3 EDITION

COGNITIVE PSYCHOLOGY

Theory, Process, and Methodology

Dawn M. McBride | J. Cooper Cutting | Corinne Zimmerman

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Cognitive Psychology

Third Edition

Dedicated to Jeff, Connor, Willow, and Neko, and to all the students who have inspired my teaching throughout the years.

—DMM

Dedicated to Adena, Charlie, and Isabel for their understanding and patience while I spent many afternoons, nights, and weekends away from them while writing.

—JCC

Dedicated to Steve for his constant love and support and to Dr. Siu Chow for showing me that cognitive psychology is far more interesting than clinical psychology.

—CZ

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PREFACE

We are excited to welcome new coauthor, Corinne Zimmerman, on our third edition of *Cognitive Psychology: Theory, Process, and Methodology*. We wrote this text to share our love of cognitive psychology with students learning about this exciting area of psychology. This revision reflects comments made by instructors and students who have used the text in its earlier editions, and with Corinne's added expertise in reasoning, problem solving, and decision making, and the development of these processes, we have expanded our coverage of these topics.

Our main goal in writing this text was to engage students in the topics through *connections to everyday situations* they might encounter (each chapter begins with one of these real-world situations or stories, and several chapters end with sections on how to use the knowledge presented in the chapter to improve these processes) and with a student-friendly and personal writing style. However, we also focused on methodology in this field as a way to allow students to gain the researcher's perspective in studying these topics and to understand how such research aids in evaluating theoretical perspectives on cognitive psychology, which are constantly changing as new data are collected. To illustrate the different methodologies, we have chosen a mix of classic studies and more recent findings in the areas covered in each chapter, which have been significantly updated since the second edition of the text.

Each chapter is written to be encapsulated as much as possible, such that instructors can choose to cover topics in the order they wish. We also worked to show connections between the different topics (as well as to other fields of study, such as social psychology, philosophy, linguistics, and biology) within the chapters to help students see the large overlap between the mental processes studied in cognitive psychology and other fields.

Chapter 1 is an introductory chapter covering general research methodology in cognitive psychology to help students better understand the studies presented in the chapters to come. Chapter 2, "Cognitive Neuroscience," is presented early in the text to provide students with the necessary background on the methods used in this subfield and the biological mechanisms the methods rely on for measurement. Neuroscience studies are then embedded within the subsequent chapters, where these studies provide evidence for different theoretical and conceptual descriptions of the cognitive processes discussed in each chapter. Chapters 3 through 14 then cover the major topics in the field including perception, attention, memory, language, concepts, imagery, reasoning, problem solving, decision making, and cognitive development.

Each chapter ends with a *Thinking About Research* activity that provides a description of a current study in that area of cognitive psychology from empirical journal articles. These descriptions are summary versions of the published studies, organized by APA-style sections, to help scaffold student learning of journal article reading skills. The full reference for each article is provided to allow instructors to assign and/or discuss the full article in their courses. Each *Thinking About Research* section also includes *critical thinking questions* to help students connect the study to the topic of the chapter and think about the design (and reasons for the design) used in the study.

Chapters include *Stop and Think* sections throughout to help students pause at the end of a reading section to consider the information they have just read. Some questions are designed to help students do a quick review of the material to gauge their learning. Other questions are designed to help them think critically about the material and connect it to their own lives. Answers are provided for these questions at the end of the text in an Appendix.

The text can also be paired with an interactive ebook that contains links to lab exercises and demonstrations, with follow-up questions to help students make connections between the methods of study presented in the text and the suggested exercises. The exercises and related assessments are also available via the book's SAGE edge website, described in more detail following. At the end of each chapter look for information on how to visit the SAGE edge website to find additional resources, such as the following:

- Watch a video clip with an example or demonstration of the concept.
- Listen to a clip from a news story or podcast about the concept.
- Read a SAGE journal article demonstrating research on the concept.
- Visit a website with more information, an interactive exercise, or a demonstration related to the concept.
- Practice the activities tied to learning objectives in each chapter that students can do on their own as they read.

We have provided an outline of the most significant changes from the previous edition to the current edition:

- Added a new chapter on Cognitive Development (Chapter 14)
- Separated the former Chapter 12 on Reasoning and Decision Making into two separate chapters (now Chapters 12 and 13), one for each topic, adding content on each topic to provide more depth on these topics
- Added learning objectives (LOs) to the beginning of each chapter that correspond to each major section of the chapter to clarify what is covered in each section
- Updated all *Thinking About Research* articles that appear at the ends of the chapters and the accompanying critical thinking questions
- Reorganized and revised Chapters 4 (Attention) and 11 (Problem Solving) to focus more on uses of these processes in everyday tasks

We hope you enjoy reading *Cognitive Psychology* as much as we enjoyed writing it!

Dawn M. McBride

J. Cooper Cutting

Corinne Zimmerman

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We'd like to acknowledge a number of important people who helped in many ways in the writing of this text and helped improve it from its initial drafts. First are Jeff Wagman and Adena Meyers. Jeff read some chapters and both Jeff and Adena offered feedback and provided essential support during the initial writing and subsequent revisions of the text. Steve Zimmerman provided valuable feedback on the new chapters in the third edition. In addition, our family, friends, and colleagues provided support and helpful feedback during the writing process. Several reviewers also provided valuable suggestions that greatly improved the quality of the text. At SAGE, we'd like to thank Reid Hester for his valuable encouragement in getting this project approved, keeping it going, and providing important discussion of issues that arose in the first edition. Abbie Rickard, Elizabeth Cruz, Sam Rosenberg, and Ivey Mellem also provided much appreciated support and feedback about the text. We especially thank Lara Parra for her dedication to her authors. Dawn also thanks the students at Illinois State University who have taken her PSY 253 course and influenced her teaching of this material. All the individuals named here contributed in important ways to the production of this text and have our sincere thanks and gratitude.

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1 INTRODUCTION TO COGNITIVE PSYCHOLOGY

LEARNING OBJECTIVES

1.1 Describe cognitive psychology and its historical origins.

1.2 List the different approaches to the study of cognition.

1.3 Describe the scientific method and how it allows us to test hypotheses about cognition.

1.4 Compare the different research methods used by cognitive psychologists.

1.5 Identify the observable behaviors that are used to understand cognitive processes.

QUESTIONS TO CONSIDER

- What is cognitive psychology?
- How did it develop as a field?
- How have psychologists approached the study of cognition?
- What types of research methods are useful in the study of cognition?
- What behaviors do psychologists observe to study cognition?

INTRODUCTION: COGNITION AND SHOPPING

Last night, as I wandered into the kitchen, I noticed that the lighting looked dim. As I looked up, I realized that three light bulbs had burned out. I also noticed that they were each a different type of bulb. I jumped into the car and headed to the grocery store for more light bulbs. I wandered into the store, grabbed a cart, and headed down the aisle. "While here," I thought to myself, "I may as well pick up some other things that we need." As I passed through the cereal aisle, I noticed a brightly colored sign announcing, "Buy 2, get 30% off" for Fruity O's. Next to it, the price for the generic brand was, "Buy one, get one free." I did some mental math and decided that even though the generic cereal was a better deal, my daughter would only eat brand name Fruity O's, so it would be a bad idea to get the less expensive cereal. Thinking about breakfast, I remembered we also needed milk and orange juice plus bread, butter, and Swiss cheese to make lunches. Since this is the store that I usually shop at, I wandered through quickly, checking things off my mental list. At the checkout counter, I'm asked, "Paper or plastic?" and I hesitated while realizing that I left my reusable bags in the trunk of the car and then replied, "Plastic, please." After paying, I exited the store, drove home, unloaded, and put away the groceries. Afterward, I sat down at the kitchen table and noticed how dim it was. I suddenly realized that I had forgotten the very thing I ran out to the store to get: light bulbs!

WHAT IS COGNITIVE PSYCHOLOGY?

In the shopping story you just read, cognition is involved in many of the tasks described. In fact, cognition is used in most of the tasks that people do every day, from ordinary tasks like grocery shopping to more complex tasks like deciding what to major in or studying for a difficult exam. You may have related the preceding story to things that have happened to you: walking upstairs in your house and then forgetting why you went up there, making a decision about whether an offered deal will really save you money, trying to remember things you have to do or things you need to buy. Cognition is involved in so many things we do that it is difficult to come up with events in our lives that do not involve cognition. In fact, just thinking about what cognitive psychology is involves cognition. As a simple answer, cognition involves thinking and other mental processes. However, as a student of psychology, you probably already know that few questions in psychology have simple answers, and the question of "What is cognitive psychology?" is no exception. A more complete answer to this question is that cognitive psychology includes the following:

- Our perception of the world around us through our senses and how we interpret the sensations brought in by our senses (e.g., noticing that the lights are dim in your kitchen and that there are three different sized light bulbs)
- The attentional processes that allow us to focus on a particular stimulus in our environment (e.g., a brightly colored sign catching our attention in a grocery store)

- How our memory operates to allow us to remember episodes, information, and intentions when we attempt to retrieve them (e.g., remembering—or not remembering—to buy light bulbs at the store)
- Our language processes that help us communicate our thoughts and ideas with others (e.g., being able to read the advertisement for the cereal or understanding the cashier's question of "Paper or plastic?")
- The processes that contribute to our decision making, both helpful and hindering (e.g., trying to decide if the "Buy one, get one free" deal is really going to save you money if no one in your family likes that brand of cereal)
- Being able to monitor your thought processes while you work through the steps of a problem (Which cereal is the better deal? Is paper or plastic better for the environment?)
- The brain activity that controls all the processes described so far

This may seem like a long list, but it only touches briefly on the major areas studied in the field of cognitive psychology. Current research in cognitive psychology also connects cognition with other areas of psychology as well as linguistics, cognitive science, and neuroscience. For example, some cognitive psychologists are interested in the role of consciousness in our cognitive processes and how much conscious choice we actually have in our behaviors. Others consider how brain function might affect our social interactions and be involved in social dysfunction, such as autism spectrum disorders. Cognitive psychology also informs educators about the processes involved in teaching and learning, including the metacognitive strategies that differentiate more and less successful learners. **Metacognition** is being aware of one's own cognitive abilities and processes and will be discussed in the context of different areas of cognition throughout this text. Thus, cognitive psychology is broad and overlaps with many other fields (e.g., social and biological psychology, philosophy), both inside and outside of psychology.

History of Cognitive Psychology

Cognitive psychology in some form has been a field of study for thousands of years. Early philosophers addressed questions about cognition that are still relevant today. For example, Aristotle suggested an early metaphor for the mind to explain how memory processes work. He proposed that our memory could be envisioned as a wax tablet, with memories formed in the tablet like molds in hot wax. The durability of the memory depended on different factors in the same way that the durability of molds in wax can vary; if the wax tablet is heated, the form can become distorted or disappear. As you will read in Chapters 5, 6, and 7, memory researchers still propose, test, and refine theoretical models of memory.

As scientific methods were developed in other fields (e.g., physics, biology, chemistry), researchers began to apply these methods to the study of the mind. The earliest psychological research can be described as physiological studies designed to answer longstanding philosophical questions. Hermann von Helmholtz, a professor of physiology, conducted research on the speed of nerve conduction by isolating the nerve fiber in the leg of a frog. After determining that nerve impulses travel approximately 90 feet per second, he began rudimentary response time experiments with humans. He estimated human nerve conduction to be about 165 to 330 feet per second (Hergenhahn, 1986). Gustav Fechner conducted some of the first experiments in **psychophysics** (described in Chapter 3) with the goal of developing laws of perception.

In 1879, Wilhelm Wundt opened one of the first laboratories dedicated to psychological research at the University of Leipzig. Considered one of the founders of psychology, Wundt studied conscious experience through methods that involved systematic self-reports of a person's thoughts. Wundt and other early psychologists studied how people perceived sounds, colors, and other sensory experiences using **introspection**. Their goal was to study consciousness "as it occurs." Another early psychologist, Hermann Ebbinghaus, studied the processes of remembering and forgetting by testing his own memory extensively to determine the savings in relearning that can be gained from previous exposures to information. He measured the decline in his memory performance over time and thus mapped out the forgetting curve that researchers still find in current studies measuring memory performance over time (see Chapter 6 for further discussion of the forgetting curve).

In the early to mid-twentieth century, the study of cognition fell out of favor in psychology with the rise in popularity of the **behaviorist** perspective. Inspired by the scientific advances in physiology (such as the Nobel prize-winning work on conditioned reflexes by Ivan Pavlov), prominent behaviorists John Watson and B. F. Skinner argued that introspective methods were biased by the perspective of the subject. How did the researcher know that the mental processes of the mind were consciously accessible and could be verbally reported in an accurate way? Instead, behaviorists focused only on behaviors they could directly observe, with the thought processes behind the behaviors of less interest.

Although the behaviorist perspective was common in psychological research in the United States for almost half a century, in Europe, work that acknowledged the existence and importance of mental events was being conducted by the Gestalt psychologists in Germany. In the 1920s and 1930s, the Swiss psychologist Jean Piaget began studying the development of children's thinking. Sir Frederick Bartlett, an English experimental psychologist at the University of Cambridge, published a book entitled *Remembering* in 1932 based on his work with memory for text.

An important event that led to a return to a focus on cognition in psychology was an attack on the behaviorist approach to language learning by the linguist Noam Chomsky. Skinner (1957) proposed that language learning occurs through operant conditioning processes, consistent with the popular behaviorist view at that time. He suggested that language abilities develop through the imitation of speakers around a child and the feedback (reinforcement or punishment) the child's speech elicited. Chomsky (1959) presented a strong counterargument to this proposal; a critical piece of evidence against the behaviorist account of language development was the simple fact that children produce language that has never been produced around them or been reinforced (e.g., original sentences never heard before, incorrect grammar that has never been modeled). Instead, Chomsky suggested that children have the mental capacity to learn the rules of the language(s) spoken around them without explicit feedback on the language they produce. In other words, language abilities result from cognitive processes inherent in humans. From Chomsky's argument, psychologists began to realize that the study of non-observable cognitive processes is an important part of understanding behavior—that understanding the processes behind the overt behaviors would advance our understanding of the mind and behavior in important ways. Still, behaviorism did influence the way we study cognitive processes today. Its focus on the experimental examination of behavior shaped the way researchers approach the study of mental processes. Experimentation is still the focus, but cognitive psychologists examine the behaviors resulting from the mental processes being studied.

Another influential event in the development of cognitive psychology research was the invention of the computer. Herbert Simon recounts in his autobiography that he began a graduate class in 1956 by announcing, "Over the Christmas holiday, Al Newell and I invented a thinking machine" (Simon, 1991, p. 206). Computers presented an information-processing model as an analogous way of thinking about cognitive processes. In this new metaphor for the mind, the brain could be thought of as a biological computer, capable of storing large amounts of information and acting to alter that information as learning takes place. Cognitive processes were the "software" that processed the information (with the brain as the "hardware"). The information-processing model helped psychologists think about cognition in a new way, which spurred research on how information is processed in a way that could be stored in our minds and how that information is acted on as we encounter new information related to what is already stored. This model also provided a universal language that allowed researchers to discuss the processes of the mind and their connection to the brain.

Another milestone in the development of cognitive psychology as a coherent field of study was a 1967 book by Ulric Neisser that integrated such topics as memory, perception, attention, and language as a unified field. Neisser coined the term cognitive psychology (hence the title of this text) and, due to this contribution, is widely viewed as the father of the field. Throughout his career, Neisser conducted research in different areas of *cognitive psychology* with a focus on cognition in everyday behaviors.

PHOTO 1.1 Noam Chomsky; his work in linguistics had a fundamental impact on the early development of cognitive psychology.

Andrew Rusk/CC-BY-2.0

Despite his important contribution, the field of cognitive psychology now differs somewhat from the approach Neisser discussed in his book. For one thing, the topics in this text are broader in scope than those from Neisser when he first described cognitive psychology. For example, in each chapter of this text, you will find a discussion of work in neuroscience, a field that examines the biological underpinnings of cognitive processes. Cognitive neuroscience has become one of the most influential areas of cognitive psychology. It is a topic introduced in Chapter 2 and comes up throughout the book, as research in neuroscience informs theory about many different cognitive processes. Thus, this area of cognitive psychology brings together different topics under the umbrella of a biological approach to the study of cognition. In another example, researchers today take a more holistic approach to memory than was taken in Neisser's book. He discussed memory by modality of information (e.g., "visual memory," "active verbal memory") instead of as one connected topic. In fact, the study of memory has become a large part of the study of cognition in the decades that followed the publication of Neisser's book. A glance at the table of contents of this text shows three chapters (Chapters 5–7) devoted to memory, and this topic is touched on in additional chapters as it connects with other topics (e.g., concepts, imagery). Finally, cognitive psychology is not an isolated field. It has important connections to other fields, such as social psychology, philosophy, biology, economics, and the law. You will see some of these connections illustrated in the text as we discuss the mental processes that make up the field.

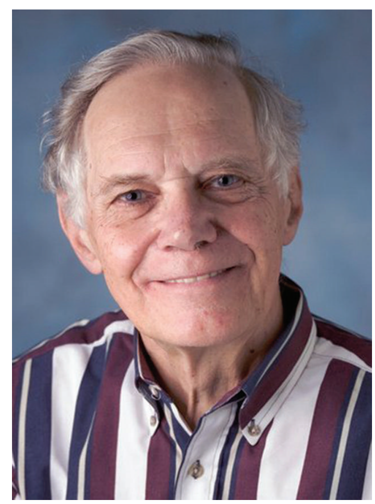

PHOTO 1.2 Ulric Neisser; in addition to his body of research, the publication of his 1967 textbook ***Cognitive Psychology*** led to him being referred to as the "Father of Cognitive Psychology."

Sandra Condry/Cornell Department of Psychology

STOP AND THINK

1.1 List four cognitive processes studied by cognitive psychologists.

1.2 What three historical events influenced the development of cognitive psychology?

1.3 From the description of the types of processes studied in cognitive psychology, what processes do you think were involved in generating your responses to the two previous questions?

CURRENT APPROACHES TO THE STUDY OF COGNITION

Cognitive psychology has risen as a major field of study in psychology, with a large number of researchers investigating questions about cognition and its relation to everyday experiences. Current research takes a number of approaches to understanding cognition. We discuss a few of the most influential approaches to allow you to better understand why researchers have focused on some of the research questions we discuss later in this text. These approaches represent some of the ways that researchers think about how cognition works, which in turn influences the way they design research studies to investigate these processes.

PHOTO 1.3 How do you think a concept like "armadillo" is mentally stored in our minds?

Mark Dumont/CC-BY-2.0

Representationalism

A popular perspective in cognition is to consider information from the world as being represented in some form in our minds. For example, we might store the concept of *armadillo* in various ways. We could represent armadillo as an exemplar of the category of animals or in interconnections with related animals. We might also represent it as a concept with characteristic features (e.g., mammal, hard shell, digs). The basic aspect of the **representationalist** approach is that knowledge about the world is represented in our minds such that cognitive processes can "operate" on the representations. If we read about armadillos or see a documentary about them, we might change or add to this stored information as we learn more about armadillos than we previously knew.

In early representationalist models (Rumelhart & Norman, 1988), information was thought to be stored as symbols that could be operated on in the way that mathematical variable symbols (e.g., *2* and II are both symbols used to represent the concept of two) are operated on (we can manipulate these symbols using operations such as addition or multiplication). This approach allowed researchers to study the operations as processes of cognition. For example, models of perception relied on feature detectors that stored information about features encountered in the world (e.g., lines, curves, colors). We can identify objects when our feature system identifies particular features that we know to be a part of an object. If we detect perpendicular edges on an object, then the feature system can rule out objects with rounded edges and narrow identification down to objects with sharper edges. In this way, the features we see are stored as feature symbols in our minds. As knowledge of cognition has advanced, these symbol systems have become more complex in representing the knowledge stored in our minds.

The representationalist approach arose from the computer and information-processing models of cognition. Information is stored in computers in the form of 0's and 1's that form chains of "off" and "on" signals. This is similar to the way that neurons either fire or do not fire at any given time. In this way, the computer model is analogous to how the brain functions. Seeing this similarity, some cognitive and physiological psychologists have considered information as being represented in the mind through the "on" and "off" firing patterns of groups of neurons. This allows researchers to think of information as being stored in the mind and available for processing as we interpret, analyze, and alter this information in our thinking.

The representationalist perspective connects well with the biological perspective (see later in this section), as it provides a model of cognition in sync with the physiological processes that occur in the brain. However, the primary model for representationalism is the computer metaphor for the mind. The language of computers is typically evoked in describing the representations found in the mind. For example, "concepts" are often described as storage nodes of information in a hierarchical network (see Chapter 9 for further discussion of concepts). Thus, this approach has a different origin and conceptual structure than the biological approach described shortly.

PHOTO 1.4 Researchers who adhere to the embodied cognition approach believe that perception serves as a process to aid interaction with the environment.

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Embodied Cognition

Another approach to the study of cognition views our cognitive processes as providing a means of interacting with the world around us. In this view, our visual sense doesn't simply create representations of objects and scenes from the world for us to interpret and process. Instead, it provides information about the world that allows us to do things in that world, such as walking through a doorway or catching a ball. In other words, our cognitive processes have evolved to allow us to interact with the world (e.g., objects, people, conversations) and should be studied according to the purpose they serve. As such, our motions and interactions with objects and people in the world will influence our cognition. Researchers who adhere to the **embodied cognition** perspective examine cognition as an interaction between humans (and other animals) and their environment. Studies from this area have shown, for example, that memory of a text is better when people act it out as compared with other learning strategies, like rereading the text (Scott et al., 2001); that people will look at the space on an empty screen when recalling information previously presented at that location on the screen (Richardson & Spivey, 2000); and that people with experience wearing the shoulder pads used in American football pass through a small open space in a different way than those without experience playing the sport (Higuchi et al., 2011). These results show that our memory, language, and perception processes depend on our interactions with the world around us. More about this perspective is discussed in each of the topical chapters where this approach has been applied.

Biological Perspective

We have already had some discussion of the role biology plays in the study of cognition as we have considered the area of cognitive neuroscience and its connection to the representationalist approach. However, some researchers have considered a **biological perspective** of cognition, a view beyond just the specific brain activity associated with different cognitive processes. These researchers build theories of cognition using a different metaphor for the mind, one not based on a computer but rather on how the brain works. In other words, they propose theories based not on the manipulation of symbols but rather on networks of connections loosely analogous to networks of neurons. For example, in attempting to model how our memory system learns new information, researchers have considered the way in which neurons are connected in networks in the brain and simulated such networks in models of memory (McClelland, 1999). Models of this sort, known as connectionist models, have also been developed to explain how we identify language through individual features of letters and spoken words. Thus, our knowledge of the biological architecture of the brain and the neurological functioning of the brain has guided researchers in their attempts to better understand how different cognitive processes work.

STOP AND THINK

1.4 How are the representationalist and biological approaches connected?

1.5 What does embodied cognition mean?

1.6 In what ways are the biological features of the brain important in the study of cognition?

1.7 Given what you know so far about cognitive psychology, which of the approaches described in this section do you think you would follow as a researcher in psychology? Why?

RESEARCH IN COGNITIVE PSYCHOLOGY

One thing is clear from the preceding review of the historical and theoretical perspectives: The field of cognitive psychology relies heavily on research and more broadly on observations of behavior. Throughout this text, you will review research used to develop many of the major theories within cognitive psychology. The following sections briefly review some basics of the scientific method and different research methodologies, and the chapter ends with a review of measurements commonly used in the discipline.

The Scientific Method

The **scientific method** is grounded on four core principles: empiricism, determinism, testability, and parsimony. **Empiricism** is the principle that the key to understanding new things is through systematic observation. In the case of cognitive psychology, the "things" that we want to know are the mental processes that underlie human behavior. This is tricky for most cognitive psychologists because it is difficult to directly observe mental processes. Sometimes, there are observable outcomes of these processes that are readily measured (e.g., remembering or forgetting to do something, buying cereal, selecting plastic instead of paper bags). These outcomes, however, are often assumed to be the result of a string of different mental processes. As a result, much of cognitive psychological theory is based on clever indirect measurements of these processes. **Determinism** is the principle that behaviors have underlying causes and that "understanding" involves the identification of what these causes are and how they are related to the behavior of interest. These sets of cause-and-effect relationships between variables (the "causes" and the "behaviors" that they influence) are what make up theories of behavior. **Testability** is the principle that theories must be stated in ways that allow them to be evaluated through observation. In many respects, the scientific process is a competitive one in which the predictions of different theories are like players pitted against each other and research studies are the playing field. Research consists of systematically collecting observations designed to test the predictions of multiple theories, ruling some out and leaving only those consistent with the data left standing. **Parsimony** is a kind of tiebreaker in this competition. It is the principle to prefer the simple explanations over more complex ones. If there are two or more theories left standing (accounting for the same amount of data), then adopting the least complex one is preferred (at least until further data are collected that refute the simpler theory).

Consider once again the shopping story with which we started the chapter. This story includes many behaviors that we (as cognitive psychologists) may wish to understand. Let's focus on one of them: deciding whether to take the "buy 2, get 30% off" or the "buy one get one free" deal. Our behavior of interest here is how one makes this and other similar decisions. In the context of research, the behavior of interest is typically referred to as the **dependent variable (or response variable)**. Having identified what we want to explain, the next step is to identify which different variables might affect this dependent variable and how those effects occur. The variable you have control over and can control and manipulate is known as the **independent variable (or explanatory variable)**. The set of variables and how they are hypothesized to be related to each other is what constitutes our theory. For this example, there may be many relevant variables, but for our purposes here, let's keep it simple and just pick two: the type of deal being offered and the starting price of the product. Here, we have the choice of 30 percent off a higher-priced cereal that your family will eat or 50 percent off a lower-priced cereal that your family doesn't like.

Suppose our theory says that people make decisions based on how they frame their potential gains and losses (e.g., Sinha & Smith, 2000; Thaler, 1985). In other words, the shopper's decision may depend on whether he or she is thinking about the deal as either a gain or a reduced loss. How the deal is presented may have an impact on how shoppers view the deal. Imagine that there is a new type of cereal at the store, and you're not sure if you or your family will like it. Consider three ways of presenting what is essentially the same deal: "50% off," "buy one, get one free," and "buy 2, get 50% off" (so if you buy two boxes with an initial price of $1 each, you'll pay only $1 total with all three deals. The first case frames the deal in terms of price savings (a reduced loss), the second in terms of getting extra product (a gain), and the third is a mixture of the two. With a starting price of $1, consumers may view the potential of gaining an extra product as most important. However, if the starting price of the product is larger (e.g., $5), then consumers may change their decision-making processes in favor of reduced losses. These last statements amount to predictions or hypotheses made by the theory. The next step is to design research studies to test the predictions derived from the theory.

PHOTO 1.5 How we make decisions in our daily lives depends on a variety of different variables.

iStock.com/VLG

RESEARCH METHODOLOGIES

While the following chapters describe research and theories across a broad spectrum of behaviors, the methods used can generally be classified into three approaches: case studies, correlational studies, and experimental studies.

Case Studies

A **case study** focuses on intensive analyses of a single individual or more broadly on a single observation unit (e.g., the unit of analysis for the research could be on a couple or on a single institution). Often, the focus of case studies is on unique individuals who display characteristics outside of what is considered the norm. Henry Molaison (H. M.) was one of the most studied individuals of all time. In 1953, to relieve his severe epileptic seizures, H. M. had brain surgery to remove parts of his medial temporal lobe. Following the surgery, it was revealed that H. M. had lost the ability to remember events of his life that occurred after his surgery (anterograde amnesia). H. M. was the subject of intense observation from 1957 to his death in 2008 (Squire, 2009). Theories of how memory is organized are largely based on this work.

Returning to our shopping and decision-making example, you may decide to make a case study of somebody who identifies himself as an "extreme couponer." To investigate his decision-making processes, you systematically observe his behavior over a long period, using a variety of ways to collect the observations. For example, you may directly observe him while he shops, ask him to keep detailed records of his shopping behaviors, and ask him to "think out loud" as he engages in his shopping-related decision processes. The advantage of a case study is the sheer number of intensive observations that may be collected and examined. This allows the researcher to identify many of the variables that may be relevant and to speculate about the relationships between these variables. The major disadvantage of this approach is that it centers on describing and explaining the behavior of a single, often unique, exemplar. As a result, it is often difficult to make broad generalizations of the results to other individuals.

Correlational Studies

A **correlational study** allows researchers to systematically observe groups, recording the frequency and/or intensity of many variables at once. These observations may include indirect measures such as self-report (i.e., asking the participant to report about his or her own behaviors). The key feature of this method is that researchers are attempting to collect the observations with minimal impact on the variables of interest. So in our shopping story, we might set up a camera in the cereal aisles of fifteen grocery stores and record video of customers' buying behaviors over the course of a month. As stores change prices and deals, we might record how frequently people buy the cereal. Additionally, we may wish to systematically observe other potentially relevant variables (e.g., size of boxes, time of day, gender of people). Not surprisingly, correlational studies are often analyzed using correlational procedures. Suppose, in our example, the researchers found a negative correlation between the price of cereal and the amount consumers purchased. This negative correlation simply states that as prices drop, the rate of buying tends to increase (a positive correlation would describe a relationship in which the change in the variables moves in the same direction rather than opposite directions). Data like these may be used for theory testing. For example, if our theory predicts a negative relationship between price (an explanatory variable) and the amount of buying (our response variable), then these data may be considered support for the theory. However, had the result been a positive correlation, that could be used as evidence against the theory. It is important to remember that evidence of a correlation between two variables does not mean that the relationship between them is causal. Because the researchers are just observing things as they naturally occur, determining the causal relationships between variables is extremely difficult. Thus, while correlational studies have the advantage(s) of allowing the observation of many variables at once, within relatively natural contexts, one should not make cause and effect generalizations based on these methods.

Experimental Studies

The majority of the research reviewed in this text uses an experimental approach. An **experimental study** is designed to simplify the contexts surrounding the behavior of interest, allowing for a focused investigation of the impact of a relatively small set of variables on a behavior of interest. In contrast to correlational studies, experiments intentionally involve the manipulation of variables.

Manipulated variables include both independent and control variables. Let's consider a simple example. Suppose that you want to know whether people prefer the taste of cane sugar or a sugar substitute. You design an experiment in which you ask two groups of people to taste one of the types of sweetener and then rate how much they like the taste. Then you compare the ratings of the two groups. In this example, the behavior of interest (our dependent variable) is taste, as measured by the tasters' ratings. The independent variable is which sweetener is presented to each group. However, how something tastes is complex, with many different variables influencing it (e.g., whether in food or drink, what smells are present, how the food looks). To keep your observations focused on the sweetener, you may also manipulate these other variables by keeping them constant for everybody in both groups (e.g., use lemon cookies baked using the same recipe with the only difference being the kind of sweetener used). The logic of controlling variables is to try to ensure that the only difference between the two groups is the independent variable. Thus, if a difference in the dependent variable is found between the two groups, the most likely explanation for this difference is the manipulated independent variable.

Researchers often include more than one independent variable in an experiment to allow for efficiency in examining multiple variables at once but also to be able to see how these variables *interact* to affect the dependent variable. For example, a perception researcher might be interested in how much sweetener should be added to a cola product to optimize flavor. They might manipulate the amount of sweetener and ask people to rate how much they like the cola. But suppose that the amount of sodium in the cola influences how the sweetener affects the taste, such that more sweetener tastes better with less sodium but less sweetener tastes better with more sodium. The only way a researcher will be able to determine this is to manipulate *both* sweetener and sodium in the same study. The researcher can then compare whether the high sweetener/low sodium condition is preferred to the low sweetener/high sodium condition and choose the best one for the cola product to optimize flavor. This is known as a *factorial design*.

Earlier, we described a hypothetical correlational study to examine our decision making in shopping behavior. Imagine designing an experiment to look at the same issues. From the theory outlined earlier, we may predict that the framing (focusing on reduced price or increased product) and the initial price of items will have an impact on the decision making of shoppers. To examine this hypothesis experimentally, we randomly assign people to one of four conditions (see Figure 1.1). We manipulate two different independent variables. To examine the impact of the framing variable, we provide two of the groups with products labeled "50% off" (emphasizing reducing price) and the other two groups with products labeled "buy one, get one free" (emphasizing gaining product). To examine the pricing variable, the products in one group will be given an initial price of $1, and the other group will get items priced at $5.

For our dependent variable, each participant will be asked to consider the "sale" and rate how likely they are to buy two boxes of the product. This experimental design allows us to examine three separate effects. We can examine the effect of the initial price variable and the effect of the framing of the deal variable on purchasing decisions separately. However, the design also allows us to examine how these two variables interact with one another to influence purchasing decisions. For example, consider the fictional set of data presented in Figure 1.2. We can see that the overall effect of framing was that participants had a higher likelihood of buying two boxes with the 50 percent off deal than the buy one, get one free deal. The overall effect of pricing was that participants were more likely to buy two boxes when the initial price was low. The final graph shows how these two variables interact with one another to form a more complex relationship. Here it becomes apparent that the framing effect really only has an impact when the initial price is high, with participants much more likely to buy two boxes with the 50 percent off deal than the buy one, get one free deal. However, when the initial price was low, there was no difference in likelihood between the two framing conditions.

By virtue of experimental control and the explicit manipulation of independent variables, researchers can be more confident about testing cause and effect relationships between variables. This ability to make causal inferences is the biggest advantage of using experimental approaches. However, this advantage comes at the cost of an ability to generalize to other contexts (also known as *external*

FIGURE 1.1 ■ Possible Variables in Cereal Choice: Ad Framing and Initial Price

Consider how different variables are used to frame products to influence our buying behaviors. This experimental design examines how "deals" may work by looking at the impact of price starting point and how the price change is framed.

Photo credits: Hemera Technologies/PhotoObjects.net/Thinkstock.

FIGURE 1.2 ■ Fictional Data From Framing and Pricing Experiment

The left graph shows that overall, buyers find the 50% off condition more favorable. The center graph shows that overall, buyers are more likely to purchase two boxes if the starting price was low. The right graph shows the interaction of these two effects, such that the framing effect mostly happens when the starting price is high.

validity). Because the experiment is explicitly designed to simplify the context surrounding the behavior of interest, it opens the door to the potential that the results are applicable only to those simplified contexts. In other words, one must be careful in generalizing the conclusions drawn from experiments to the more complex, naturally occurring contexts in which the behavior normally occurs.

Sometimes a complete experimental design isn't possible because we may not be in a position to truly manipulate the independent variable. For example, suppose we think that men and women may differ with respect to their decision-making behaviors when shopping. We would design an experiment like the one described earlier but add gender as an additional variable. In this example, gender is a **quasi-independent variable** because we are not actually able to manipulate our participants' gender (i.e., we can't randomly assign some people to the male condition and others to the female condition). Because gender is a preexisting characteristic, it should be treated like an explanatory variable in a correlational design. As a result, when interpreting any of the results that involve the gender variable, one needs to be appropriately conservative about making causal claims.

STOP AND THINK

1.8 What core principles is the scientific method founded on?

1.9 What are the main differences between a case study, correlational designs, and experimental designs?

1.10 What are the main advantages and disadvantages of each of the different research designs?

1.11 Consider one of the other behaviors described in the shopping example at the beginning of this chapter. Identify potential variables that may impact that behavior and then design a research study to examine how those variables are related.

COMMONLY USED MEASURES WITHIN COGNITIVE PSYCHOLOGY

In most of the examples given, the behavior of interest allowed us to observe how different variables influenced the outcome of the decision processes (how much cereal they bought). However, not all cognitive processes have such obvious, directly observable outcomes or behaviors. And even in the cases where they do, we may be interested in more than just the final outcome; we may also be interested in the mental processes as they occur (i.e., not just after a decision has been made and is then acted on). This section provides a brief introduction and review of some of the most commonly used measures in cognitive psychological research.

Our intuition tells us that we experience the world as it happens. Thinking feels very fast, and until the mid-1850s, it was generally assumed that thought moved at speeds similar to the speed of light. That, combined with the internal nature of thought (as something that goes on inside the head), led most to assume that thought was unmeasurable. That changed when von Helmholtz (1850/1853) began attaching electrical wires to the leg muscles of frogs as described earlier in this chapter. His studies established that the speed of neural transmission is substantially slower than the speed that light travels. Suddenly, the potential to measure mental processes did not seem so out of reach. Following Helmholtz's discovery, researchers began using measures like accuracy (i.e., percentage of correct responses) and response time (i.e., how fast subjects make a response to a stimulus) as indicators of mental processes.

Accuracy

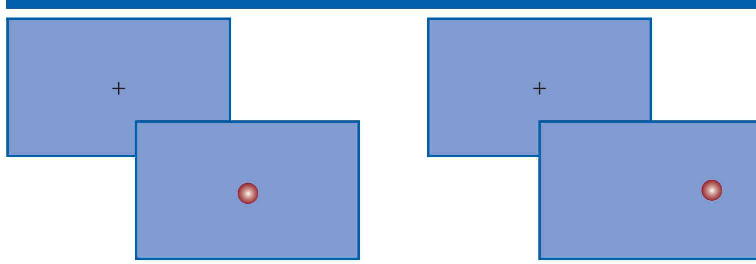
Accuracy measurements are common in research designs in which there are right and wrong responses. For example, when probing how we comprehend language, participants may be asked questions about facts from a passage they read (e.g., in the shopping story, "How many light bulbs were burned out?" "What brand of cereal did the shopper end up buying?"). In a reasoning task, researchers may measure how often participants arrive at the correct solution to a target problem as a function of how similar it is to example problems. Research examining the nature of memory has a long tradition of using accuracy as a measure of mental processing. Without looking back, make a list of all the details that you can recall from our shopping example. After you've made your list, go back and compare your list with the story itself. How many details did you remember? How many details did you leave out? Memory researchers have been using questions like these, about the percentage of correctly remembered details or items, for over 150 years to investigate factors that influence memory (e.g., what kinds of things you are memorizing, the time between learning and testing, what sort of study you do when trying to memorize things).

However, accuracy isn't always just about how many items you can correctly recall; it can also be about the number and kinds of errors you make. Bartlett (1932) reported a series of experiments he conducted in which he presented British students with a brief Native American folktale and later tested their memories for details from the story. Bartlett discovered that their memories were dramatically influenced by their own cultural experiences and stereotypes. This was primarily evidenced by the memory distortion errors his participants made. Consider, too, the case of eyewitness testimony. When witnesses are asked to recall details of an event, some of the details they "remember" are often not accurate. Research examining how and why people have these "false memories" has greatly shaped our theories explaining how memory works.

Response Time

Another widely used method to examine cognitive processes is to measure how long it takes to respond to a stimulus. One of the earliest and most influential sets of experiments was conducted by Franciscus Donders (1969/1868). Donders developed a response time technique called the subtractive method to examine cognitive processing (Figure 1.3). His technique combined two measurements from two slightly different tasks. In the first task (simple response time procedure), he measured the time it took for a person to respond to a simple stimulus (e.g., push the button when you see a light). The second task was similar, but instead of having a single button to press, there were multiple lights and buttons. If the left light came on, the person was to press the left button, and if the right light came on, then the right button (choice response time procedure). Having multiple lights and buttons required the same set of processes needed in the simple response time procedure but also required discrimination (left or right light) and decision (left or right button) processes. Donders's methodology assumes that components of mental processes are strictly discrete and serial. That is, each stage operates separately and in sequence. With these assumptions, one may subtract the response times of the first task from the response times of the second task, leaving a measurement of the time required to perform discrimination and choice.

FIGURE 1.3 ■ Donders's (1969/1868) Subtraction Methodology



Simple Reaction Time
Press the button when you see the light.

Choice Reaction Time
Press a button when you see the light, which button depends on where the light was located ("a" for left, "l" for right).

In the years since Donders's experiments, response time procedures have become more sophisticated. Not all of the underlying assumptions of his task have turned out to be true. However, the same basic underlying logic that mental processes are measurable is still present in the bulk of cognitive psychology research. Consider two popular paradigms currently used in cognitive psychology laboratories: priming and eye movement studies.

Priming tasks are pervasive in the field of cognitive psychology (typing "priming" into the search field of an article database yields thousands of articles). In a typical priming task, participants respond to a series of stimuli (e.g., "Press the right button if the string of letters is a real word. Press the left button if the string of letters is not a real word."). Embedded within the list of stimuli are sets of paired trials, the first of which is called the "prime" and the second the "target." Researchers are typically interested in how quickly participants respond to the target stimuli when it follows a related prime compared to when it follows an unrelated prime. For example, suppose the target is the word DOCTOR and it is preceded by either the word NURSE (related) or BREAD (unrelated). Typically, participants would respond faster to DOCTOR when NURSE precedes it than when it is preceded by BREAD (Meyer & Schvaneveldt, 1971). Following logic similar to that proposed by Donders, this difference in reaction time between the two conditions is thought to reflect cognitive processing differences.

After reading the previous examples, you might have the impression that all response time studies focus on button pressing. That isn't the case. Throughout this textbook, you'll see a wide variety of response time measurements involving other behaviors (e.g., naming times, reaching times, recognition judgments). Recently, monitoring eye movements has become a popular behavioral measurement in cognitive psychology. Our eyes are constantly jumping around, moving from one fixation (keeping still with one thing in focus for 200–350 milliseconds) to another. The fundamental assumption with this methodology is that there is a tight coupling between the eyes and the mind. In other words, we think about what we look at, and how long we look at something reflects underlying mental processing. Initial interest in using eye movements to measure cognition focused on attempts to understand the processes involved in reading. However, recent technological advancements have led to an explosion of the use of eye movements to address research questions across a wide range of cognitive psychology subdomains (e.g., spoken language comprehension, language production, attention and visual search, scene perception). Similar to the work with the button-pressing method discussed earlier, researchers typically compare how long participants fixate on stimuli from different experimental conditions to test their theories.

Beyond Accuracy and Response Time

While much of the research that you will read about in the following chapters reports dependent variables using either response time or accuracy alone, many other measures are used as well. Think of your own experiences. When you try to do something very quickly, your error rate increases; as a task gets harder, your performance may get slower and you make more errors. Some research focuses on this tight tradeoff between speed and accuracy (e.g., Kahana & Loftus, 1999; Meyer et al., 1988). Other research focuses not on the time taken to initiate a response but rather on other characteristics (e.g., duration, velocity, direction of movement) of responses (e.g., Abrams & Balota, 1991).

Within the rapidly growing field of cognitive neuroscience, recent technological advances in brain imaging techniques have led to the development of brain visualization measures. For example, using methods like electroencephalography (EEG) and functional magnetic resonance imaging (fMRI), researchers are able to "watch" the neural activity of the brain while it is processing information. We describe some of these procedures in greater detail in Chapter 2. Often these new techniques are combined with the old standbys of accuracy and response time to gain new insights into the nature of mental processing (e.g., Posner, 2005).

One thing to keep in mind with nearly all these measures is that they are indirect measurements. Regardless of whether we are examining response times (e.g., to push a button, read a sentence, or stare at an object), accuracy measures (e.g., how often we arrive at the correct solution to a problem or remember all the items from a list), or brain activity within a particular region, in all cases, we are measuring something we assume to be correlated with the cognitive processes, not the processes themselves. Given this, you should always critically evaluate the assumed connection between the behavior measured and the cognitive process being tested.

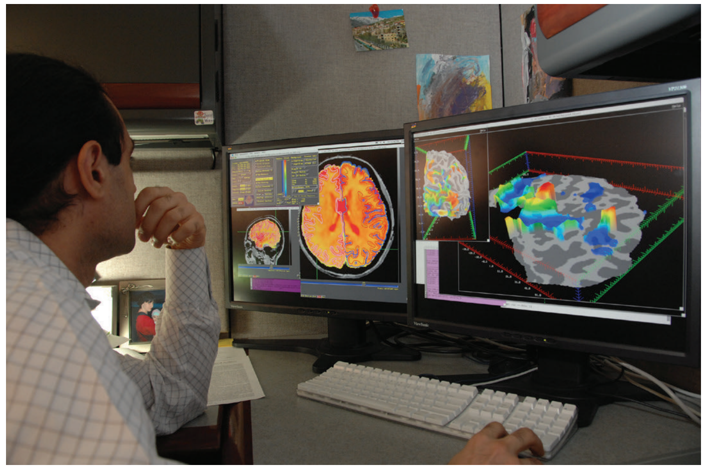


PHOTO 1.6 Brain imaging techniques like fMRI allow researchers to observe areas of the brain as they function during experiments.

National Institute of Mental Health

STOP AND THINK

1.12 What are two commonly used dependent measures in cognitive psychology?

1.13 Briefly explain the logic used in Donders's subtractive method.

1.14 Think back to the shopping story that started the chapter. Suppose that you were interested in studying how the shopper understood the bagger's question, "Paper or plastic?" How might you design a study to investigate this issue?

THINKING ABOUT RESEARCH

As you read the following summary of a research study in psychology, think about the following questions:

1. Which approach to the study of cognition is being used in this study?
2. What type of research design are the researchers using in this study?
3. What is the independent variable in this study?
4. What is the dependent variable in this study?

Study Reference

Ward, E. V., Berry, C. J., Shanks, D. R., Moller, P. L., & Czsiser, E. (2020). Aging predicts decline in explicit and implicit memory: A life-space study. *Psychological Science, 31*, 1071–1083.

Purpose of the study: Because methods and results have differed in past studies that examined implicit (automatic) and explicit (intentional) memory across the lifespan, the purpose of this study was to measure these forms of memory for a large sample of individuals with ages ranging from 12 to 82 years. Memory tasks were chosen such that instructions differed across the two types of memory test but the tests were otherwise very similar. The researchers' goal was to clarify past results showing declines in explicit memory and unclear changes in implicit memory across the lifespan.

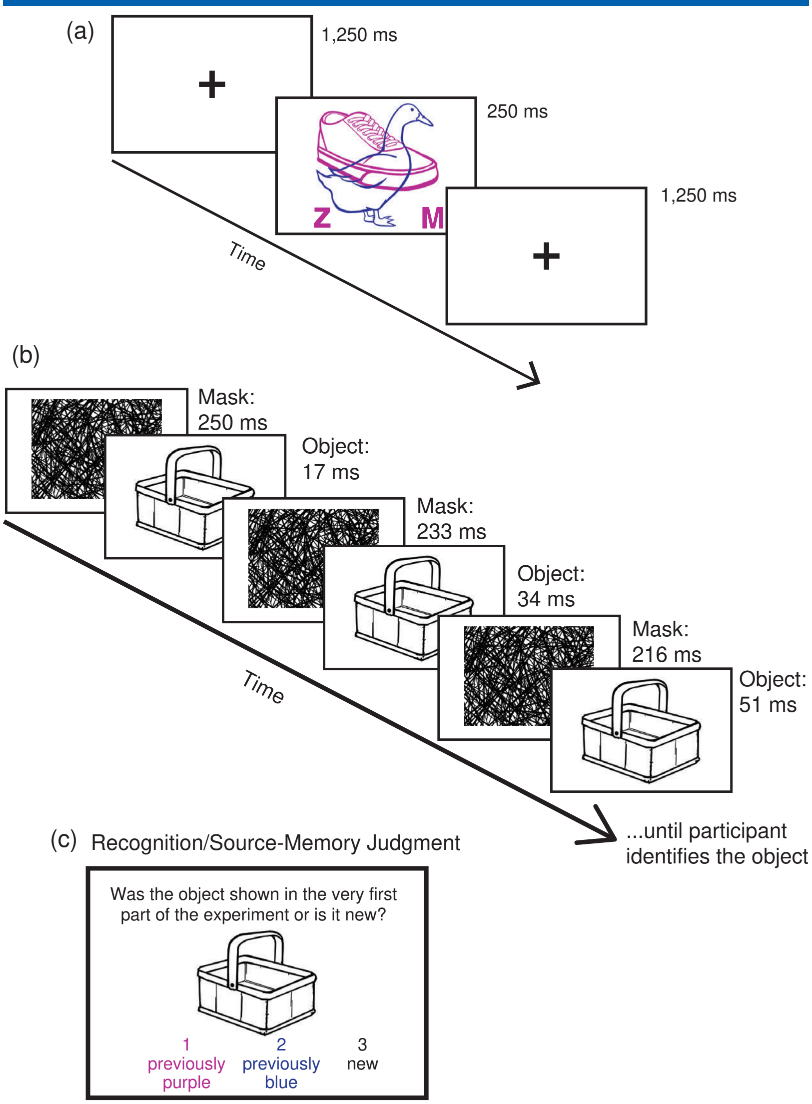
Method of the study: Participants were 1,072 visitors to a science museum in the United Kingdom. They were classified by age into six groups: 12–17 years, 18–24 years, 25–34 years, 35–49 years, 50–64 years, and 65–82 years. Participants studied sets of overlapping objects, with each object in the set presented in a different color (see top panel of Figure 1.4). They were told to pay attention to one of the colors (either purple or blue) and ignore objects presented in the other color during presentation. They also performed one of two tasks during the presentation: (a) Decide if the attended to object was natural or manufactured (press Z key for natural; M key for manufactured) or (b) determine if the attended to object was angled or round. In Figure 1.4a, a blue goose and a purple shoe are presented at the same time.

About 3 minutes after the study presentation, the participants began the test trials. On each test trial, they completed identification (implicit memory task), recognition (explicit memory task), and source (explicit memory task) judgments. For the identification judgments, an object was shown (either studied or new) for a very brief time (17 milliseconds) followed by a jumbled screen (also called a "mask") to prevent afterimages. The object was displayed again for a slightly longer period of time (34 milliseconds) and then the jumbled screen appeared. This process continued (with the object displayed for increasing periods of time) until the participant indicated they could identify the object (see the middle panel of Figure 1.4). Then they judged whether the object had been seen in the study portion (it could have been attended to not attended to) and then which color the object was presented in if it was an object they had studied (see the bottom panel of Figure 1.4).

Results of the study: The results showed that memory performance declines in older age for both implicit and explicit tasks, particularly for the participants over age 50 years (as shown in Figure 1.5). These results apply to the attended to objects during a study. Unattended to objects had memory scores similar to chance across all age groups, suggesting that these objects were not encoded when attention was not paid to them during a study. The study task (natural vs. manufactured or angled vs. round) did not affect memory scores.

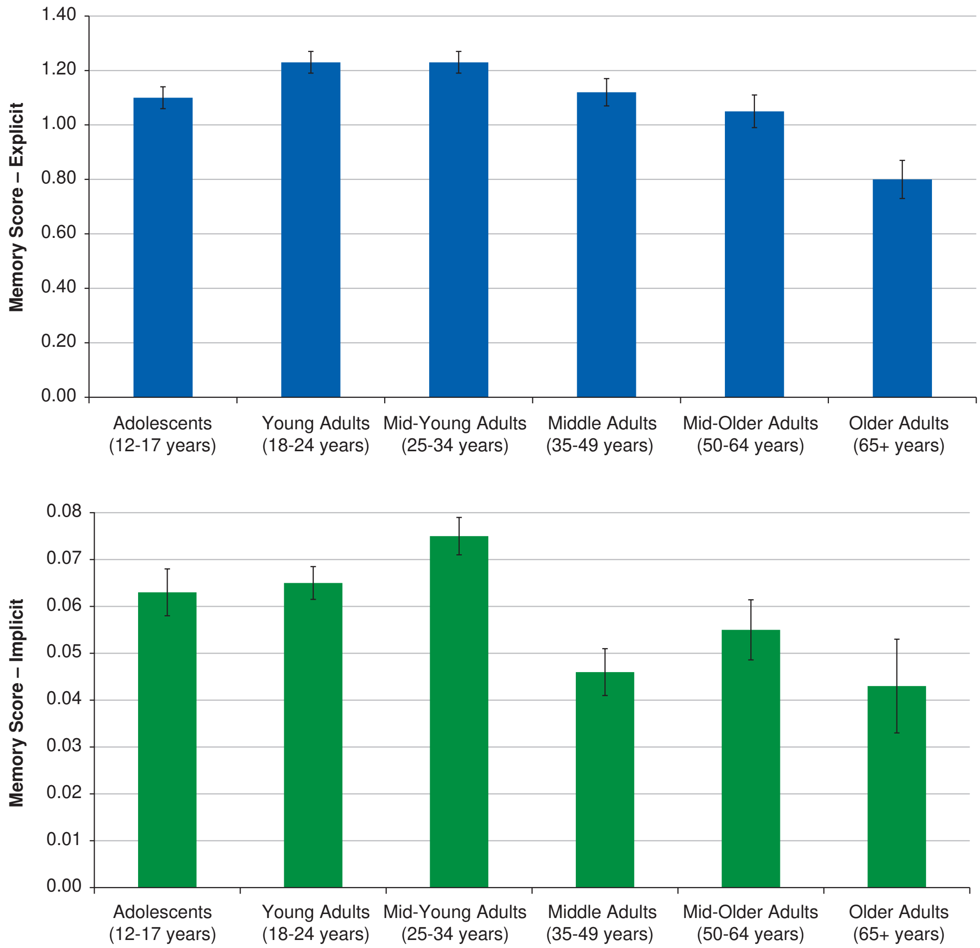
Conclusions of the study: The results of the study clarified mixed findings from past studies in showing clear age-related declines in implicit memory performance in older age. These results suggest that implicit and explicit memory have more similarities with respect to change over the lifespan than previously thought.

FIGURE 1.4 ■ Stimulus Materials Used by Ward et al.



Source: Adapted from Ward et al. (2020, Figure 1). Licensed under CC-BY 4.0, https://creativecommons.org/licenses/by/4.0/.

FIGURE 1.5 ■ Mean Memory Scores as a Function of Type of Test and Age Group



Source: Adapted from Ward et al. (2020, Figure 2).

CHAPTER REVIEW

- **What is cognitive psychology? How did it develop as a field?**

  Cognitive psychology is the study of how our minds receive, store, and use information. This includes theory and research about perception, attention, memory, language use, decision making, and problem solving. The roots of the discipline may be traced to philosophy and physiology before the twentieth century. However, modern cognitive psychology primarily developed since the mid-twentieth century. This was in part a reaction to the behaviorist tradition within psychology but also is a reflection of developments within other disciplines, including biology, linguistics, and computer science.

- **How have psychologists approached the study of cognition?**

  Explanations of cognitive processes have been developed within three general approaches: representationalist, embodied, and biologically motivated. Representationalist theories of cognition generally view the mind as a symbolic processor, similar to a computer. In these views, information is conceptualized as abstract representations that may be acted on by mental operations. Embodied approaches envision the mind as something situated within a body and an environmental context. These approaches examine cognition as interactions between individuals and their environment. Biologically motivated approaches to cognition focus on theories based on neurologically inspired elements.

- **What types of research methods are useful in the study of cognition?**

  Three main types of research designs are employed in research in cognition: (1) case studies that focus on the behaviors of a distinct individual or group, (2) correlational studies that examine relationships between sets of dependent (or response) variables, and (3) experiments that test causal relationships between variables through the manipulation of independent variables and control of the conditions under which the dependent (or response) variables are measured. Researchers may also use quasi-independent variables (group subjects based on a particular characteristic, such as gender or age) to compare groups for the dependent variable when manipulation of a variable is not possible.

- **What behaviors do psychologists observe to study cognition?**

  There is a range of behaviors studied by cognitive psychologists. A common measure is accuracy for a task (such as memory or perceptual judgments). Another common measure is the speed to complete a task (such as identify a word or solve a problem). There are also behaviors specific to an area of cognitive psychology (such as the measurement of brain activity in cognitive neuroscience).

CHAPTER QUIZ

1. Enter the letter for the approach to the study of cognition next to its corresponding definition below:

a. representationalism
b. embodied cognition
c. biologically motivated models

___ describe cognitive processes in a similar fashion to the physiological functioning of the brain
___ describe cognitive processes as operating on knowledge concepts represented in our minds
___ describe cognitive processes as the interplay between the body and the environment

2. Which core principle of the scientific method involves the identification of the underlying causes of behavior?

a. empiricism
b. determinism
c. parsimony
d. testability

3. Which core principle of the scientific method involves the assumption that simpler explanations of behavior are preferred?

a. empiricism
b. determinism
c. parsimony
d. testability

Use the following study description to answer questions 4 through 7:

A researcher is interested in examining the relationship between one's actual memory abilities and one's perception of how good his or her memory abilities are. Subjects in this study are given a study list of words and asked to remember these words after a short delay. They are also given a questionnaire and asked how good the subject thinks his or her memory is, where a high score means the subject thinks he or she has high memory abilities. The researcher finds a small but positive relationship between the memory test scores and the questionnaire scores.

4. What type of research design is used in this study?
   a. experiment
   b. case study
   c. correlational study
5. Explain how you know which research design is being used.
6. Which of the following are dependent (response) variables in this study? (Choose all that apply.)
   a. The delay between the study list and the memory test
   b. The score on the questionnaire
   c. The score on the memory test
   d. The number of words in the study list
7. *The results indicated a positive relationship between the variables that were measured*. Explain what this means.
8. In what way does an experiment differ from other research designs?
9. What is the key difference between an independent variable and a quasi-independent variable?
10. The measure used by researchers that indicates the speed with which someone completes a task is known as
    a. accuracy
    b. reaction time
    c. self-report
    d. an independent variable
11. What are two "metaphors of the mind" that have influenced the development of theories of cognition?
12. What are two developments that led to a rapid expansion of the field of cognitive psychology after the mid-twentieth century?
13. Describe Donders's experiments and explain how they propose to measure cognitive processes.

KEY TERMS

Behaviorist (p. 4)
Biological perspective (p. 7)
Case study (p. 10)
Correlational study (p. 10)
Dependent variable (response variable) (p. 9)
Determinism (p. 8)
Embodied cognition (p. 7)
Empiricism (p. 8)
Experimental study (p. 10)
Independent variable (explanatory variable) (p. 9)
Introspection (p. 3)
Metacognition (p. 3)
Parsimony (p. 8)
Priming (p. 15)
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2 COGNITIVE NEUROSCIENCE

LEARNING OBJECTIVES

2.1 Connect clinical case studies to our understanding of cognitive neuroscience.

2.2 Describe the basic structures of the nervous system and how they function.

2.3 Compare the strengths and limitations of different electrical recording techniques.

2.4 Compare the strengths and limitations of different brain imaging techniques.

QUESTIONS TO CONSIDER

- How do cognitive researchers make use of information about brain structure and activity?
- How do case studies of individuals with cognitive deficits inform us about the connection between cognition and brain function?
- What techniques do researchers use to examine brain structure and function?
- What can be learned about cognition through measurements of neuron activity in the brain?

INTRODUCTION: KNOWLEDGE FROM COGNITIVE DEFICITS

Imagine that you are a neurologist focusing on cognitive deficits in your patients. You see several patients in a day. One is an older woman who is having some memory problems. Another patient is a man who can identify which words on a page represent animals but cannot distinguish between an elephant and a horse or identify that a tiger is an animal that has stripes. Another patient is a veteran who lost a leg in a bombing in Afghanistan but still feels pain where the leg should be. A fourth patient can understand and follow verbal instructions but cannot produce verbal speech.

As you further examine each one of these patients, you realize that they illustrate the connection between brain function and cognitive abilities. The first patient is tested with some cognitive tasks, including remembering words and numbers for a short time. She shows lower functioning on these tasks compared with typical scores of nonclinical individuals, and you conclude that she may be showing the first signs of Alzheimer's disease. The second patient is one you have seen in your office several times before. He has Pick's disease, a disorder where fine-grained conceptual knowledge is gradually lost due to deterioration of the neurons that help us retrieve general knowledge. The veteran is suffering from a condition known as phantom limb syndrome, where a patient has perceptions of feeling from a limb that has been removed. The last patient is suffering from Broca's aphasia, a language disorder where comprehension abilities are spared but production abilities show a deficit.

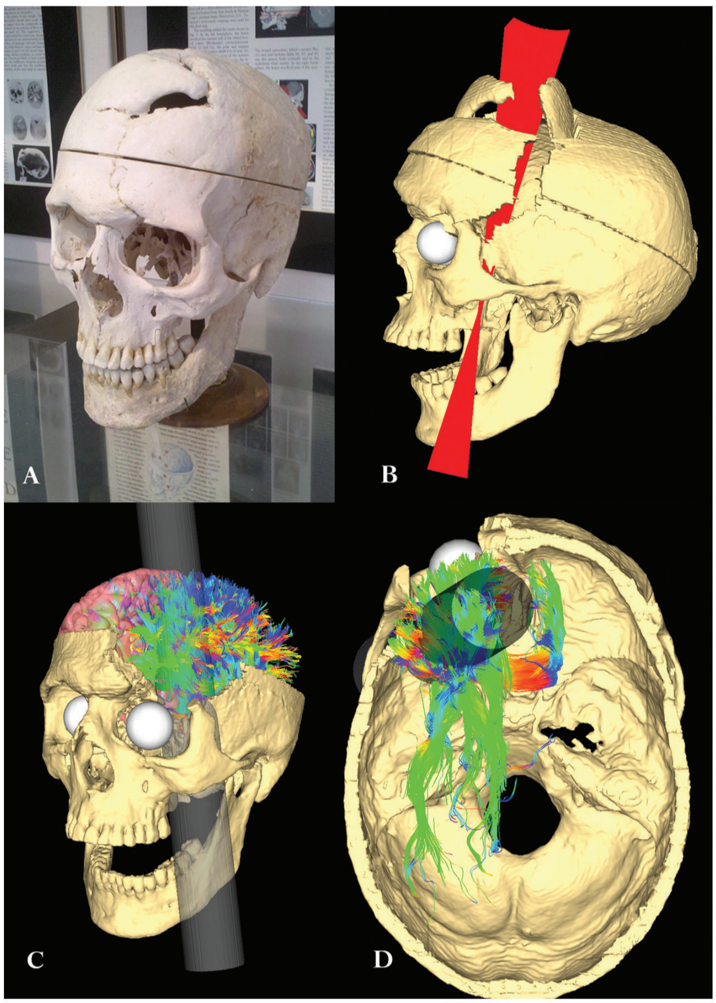
We can learn quite a lot about the connection between brain activity and cognitive abilities by examining patients with cognitive deficits. The first neuroscientists relied on such patients to learn about brain function and how it relates to different cognitive processes. When a patient showed a particular deficit, neuroscientists would identify the area of the brain that was damaged by learning about the patient's disease or accident and, in some cases, by examining their brain after the patient's death. These clinical case studies allowed neuroscientists to begin mapping out the cognitive functions of specific brain areas. However, in more recent years, new brain recording techniques allow researchers to examine brain activity in cases where there is no deficit and to more precisely pinpoint the affected areas in cases where a patient shows a deficit. In this chapter, we consider how cognitive neuroscientists study brain function and review some of the important case studies of clinical patients that helped us learn about the connection between brain function and cognitive processes. In upcoming chapters, we discuss current studies in cognitive neuroscience that contribute knowledge about brain functions that underlie attention, perception, memory, and language abilities.

CLINICAL CASE STUDIES IN COGNITIVE NEUROSCIENCE

As just described, early neuroscientists learned a lot about which brain areas contribute to different cognitive abilities through the examination of clinical patients. Although technological advances have increased the research techniques available, clinical case studies continue to contribute to our knowledge in this area. In this section, we review some well-known clinical case studies to show how these studies have contributed to the field of cognitive neuroscience and discuss the advantages and disadvantages of the case study methodology.

One of the first clinical cases to contribute knowledge about brain function was that of Phineas Gage (Damasio et al., 1994; Harlow, 1868/1993). Gage was a railroad foreman in the mid-1800s. While on the job, a blasting cap drove a metal rod through the left side of his face, up through the frontal lobe of his brain, and out the top of his skull (see Figure 2.1). Gage survived the accident and lived for several more years, but his personality and cognitive abilities were altered from the way he was before the accident. He was less able to control his emotions, and his decision-making abilities suffered. He was no longer able to serve as a foreman because he lacked the cognitive control needed for this role. From this clinical case, we learned that the frontal lobes are important in emotional regulation and decision making.

FIGURE 2.1 ■ Phineas Gage's Brain

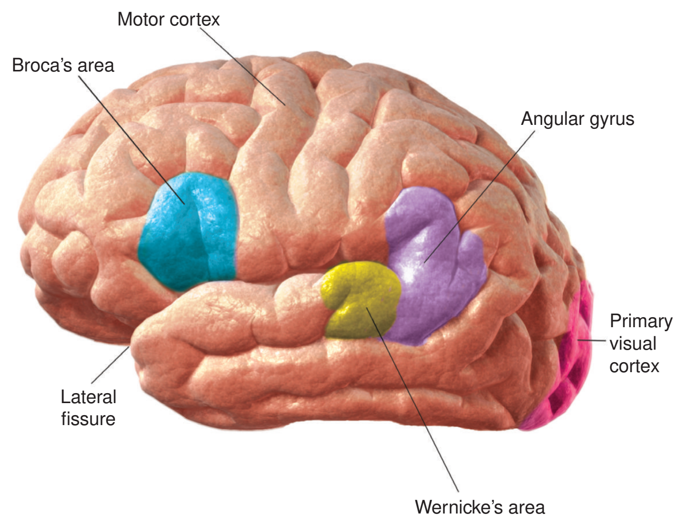


The area of damage to Phineas Gage's brain can be identified by examination of the path of the rod that went through his head.

Source: Van Horn, J. D., Irimia, A., Torgerson, C. M., Chambers, M. C., Kikinis, R., & Toga, A. W. (2012). Mapping connectivity damage in the case of Phineas Gage. *PLoS One, 7*(5), e37454. doi:10.1371/journal.pone.0037454.

Other clinical studies have helped researchers localize language functions in the frontal and temporal lobes of the brain (Rorden & Karnath, 2004). A patient named Tan was studied by Paul Broca in the late 1800s. Tan had been unable to speak for many years ("tan" was one of the only sounds he could produce). After Tan's death, Broca examined Tan's brain and found damage to the left frontal lobe, near the front of the temporal lobe (see Figure 2.2). This location was named Broca's area, and damage to this area causes *Broca's aphasia*, a disorder where a person has difficulty producing speech. Around this same time, another important brain area for language was identified by Karl Wernicke. This area is in the left temporal lobe close to the front of the occipital lobe and is known as Wernicke's area (see Figure 2.2). Damage to Wernicke's area causes a deficit in language comprehension and meaningful language production. A person with *Wernicke's aphasia* can speak, but his or her speech is meaningless. The person produces what is known as a "word salad," where the speech is fluent but incomprehensible. For Broca and Wernicke, clinical case studies were instrumental and contributed to our knowledge about the brain areas responsible for language abilities.

FIGURE 2.2 ■ Broca's and Wernicke's Areas



Broca's and Wernicke's areas can be seen in reference to motor and primary visual cortex areas.

A more recent case study illustrates the role of brain function in a more specific skill: object identification. Oliver Sacks (1990) described a patient who had difficulty in distinguishing between living and nonliving objects. For example, the patient mistook parking meters for children and furniture for people. However, the patient was an academic in the field of music and had little difficulty with other cognitive abilities. He could even identify objects by touch and describe them in detail. His deficit only occurred in visual recognition of the objects. This condition is known as *object agnosia*, the inability to correctly recognize objects. Patients with object agnosia typically have damage in the inferior (lower) temporal cortex, suggesting that the deficit is related to language abilities.

Knowledge about localization of memory function has also been gained from clinical case studies. As discussed in the previous chapter, one of the most well known of these cases is that of H. M., a man who we now know as Henry Molaison, since his death in 2008, who suffered from a form of amnesia where he could remember portions of his life before the damage occurred but could not remember episodes of his life that occurred after the damage (Hilts, 1996). H. M.'s brain lesion was caused by a surgical procedure he received early in his life to help diminish the severity of epileptic seizures from which he was suffering. During the surgery, a brain area known as the **hippocampus** and its surrounding tissue were damaged. After the surgery, H. M. seemed to have lost the ability to form new memories. He would meet new people but would not remember them a few minutes later when they came back into his room. He did not remember world events that occurred after the time of his surgery. It seemed as if the timeline of his life stopped at the point of his surgery. From H. M.'s case, researchers learned about the importance of the hippocampus in memory abilities, but they also learned that the hippocampus is not the only brain structure involved in forming and retrieving all types of memories.

H. M. showed the ability to improve on tasks requiring motor skills, indicating that he could still retain new information and retrieve implicitly (i.e., without intention). Thus, H. M.'s case taught us that the hippocampus is not necessary for all types of memory formation and retrieval but is important for intentional retrieval of memories.

Clinical case studies have revealed important connections between brain function and cognitive abilities. They provide clues to the brain areas most important for different types of cognitive tasks based on an examination of the damaged areas in these patients. However, this points to the major disadvantage of using case studies in neuroscience—the researchers do not control the brain damage. If, for example, the damage is spread across multiple brain areas, it may be difficult for researchers to pinpoint the specific brain areas connected to the cognitive deficits seen in the patients. In addition, researchers are limited to studying those damaged brain areas in patients that are available for them to study. Current neuroscience brain recording techniques provide a means to more precisely identify the brain areas most active during different tasks and to examine the brain areas researchers are most interested in studying. Thus, these recording techniques have helped us overcome the disadvantages present in clinical case studies to further add to the knowledge gained in these studies. In the next sections, we describe some of the techniques cognitive neuroscientists have employed in recent research, but first, we will review the general structure of the nervous system that the brain is a part of.

STOP AND THINK

2.1 Explain why controlled experiments cannot always be conducted to determine how different types of brain damage cause cognitive deficits.

2.2 Describe some of the limitations of using the clinical case study method in cognitive neuroscience.

STRUCTURE OF THE NERVOUS SYSTEM

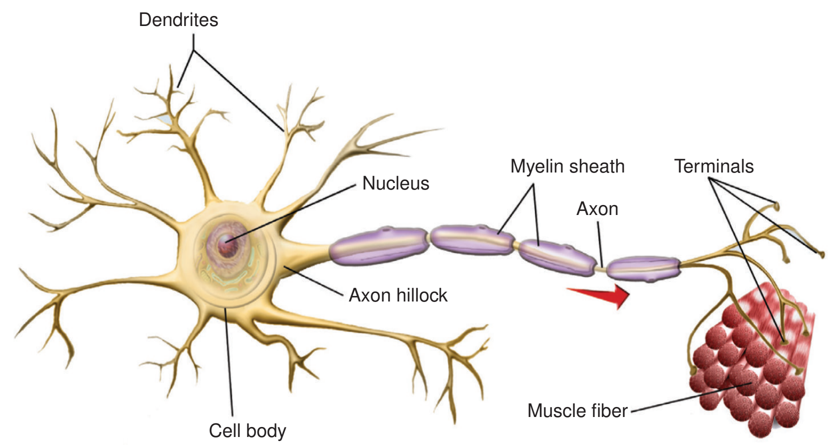
Clinical case studies are still used as a method of study in cognitive neuroscience research. However, advances in technology have also allowed researchers to record the brain activity present in clinical and nonclinical subjects to test hypotheses about what kind of activity is involved in different tasks and where in the brain that activity should be located under different task conditions. The specifics of how these recording techniques work rely on some understanding of the brain and the nervous system, so we will first review the relevant physiology in this section before we introduce the most common brain recording techniques used in cognitive neuroscience research.

The Neuron

The brain is composed of billions of microscopic **neuron** cells forming the basic structure seen in Figure 2.3. Neuron activity is both chemical and electrical. Chemicals called neurotransmitters are first brought into the cell by the **dendrites** at the top end of the neuron. These neurotransmitters provide signals to the cell that are either excitatory (i.e., more likely to fire) or inhibitory (i.e., less likely to fire). The cell body of the neuron takes in these chemical signals from the dendrites and determines if there is enough of an excitatory signal to allow the neuron to fire. If so, an action potential occurs that creates an electrical signal that travels down the neuron's **axon**. This electrical signal is detected in some of the brain recording techniques used by researchers. Once the electrical signal reaches the end of the axon, the terminal buttons release neurotransmitters into the **synapse** to be collected by other neurons nearby. Then the process begins again.

The process of the action potential is what creates the electrical signal in the neuron when it fires. This activity occurs within the axon of the cell. Before the neuron fires, the inside of the axon contains a resting state negative charge due to the division of ions in the fluid inside and outside the cell (see Figure 2.4). The action potential redistributes these ions through channels in the axon's membrane that control the

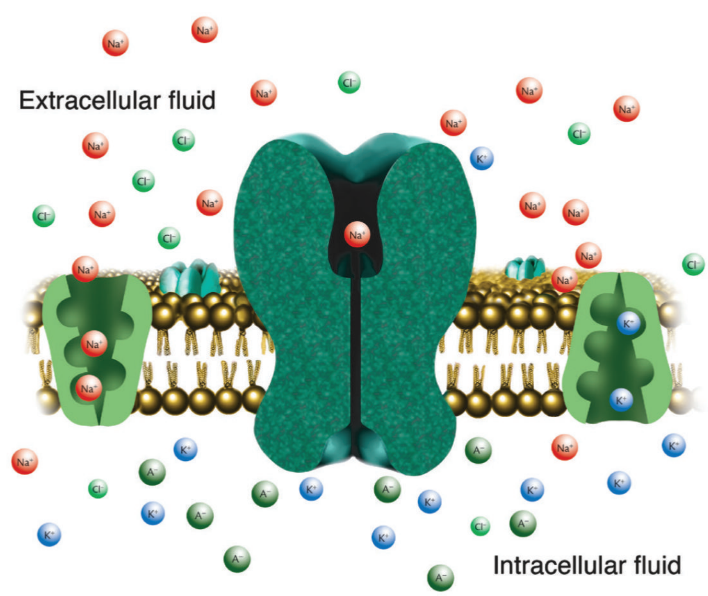
FIGURE 2.3 ■ A Neuron



The neuron is the primary cell that transmits information through electrical and chemical signals in the brain and nervous system. Information is received by the network of dendrites. When enough information is collected by the cell body to reach threshold, an electrochemical signal is triggered, which flows down the axon. At the ends of the axon at the terminal sites, the signal results in the release of neurotransmitters that carry the signal to the dendritic network of other neurons.

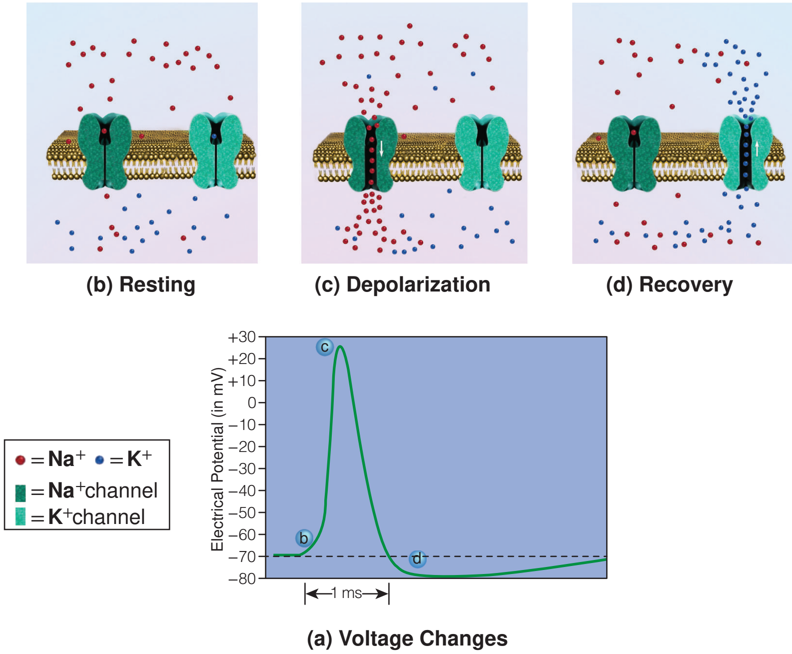
flow of potassium (K^+), sodium (Na^+), and chlorine (Cl^-) ions in and out of the cell (Figure 2.5). When the excitatory signal comes down the axon from the cell body, the axon opens specific channels in the axon membrane to allow sodium to flow into the axon, producing a positive charge inside the cell. The channels open quickly in sequence from the top of the axon (at the axon hillock) near the cell body down to the end near the terminals that contain the neurotransmitter (see Figure 2.6). This positive charge can be detected and recorded by electrodes that are placed either inside the cell or on top of the scalp, as described shortly in the discussion of brain recording techniques. Once the action potential is complete, other channels open in the axon membrane to allow potassium (K^+) to flow out of the cell and the sodium channels close. This redistributes the ions back to the resting negative state inside the axon. The excitatory message then reaches the terminals, and a neurotransmitter is released into the synapse.

FIGURE 2.4 ■ Distribution of Ions Inside and Outside the Resting Neuron



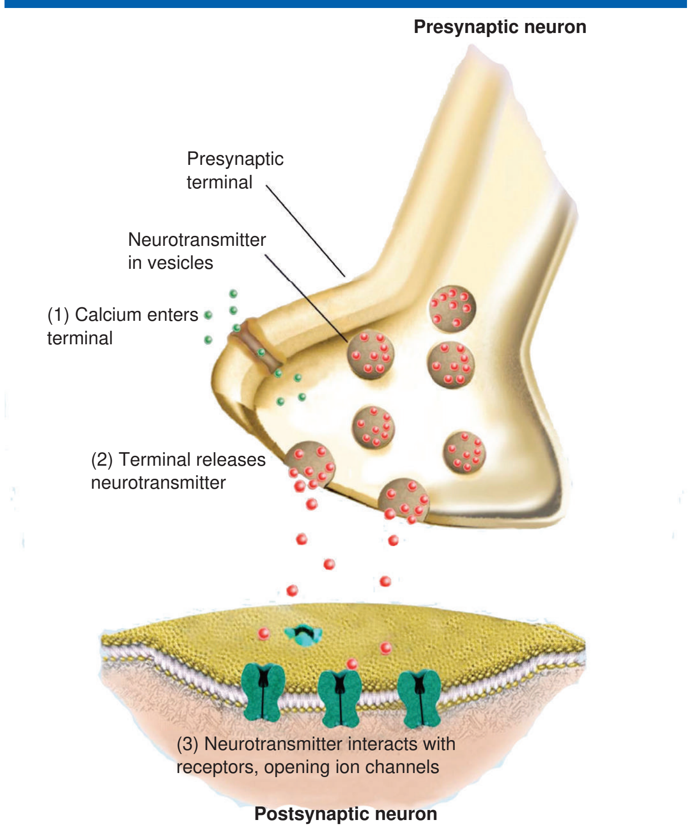
The electrochemical signal that travels down the axon is created by changing the electrical potential inside (intracellular) and outside (extracellular) of the neuron.

FIGURE 2.5 ■ Ions' Movement and Voltages During and After an Action Potential



The electrical potential (voltage—see the curve in the graph) inside and outside of the neuron is changed by the "opening" and "closing" (see panels b, c, and d) of ion channel proteins in the cell membrane.

FIGURE 2.6 ■ Release of Neurotransmitter by the Presynaptic Neuron Into the Synapse



When the signal reaches the end of the axon, it causes vesicles of neurotransmitters to be released into the space between the axon terminal and a dendrite of another neuron. Neurotransmitters flow across this space and attach to receptors on the postsynaptic membrane surface, resulting in the opening of ion channels.

The synapse is the small gap between neurons. Each neuron is connected across synapses to other neurons in an organized network that allows the pattern of firing in the network to translate into specific thoughts or behaviors. This is how information is processed and stored in the brain: through the pattern of firing across multiple neurons within the network (i.e., specific neurons being active or not active or firing at different rates) and types of connections (excitatory or inhibitory) across the neurons connected in each network.

The Brain

The brain is composed of the neural networks described in the previous section, which are organized according to their cognitive functions. This is known as **localization** of function. Many of the clinical cases reviewed in the previous section provided the initial information we have about localization and **lateralization** (i.e., the two hemispheres of the brain contribute to different types of tasks) of brain function through the deficits present in different areas of brain damage. Looking at the kind of task deficits these patients exhibited helped researchers to identify brain areas (i.e., the damaged areas) that were important for completing those tasks. These early studies suggested that different areas of the brain specialized in different functions. Figure 2.7 shows the four lobes of the brain and functions that are localized in those brain areas. Recent research in cognitive neuroscience has used the knowledge gained in early case studies to focus on different areas of the brain as researchers examine the functioning in different cognitive tasks. The brain recording techniques described in the next sections have allowed researchers to go beyond the basic knowledge of localization and lateralization of function to map out more specific brain areas and to piece together full neural systems (i.e., a collection of brain areas organized in pathways) that are involved in different tasks. We explore some of the most recent research in cognitive neuroscience throughout the subsequent chapters that cover different cognitive processes in further detail.

FIGURE 2.7 ■ Diagram of the Four Lobes of the Brain and Functions Localized in These Areas

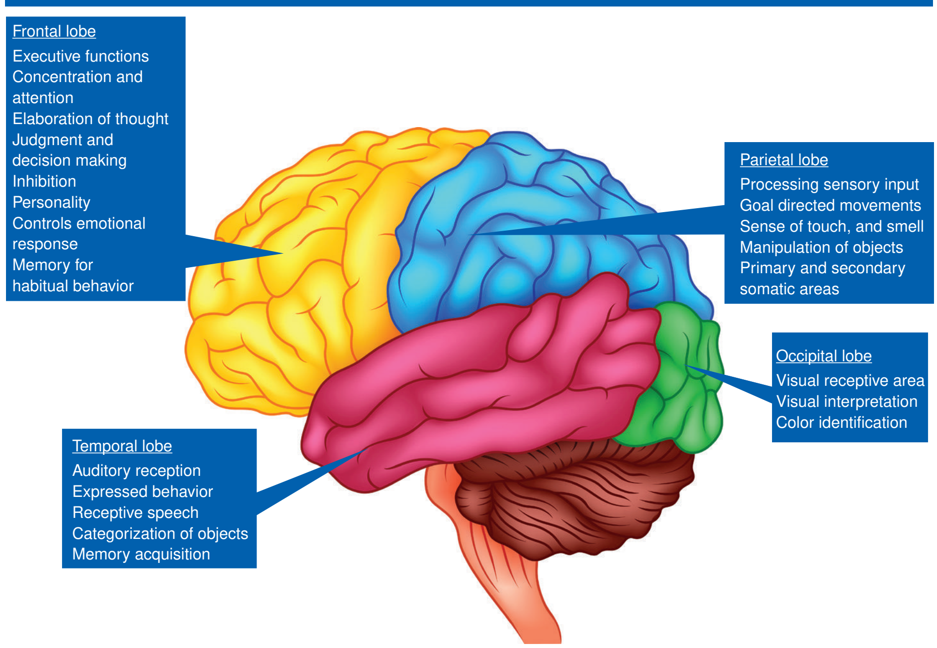


Image credit: iStock.com/Ciawitaly.

Although localization of function can be described as a general feature of the brain, many complex cognitive tasks (e.g., memory retrieval, object identification) have been shown to be a function of distributed processing in the brain. In other words, brain areas work together in systems to process different kinds of information. This idea is supported by research in different areas of study.

For example, a series of brain areas has been found to support explicit memory retrieval (i.e., intentionally retrieving a memory). This system seems to be separate from more automatic or unintentional uses of memory, such as those relied on when we perform a skill or task we know how to do (Squire, 2004). Pulvermüller (2010a) also describes neural circuits for lexical and semantic processes underlying language abilities as "distributed neural assemblies reaching into sensory and motor systems of the cortex" (p. 167). In other words, the processing of spelling, grammar, and meaning of words is distributed across several areas of the brain. Thus, there is localization of function for cognitive processes, but for most functions, multiple areas are organized into processing systems for different cognitive abilities.

MEASURES IN COGNITIVE NEUROSCIENCE: ELECTRICAL RECORDINGS

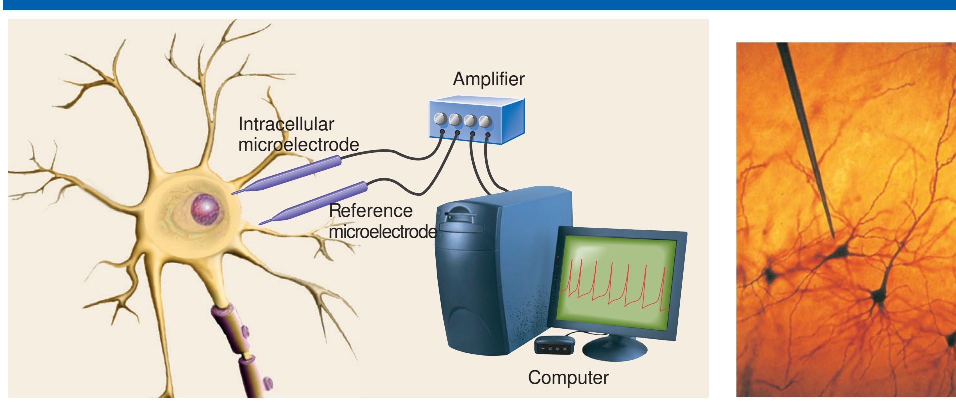
In Chapter 1, we described cognitive research that is conducted within the biological perspective. Using this approach, researchers attempt to connect brain activity with cognitive processes they observe along with some of the other behavioral measures they observed (e.g., accuracy, response time). For example, cognitive neuroscientists have investigated how brain activity differs for accurate and false memories (e.g., Düzel et al., 1997; Webb & Dennis, 2019), which areas of the brain are involved in language production and comprehension (e.g., Gernsbacher & Kaschak, 2003; Hamilton & Huth, 2020), and whether visual areas of the brain are involved in imagery (e.g., Kosslyn et al., 1993; Xie et al., 2020).

Advances in technology have allowed researchers to record different types of brain activity. Some techniques are considered too invasive and are typically only performed with laboratory animals (e.g., single-cell recordings), but many of the brain imaging techniques in use today can record brain activity in humans while they perform various cognitive tasks. However, all the techniques rely on activity of the neuronal cells in the brain. In this section, we review the primary techniques that rely on the recording of electrical charges from neurons in the brain.

Single-Cell Recording

A technique available to record the electrical signals from neurons is single-cell recording. In this technique, a tiny recording needle is inserted into a neuron or set of neurons in an area of the brain the researcher is interested in (see Figure 2.8). However, this technique requires surgical insertion of the needle and bonding to the head to keep the needle steady (see Figure 2.9). Thus, this technique is typically used only in research with laboratory animals. Such recordings have contributed important

FIGURE 2.8 ■ Recording Electrical Activity in a Neuron

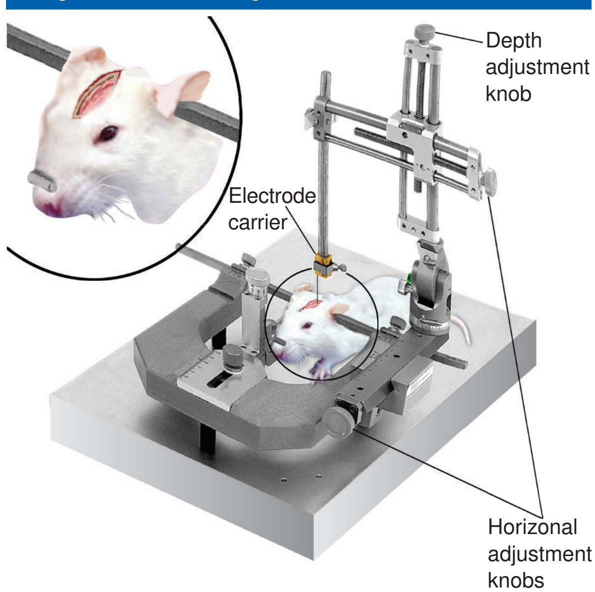


Microelectrodes are inserted into the brain, within the cell membrane. This allows the recording of electrical potential changes over time.

Source: Photo at right courtesy of Bob Jacobs.

information about cognition. For example, using **single-cell recordings** from monkeys, Rizzolatti et al. (1996) discovered an interesting activity in what they called a *mirror neuron*. This neuron fired both when the monkeys picked up an object and when the monkeys were watching the researchers or other monkeys perform that action. In other words, these neurons were active when motor actions were performed and when the monkeys were just watching a motor action they knew how to perform. Since this discovery, researchers have suggested that mirror neurons may play a role in many sorts of social cognition, including understanding others' actions, imitation of others' actions, and facilitation of language through gestures (Rizzolatti & Craighero, 2004). Other work using single-cell recordings has shown that neuronal cell responses can be extremely specific. For example, Quiroga et al. (2005) found neurons in the hippocampus (known to be involved in memory functioning) that were selectively responsive to photos of celebrities such as Jennifer Aniston and Halle Berry in recordings from epilepsy patients undergoing treatment. These results are consistent with the idea that neurons serve as feature detectors (see Chapter 3 for more discussion of feature detection); in this case, the features are specific faces. These neurons have been called "grandmother cells" (Gross, 2002), because they suggest that we might even have a neuron (or set of neurons) that selectively responds to the face of an individual person we know, such as our grandmother.

FIGURE 2.9 ■ Stereotaxic Instrument Used in Single-Cell Recordings



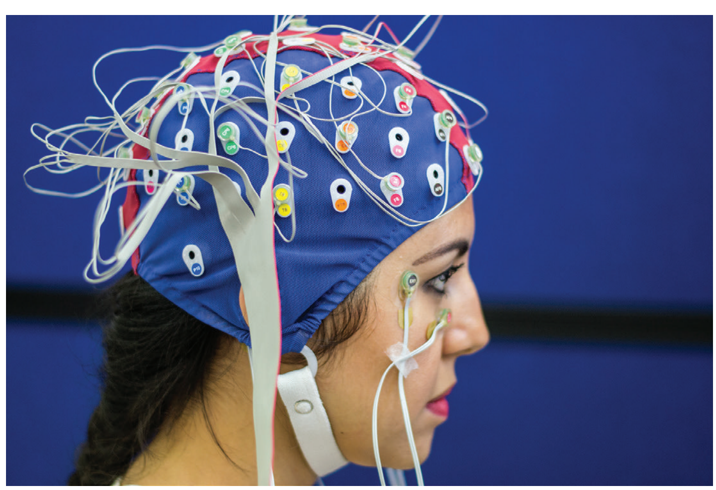


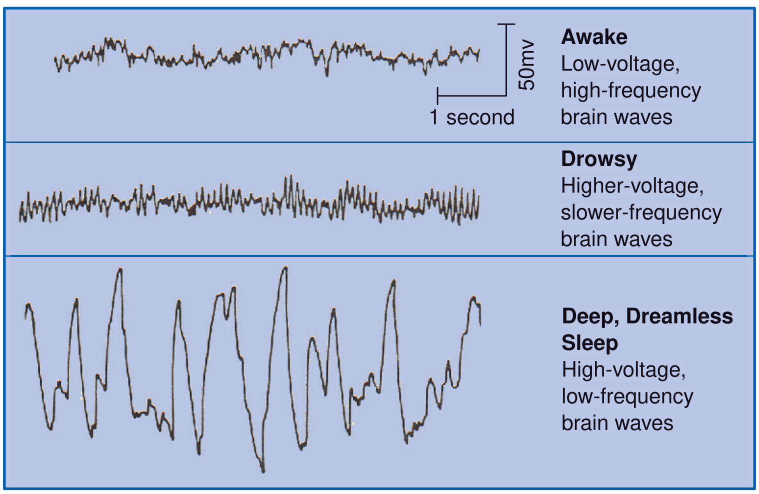
PHOTO 2.1 In recording an EEG, a scalp cap with electrodes in different locations on the head is worn by the participant.

iStock.com/latsalomao

Electroencephalography (EEG)

Another technique that records the electrical signals from neurons is **electroencephalography or EEG**. When recording an EEG, a set of electrodes is placed on the head to record the electrical signals from groups of neurons in different areas of the brain. Because the electrodes are recording from outside the skull, it is the activity of the neurons closest to the skull (primarily neurons in the outer cortex) that is being recorded. The activity is recorded over time to detect changes (positive or negative) in the electrical signals (see Figure 2.10). Researchers can use EEG recordings to examine an **event-related potential (ERP)**, which is a change in activity related to a specific event like the presentation of a stimulus. In that way, they can determine if there is an effect of the presentation of that stimulus on neuron activity and in what general area of the brain the effect occurs. Electrical activity patterns can be overlaid onto a map of the brain to show the general location on the cortex of the different levels of electrical activity.

FIGURE 2.10 ■ Sample EEG Recording



Source: Based on Hauri (1982).

An example of EEG/ERP research is provided by Gibbons et al. (2018), who recorded ERPs during a simple classification task ("Is this an animal or a plant?"). Prior to completing the task, each participant randomly selected two of the stimuli that they were instructed to intentionally mis-categorize (e.g., press the "plant" button when seeing the word "frog"). Voltage recordings were similar for items the participants truthfully classified. However, the electrical activity recorded in the ERP showed different patterns for the trials on which the participants intentionally responded incorrectly. For these trials, the recordings of the signals contained artifacts from areas associated with increased visual attention.

Magnetoencephalography (MEG)

A newer technique that records electrical signals from neurons in the brain is **magnetoencephalography (MEG)**. Instead of electrodes placed on the head as for an EEG, MEG involves placing the head in or near an electrical scanner that can detect electrical activity with better location accuracy than EEG. As with EEG recordings, MEG recordings can occur during a task such that changes in activity can be detected that correspond to the presentation of cognitive stimuli. However, as with EEG, MEG is limited to recordings on the outer cortex and cannot provide a good measure of activity occurring below the cortex (Gross, 2019).

Although MEG seems to be used less often than EEG due to equipment costs, it has been used in a number of studies for recording electrical activity. For example, Alexandrou et al. (2017) used MEG to examine the brain activity of participants who were processing naturalistic speech. In

PHOTO 2.2 A patient sits in a new brain scanner at the magnetoencephalography department of the Erasme hospital of Anderlecht in Brussels, Belgium.

Mark Renders/Stringer/Getty Images Entertainment/via Getty Images

contrast to many results of studies that focus on isolated words and sentences, they demonstrated that processing naturalistic language engages cortical areas not only in the left hemisphere but also in the right hemisphere.

Electrical Stimulation/Inhibition of Neurons

Another technique that relies on the electrical activity in the brain involves **transcranial magnetic stimulation (TMS)**. With TMS, researchers use a magnetic field to excite or inhibit neuron activity to investigate functioning in specific areas or processing systems of the brain. Like EEG and MEG, this technique is noninvasive, as it involves tracing a magnetic coil over the area of the brain the researcher wishes to study (see Figure 2.11). The electrical activity (an increase or decrease) can then be recorded using one of the brain imaging techniques discussed in the next section (e.g., magnetic resonance imaging). Studies using TMS have shown that some cognitive tasks (e.g., making spatial judgments for visual stimuli) use a broader range of brain areas than what was previously thought using other brain recording techniques (e.g., Sach et al., 2007).

A similar technique is **transcranial direct current stimulation (tDCS)**. Like TMS, neuron activity can either be excited or inhibited using this technique. However, where TMS uses a magnetic field to create the electrical current, tDCS delivers a small electric current to the brain through electrodes attached to the scalp. Thus, it is also a noninvasive technique. The tDCS technique is cheaper and easier to use than TMS but produces a weaker effect on neuron activity than TMS.