapter 1, we defined the mind as *a system that creates representations of the world so that we can act within it to achieve our goals* (page 4). The key word in this definition is *representations* because everything we experience is the result of something that *stands for* (or "represents") that experience. Putting this in neural terms, the **principle of neural representation** states that everything a person experiences is based on representations in the person's nervous system. Adrian's pioneering research on how nerve impulses represent the intensity of a stimulus marked the beginning of research on neural representation.

The Story of Neural Representation and Cognition: A Preview

In the 1960s, researchers began focusing on recording from single neurons in the primary visual receiving region, the place where signals from the eye first reach the cortex (**Figure 2.9a**). The question these experiments asked was "what makes this neuron fire?" Vision dominated early research because stimuli could be easily controlled by creating patterns of light and dark on a screen and because a lot was already known about vision.

As research progressed, researchers began recording from neurons in regions outside the primary visual region and discovered two key facts: (1) Many neurons at higher levels of the visual system fire to complex stimuli like geometrical patterns and faces; and (2) a specific stimulus causes neural firing that is distributed across many regions of the cortex (**Figure 2.9b**). Vision, it turns out, is not generated only by the primary visual region—but in many different brain regions. Later research, extending beyond vision, found similar results for other regions of cognition. For example, it was discovered that memory is not determined by a single "memory region" because there are many regions involved in creating and recalling memories. In short, it became obvious that large regions of the brain are involved in generating cognition.

As it became clear that understanding neural representation involves casting a wide net across the brain, many researchers began considering the way different regions are connected to one another. The idea of neural signals transmitted between many destinations in an interconnected brain has led to today's conception of the brain as containing a vast highway system that can be described in terms of "neural networks" (**Figure 2.9c**). We will now fill in the details, beginning with the discovery of neural feature detectors.

Feature Detectors

One possible answer to the question "how can nerve impulses stand for different qualities?" is that perhaps there are neurons that fire only to specific qualities of stimuli. Early research found some evidence for this theory (Hartline, 1940; Kuffler, 1953), but the idea of neurons that respond to specific qualities was brought to the forefront by a series of papers by David Hubel and Thorsten Wiesel, which would win them the Nobel Prize in Physiology or Medicine in 1981. The third recipient was American neuropsychologist Roger Wolcott Sperry.

In the 1960s, Hubel and Wiesel started a series of experiments in which they presented visual stimuli to cats, as shown in **Figure 2.10a**, and determined which stimuli caused specific neurons to fire. They found that each neuron in the visual region of the cortex responded to a specific type of stimulation presented to a small region of the retina. **Figure 2.10b** shows some of the stimuli that caused neurons in and near the visual

Figure 2.9 **(a) Early work on neural representation and cognition focused on recording from single neurons in the visual cortex, where signals first arrive at the cortex. (b) Researchers then began to explore other places in the brain and found that visual stimulation causes activity that is distributed across many regions of the cortex. (c) Recent work has focused on examining how these distributed regions are connected by neural networks and how activity flows in these networks. Note that, with the exception of the primary visual region in (a), the locations of the regions in this figure do not represent the locations of actual regions of the brain. They are for illustrative purposes only.**

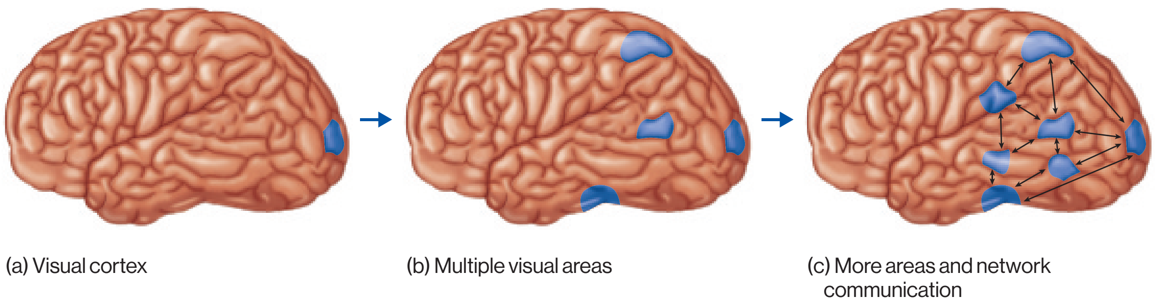
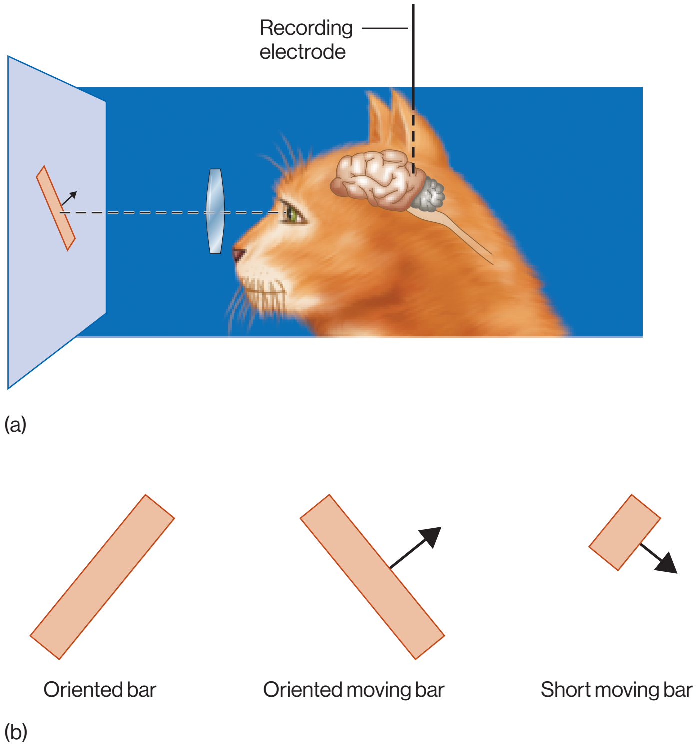


Figure 2.10 **(a) An experiment in which electrical signals are recorded from the visual system of an anesthetized cat that is viewing stimuli presented on the screen. The lens in front of the cat's eye ensures that the images on the screen are focused on the cat's retina. The recording electrode is not shown. (b) A few of the types of stimuli that cause neurons in the cat's visual cortex to fire.**



Feature detectors Neurons that respond to specific visual features, such as orientation, size, or the more complex features that make up environmental stimuli.

Experience-dependent plasticity A mechanism that causes an organism's neurons to develop so they respond best to the type of stimulation to which the organism has been exposed.

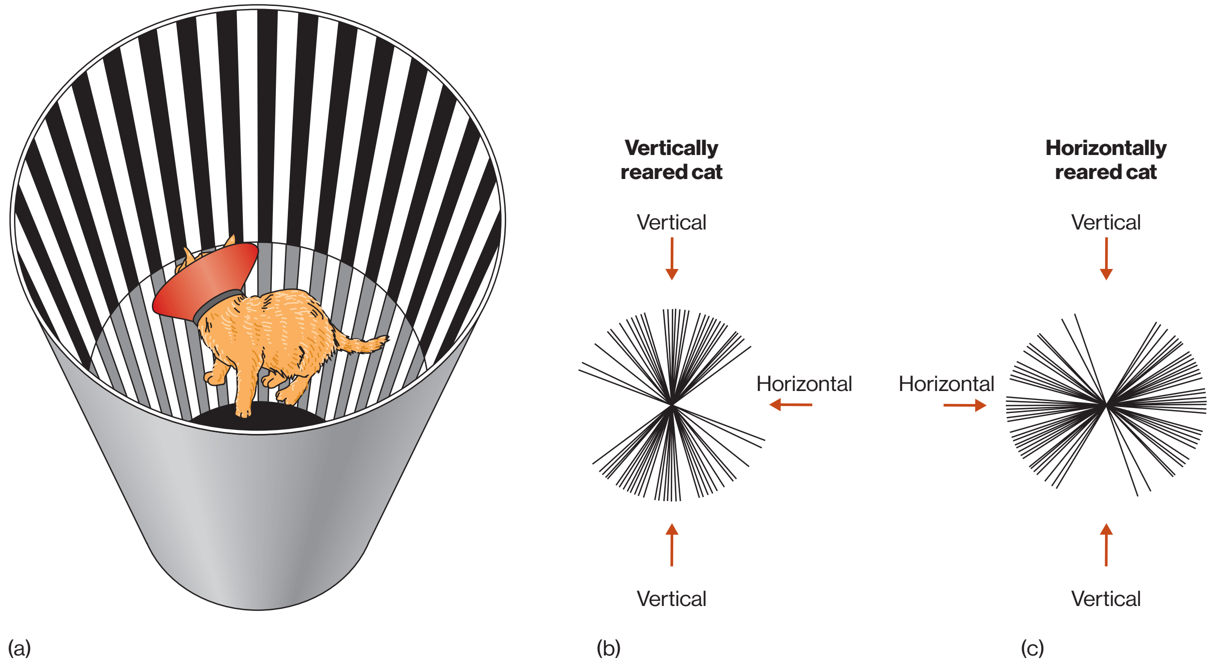
cortex to fire (Hubel, 1982; Hubel & Wiesel, 1959, 1961, 1965). They called these neurons **feature detectors** because they responded to specific stimulus features such as orientation, movement, and length.

The idea that feature detectors are linked to perception was supported by many different experiments. One of these experiments involved a phenomenon called **experience-dependent plasticity**, in which the structure of the brain is changed by experience. For example, when a kitten is born, its visual cortex contains feature detectors that respond to oriented bars (see Figure 2.10). Normally, the kitten's visual cortex contains neurons that respond to all orientations, ranging from horizontal to slanted to vertical, and when the kitten grows up into a cat, the cat has neurons that can respond to all orientations.

What would happen if kittens were reared in an environment consisting only of vertical contours? Colin Blakemore and Graham Cooper (1970) answered this question by rearing kittens in a space in which they saw only vertical black and white stripes on the walls (**Figure 2.11a**). After being reared in this vertical contour environment, kittens would bat their paws at a moving vertical stick but ignore horizontal objects. The basis of this lack of response to horizontal contours became clear when recording from neurons in the kittens' brains revealed that the visual cortex had been reshaped so it contained neurons that responded mainly to vertical contours and had no neurons that responded to horizontal contours (**Figure 2.11b**). Similarly, kittens reared in an environment consisting only of horizontal contours developed a visual cortex that contained neurons that responded mainly to horizontal contours (**Figure 2.11c**). Thus, the kittens' brains had been shaped to respond best to the environment to which they had been exposed.

Blakemore and Cooper's experiment is important because it is an early demonstration of experience-dependent plasticity. The environment in which our brain develops can literally

Figure 2.11 **(a) Striped tube used in Blakemore and Cooper's (1970) selective rearing experiments. (b) Distribution of orientations that caused maximum firing for 72 cells from a cat reared in an environment of vertical stripes and (c) for 52 cells from a cat reared in an environment of horizontal stripes.**



change the physical organization of the brain. These findings have an important message regarding neural representation: When a kitten's cortex contained mainly vertically sensitive neurons, the kitten *perceived* only vertical contours, and a similar result occurred for horizontal contours. This result supports the idea that perception is determined by neurons that fire to specific qualities of a stimulus (orientation, in this case).

If we understand that neurons in the visual system fire to specific types of stimuli, we can consider the way that specific objects stimulate neural activity. For example, each of the thousands of neurons that fire when we look at a tree do so in response 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 miscellaneous features. The idea that a tree is represented by the combined response of many feature detectors is similar to building objects by combining building blocks like Legos. Visual processing begins in the visual cortex, and our experience of vision depends on signals that are sent from the visual cortex to other regions of the brain.

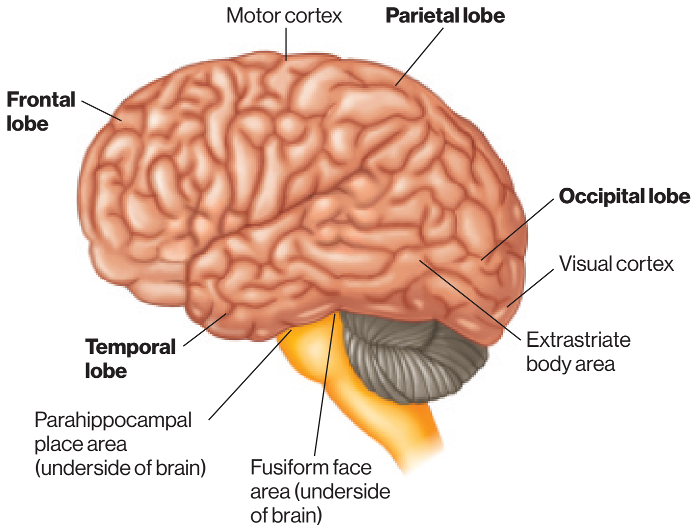
Figure 2.12 indicates the location of the **visual cortex** in the human brain, as well as additional regions that are involved in vision, and some other regions we will be discussing later. The vision regions are part of a vast network of regions that make up about 30 percent of the cortex (Felleman & Van Essen, 1991). Some of these visual regions receive signals directly from the visual cortex. Others are part of a sequence of interconnected neurons, some of which are far down the line from the visual cortex. Following Hubel and Wiesel's pioneering research, other researchers who began exploring these "higher" levels of the visual pathway discovered neurons that respond to stimuli more complex than oriented lines.

Visual cortex Area in the occipital lobe that receives signals from the eyes.

Neurons That Respond to Complex Stimuli

How are complex stimuli represented by the firing of neurons in the brain? One answer to this question began to emerge in the laboratory of Charles Gross. Gross's experiments, in which

Figure 2.12 Some of the structures of the human brain that we will be referring to in this chapter. Pointers indicate the locations of these regions, each of which extends over a region of the cortex.

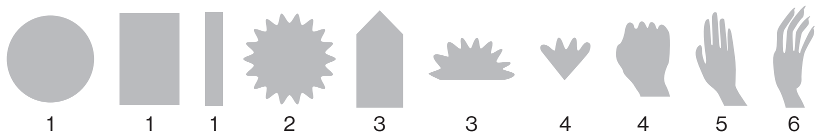


Temporal lobe The lobe on the side of the brain that contains mechanisms responsible for language, memory, hearing, and vision.

he recorded from single neurons in the **temporal lobe** of monkeys (Figure 2.12), required a great deal of endurance by the researchers because the experiments typically lasted 3 or 4 days. In these experiments, the results of which were reported in now-classic papers in 1969 and 1972 (Gross et al., 1969, 1972), Gross's research team presented a variety of different stimuli to anesthetized monkeys. On a projection screen like the one shown in Figure 2.10a, they presented lines, squares, and circles. Some stimuli were light and some were dark.

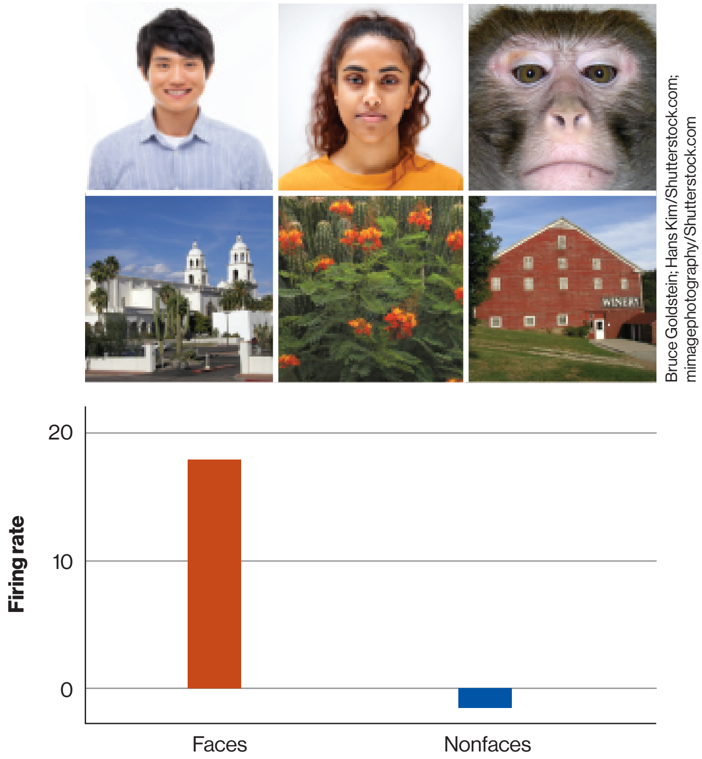
The discovery that neurons in the temporal lobe respond to complex stimuli came a few days into one of their experiments when they found a neuron that refused to respond to any of the standard stimuli, like oriented lines or circles or squares. Nothing worked, until one of the experimenters pointed at something in the room, casting a shadow of his hand on the screen. When this hand shadow caused a rapid increase in the rate of firing, the experimenters knew they were on to something and began testing the neuron with a variety of stimuli, including cutouts of a monkey's hand. After a great deal of testing, they determined that this neuron responded best to a handlike shape with fingers pointing up (far-right stimuli in **Figure 2.13**) (Rocha-Miranda, 2011; also see Gross, 2002). After expanding the types of stimuli presented, they also found some neurons that responded best to faces. Later researchers extended these results and provided many examples of neurons that respond to faces but do not respond to other types of stimuli (Perrett et al., 1982; Rolls, 1981) (**Figure 2.14**).

Figure 2.13 Some of the shapes used by Gross et al. (1972) to study the responses of neurons in the temporal lobe of the monkey's cortex. The shapes are arranged in order of their ability to cause the neuron to fire, from none (1) to little (2 and 3) to maximum (6).



(Source: Based on Gross et al., 1972.)

Figure 2.14 **Firing rate, in nerve impulses per second, of a neuron in a monkey's temporal lobe that responds to face stimuli but not to nonface stimuli.**



(Source: Based on E. T. Rolls & M. J. Tovee, 1995.)

Let's stop for a moment and consider the results we have presented so far. We discussed that neurons in the visual cortex respond to simple stimuli like oriented bars, neurons in the temporal lobe respond to complex geometrical stimuli, and neurons in another region of the temporal lobe respond to faces. What is happening is that neurons in the visual cortex that respond to relatively simple stimuli send their axons to higher levels of the visual system, where signals from many neurons combine and interact; neurons at this higher level, which respond to more complex stimuli such as geometrical objects, then send signals to even higher regions, combining and interacting further and creating neurons that respond to even more complex stimuli such as faces. This progression from lower to higher regions of the brain is called **hierarchical processing**.

Does hierarchical processing solve the problem of neural representation? Could it be that higher regions of the visual system contain neurons that are specialized to respond only to a specific object, so that object would be represented by the firing of that one type of specialized neuron? As we will explore, this is probably not the case, because neural representation most likely involves a network of many neurons working together.

Sensory Coding

The problem of neural representation for the senses has been called the **problem of sensory coding**, where the **sensory code** refers to how neurons represent various characteristics of the environment. The idea that an object could be represented by the firing of a specialized neuron that responds only to that object is called **specificity coding**.

Beginning in the 1970s, it was proposed (and often scoffed at) that individual cells were responsible for the apex of specialization—they represented a specific person, your grandmother for example. For this reason, they earned the name *grandmother cells* (Barlow, 1972; Blakemore, 1973). The debate about how memories are stored continued for decades. Can

Hierarchical processing Processing that occurs in a progression from lower to higher areas of the brain.

Problem of sensory coding The problem of determining the neural representation for the senses.

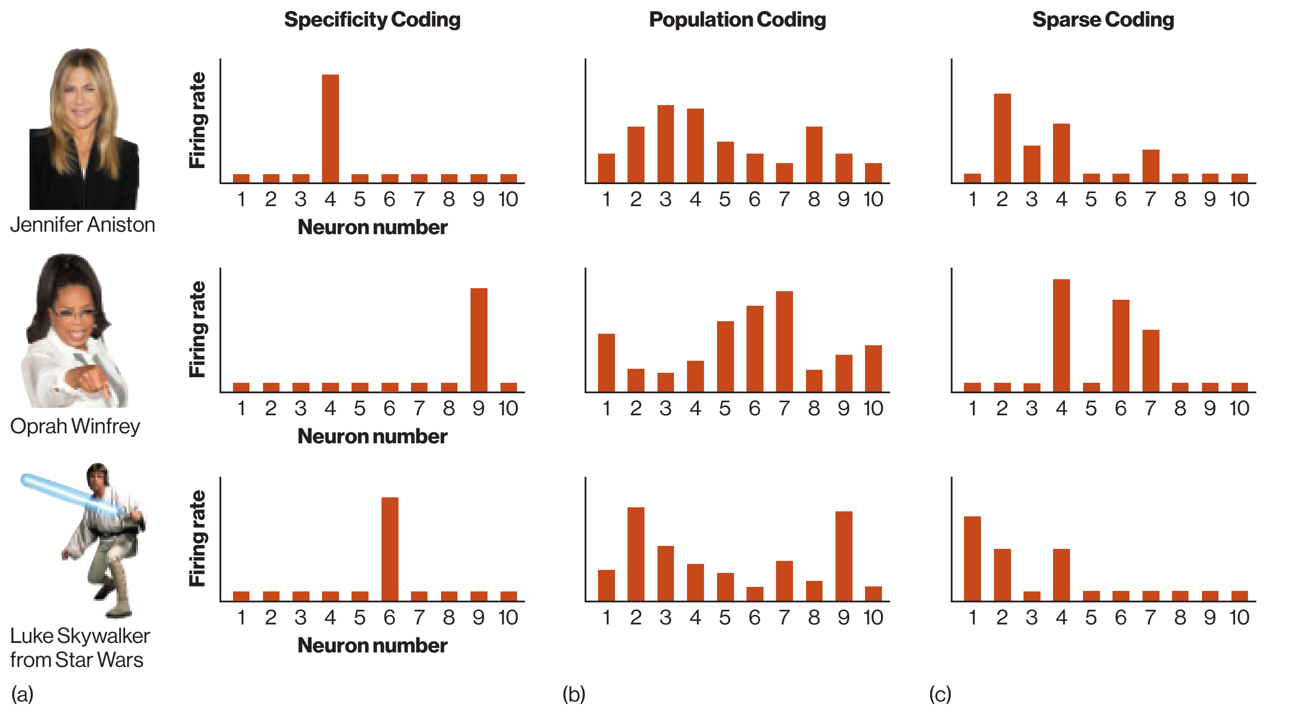
Sensory code How neural firing represents various characteristics of the environment.

Specificity coding The representation of a specific stimulus by the firing of neurons that respond only to that stimulus. An example would be the signaling of a person's face by the firing of a neuron that responds only to that person's face.

a single neuron hold the knowledge of your grandmother, or is it distributed across millions of cortical neurons? In a 2013 issue of *Scientific American*, Rodrigo Quiroga and colleagues describe how certain cells seem to respond selectively to specific individuals with whom someone is familiar. Quiroga and colleagues discovered individual cells in the hippocampus that responded specifically to Jennifer Aniston—but did not respond to other celebrities or people generally. This was termed the *Jennifer Aniston neuron*. However, Aniston was not alone. Quiroga and his team found cells that responded selectively to Oprah Winfrey and to Luke Skywalker from *Star Wars*. But there was a catch. Researchers noticed the Luke Skywalker neuron also fired in response to images of Yoda, also from *Star Wars*. So is this a *Star Wars* neuron instead? Barwich (2019) pushes back against the notion of grandmother (or Jennifer Aniston) cells, indicating instead the value of "failures" in science as they lead us forward to new discoveries and explanations. Barwich calls grandmother cells an "almost successful idea" that led to two decades of scientific inquiry and discussion. In the 1990s, the notion of specificity coding was losing favor, but scientific failures of this nature (as Barwich characterized it) are integral to scientific exploration and understanding. This is not to say these neurons do not respond selectively to specific concepts. They certainly do! However, there may be more to the story.

The concept of specificity coding is illustrated in **Figure 2.15a**, which shows how a number of neurons respond to three different faces. Only neuron 4 responds to Jennifer Aniston's face, only neuron 9 responds to Oprah Winfrey's face, and only neuron 6 responds to Luke Skywalker's face. Also note that the neuron specialized to respond only to Jennifer Anniston, which we have called a "Jennifer Aniston neuron," does not respond to Oprah Winfrey or Luke Skywalker. In addition, other faces or types of objects theoretically should not affect this neuron. It fires only to Aniston's face. (However, remember we already noted that the Luke Skywalker neuron also responds to images of Yoda.)

Figure 2.15 **Three types of coding: (a) Specificity coding. The response of 10 different neurons to each face on the left is shown. Each face causes a different neuron to fire. (b) Population coding. The face's identity is indicated by the pattern of firing of a large group of neurons. (c) Sparse coding. The face's identity is indicated by the pattern of firing of a smaller group of neurons.**



Although the idea of specificity coding is straightforward, it is unlikely to be correct. Even though there are neurons that respond to faces, these neurons usually respond to several different faces (not just Jennifer Aniston's). There are just too many different faces and other objects (and colors, tastes, smells, and sounds) in the world to have a separate neuron dedicated to each object. An alternative to the idea of specificity coding is that several neurons are involved in representing an object.

Population coding is the representation of a particular object by the pattern of firing of a large number of neurons (**Figure 2.15b**). According to this idea, Jennifer Aniston's, Oprah Winfrey's, and Luke Skywalker's faces are each represented by a different pattern. An advantage of population coding is that a large number of stimuli can be represented because large groups of neurons can create a huge number of different patterns. There is good evidence for population coding in the senses and for other cognitive functions as well. However, some functions only require a small number of neurons.

Population coding Neural representation of a stimulus by the pattern of firing of a large number of neurons.

Sparse coding occurs when a particular object is represented by a pattern of firing of only a small group of neurons. As shown in **Figure 2.15c**, sparse coding would represent Jennifer Aniston's face by the pattern of firing of a few neurons (neurons 2, 3, 4, and 7). Oprah Winfrey's face would be signaled by the pattern of firing of a few different neurons (neurons 4, 6, and 7), but possibly with some overlap with the neurons representing Jennifer Aniston, and Luke Skywalker's face would have yet another pattern (neurons 1, 2, and 4). Notice that a particular neuron can respond to more than one stimulus. For example, neuron 4 responds to all three faces, although most strongly to Oprah's.

Sparse coding Neural coding based on the pattern of activity in small groups of neurons.

Other evidence suggests that the code for representing objects in the visual system, tones in the auditory system, and odors in the olfactory system may involve the pattern of activity across a relatively small number of neurons, as sparse coding suggests (Olshausen & Field, 2004; Mi, Lu, & Kong, 2020).

Memories are also represented by the firing of neurons, but there is a difference between the representation of perceptions and the representation of memories. The neural firing associated with experiencing a perception is associated with what is happening while a stimulus is physically present. In other words, it is happening in real time. The neural firing associated with memory is associated with information about the past that has been stored in various locations in the brain. We know less about the actual form of the stored information for memory, but it is likely that the basic principles of population and sparse coding also operate 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.

Recognizing that individual neurons and groups of neurons contain information for perception, memory, and other cognitive functions is the first step toward understanding representation. Next, we will discuss how different types of neurons and functions are organized within the brain.

Test Yourself

1. Describe the idea of levels of analysis.
2. 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?
3. Describe the research that led Cajal to propose the neuron doctrine.
4. Describe the structure of a neuron. Describe the synapse and neural circuits.
5. 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?
6. How has the question of how different perceptions can be represented by neurons been answered? Consider both research involving recording from single neurons and ideas about sensory coding.
7. How is neural representation for memory different from neural representation for perception? How is it similar?

2.4 Localized Representation

Localization of function Location of specific functions in specific areas of the brain. For example, areas have been identified that are specialized to process information involved in the perception of movement, form, speech, and different aspects of memory.

Cerebral cortex The 3-mm-thick outer layer of the brain that contains the mechanisms responsible for higher mental functions such as perception, language, thinking, and problem solving.

Subcortical regions Areas of the brain below the cerebral cortex. Two examples of subcortical structures are the amygdala and the hippocampus.

Neuropsychology The study of the behavioral effects of brain damage in humans.

Cortical equipotentiality The idea, popular in the early 1800s, that the brain operates as an indivisible whole, as opposed to operating based on specialized areas.

Broca's area An area in the frontal lobe associated with the production of language. Damage to this area causes Broca's aphasia.

One of the basic principles of brain organization is **localization of function**, in which specific functions are performed by specific regions of the brain. Many cognitive functions are served by the **cerebral cortex**, a layer of tissue about 3 mm thick covering the brain (Fischl & Dale, 2000). The cortex is the wrinkled covering you see when you look at an intact brain (Figure 2.11). Other functions are served by **subcortical regions** that are located below the cortex. Early evidence for localization of function came from **neuropsychology**—the study of the behavior of people whose brains have been damaged by traumatic injury.

Localization Determined by Neuropsychology

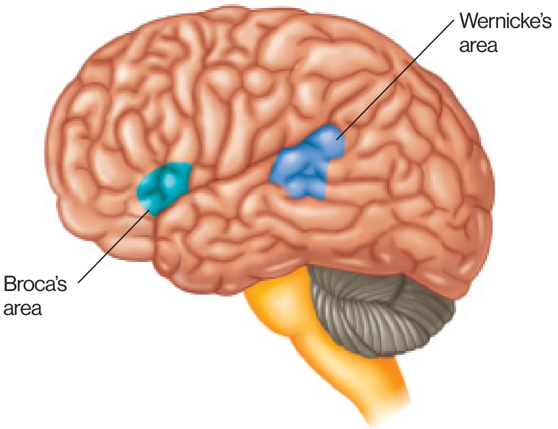
In the early 1800s, an accepted theory of brain function was **cortical equipotentiality**, the idea that the brain operated as an indivisible whole as opposed to consisting of specialized regions (Flourens, 1824; Pearce, 2009). However, in 1861, Paul Broca published work based on his study of patients whose brains had been damaged by strokes that disrupted the blood supply to the brain. These strokes caused damage to a region in the frontal lobe that came to be called **Broca's area** (**Figure 2.16**).

One of Broca's patients was famously called *Tan* because the word *tan* was the only word he could say. Other patients with frontal lobe damage could say more, but their speech was slow and labored and often had jumbled sentence structure. Patients with this problem—slow, labored, ungrammatical speech caused by damage to Broca's area—are diagnosed as having **Broca's aphasia**. The fact that damage to a specific region of the brain caused a specific deficit of behavior was striking evidence against the theory of equipotentiality and the theory of localization of function.

Eighteen years after Broca reported on his frontal lobe patients, Carl Wernicke (pronounced VUR / NI / KUH) described a series of patients who had damage to a region in their temporal lobe that came to be called **Wernicke's area**. Wernicke's patients produced speech that was fluent and grammatically correct but tended to be incoherent; this is known as **Wernicke's aphasia**. Patients such as this not only produce meaningless speech but are unable to understand other people's speech. Their primary problem is their inability to match words with their meanings, with the defining characteristic of Wernicke's aphasia being the absence of typical grammar (Traxler, 2012).

The observations of Broca and Wernicke showed that different aspects of language—production of language and comprehension of language—were served by different regions in the brain and that these regions of the brain were roughly the same for most people.

Figure 2.16 **Broca's region, in the frontal lobe, and Wernicke's region, in the temporal lobe, were identified in early research as being specialized for language production and comprehension, respectively.**



As we will explore later in this chapter, modern research has shown that the strict separation of language functions in different regions was an oversimplification. Nonetheless, The 19th-century observations of Broca and Wernicke set the stage for later research that confirmed the theory of localization of function.

Further evidence supporting the theory of localization of function came from studying soldier's traumatic brain injuries in the early 20th century. Studies of Japanese soldiers in the Russo-Japanese war of 1904–1905 and Allied soldiers in World War I showed that damage to the **occipital lobe** of the brain, where the visual cortex is located (Figure 2.12), resulted in blindness. These studies also suggested there was a connection between the specific portion of the occipital lobe that was damaged and the specific location in the visual field that soldiers were no longer able to see (Glickstein & Whitteridge, 1987; Holmes & Lister, 1916; Lanska, 2009). For example, damage to the left part of the occipital lobe often resulted in blindness in the upper-right visual field.

As noted earlier, other regions of the brain have also been associated with specific functions. The auditory cortex, which receives signals from the ears, is in the upper *temporal lobe* and is responsible for hearing. The somatosensory cortex, which receives signals from the skin, is in the **parietal lobe** and is responsible for perceptions of touch, pressure, temperature, and pain. The **frontal lobe** receives signals from all the senses and is responsible for the coordination of the senses, as well as higher cognitive functions like thinking and problem-solving.

Another effect of injury to the brain on visual functioning, reported in patients who have damage to the temporal lobe on the lower-right side of the brain, is **prosopagnosia**—an inability to recognize faces. For some with prosopagnosia, people can tell that a face is a face, but they cannot recognize whose face it is—even for people they know well such as friends and family members. In other cases of prosopagnosia, people may look into a mirror and, seeing their own image, wonder who the stranger is looking back at them (Burton et al., 1991; Hecaen & Angelergues, 1962; Parkin, 1996). Artist Chuck Close (seen in **Figure 2.17**) was famous for his pixelated painted likenesses of himself and others

Broca's aphasia A condition associated with damage to Broca's area, in the frontal lobe, characterized by labored ungrammatical speech and difficulty in understanding some types of sentences.

Wernicke's area Area in the temporal lobe associated with understanding language. Damage to this area causes Wernicke's aphasia.

Wernicke's aphasia A condition, caused by damage to Wernicke's area, that is characterized by difficulty in understanding language, and fluent, grammatically correct, but incoherent speech.

Occipital lobe The lobe at the back of the brain that is devoted primarily to analyzing incoming visual information.

Parietal lobe The lobe at the top of the brain that contains mechanisms responsible for sensations caused by stimulation of the skin and also some aspects of visual information.

Figure 2.17 Here, artist Chuck Close is painting a self-portrait using a series of colored squares in a grid. Close has a condition known as prosopagnosia, which renders him unable to perceive faces.

Frontal lobe The lobe in the front of the brain that serves higher functions such as language, thought, memory, and motor functioning.

Prosopagnosia Condition caused by damage to the temporal lobe that is characterized by an inability to recognize faces.

Double dissociation A situation in which a single dissociation can be demonstrated in one person and the opposite type of single dissociation can be demonstrated in another person (i.e., Person 1: function A is present, function B is damaged; Person 2: function A is damaged, function B is present).

across his career, despite suffering from prosopagnosia for his entire life. Before Close's death in 2021, Close said "I don't know who anyone is and essentially have no memory at all for people in real space, but when I flatten them out in a photograph I can commit that image to memory."

One of the goals of the neuropsychology research we have been describing is to determine whether a particular region of the brain is specialized to serve a particular cognitive function. Although it might be tempting to conclude, based on a single case of prosopagnosia, that the damaged brain region in the lower temporal lobe is responsible for recognizing faces, modern researchers realized that we have to use caution when determining the function of specific brain regions. Some brain regions can have many functions. Also, some functions (like vision or memory) require coordination between many different brain regions. To reach more definite conclusions about the function of a particular region, it is necessary to test several different patients with damage to different brain regions to demonstrate a *double dissociation*.

The results of the neuropsychology studies described above indicate that face recognition is served by one region in the temporal lobe and that this function is separate from mechanisms associated with recognizing other types of objects, which is served by another region of the temporal lobe. Neuropsychological research has also identified regions that are important for perceiving motion and for different functions of memory, thinking, and language, as we will consider later in this text.

It is important to note, however, that just because a brain region accomplishes one task (face perception) but not another (recognizing other objects) does not mean that region only serves a single function. Instead, we must always consider the possibility that brain regions can serve multiple functions. Consider the following thought experiment. If an alien race with no knowledge of humans were to arrive on Earth, they may wonder what humans are and what purpose they serve. Let's say they conduct an experiment. If they dump water on a human, the human will likely respond by screaming or running away. The alien may infer that humans are water detectors. Yes, humans can detect water being dumped on our heads, but we can do so much more! So too can regions of the brain.

If a region of the brain can detect faces, can it detect other things? In fact, we know the fusiform gyrus (sometimes called the fusiform face region) can detect much more than faces. It is a region of visual expertise. You will notice that brain regions are usually named in one of three ways: after the person who "discovered" it, after its proposed function, and after its location in the brain. For instance, Broca's and Wernicke's regions are named after the researchers who "discovered" them. These names tell us neither their functions nor their locations. Alternatively, the fusiform face region indicates the proposed purpose of a region. However, the fusiform gyrus indicates a broader location that includes the fusiform face region but without naming its proposed purpose. The latter, naming something based on its location rather than trying to name based on a proposed function, may be preferable as it does not oversimplify or wrongly (or incompletely) propose the function of a given region.

Method

Demonstrating a Double Dissociation

A **double dissociation** occurs if damage to one region of the brain causes function A to be absent while function B is present, and damage to another region causes function B to be absent while function A is present. To demonstrate a double dissociation, it is necessary to find two people whose brains have been damaged by traumatic injury to match the above conditions.

Double dissociations have been demonstrated for face recognition and object recognition, by finding patients with traumatic brain injury who have an inability to recognize faces (Function A) but who can recognize objects just fine (Function B), and other patients, whose brains have been damaged in a different region, who are unable to recognize objects (Function B) but who have no problem recognizing faces (Function A) (McNeal & Warrington, 1993; Moscovitch et al., 1997). The importance of demonstrating a double dissociation is that it enables us to conclude that functions A and B are served by different mechanisms, which operate independently of one another.

Localization Determined by Recording from Neurons

Another tool for demonstrating localization of function is recording from single neurons. Numerous studies, mostly on animals, used single-neuron recording to demonstrate the localization of function. For example, Doris Tsao and coworkers (2006) found that 97 percent of neurons within a small region in the lower part of a monkey's temporal lobe responded to pictures of faces but not to pictures of other types of objects. This "face region," as it turns out, is located near the region in humans that is associated with prosopagnosia. The idea that our perception of faces is associated with a specific region of the brain is also supported by research using the technique of brain imaging (see Chapter 1, page 18), which makes it possible to determine which regions of the brains of humans are activated by different cognitions.

Localization Demonstrated by Brain Imaging

We noted in Chapter 1 that technological advances that cause a shift in the way science is done can be called a revolution. On that basis, it could be argued that the introduction of the brain-scanning techniques positron emission tomography (PET) in 1976 and functional magnetic resonance imaging (fMRI) in 1990 marked the beginning of the "imaging revolution."

While this chapter and text will focus primarily on fMRI and PET imaging technologies as they have arguably had the largest impact on cognitive psychology, there are a variety of other important brain imaging technologies worth mentioning:

(1) Electroencephalography (EEG), first used on humans in the 1920s, uses electrodes placed on the scalp to measure and record brain activity. If you break the name down, "electro" refers to electrical activity on neurons, "encephalo" refers to the brain or head, and "ography" means "writing" or "describing." Therefore, EEG is the measuring and recording of electrical activity in the brain. EEG has excellent temporal resolution capable of "millisecond level recording"—or up to 1,000 times per second. However, this technology has poor spatial resolution, meaning EEG cannot precisely locate from where in the brain the activity originates. EEG can measure with some accuracy general locations across the cortex, but it typically cannot measure activity in deeper brain regions.

(2) Magnetoencephalography (MEG), first used in the 1960s, measures and records the magnetic fields generated by neural activity. Refer back to our EEG name breakdown above. The only new part for MEG is "magneto," which refers to magnetic fields. Similar to EEG, this technology has very good temporal resolution. However, MEG tends to have better spatial resolution than EEG.

(3) Near-Infrared Spectroscopy (NIRS), first used on humans in the 1970s, measures and records changes in blood oxygenation in the brain by projecting near-infrared light (as the name implies) through the scalp and skull. This may sound scary but is actually considered to be quite safe. In fact, due to its non-invasive nature, NIRS is a common technique now used to study children.

(4) Transcranial Magnetic Stimulation (TMS), developed in the 1980s, uses magnetic coils that can be orientated over specific brain regions to induce electrical currents that temporarily lesion the area. In other words, the magnetic field can interrupt and effectively stop brain processes in a given region for a short amount of time. As with NIRS, this may sound scary but is actually considered to be non-invasive and quite safe.

(5) Diffusion Tensor Imaging (DTI), developed in the 1980s and 1990s, measures diffusion (as the name implies) of water across the brain. This process allows for the mapping of white matter tracks throughout the brain, essential for understanding how brain regions are interconnected and how various brain regions communicate to complete tasks.

As you will observe throughout this text, brain scanning, and especially fMRI, has played an important role in understanding the physiological basis of cognition. Here we consider what fMRI research tells us about localization of function in the brain. We begin by describing the basic principle behind fMRI.

Many of the brain-imaging experiments that have provided evidence for localization of function have involved determining which brain regions were activated when people observed pictures of different objects.

Electroencephalography (EEG) A non-invasive neuroimaging method used to record electrical activity of the brain that involves placing electrodes on the scalp to detect and measure the electrical signals produced by neurons.

Magnetoencephalography (MEG) A non-invasive neuroimaging technique that measures the magnetic fields produced by neural activity in the brain. These magnetic fields are generated by electrical currents in neurons

Near-Infrared Spectroscopy (NIRS) A non-invasive imaging technique that uses near-infrared light to measure changes in blood oxygenation and blood volume in the brain. NIRS can infer the levels of oxygenated and deoxygenated hemoglobin in the brain by producing near-infrared light and detecting the light that is reflected.

Transcranial Magnetic Stimulation (TMS) A non-invasive procedure that uses magnetic fields to stimulate nerve cells in the brain. A TMS device generates a magnetic pulse that induces an electrical current in specific areas of the brain, which can temporarily disrupt localized brain activity.

Diffusion Tensor Imaging (DTI) A specialized type of magnetic resonance imaging (MRI) that focuses on measuring the diffusion of water molecules in human (or other animal) tissue, particularly in white matter tracts of the brain. This technique allows for the visualization and mapping of the brain's structural connectivity by revealing the pathways of white matter fibers.

Method

Brain Imaging

Functional magnetic resonance imaging (fMRI) takes advantage of the fact that neural activity causes the brain to bring in more oxygen, which binds to hemoglobin molecules in the blood. This added oxygen increases the magnetic properties of the hemoglobin, so when a magnetic field is presented to the brain, these more highly oxygenated hemoglobin molecules respond more strongly to the magnetic field and cause an increase in the fMRI signal.

The setup for an fMRI experiment is shown in **Figure 2.18a**, with the person's head in the scanner. As a person engages in a cognitive task such as perceiving an image, the activity of the brain is determined. Activity is recorded in **voxels**, which are small, cube-shaped regions of the brain about 2 or 3 mm on a side. Voxels are not brain structures but are simply small units of analysis created by the fMRI scanner. One way to think about voxels is that they are like the small, square pixels that make up digital photographs or the images on your computer screen, but because the brain is three-dimensional, voxels are small cubes rather than small squares. **Figure 2.18b** shows the result of an fMRI scan. Increases or decreases in brain activity associated with cognitive activity are indicated by colors, with specific colors indicating the amount of activation.

It bears emphasizing that these colored regions do not appear as the brain is being scanned. They are determined by a procedure that involves taking into account how the brain is responding when the person is not engaged in a task and the change in activity triggered by the task. Complex statistical procedures are used to determine the **task-related fMRI**—the change in brain activity that can be linked specifically to the task. The results of these calculations for each voxel are then displayed as colorful activation patterns, like the one in Figure 2.18b.

Looking at Pictures We have already considered how neuropsychology research and single neuron recording identified regions that are involved in perceiving faces. Researchers have also identified a face region of the brain by having people in a brain scanner look at pictures of faces. This region, which is sometimes called the **fusiform face area (FFA)** and is part of the **fusiform gyrus**, is located on the underside of the temporal lobe (Kanwisher et al., 1997). Damage to this brain region can result in prosopagnosia (Figure 2.11).

Further evidence for localization of function comes from fMRI experiments that have shown that perceiving pictures representing indoor and outdoor scenes like those shown in **Figure 2.19a** activates the **parahippocampal place area (PPA)** (Aguirre et al., 1998; Epstein et al., 1999). Apparently, what is important for this region is information about spatial layout because increased activation occurs when a person views pictures both of empty rooms and of rooms that are completely furnished (Kanwisher, 2003). Another specialized region, the **extrastriate body area (EBA)**, is activated by pictures of bodies and parts of bodies (but not by faces), as shown in **Figure 2.19b** (Downing et al., 2001).

Looking at Movies Our usual experience, in everyday life, involves perceiving scenes that contain many different objects, some of which are moving. Therefore, Alex Huth and coworkers (2012)

Figure 2.18 **(a) Person in a brain scanner. (b) fMRI record. Colors indicate locations of increases and decreases in brain activity. Red and yellow indicate increases in brain activity; blue and green indicate decreases.**

(a) (b)

(Source: Part b from Ishai et al., 2000)

Functional magnetic resonance imaging (fMRI) A brain imaging technique that measures how blood flow changes in response to cognitive activity.

Voxel Small cube-shaped areas in the brain used in the analysis of data from brain scanning experiments.

Task-related fMRI The fMRI response that occurs in response to a specific cognitive task.

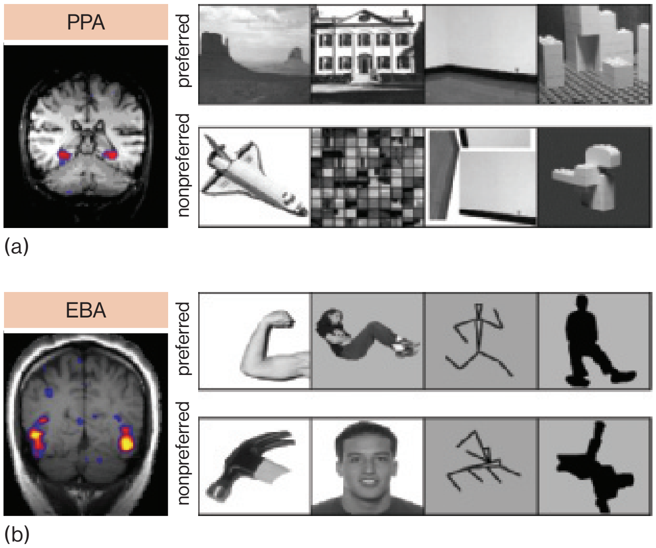
Fusiform face area (FFA) An area in the temporal lobe that contains many neurons that respond selectively to faces.

Fusiform gyrus A brain structure that spans the basal surface of the occipital and temporal lobes of both hemispheres.

Parahippocampal place area (PPA) An area in the temporal lobe that contains neurons that are selectively activated by pictures of indoor and outdoor scenes.

Extrastriate body area (EBA) An area in the temporal cortex that is activated by pictures of bodies and parts of bodies, but not by faces or other objects.

Figure 2.19 **(a) The parahippocampal place area (PPA) is activated by places (top row) but not by other stimuli (bottom row). (b) The extrastriate body area (EBA) is activated by bodies (top) but not by other stimuli (bottom).**

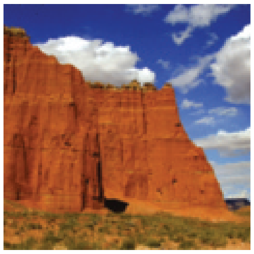
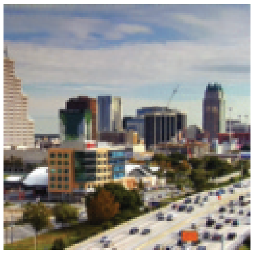


(Source: Chalupa & Werner, 2003)

conducted an fMRI experiment using stimuli similar to what we observe in the environment, by having participants view film clips. Huth's participants viewed 2 hours of film clips while in an fMRI brain scanner. To analyze how the voxels in these participants' brains responded to different objects and actions in the films, Huth compiled a list of over 1,700 object and action categories and determined which categories were present in each film scene.

Figure 2.20 shows four scenes and the categories (labels) associated with them. By determining how each voxel responded to each scene and then analyzing his results using a complex

Figure 2.20 **Four frames from the movies viewed by participants in Huth et al.'s (2012) experiment. The words on the right indicate categories that appear in the frames (n = noun, v = verb).**

Movie Clip	Labels	Movie Clip	Labels
	butte.n desert.n sky.n cloud.n brush.n		city.n expressway.n skyscraper.n traffic.n sky.n
	woman.n talk.v gesticulate.v book.n		bison.n walk.v grass.n stream.n

(Source: Huth et al., 2012)