

Preface

Welcome to cognitive psychology! We wrote this text to share our love of cognitive psychology with students learning about this exciting area of the field. This latest revision reflects feedback from instructors and students who have used the text in its earlier editions.

Our main goal in writing this text is to engage students in this exciting field through connections to everyday situations they might encounter. Each chapter begins with a real-world situation or story, and we include further everyday examples in a student friendly and personal writing style throughout the chapter content. However, we also focus on the methodology of obtaining new knowledge in this field as a way to allow students to gain a researcher's perspective in studying these topics. This focus also helps students 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 third edition.

Each chapter contains connections to other chapters in the text, such that instructors can choose to cover topics in the order they wish. We also focus on connections across the different topics (as well as 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 understand the studies presented in the chapters to come. Chapter 2, "Cognitive Neuroscience," is presented early in the text to give students background on the methods used in this subfield and the biological mechanisms the methods rely on for measurement. We then embed neuroscience studies in the subsequent chapters, where they supply 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. We include the full reference for each article 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 chapter topics and think about the design (and reasons for the design) used in the study.

Chapters also include Stop and Think sections throughout to help students pause at the end of a reading section to consider and apply 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 in an Appendix at the end of the text.

An outline follows of the most significant changes to the current edition:

- Updated research examples and citations throughout the text
- Added additional key concepts to the Glossary and as Key Terms in the chapters
- In Chapter 1, added a new section—Theory, Process, and Methodology—to set up the text themes, plus a new section on the importance of diversity in participant populations in the field

- Added new research on forgetting in Chapter 6 and updated research on Highly Superior Autobiographical Memory
- Updated examples of the Seven Sins of Memory in Chapter 7
- Reorganized the Language topics in Chapter 8 to focus on key concepts and add new topics on Sign Languages and Language in Technology Use
- Added discussion of aphantasia and hyperphantasia and reorganized topics to include nonvisual imagery at the beginning of Chapter 10
- Added new real-world reasoning examples and expanded discussion of theory in Chapter 12
- Added a section on AI-assisted decision making and updated neuroscience research on this topic in Chapter 13
- Added a few additional concepts on cognitive development based on reviewer feedback to Chapter 14

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

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Chapter 1

Introduction to Cognitive Psychology



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Learning Objectives

- 1.1 Describe cognitive psychology and its historical origins.
- 1.2 List the different perspectives that guide the study of cognition.
- 1.3 Compare the different scientific methods used by cognitive psychologists.
- 1.4 Identify the observable behaviors that are used to understand cognitive processes.

Questions to Consider

- What is cognitive psychology and how did it develop as a field?
- How have psychologists approached the study of cognition?
- What types of research methods are used 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 was dim. As I looked up, I realized that three light bulbs had burned out. I also noticed they were each a different type of bulb. I jumped into the car and headed to the grocery store for more light bulbs. I entered the store, grabbed a cart, and headed down an aisle. “While here,” I thought to myself, “I may as well pick up some other things that we need.” As I walked 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 a similar generic brand was listed as, “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. Because I usually shop at this store, I navigated it quickly, checking items off my mental list as I selected them. At the checkout counter, the cashier asked me, “Paper or plastic?” I hesitated, realizing I left my reusable bags in the trunk of the car and replied, “Plastic, please.” After paying, I exited the store, drove home, then 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 went to the store to get: light bulbs!

What Is Cognitive Psychology?

In the story about grocery shopping 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 such as grocery shopping to more complex tasks. Reading the preceding story may have brought to mind similar events that have happened to you: walking upstairs in your house and then forgetting why you went up there, making a decision about whether a “deal” will actually save you money, trying to remember tasks you have to do or items you need to buy. Cognition is involved in so much of what we do that it is difficult to come up with events in our lives that do not involve cognition. In fact, thinking about what cognitive psychology is involves cognition. A simple answer to the question about cognitive psychology is that it is the study of mental processes. However, as a student of psychology, you probably already know that few questions in psychology have simple answers, and the question “What is cognitive psychology?” is no exception. A more complete answer to this question is that cognitive psychology includes the following:

- The perceptual processes we use to make sense of the world around us. Our sensory systems provide us the raw material we need to interpret what is around us, such as noticing that the kitchen lights are dim and that there are three different sized light bulbs.
- The attentional processes that allow us to focus on a particular stimulus in our environment, such as the brightly colored sign advertising a sale price in a grocery store.
- The memory processes that allow us to remember episodes, information, and intentions when we attempt to retrieve them, such as remembering—or not remembering—to buy light bulbs at the store.
- The language processes that help us communicate our thoughts and ideas with others, such as reading the advertisement for the cereal or understanding that the cashier’s question (“Paper or plastic?”) refers to the type of shopping bag.
- The decision-making processes that can be both helpful and hindering, such as trying to decide if the “buy one, get one free” deal is truly going to save money if no one in your family will actually eat that brand of cereal.
- The metacognitive processes that are used 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 list may seem long, but it only touches briefly on some of the major areas studied in the field of cognitive psychology.

Theory, Process, and Methodology

As just described, cognitive psychology involves the study of mental processes with a focus on language, perception, attention, memory, decision making, problem solving, and reasoning. To study these processes, cognitive psychologists develop a **theory** or testable description about how the processes work and what effects they will have on behavior. These theories are then tested in research studies using one of several different kinds of methods designed to examine the processes of interest.

Consider a simple example: A researcher has a theory that memory can be strengthened by retrieval practice, meaning that the more often someone practices remembering something, the more likely they will remember it accurately in the future. To test this theory and the prediction it suggests, the researcher designs a study comparing memory accuracy for groups of people who complete different activities after reading a paragraph about sea otters (see Chapter 6 for research testing this idea). After initially reading the passage, one group is asked to reread the paragraph over and over for 5 minutes. The other group is asked, after the initial reading, to write down everything they remember from the paragraph for 5 minutes. The researcher then gives both groups a final memory test on the main concepts from the paragraph and compares the scores.

This example shows the three key elements of cognitive psychology: a *theory* about how cognition works (practice remembering improves memory), the *process* of interest (memory retrieval), and a research *methodology* for studying the theory and process (conducting a study to compare data from groups of people who do different cognitive tasks). Put simply, this is what you will be reading about in this text. In this chapter we introduce some of the main ways that cognitive psychologists think about the processes they study and the most common methods they use to study those processes. But first, let's briefly consider how the field of cognitive psychology developed into what it is today.

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. Some of the earliest psychological research studies were designed to answer longstanding philosophical questions about human cognition. 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 conducting basic 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 by examining the relation between changes in environmental stimuli, such as light and sound, and how those changes were experienced by people in his studies.

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 classical conditioning by Ivan Pavlov), prominent behaviorists John Watson and B. F. Skinner argued that introspective methods were subjectively biased, unreliable, and impossible to observe and measure. 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 little to no interest in mental processes.

Although the behaviorist perspective was common in the United States for almost half a century, in Europe, psychological research 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. In 1932, Sir Frederick Bartlett, an English experimental psychologist who conducted memory research at the University of Cambridge, published a book entitled *Remembering*.



Noam Chomsky: His work in linguistics had a strong impact on the early development of cognitive psychology.

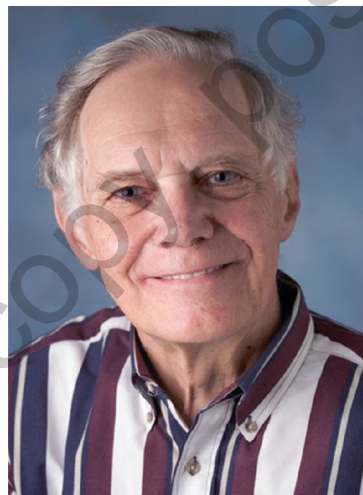
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An important event that weakened the stronghold of the behaviorist perspective was an argument against the behaviorist approach to language learning by the linguist Noam Chomsky. Skinner (1957) proposed that language learning occurs through operant conditioning processes, consistent with the popular behaviorist perspective at that time. He suggested that language abilities develop through the imitation of speakers around a child and the feedback the child's speech elicits (i.e., reinforcement or punishment). Chomsky (1959) presented a strong counterargument to this proposal: A critical piece of evidence against the behaviorist perspective of language development was the simple fact that children produce language that they have never heard before and for which they have never been reinforced. Children produce original sentences that do not imitate adult speech. They use incorrect grammar that has never been modeled for them. 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 that occur in humans.

From Chomsky's argument, psychologists began to realize that the study of nonobservable cognitive processes is an important part of understanding behavior—and that understanding the processes behind the visible behaviors is necessary to advance our understanding of the mind and behavior in important ways. Still, the behaviorist focus on the experimental examination of behavior shaped the way cognitive researchers approach the study of mental processes. Experimentation is still the focus, but cognitive psychologists examine behaviors (such as response times and accuracy in task performance) that result 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 class session in 1956 by announcing to his students that, “Over the Christmas holiday, Al Newell and I invented a thinking machine” (Simon, 1991, p. 206). Computers presented an information-processing model that could be applied to 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 changing that information as learning takes place. Cognitive processes were the “software” that processed the information, whereas the brain was the “hardware.” The information-processing model helped psychologists think about cognition in a new way, which led to 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 common language that allowed researchers to discuss the processes of the mind and their connection to the brain.

Another important milestone in the development of cognitive psychology as a coherent field of study was a 1967 book by Ulric Neisser that integrated memory, perception, attention, and language as a unified field. Neisser created the term *cognitive psychology* (and used it as 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.



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.”

Source: Sandra Condry/Cornell Department of Psychology

If we consider Neisser's 1967 book to be the first cognitive psychology textbook, we can compare his with the current text to see some of the ways that the field has changed in the intervening decades. For one thing, the topics in this text are broader in scope than those considered by Neisser when he first described cognitive psychology. For example, in each chapter of this text, you will find a discussion of work in **cognitive neuroscience**, a field that examines the biological basis of cognitive processes. Cognitive neuroscience brings together different topics under the umbrella of a biological perspective on the study of cognition. Cognitive neuroscience is further discussed in Chapter 2 and

comes up throughout the book, as research in neuroscience informs theory about many different cognitive processes. In another example of how cognitive psychology has changed, 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, which is a core cognitive process that is related to attention (Chapter 4), concepts (Chapter 9) and imagery (Chapter 10). Finally, cognitive psychology is not an isolated field. It has important connections to other fields, such as social psychology, philosophy, biology, economics, and law. You will see some of these connections illustrated in the text as we discuss the interdisciplinary research that is inspired by and informs cognitive psychology.

Stop and Think

- 1.1 Which of your own everyday behaviors do you think would be of interest to cognitive psychologists?
- 1.2 Explain how cognitive psychologists have used the computer as a model for describing cognitive processes.
- 1.3 Consider your own ideas about cognitive processes. What theories do you have about how these processes operate?

Current Perspectives on 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 approaches the goal of understanding cognition through different perspectives. In this section, we discuss a few of the most influential perspectives to help you better understand why researchers have focused on some of the research questions we discuss later in this text. These perspectives 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.

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 perspective** is that knowledge about the world is represented in our minds such that cognitive processes can "operate" on the representations. If you read about armadillos or see a documentary about them, you might change or add to this stored information as you learn more about armadillos than you 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 symbols (e.g., 2 and II are both symbols used to represent the concept of two) are operated on, such that we can manipulate these symbols using different types of operations. This perspective allowed researchers to study these 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 (or



How do you think a concept like “armadillo” is mentally stored in our minds?

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hear or taste) 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 perspective arose from the computer and information-processing models of cognition described in the previous section. Information is stored in computers in the form of 0s and 1s that form chains of “off” and “on” signals. This process 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 psychologists and neuroscientists have considered information as being represented in the mind through the “on” and “off” firing patterns of groups of neurons. This comparison 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 **cognitive neuroscience perspective** (described 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 used 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 cognitive neuroscience perspective described later in this section.

Embodied Cognition

Another perspective on the study of cognition views our cognitive processes as providing a means of interacting with the world around us. In this view, for example, 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, such as 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 perceptual processes depend on our interactions with the world around us. More about this perspective is discussed in each of the later chapters where this perspective has been applied.



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

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Cognitive Neuroscience

We have already briefly discussed the role biology plays in the study of cognition when we considered the area of cognitive neuroscience and its connection to the representationalist perspective. However, some researchers have considered the study of cognition from a neuroscience perspective, a view beyond just the specific brain activity associated with different cognitive processes. These researchers build theories of cognition using knowledge of how the brain works and which areas of the brain play a primary role in different cognitive behaviors. In other words, cognitive neuroscientists propose theories and develop models based on networks of neurons and knowledge of brain structures. Research in cognitive neuroscience has revealed important differences across many of the processes discussed in this text. For example, studies of patients with amnesia have shown that some types of new memories can be encoded and retrieved (Warrington & Weiskrantz, 1974), and studies examining brain activity have shown that distracted driving shows distinct neural activity from undistracted driving, which may eventually help

reduce distracted driving behaviors (Bargshady et al., 2025). 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. In the next sections of this chapter, we will introduce some of the research methods used by cognitive neuroscientists in their studies. In Chapter 2, the cognitive neuroscience perspective is discussed in more detail, along with some key findings from this area of research.

Stop and Think

- 1.4 Compare and contrast the three perspectives on the study of cognition described in this section.
- 1.5 Given what you know so far about cognitive psychology, which of the perspectives 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 methodology and more broadly on observations of behavior to understand cognitive processes. Throughout this text, we review research used to develop many of the major theories and knowledge within cognitive psychology. In this section, we briefly review some basics of the scientific method and different research methodologies commonly used in the discipline.

The Scientific Method

Researchers in psychology rely on the **scientific method** to gain knowledge about behavior. This method is grounded in four core principles: empiricism, determinism, testability, and parsimony. **Empiricism** is the principle that systematic observation is the key to understanding new things. In the case of cognitive psychology, the “things” that we want to know are the mental processes that underlie human (and sometimes other animal) behavior. These observations can be tricky for cognitive psychologists because it is difficult to directly observe mental processes. However, there are observable outcomes of these processes that can be readily measured (e.g., remembering—or forgetting—to buy lightbulbs, deciding which cereal to buy, selecting plastic instead of paper bags). These outcomes (remembering something, selecting X rather than Y) are assumed to be the result of internal mental processes. Therefore, much of cognitive theory is based on clever, indirect observations and measurements of these processes. **Determinism** is the principle that behaviors have underlying causes and that “understanding” involves identifying these causes 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 explanation 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 grocery shopping story that started this 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% off a higher-priced cereal that your family will eat or 50% off a lower-priced cereal that your family will not eat.

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 they are thinking about the deal as either a gain or as reducing potential loss. How the deal is presented may have an impact on how shoppers view the deal. Imagine that the store is selling a new type of cereal, and you’re not sure if you or your family will like it. Consider two ways of presenting what is essentially the same deal for the new cereal: “buy 2, get 50% off,” or “buy one, get one free.” If you buy two boxes with an initial price of \$1 each, you’ll pay only \$1 total with either deal. The first case frames the deal in terms of price savings (a reduced loss), the second in terms of getting extra product (a gain). With a starting price of \$1, consumers may perceive 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. In the sections that follow, we briefly review the types of research methods commonly use in cognitive psychology and how they are used by cognitive psychologists. These methods can generally be classified into three types: case studies, correlational studies, and experimental studies.



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

Source: iStock.com/VLG

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.), who died in 2008, was one of the most studied individuals in psychology (while they are alive, initials or pseudonyms are often used to protect patient identities in this type of research). 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 (i.e., anterograde amnesia). H. M. was the subject of numerous studies from 1957 to his death in 2008 (Squire, 2009). Theories of how memory is organized are largely based on this work.

Let's apply the case study methodology to our shopping and decision-making example from the beginning of the chapter. A researcher might decide to make a case study of someone who identifies as an "extreme couponer." To investigate their decision-making processes, you systematically observe this person's behavior over a long period of time, using a variety of measures to collect the observations. For example, you may directly observe them while they shop, ask them to keep detailed records of their shopping behaviors, and ask them to "think out loud" as they engage in shopping-related decision processes. The advantage of a case study is the sheer number of intensive observations that may be collected and examined. This method allows the researcher to identify many of the variables that may be relevant to the processes of interest and to speculate about the relations between these variables. The major disadvantage of this approach is that it centers on describing and explaining the behavior of a single, often unique, individual. As a result, it can be difficult to make broad generalizations of the results to other individuals.

Correlational Studies

A **correlational study** allows researchers to systematically observe individuals, 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 their 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. Turning again to the shopping story, a researcher might set up a camera in the cereal aisles of 15 grocery stores and record video of customers' buying behaviors over the course of a month. As stores change prices and deals, how frequently people buy the cereals can be recorded. Additionally, other potentially relevant variables (e.g., size of boxes, time of day, gender of people) can be considered. Not surprisingly, correlational studies are often analyzed using correlational procedures. Suppose that in this example, the researchers found a negative correlation between the price of cereal and the amount consumers purchased. This negative correlation simply shows 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, such that both go up or down together). Data like these may be used for theory testing. For example, if the researchers' theory predicts a negative relationship between price (an explanatory variable) and the amount of buying (a response variable), then these data may provide 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 behaviors as they naturally occur, determining the causal relationships between variables is extremely difficult. Thus, although correlational studies have the advantage(s) of allowing the observation of many variables at once, within relatively natural situations, one should not make cause and effect generalizations based on these methods. For example, it is possible that the price did not cause the change in buying behavior, but instead, something related to the price caused the buying behavior (e.g., advertisements showing the low price grabbed the attention of shoppers). Without having control over these other variables, researchers won't know if the relation between the measures (in this case, price and number of boxes bought) is a causal one.

Experimental Studies

A research method that allows for a better test of a causal relation is an experiment. The majority of the research reviewed in this text uses an experimental method. An **experimental study** is designed to simplify the situation 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 you want to know whether people prefer the taste of one type of sugar substitute over another. You design an experiment in which you ask one group of people to taste a beverage with one type of sugar substitute (Sweetener A) and rate how much they like the taste. You ask another group to rate how much they like the taste of a beverage with the other sugar substitute (Sweetener B). Then you compare the ratings of the two groups. In this example, the behavior of interest (the dependent variable) is measured by the tasters' ratings. The independent variable is which sugar substitute is presented to each group (A vs. B). However, the perception of taste is complex, with many different variables influencing it (e.g., the temperature of the drink, what smells are present, appearance). To keep your observations focused on the sweetener, you should keep all other variables constant for everybody in the study. That is, the *only* difference between the beverages in the two groups is the type of sweetener used, which means that the same type of beverages would be used (e.g., cola), at the same temperature, in the same type of glass, in the same setting. 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. If you served Sweetener A in cola, but Sweetener B in lemonade, would you be able to say that any difference in ratings was due to a preference for one of the sugar substitutes?

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. In this example, a researcher might design a study to determine if ratings for Sweetener A and Sweetener B are different when they are in cola versus when they are in lemonade (which has a tart taste). This study would end up with four combinations of Sweetener Type (A vs. B) crossed with Beverage Type (Cola vs. Lemonade). Here, the researcher is manipulating two independent variables. This is known as a factorial design. This type of design allows us to determine if the perception of the sugar substitute *depends* on the type of drink (cola vs. lemonade).

To further describe how a factorial design works, let's go back to the example from the previous section. Imagine designing an experiment to look at how advertising type affects cereal buying behaviors. From the theory outlined earlier, we may predict that the framing (focusing on reduced price or product gain) and the initial price of items will have an impact on the decision making of shoppers. To examine this hypothesis experimentally, we use a factorial design and 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 "buy two, get 50% off" (emphasizing reduced price) and the other two groups with products labeled "buy one, get one free" (emphasizing product gain). 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. Notice that everything else about the ads is the same, except for these two variables (price and framing). This type of experimental control ensures that other differences between the ads can't be the cause of differences in buying behavior across the groups.

For the 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: the effect of the initial price variable and the effect of the framing of the deal variable are tested separately. However, the design also allows us to examine how these two variables interact with one another to influence purchasing decisions. The test of the interaction between the variables will tell us if the framing effect *depends* on the price listed for the cereal. 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 "buy 2, get 50% off" deal than the "buy one, get one

free” deal. In addition, the overall effect of pricing was that participants were more likely to buy two boxes when the initial price was \$1 than \$5. The final graph shows how these two variables interact with one another to form a more complex relationship. In this graph (right side of Figure 1.2) it becomes apparent that the framing effect really only has a strong impact on likelihood to buy two boxes when the initial price is \$5, with participants much more likely to buy two boxes with the 50% off deal than the buy one, get one free deal. However, when the initial price was \$1 (left side of Figure 1.2), there was no difference in likelihood between the two framing conditions.

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 while keeping all other features of the advertisement the same.

	Price-reduction focused	Product-gain focused
Low initial price	 \$1.00 SALE 50% off	 \$1.00 SALE Buy 1, get 1 free
High initial price	 \$5.00 SALE 50% off	 \$5.00 SALE Buy 1, get 1 free

Source: Hemera Technologies/PhotoObjects.net/Thinkstock

By virtue of experimental control and the explicit manipulation of independent variables, researchers can be more confident about testing cause and effect relations 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 validity*). Because the experiment is explicitly designed to simplify the situation surrounding the behavior of interest, it opens the door to the potential that the results are applicable only to those simplified situations. 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 because sometimes the control used in the experiment results in behavior that is not typical for the participants.

Furthermore, a complete experimental design isn't always possible because we may not be in a position to truly manipulate the independent variable. For example, suppose we think that older and younger adults may differ with respect to their decision-making behaviors when shopping. We could design an experiment like the one described earlier but add age group as an additional variable. In this example, age group is a **quasi-independent variable** because we are not actually able to manipulate our

participants' age (i.e., we can't randomly assign some people to the older adult condition and others to the younger adult condition). Because age 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 age variable, one needs to be appropriately conservative about making causal claims.

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.



Stop and Think

- 1.6 What core principles is the scientific method founded on?
- 1.7 What are the main differences between a case study, correlational designs, and experimental designs?
- 1.8 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, then design a research study to examine how those variables are related.

Measuring Cognitive Processes

In most of the examples we've discussed so far in this chapter, the behavior of interest was an observation of 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, 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 belief, combined with the internal nature of thought (as something that goes on inside the

head), led most researchers to assume that thought was unmeasurable. That changed when 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 participants 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., for the grocery 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 grocery 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? Did you include any details that weren't in the story? 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).

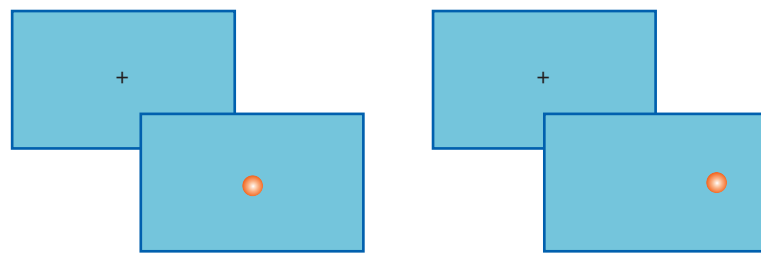
However, accuracy isn't always just about how many items you can correctly recall; it can also be about the number and kinds of errors you make. Consider the case of eyewitness testimony. When witnesses are asked to recall details of an event, some of the details they "remember" can be inaccurate. As you will read in Chapter 7, research examining how and why people have these "false memories" has greatly shaped our theories explaining how memory works. Similarly, perception researchers have examined perceptual illusions (inaccuracies in how we perceive the world) to better understand how we perceive different kinds of stimuli (see Chapter 3).

Response Time

Another widely used method to examine cognitive processes is a measure how long it takes to respond to a stimulus. One of the earliest and most influential sets of experiments on response time was conducted by Franciscus Donders (1869/1868). 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 (i.e., a choice response time task). 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 operate 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.

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.

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

**Simple response time**

Press the button when you see the light.

Choice response time

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

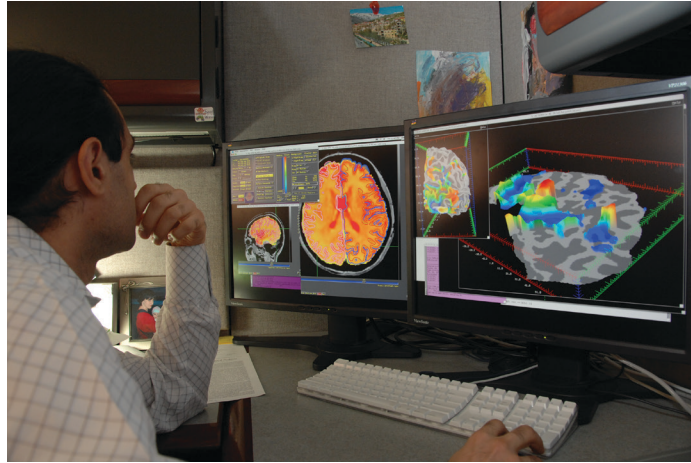
Priming tasks are common in the field of cognitive psychology (a search for “priming” in an article database yields thousands of articles). In a typical priming task, participants respond to a series of stimuli (e.g., “Press the right button if the string of letters is a real word. Press the left button 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 stimulus 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 response 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). Another response time measure involves monitoring eye movements during a task. 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 where the eyes look and processing in 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, 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. This is also a common measure used to determine what preverbal infants are interested in, which tells us about what they find to be new or novel. You will read about research using this method in Chapter 14 on the development of cognitive processing.

Neuropsychological Measures

Within the rapidly changing field of cognitive neuroscience, technological advances in brain imaging techniques have led to the development of brain visualization measures. Brain activity from different areas of the brain can be measured and connected to processing during task performance. For example, using methods like electroencephalography (EEG) and functional magnetic resonance imaging (fMRI), researchers are able to observe 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 accuracy and response time measures to gain new insights into the nature of mental processing (e.g., Posner, 2005).



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

Source: National Institute of Mental Health

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—we are not directly measuring the processes themselves. Given this limitation, you should always critically evaluate the assumed connection between the behavior measured and the cognitive process of interest in the research.

Study Participants

One issue that exists in cognitive research is who the study participants are. An assumption often made by researchers is that cognitive processes work the same way for most individuals. In many cases this assumption may be accurate, but unless we conduct cognitive research with a wide range of diverse individuals, we don't know which processes are similar across groups of people and which are different. The majority of cognitive research to date has been conducted on what have been called WEIRD populations—individuals from Western, Educated, Industrialized, Rich, and Democratic societies (Henrich et al., 2010). The common use of participant pools at colleges and universities has contributed to this issue, creating a large body of research findings based on a small subset of the people in the world, with little diversity. When researchers have recruited participants from more diverse populations, however, their findings have shown that some differences exist. For example, researchers found differences in the events people recalled from periods of history across people from different nations (Roediger & DeSoto, 2014), how faces are perceived between Eastern and Western cultures (Blais et al., 2021), and how category items are processed (Rosch, 1978). Gutchess and Rajaram (2023) argue that consideration of culture, broadly defined, can help researchers identify which cognitive processes are influenced by one's culture and which are universal across cultures. This knowledge can advance development of accurate theories in cognitive psychology. While acknowledging that not every research study in this field should focus on culture, these researchers provide suggestions for increasing the diversity of participant samples, including reporting cultural identities of research participants to provide a record of who the results may generalize to, the inclusion of international students in participant samples and research teams, and cross-cultural collaboration in research studies to provide more diverse views on the design of the studies and access to multicultural samples. There has been some

progress on this issue in recent years, but consideration of the experiences and identity of the people a researcher measures cognitive processes from is important in this field of study.

Stop and Think

- 1.9 What are two commonly used dependent measures in cognitive psychology?
- 1.10 Briefly explain the logic used in Donders's subtractive method.
- 1.11 Think back to the shopping story that started the chapter. Suppose that you were interested in studying how the shopper understood the cashier'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.

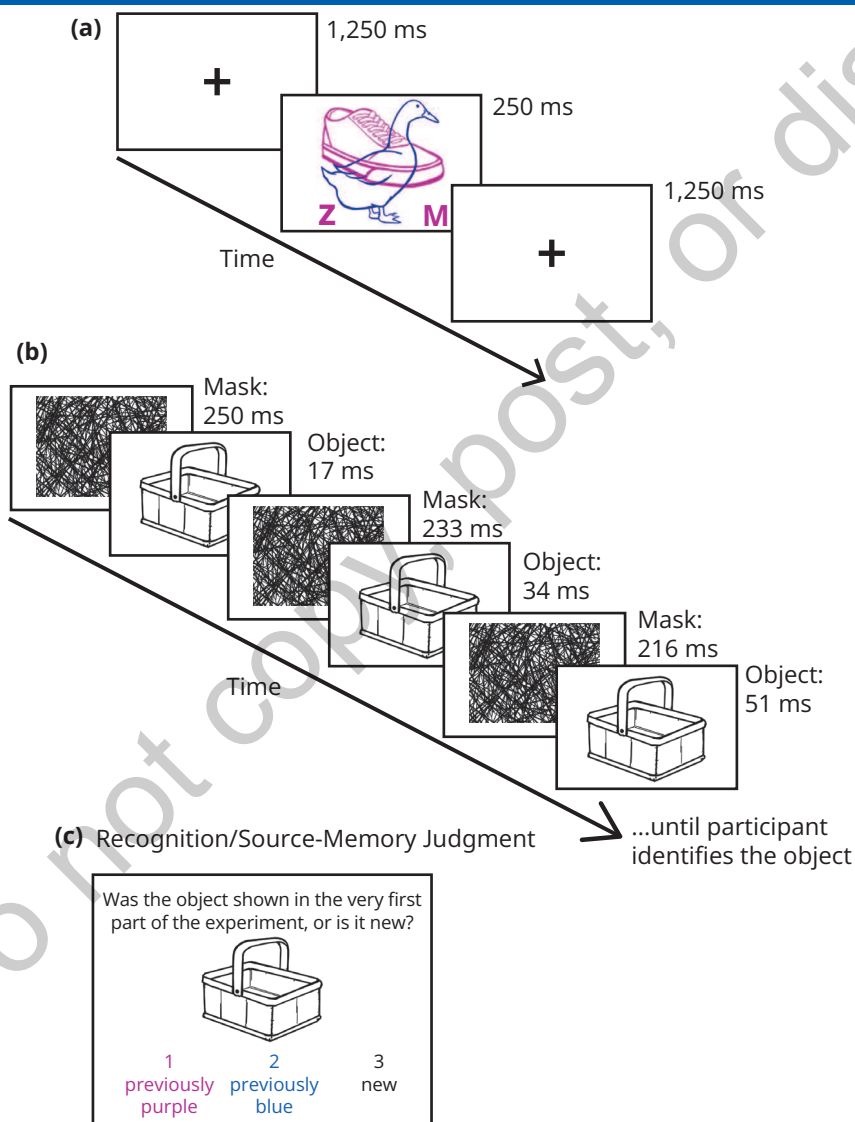
About 3 minutes after the study presentation, the participants began the test trials. On each test trial, they completed identification (implicit memory task), recognition (explicit memory task), and source (explicit memory task) judgments. For the identification judgments, an object was shown (either 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).

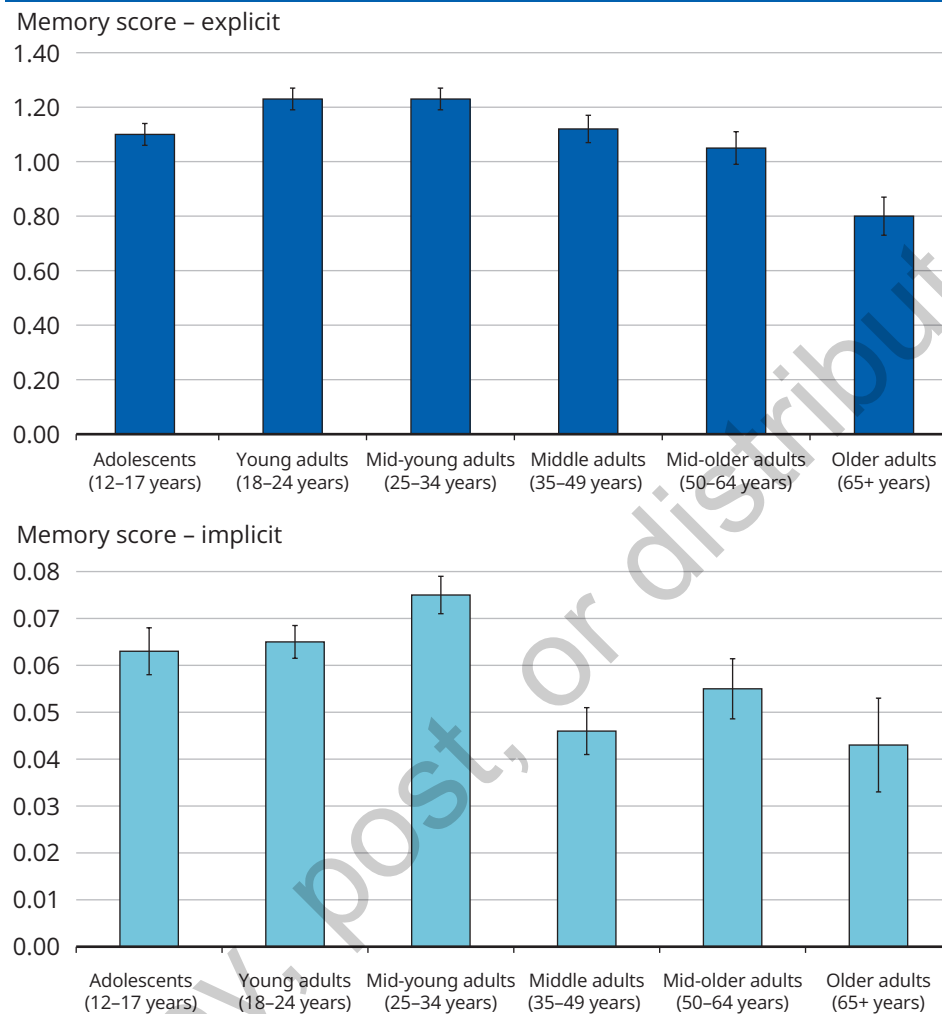
Results of the study: The results showed that memory performance declines in older age for both implicit and explicit tasks, particularly for the participants over age 50 years (as shown in Figure 1.5). These results apply to the attended to objects during a study. Unattended to objects had memory scores 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). Licensed under CC-BY 4.0, <https://creativecommons.org/licenses/by/4.0/>.

Chapter Review

- **What is cognitive psychology and 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?**

Three general perspectives have been used to develop explanations of cognitive processes: representationalist, embodied, and cognitive neuroscience. Representationalist perspectives 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. In the embodied perspective, the mind is envisioned as something situated within a body and an environmental context. That is, cognition is examined by considering the interactions between individuals and their environment. The cognitive neuroscience perspective focuses on neurologically inspired elements to explain cognitive processes.

- **What types of research methods are used 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
_____ describe cognitive processes in a similar fashion to the physiological functioning of the brain
 - b. embodied cognition
_____ describe cognitive processes as operating on knowledge concepts represented in our minds
 - c. biologically motivated models
_____ 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 their memory abilities are. Participants in this study were given a study list of words and asked to remember these words after a short delay. Participants were also

given a questionnaire and asked how good they think their memory is, where a high score means they think they have strong 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 researchers found a positive relationship between the variables that were measured.* Explain what the statement 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. response 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 measure cognitive processes.

Key Terms

Behaviorist perspective

Cognitive neuroscience perspective

Case study

Correlational study

Dependent variable (response variable)

Determinism

Embodied cognition perspective

Empiricism

Experimental study

Independent variable (explanatory variable)

Introspection

Parsimony

Priming

Psychophysics

Quasi-independent variable

Representationalist perspective

Scientific method

Testability

Theory

Chapter 2

Cognitive Neuroscience



Source: iStock.com/gorodenkoff

Learning Objectives

- 2.1 Explain how clinical case studies advance our understanding of cognitive processes.
- 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 in their research studies?
- 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 structures and functions?
- What can be learned about cognition through measurements of neural activity in the brain?

Introduction: Knowledge From Cognitive Deficits

Imagine that, in your Careers in Psychology course, you shadow different professionals. This week, you are visiting a neurologist focusing on cognitive deficits in patients. You learn about several patients during the day. One is an older woman who is having difficulty remembering to complete everyday tasks, such as turning off the stove when she has finished cooking. 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 learn more about 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. Based on experience with your grandparents, you hypothesize that she may be showing the first signs of Alzheimer's disease. The neurologist explains that second patient has been to the 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.

The first neuroscientists relied on patients with cognitive deficits like those in the neurologist's care to learn about cognitive processes and how they relate to different brain structures and functions. Patients who experienced head injuries, diseases, or strokes that resulted in cognitive deficits were of particular interest to neuroscientists. These historically important clinical case studies allowed researchers to begin mapping out the cognitive functions of specific brain areas. In many cases, the area or areas of the brain responsible for the cognitive deficits could only be identified by examining the brain after the patient's death. In more recent years, a variety of brain recording techniques have become available for medical and research purposes. These techniques allow neuroscientists to more precisely pinpoint the areas of the brain that are responsible for changes in cognitive function. Importantly, such techniques allow researchers to examine and compare the brain activity of healthy individuals.

In this chapter, we consider how cognitive neuroscientists study brain function. We begin with an overview of important clinical case studies and how studying individual patients has advanced the study of cognitive neuroscience. We then review the structure of the brain and central nervous system that are the focus of modern brain recording techniques. After a review of relevant physiology, we focus on the specific techniques and methods used to measure cognitive functioning that rely on electrical recordings and brain imaging. We end the chapter with representative examples of cognitive neuroscience research and what we have learned about cognition with the help of these techniques. In upcoming chapters, we include cognitive neuroscience studies that have contributed to our knowledge about brain functions that underlie perception, attention, memory, and language.

Clinical Case Studies in Cognitive Neuroscience

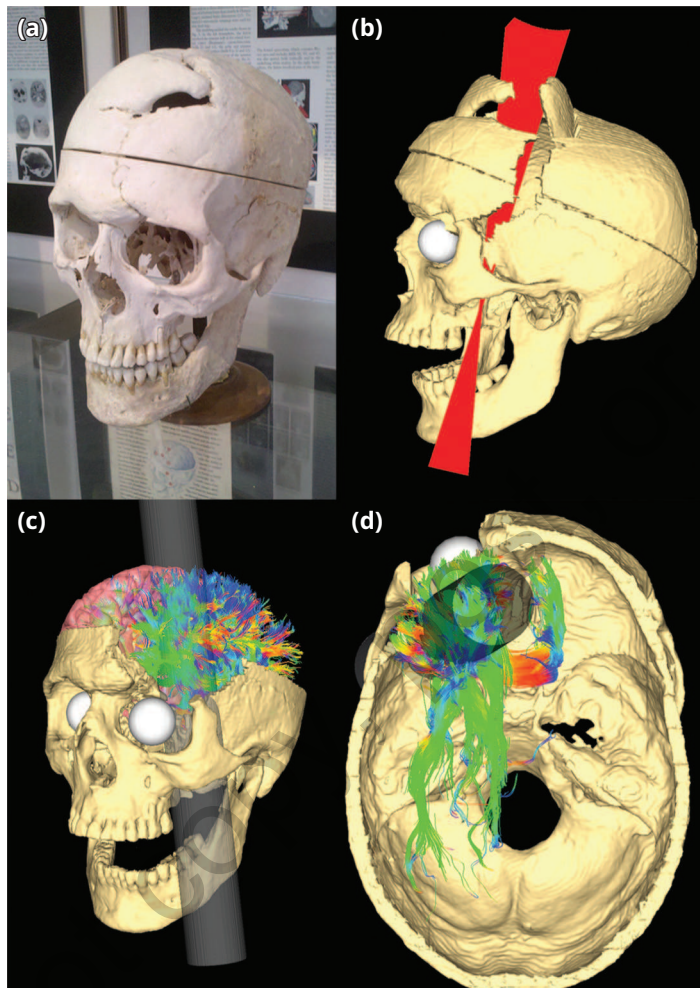
As just described, early neuroscientists learned about which brain areas contribute to different cognitive abilities through the examination of clinical patients. Although technological advances have increased the research techniques available for use in cognitive research, clinical case studies continue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

One of the first clinical cases of a severe head injury that contributed to our understanding of 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.

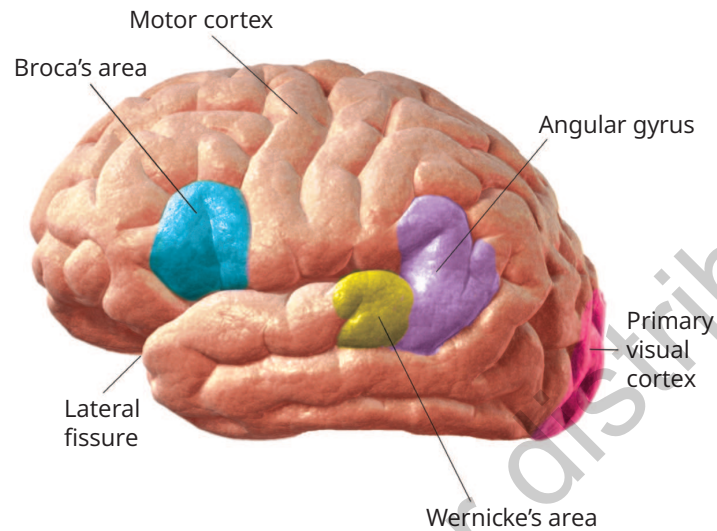


Source: Van Horn, J. D., Irimia, A., Torgerson, C. M., Chambers, M. C., Kikinis, R., & Toga, A. W. (2012). Mapping connectivity damage in the case of Phineas Gage. *PLoS One*, 7(5), e37454. doi:10.1371/journal.pone.0037454.

Other clinical case studies have helped researchers localize language functions in the frontal and temporal lobes of the brain (Rorden & Karnath, 2004). Two patients with different language deficits helped researchers determine the specific areas most important for language production and language comprehension. In the 1880s, Paul Broca examined the brain of a patient who had been unable to speak for many years. From his examination of the patient's brain at autopsy, the left frontal lobe (close to the front of the temporal lobe) was found to be essential for language production. Around the same time, Karl Wernicke examined the brain of a patient who produced what is known as a "word salad," where speech is fluent but incomprehensible. Wernicke identified the brain damage in an area in the left temporal lobe (close to the front of the occipital lobe) that is essential for language comprehension. Figure 2.2 shows the areas of the brain named after these researchers. Both of these patients had **aphasia**, a neurological disorder that causes problems with language processing. 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.

An intriguing case study illustrates the role of brain function in a 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 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.

Clinical case studies have been invaluable for learning about the localization of memory functions. As discussed in Chapter 1, one of the most well-known case studies is that of H. M., who suffered from incapacitating epilepsy and underwent a surgical procedure at age 27 to help reduce the severity of his seizures. During the surgery, a brain area known as the **hippocampus** and its surrounding tissue in the medial temporal lobes were damaged. After the surgery, H.M. seemed to have lost the ability to form new memories—he had **amnesia**. The surgical procedure caused a form of amnesia where he could remember portions of his life before the damage occurred, but he could not remember episodes of his life that occurred after the damage (Hilts, 1996). H. M. would meet new people but 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 memories. H. M. had the ability to improve on tasks requiring motor skills, indicating that he could still encode new information and retrieve that information 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 provided clues to the brain areas most important for different types of cognitive tasks based on an examination of the damaged areas and types of cognitive deficits. The case of H. M. is historically important, but it is not representative of most clinical case studies. The brain damage in H. M.'s case was the result of an untested surgical procedure. However, the benefits of clinical case studies come with a major disadvantage—neuroscience researchers do not control the brain damage

caused by an accident (like Gage's) or disease (e.g., stroke, head injury). 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 patient. In addition, researchers are limited to studying damaged brain areas only in the patients who are available for them to study. However, current neuroscience brain recording techniques provide a means to more precisely identify the brain areas most active during different cognitive 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 from those 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 central nervous system that the brain is a part of as important background knowledge for understanding the ways the different recording techniques work.

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 Central Nervous System

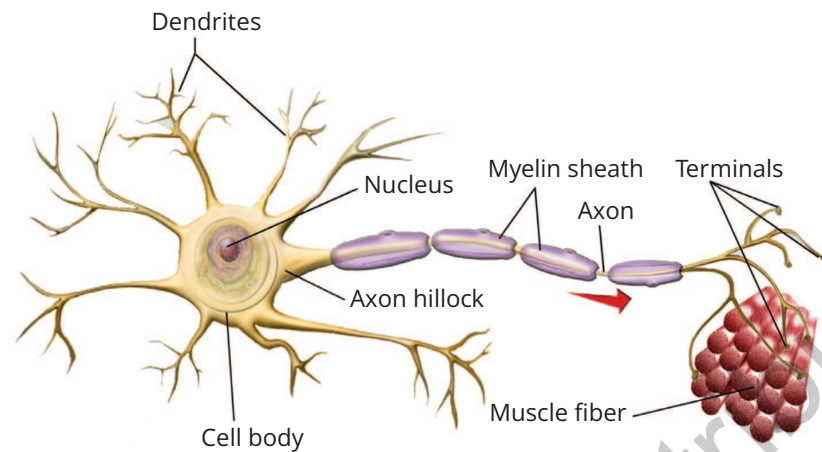
Advances in technology allow researchers to record the brain activity present in clinical and nonclinical individuals. The specifics of how these recording techniques work rely on some understanding of the brain and the nervous system, so we will first review the relevant physiology in this section before 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. Neural 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 cause 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 neuron releases neurotransmitters into the **synapse** (the gap between the neurons in the brain) 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 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, see Figure 2.3) 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 in the brain recording techniques sections. The excitatory message

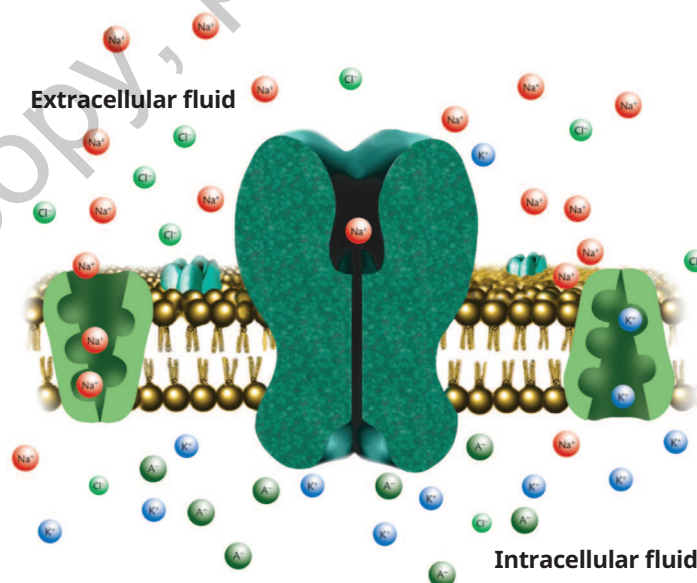
Figure 2.3 ■ A Neuron



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 that 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.

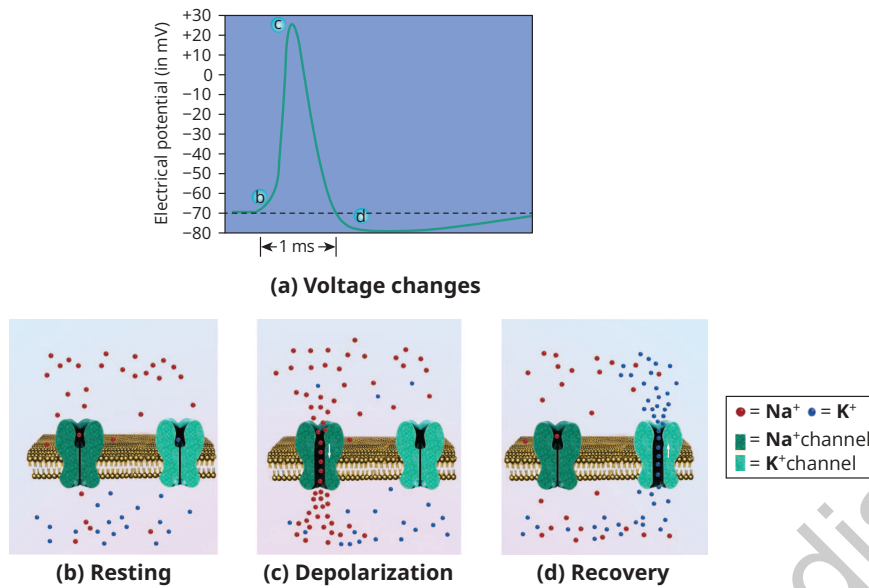
then reaches the terminals of the cell, and neurotransmitter is released into the synapse. Once the action potential is complete, other channels open in the axon membrane to allow potassium (K^+) to flow out of the cell and the sodium channels close. This process redistributes the ions back to the resting negative state inside the axon.

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

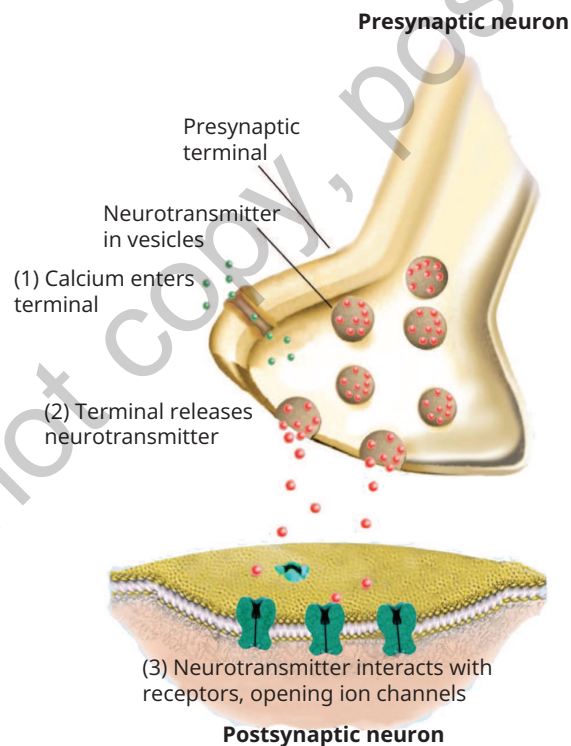


The electrochemical signal that travels down the axon is created by changing the electrical potential inside (intracellular) and outside (extracellular) of the neuron.

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. Information is processed and stored in the brain through the pattern of firing across multiple neurons within the network (i.e.,

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

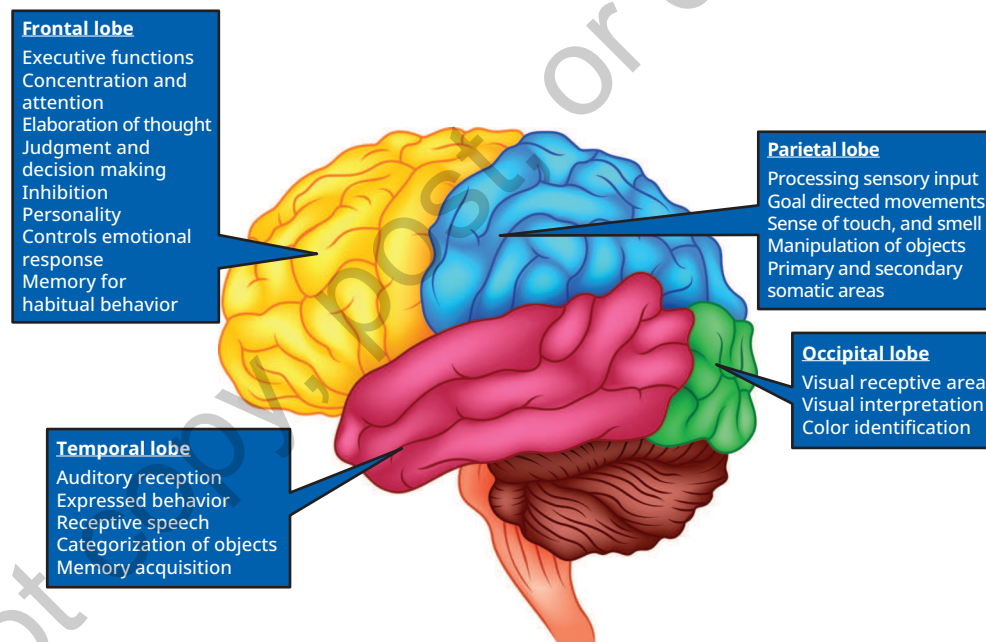
When the signal reaches the end of the axon, it causes vesicles of neurotransmitters to be released into the space between the axon terminal and a dendrite of another neuron. Neurotransmitters flow across this space and attach to receptors on the postsynaptic membrane surface, resulting in the opening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

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 neural organization is known as **localization** of function. Many of the clinical cases reviewed in the previous section provided the initial evidence for both localization and **lateralization** of brain function (i.e., the two hemispheres of the brain contribute to different types of processing) through the deficits present in different areas of brain damage. Looking at the kinds of deficits these patients exhibited helped researchers to identify brain areas (i.e., the damaged areas) that were important for completing those tasks. Figure 2.7 shows the four lobes of the brain and functions that are localized in those brain areas. 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.

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



Source: 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 throughout the brain. In other words, brain areas work together in systems to process different kinds of information. 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 uses of memory, such as those relied on when we perform a skill or task we know how to do, such as reading, typing on a keyboard, or driving a car (Squire, 2004). Pulvermüller (2010a) 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 specific cognitive processes (e.g., speech), but there are always multiple brain areas involved in most behaviors. Furthermore, the brain can shift localization of function around to different areas when

needed. This flexibility of the brain is known as **plasticity**. For example, individuals who experience early blindness (losing visual abilities before age 16) show remarkable changes in brain activity, where areas of the visual cortex begin to respond to the presentation of auditory stimuli (Fine & Park, 2018). In fact, plasticity can be shown to occur rather quickly after losing access to sensory information. Lazzouni et al. (2012) blindfolded sighted participants for 6 hr (to simulate the loss of vision). After this relatively short amount of time without sight, many of these participants began to show activity in the occipital lobe when completing an auditory detection task. These results illustrate the brain's remarkable plasticity in shifting the localization of function during sensory deprivation.

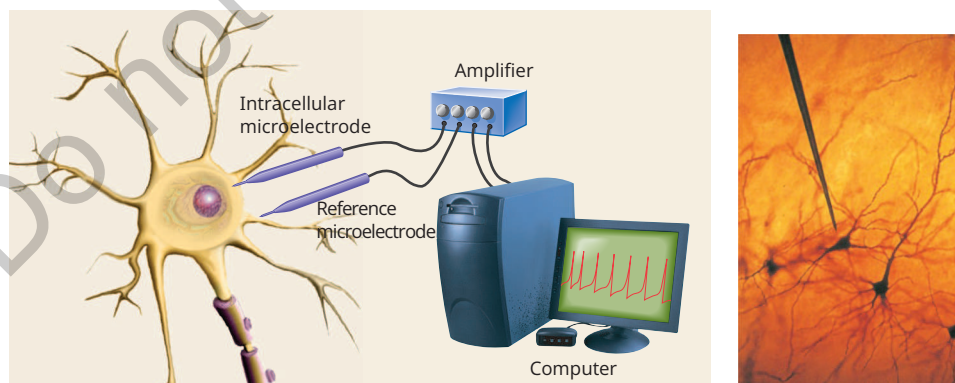
Measures in Cognitive Neuroscience: Electrical Recordings

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 electrical recording techniques in use today record brain activity in humans while they perform various cognitive tasks. However, all the techniques rely on activity of the neurons 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

The **single-cell recording** technique involves inserting a tiny recording needle into one neuron or set of neurons in an area of the brain the researcher is interested in (see Figure 2.8). 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 information about cognition. For example, using single-cell recordings from monkeys, Rizzolatti et al. (1996) discovered 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). Although the activity of a

Figure 2.8 • Recording Electrical Activity in a Neuron

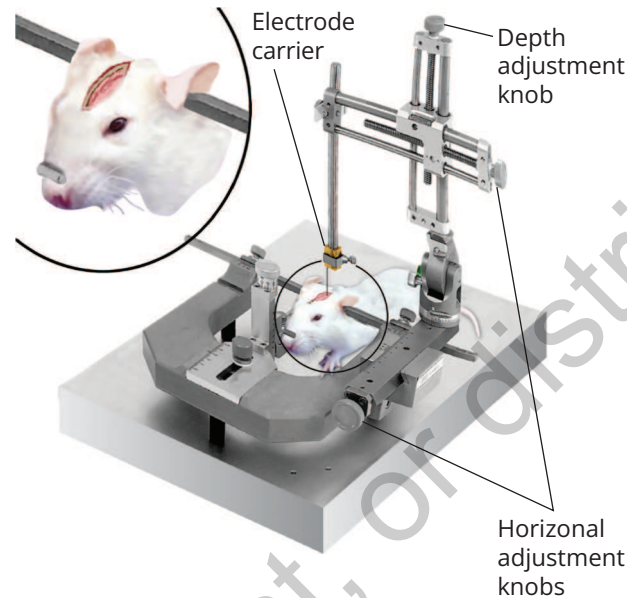


Microelectrodes are inserted into the brain, within the cell membrane. This allows the recording of electrical-potential changes over time.

Source: Photo at right courtesy of Bob Jacobs.

single neuron may not seem to relate to everyday behaviors, this type of research provides the foundation for research investigating more complex behaviors. For example, the discovery of mirror neurons resulted in new ideas about the basis for certain behaviors in social interactions, including those related to social deficits in autism spectrum disorder (e.g., Mizrachi & Maor, 2024).

Figure 2.9 ■ Stereotaxic Instrument Used in Single-Cell Recordings

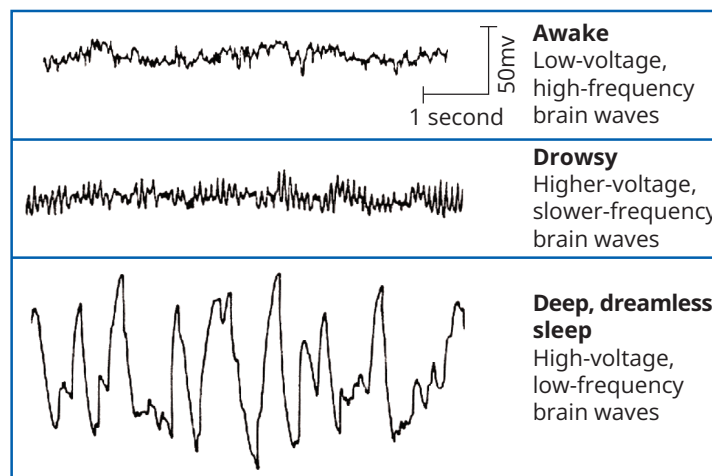


Research with human participants has shown that neuronal cell responses can be extremely specific. In one such study, epilepsy patients were implanted with electrodes to monitor the area that was the focus of their seizures. Because these electrodes were already implanted, this situation afforded the opportunity for researchers to conduct electrical recordings from specific neurons. Using single-cell recordings, 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. These results are consistent with the idea that neurons respond to specific stimuli in the environment (see Chapter 3 for more discussion of this idea); in this case, the stimuli 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.

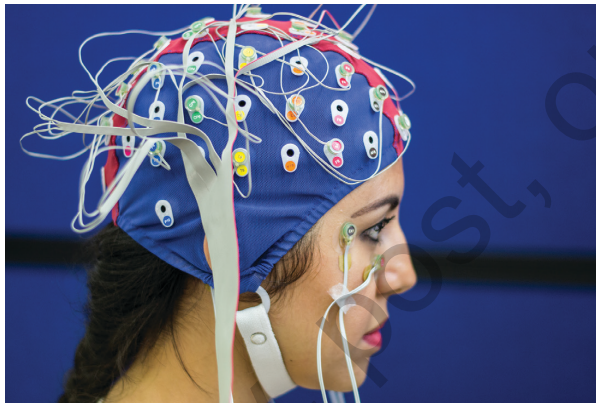
Electroencephalography (EEG)

A less invasive technique that records electrical signals from neurons is **electroencephalography (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). Although extensive recording involves wearing a scalp cap with conductive gel underneath the electrodes, the latest technology is more convenient in collecting neural activity with a small device worn in the ear or as a band on the forehead. Researchers use EEG recordings to examine an **event-related potential (ERP)**, which is a change in activity related to a specific event, such as the presentation of a stimulus (e.g., a photograph). In that way, they can determine if there is an effect of the presentation of that stimulus on neural 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).



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

Source: iStock.com/latsalomao

Research by Gibbons et al. (2018) illustrates how the EEG/ERP is utilized. ERPs were recorded during a simple classification task (“Is this an animal or a plant?”). Prior to completing the task, each participant was instructed to intentionally miscategorize two of the stimuli (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 activity from areas associated with increased visual attention.

Current research is using less invasive EEG devices to identify situations when student attention in a learning task wanes or frustration in learning increases (Gopi & Dehbozorgi, 2024; Mahantanankoon, 2025). Such studies have the potential to improve instruction in academic settings to optimize student learning.

Magnetoencephalography (MEG)

A **magnetoencephalography (MEG)** records electrical signals from neurons in the brain with an electrical scanner that surrounds the head of person who is seated lying down. An MEG can detect electrical activity with better location accuracy than an



Less invasive EEG devices can be worn as an ear-piece or a headband to record electrical brain activity.

Source: Anna Poltoratskaya/Alamy Stock Photo

EEG, but the participant is severely restricted in movement. As with EEG recordings, MEG recordings can occur during a task, which allows the detection and measurement of changes in brain activity that correspond to the presentation of 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).

MEG has been used in a number of studies to record electrical activity during different cognitive tasks. For example, Alexandrou et al. (2017) used MEG to examine the brain activity of participants who were processing naturalistic speech. In contrast to studies that focus on isolated words and sentences, this study demonstrated that processing naturalistic language engages cortical areas not only in the left hemisphere but also in the right hemisphere. Other researchers have used MEG to examine brain activity during encoding and retrieval during recognition memory and recall (Anderson et al., 2018; Prendergast et al., 2013). Like EEG, technological innovations have produced wearable MEG that are less restrictive than the original devices (Boto et al., 2018).



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

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

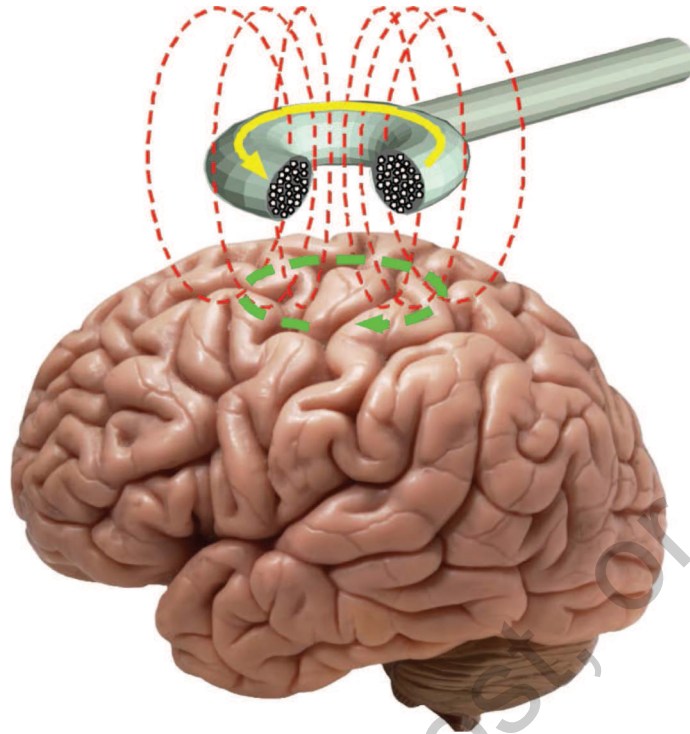
Electrical Stimulation/Inhibition of Neurons

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 neural 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 earlier brain recording techniques (e.g., Sach et al., 2007).

A similar technique is **transcranial direct current stimulation (tDCS)**. Like TMS, neural activity can either be excited or inhibited using this technique. Instead of a magnetic field, tDCS delivers a small electric current to the brain through electrodes attached to the scalp. Thus, it is a slightly more

invasive technique than TMS. The tDCS technique is cheaper and easier to use than TMS but produces a weaker effect on neuron activity than TMS.

Figure 2.11 ■ Transcranial Magnetic Stimulation (TMS)



In transcranial magnetic stimulation (TMS), a magnetic field generator placed near the target region of the brain produces a small electric field (the red dashed lines), which stimulates neuron activity (the green dashed line) in that area.

Source: Courtesy of Eric Wassermann, M.D., Behavioral Neurology Unit, National Institute of Neurological Disorders and Stroke.

In summary, there are a variety of techniques that take advantage of the electrical activity of neurons, ranging from recording the activity of a single neuron to multiple cortical areas. Although these techniques differ with respect to cost, invasiveness, and availability, they all rely on the electrochemical properties of the brain. Next, we describe measures that provide researchers with images of the structures and dynamic activities of the brain.

Stop and Think

- 2.3** What type of neural activity is recorded in single-cell and EEG techniques?
- 2.4** What is the primary disadvantage of single-cell recordings compared with the other electrical recording techniques?

Measures in Cognitive Neuroscience: Brain Imaging

Electrical recordings from the brain are useful for certain types of research, but in most cases these recordings are not very precise in the location of the brain that the measurements are coming from. The



A person undergoing transcranial magnetic stimulation.

Source: Keith Bedford/The Boston Globe/via Getty Images

exception is single-cell recordings, but, as noted, these recordings involve invasive surgical procedures. Imaging techniques provide more precise localization of the activity being measured. Although there are many advantages of brain imaging techniques, the priority for the use of scanning equipment is medical diagnosis. Gaining time for research use can be difficult, as there are limited numbers of scanners due to their high cost. However, cognitive neuroscientists are able to use these types of scanners for clinical populations and make comparisons with healthy participants. In this section, we review the most common brain imaging techniques used in cognitive neuroscientific research.

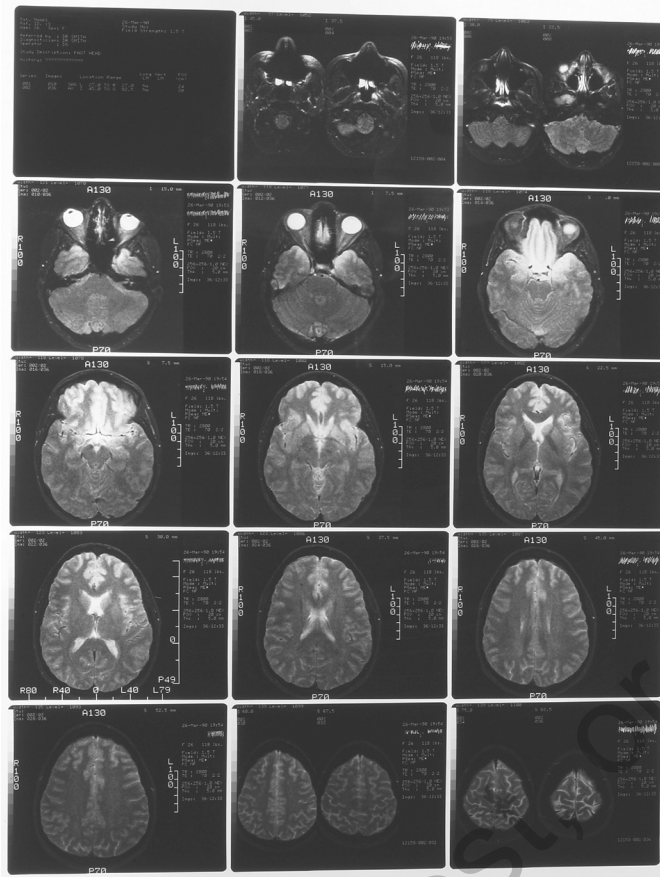
Magnetic Resonance Imaging (MRI)

Magnetic resonance imaging (MRI) was developed for medical use to gain clear images of interior structures of the body and brain (Viard et al., 2021). Perhaps you or someone you know has gotten an MRI to examine an internal injury (e.g., an injury of a knee, hand, or foot). In an MRI scan, a magnetic field is generated to create an image using recordings of the signal coming from the positive hydrogen atoms within the cells of the body. An MRI of the brain can create a clear image of the different structures of the brain that allows the identification of damage or the presence of tumors and comparisons across individuals.

Functional Magnetic Resonance Imaging (fMRI)

Functional magnetic resonance imaging (fMRI) is a technique that records brain activity over time with a scan of the magnetic properties of the blood flowing through the brain. Blood flows in greater volume to more active areas of the brain; thus, the measure of the blood flow indicates the areas of the brain most active during a cognitive task. An fMRI scan shows brighter colors to indicate increased blood flow areas, and dimmer colors to indicate lower blood flow areas. The fMRI technique relies on a *subtraction method*, where activity recorded before the task (called the baseline recording, which is a control condition in this type of study) is subtracted from the activity recorded during the task. What is left is the activity present only during the task.

Like an MRI, an fMRI requires that the participant be placed in a magnetic scanner during the task. Typically, a mirror is positioned in the scanner for the participant to view the stimuli presented. fMRI is



Images from an MRI of the brain.

Source: Thomas Northcut/Photodisc/Thinkstock

a preferred technique of researchers conducting brain scans because they are able to view brain activity during a task. For example, in one study with older adults, participants were shown a list of names and asked to indicate which names were famous people while undergoing an fMRI scan. Participants were categorized according to whether they showed a decline in scores on a cognitive function test between initial testing and testing at the time of the fMRI scans 1.5 years later. Figure 2.12 shows images from the fMRI scans. Red areas represent greater activity in those areas when responding to famous names. Blue areas represent greater activity in those areas when responding to non-famous names.

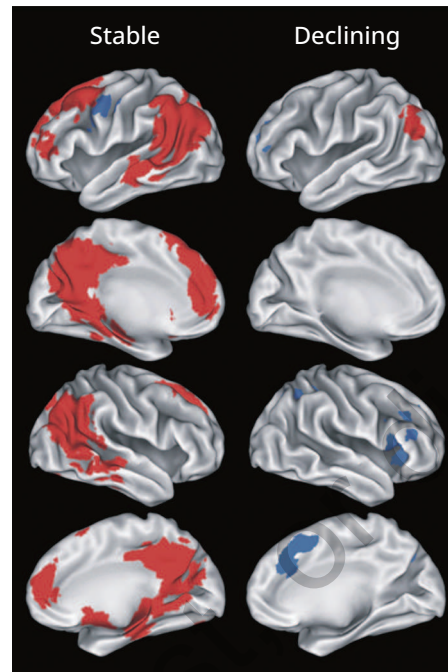
The magnetic scanners used in MRI and fMRI are large, noisy, and require people being scanned to remain very still. These are major limitations to using these scanning techniques for cognitive research. However, researchers have developed novel methods to circumvent these limitations, which have allowed them to, for example, scan awake infants who are looking at faces with fMRI (Deen et al., 2017).

Positron Emission Tomography (PET)

Instead of using the magnetic properties of blood, **positron emission tomography (PET)** involves measuring blood flow to different areas of the brain by tracking the movement of an ingested substance in the blood. Blood flow is detected through the ingestion of a small amount of a radioactive substance. The radioactive substance is absorbed into the blood and flows to the brain as blood is needed in active areas. The radioactivity in the blood is then measured in a PET scan to determine which areas of the brain are more active than others during a task. The recording of the radioactivity is then overlaid onto a map of the brain to examine which areas are the most and least active. In a PET scan, color indicates the level of activity occurring in different areas. Figure 2.13 shows PET scans for two individuals: one who has taken cocaine and one who has not. The most active areas of the brain are colored in red (followed

Figure 2.12 ■ Woodard et al.'s (2010) fMRI Results for Older Adults With Stable and Declining Cognitive Function

Shown here are fMRI scans from older adults performing a name discrimination task. Red areas represent greater activity in those areas when responding to famous names. Blue areas represent greater activity in those areas when responding to non-famous names. Different results were found for participants who did and did not experience cognitive decline over the course of the study.



Source: Woodard et al. (2010). Prediction of cognitive decline in healthy older adults using fMRI. *Journal of Alzheimer's Disease*, 21, 871–885.

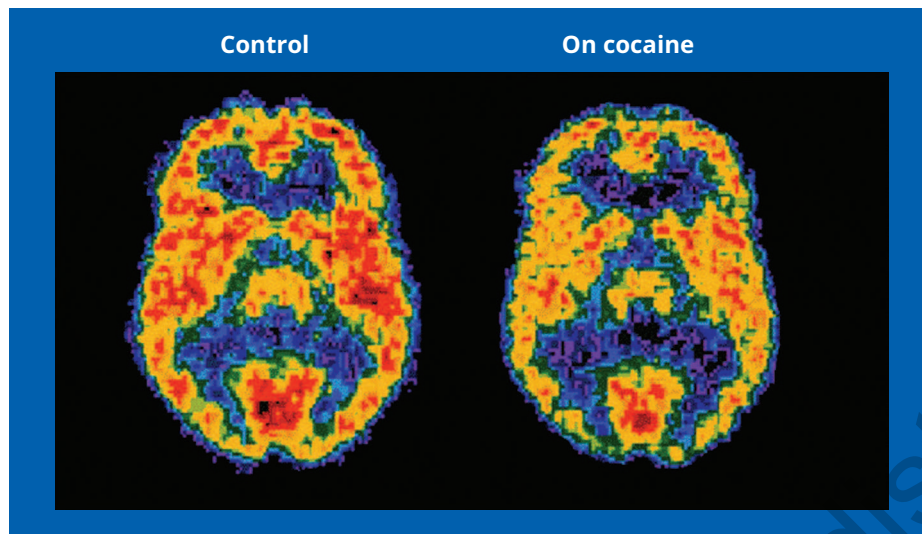
by yellow and then green, with the least amount of activity in blue). In this figure, it is clear there is less activity globally for the individual with cocaine in their system than for the individual who does not (control). As with other techniques, PET scans are prioritized for the diagnosis and monitoring of medical conditions, such as Alzheimer's disease, strokes, brain tumors, and epilepsy. One obvious downside to using PET for research purposes is the invasive ingestion of expensive radioactive chemicals by patients and healthy individuals (control participants).

Functional Near-Infrared Spectroscopy (fNIRS)

Like fMRI, **functional near-infrared spectroscopy (fNIRS)** measures neural activity from localized neural blood flow. However, the technique relies on the use of light absorption rather than magnetic signals. In fNIRS, near-infrared light is projected into the scalp. This type of light is not absorbed by the scalp or brain tissue but is absorbed by the hemoglobin in blood. It is this absorption in the blood that is measured. A person undergoing fNIRS wears a skullcap similar to when EEG is conducted. No scanner is needed, making this technique less invasive and less costly than fMRI or PET. These systems are relatively small, lightweight, quiet, and portable. For example, Skau et al. (2022) used fNIRS to examine brain activity while schoolchildren were engaged in mathematical problem solving. Thus, fNIRS can be used in less constrained, more naturalistic environments (Pinti et al., 2020). fNIRS is also better at measuring the timing of neural activity compared to the other imaging techniques described in this chapter. However, unlike the other imaging techniques, fNIRS provides less accuracy in localization of activity and is limited to cortical activity from within 2 cm of the surface of the scalp.

The use of fNIRS can also be paired with other cognitive measurement techniques to find converging evidence that can overcome the limitations of using a single imaging technique. For example, Broadbent et al. (2023) used fNIRS and eye-tracking measures (see Chapter 1) while measuring the performance of

Figure 2.13 ■ PET scans. The areas in red are the most active; those in blue are least active.



Source: NIDA (2007, January 1), The Brain & the Actions of Cocaine, Opiates, and Marijuana, <https://nida.nih.gov/sites/default/files/1885-the-brain-the-actions-of-cocaine-opioids-and-marijuana.pdf>

participants in a driving simulator. Brockington et al. (2018) report a case study in which a participant viewed a brief 15-min lecture about astronomy. While the participant was watching the lecture, the researchers simultaneously used fNIRS, eye-tracking, and pupil contractions/dilations to measure cognitive processing while the participant was learning in a realistic environment.

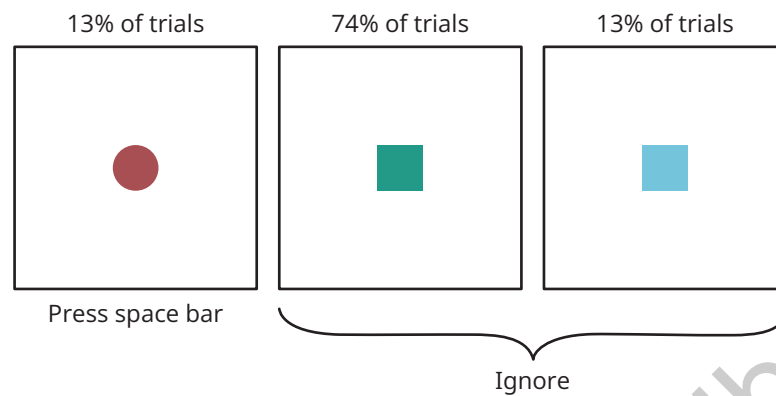
Recording Activity in the Living Brain

In upcoming chapters, we discuss studies that use the various techniques described in this chapter to illustrate the connection between brain function and the specific cognitive processes covered in those chapters (e.g., perception, attention, memory, language). In this section, we highlight two studies to illustrate the use of these techniques. Two categories of brain recording techniques were described earlier in this chapter: recordings of electrical activity of neurons (single neurons or larger groups of neurons) and brain imaging techniques.

In an example of a research study using electrical recordings, Barron and colleagues (2011) used ERP recordings to examine the factors that contribute to *mind wandering* (i.e., thinking about things other than the current task you are working on; see Chapter 4). Do you ever start thinking about something else going on in your life (e.g., an argument with your significant other or an assignment that is due at the end of the week) while you are reading or listening to a lecture? If so, then you have experienced the type of mind wandering that Barron et al. studied. These researchers recorded EEG waves of participants who were asked to respond to a rare target event. Participants were shown sequences of shapes like those shown in Figure 2.14. The task involved pressing a button whenever a red circle appeared within a series of green and blue squares. The nontarget stimuli were presented in different proportions. Green squares were presented often, and blue squares were presented as infrequently as the red circles. This type of stimulus presentation was used to determine if the blue squares would capture the participants' attention, even though they were not supposed to respond to them.

Past studies using this task reported an increase in neural activity in the parietal cortex about 300–500 ms after the red circle was presented, which is believed to be related to the maintenance of the stimulus in memory. Further, a similar increase in activity occurred in the frontal lobe when the blue square (that requires no response) was presented. The frontal lobe activity is believed to be due to attention being paid to this particular distractor stimulus because it occurs infrequently in the trials. Barron et al. (2011) replicated this pattern of results (see Figure 2.15). Immediately after finishing this

Figure 2.14 ■ Stimuli Used in the Barron et al. (2011) Study



task, participants completed a questionnaire to gauge the amount of subjectively experienced mind wandering that occurred during the task. Questionnaire scores were used to categorize participants as experiencing high, medium, or low mind wandering.

The study was designed to test different hypotheses about how mind wandering occurs for those who reported off-task thoughts during the task (i.e., the high mind wandering group). For example, mind wandering might happen because something distracts the person from their main task. If so, participants in the high mind wandering group should show greater brain activity in the frontal cortex when the novel blue squares are presented. Alternatively, mind wandering might happen because participants completely disengage from the task and focus attention on other thoughts. If so, participants in the high mind wandering group should show lower brain activity in the frontal and parietal cortices in response to the target (red circles) and nontarget rare events (blue squares) because they are not attending well to any of the stimuli in the task.

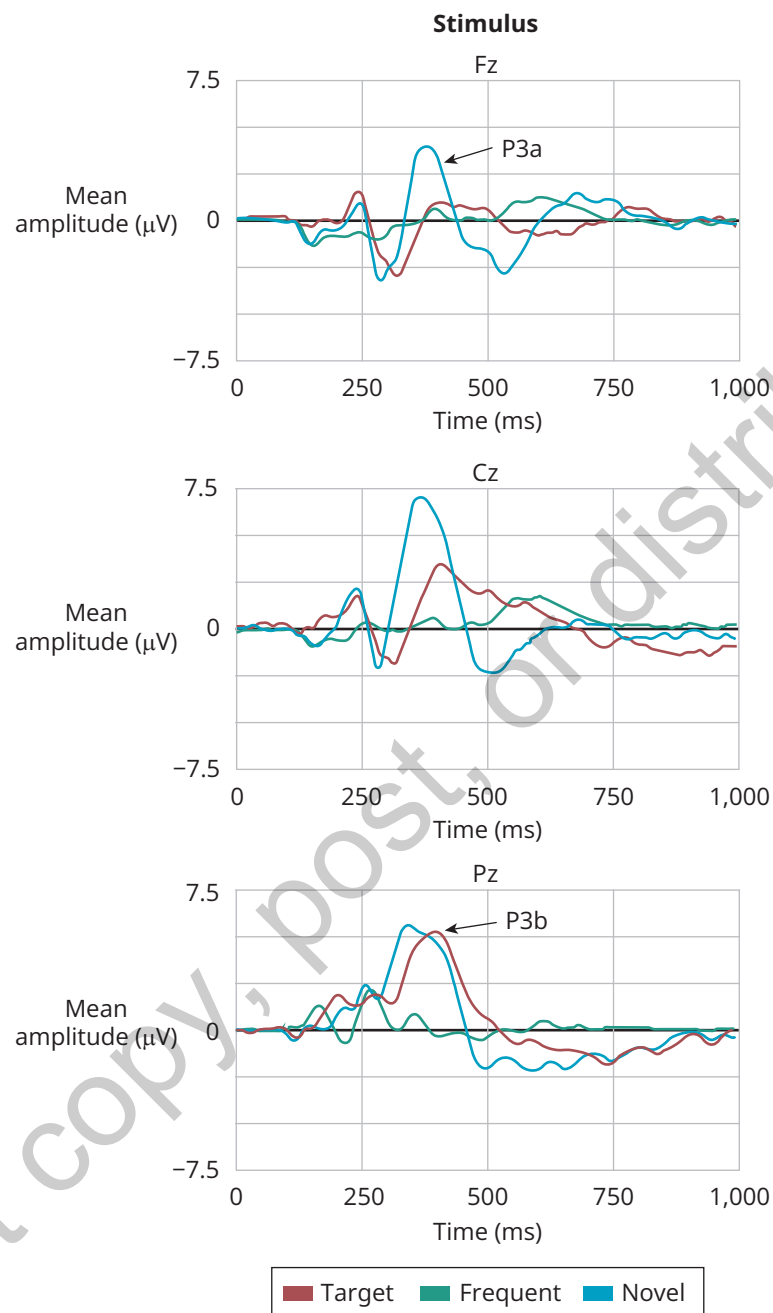
Barron et al. (2011) found that participants who reported high levels of mind wandering had lower levels of brain activity in response to both the red circles and blue squares, supporting the idea that participants were not attending to the task while their minds were wandering (see Figure 2.16). Thus, mind wandering is not simply a state of distraction. The pattern of data was consistent with the idea that mind wandering involves the suppression of externally occurring events (i.e., not paying attention to the rare events, regardless of whether a response is required) to focus on an internal train of thought. This study shows how EEG/ERP studies can be used to test competing theories about cognitive processes.

Brain imaging techniques are frequently used in cognitive neuroscience studies. An example of this type of study was done by Mulay and colleagues (2025), who used brain images to learn more about the relationship between stress and decision-making. Do you think you make different decisions in stressful situations compared to situations where you don't feel stress? When under stress, do you make more risky or less risky decisions? Mulay et al. (2025) examined the neural underpinnings of what happens when risky decision-making occurs under stressful and non-stressful conditions.

The entire experimental procedure took place in an MRI scanner. To induce stress, participants were asked to solve mental arithmetic problems under speeded conditions with negative feedback displayed for incorrect responses. In the control (non-stress) condition, arithmetic problems were solved with less time pressure and without harsh feedback. After the arithmetic task, participants completed a decision-making task that involved a choice between one safe option that had a 100% chance of winning a small amount, or one risky option that had a 10–50% chance of winning a larger amount. Skin response measures and self-rating data confirmed that the speeded version of the math task was indeed stressful.

Decisions made after the exposure to stress were less risky. That is, participants were more likely to take the safe bet when under stress. The fMRI scans revealed lower activation in two specific brain regions when making decisions immediately after the stress induction, compared to decisions made without stress. These regions are associated with cognitive control, suggesting that stress inhibits the ability to be deliberate and reflective when making decisions. Although people take the safe bet under stress, the decision-making process may not have been fully thought through. Without stress, cognitive

Figure 2.15 ■ Graphs of Brain Activity From the Barron et al. (2011) Study

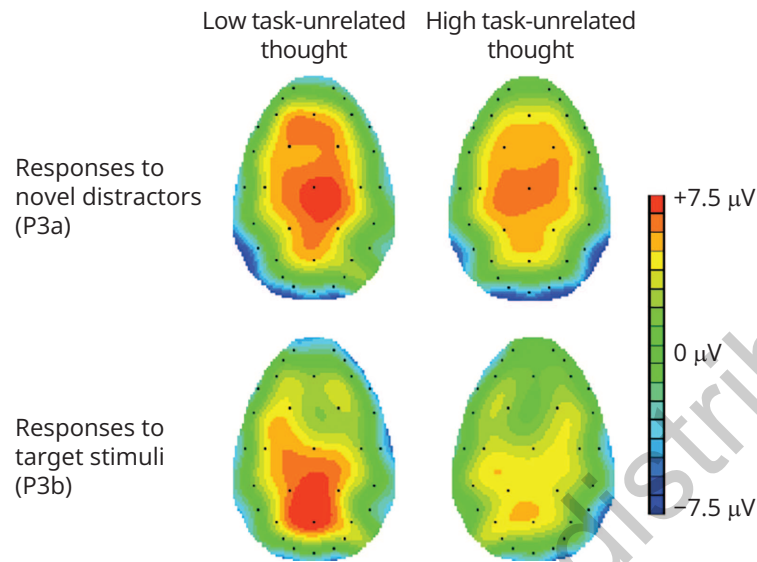


The graphs show the ERPs (collapsed across participants) measured in three regions: the frontal (Fz), the central (Cz), and the parietal (Pz). Around 300 ms after the onset of novel stimuli (blue squares, represented by the blue lines), there was increased activity in both the frontal and central regions relative to the other stimulus types (i.e., the red circle targets, represented by the red line, and the green squares, represented by the green lines). This peak pattern is sometimes referred to as P300.

Source: Barron et al. (2011, Figure 1).

control may aid people in making decisions may gain a large reward (as is the case with medical workers, firefighters, and other first responders).

Figure 2.16 ■ Brain Activity Comparison Across Conditions in the Barron et al. (2011) Study



The left two topographical maps show P300 ERPs for participants who reported few task-unrelated thoughts (low mind wandering) in the novel and target conditions. The right two maps are of participants who reported high numbers of task-unrelated thoughts. These high wanderers had lower levels of brain activity compared to the low wanderers.

Source: Barron et al. (2011, Figure 2).

What Can We Learn From Brain Recordings?

Brain recording technologies have allowed cognitive neuroscientists to gain important knowledge about the connection between brain function and cognitive processes. Pulvermüller (2010b) outlined the four key questions that can be answered by cognitive neuroscience research: (1) What brain activity occurs during specific cognitive tasks? (2) When does the brain activity occur during a task (e.g., at stimulus presentation or after a delay when processing has begun)? (3) How does the brain activity occur (e.g., in specific networks of brain areas)? and (4) Why does particular brain activity occur (i.e., testing hypotheses about how the processing occurs in particular cognitive tasks)? With these types of questions in mind, researchers can take advantage of brain recording techniques in cognitive neuroscience research to advance our knowledge about these specific aspects of cognitive functioning.

However, some disadvantages exist as well. One disadvantage is that not all cognitive tasks are easily adapted to the brain recording techniques. For example, the neuroscientific study of insight (that “aha” moment when you suddenly realize how to solve a problem; see Chapter 11) has been difficult to conduct because it is hard to predict when insight will occur for a specific problem (Luo & Knoblich, 2007). To do this type of research with some accuracy, participants would spend variable and unknown amounts of time solving problems while in a scanner or attached to recording equipment. In contrast, in the study by Mulay et al. (2025) described in the previous section, participants completed two math tasks and two decision-making tasks in an MRI scanner in less than 20 min. Another disadvantage is the limited availability of brain scan technology with some technologies, such as MRI and PET scanners, with limited availability. As mentioned previously, because MRI machines are expensive and also serve as a medical tool, it can be difficult for researchers to obtain time available for use of these devices. EEG and fNIRS devices are relatively cheaper and more readily available for research, but their use can be time-consuming for running participants. Thus, although these recording techniques represent

significant advances in our ability to connect cognitive function with brain activity, they are not without drawbacks.

Another area where progress has been made in investigating how brain activity translates into specific behaviors is in patterns of activity related to the identification of simple objects. For example, some studies have shown that a unique pattern of brain activity accompanies the identification of objects such as faces and houses (Grill-Spector, 2008). In fact, researcher Marcel Just and his colleagues (Mitchell et al., 2008) have been developing a “mind reading” program that can identify a word a person is looking at simply from the pattern of brain activity seen in an fMRI scan of the person’s brain.

The research highlighted here is promising in making specific connections between predictable brain activity and cognitive behavior. However, one criticism is that the behaviors being examined are too simple (e.g., looking at a word, listening to a sentence). It may be much more difficult or impossible to make such precise connections between brain activity and more complex behaviors, such as driving, having a conversation, and imagining yourself in a situation you have never been in. Yet, innovative techniques are being developed along with the refinement of current techniques for the future. Thus, research in this area will continue to develop in connecting cognition and brain activity.

Stop and Think

- 2.5 What type of brain activity is detected in PET and fMRI scans? Why is an fMRI scan preferred to a PET scan in some cases?
- 2.6 Does research that makes connections between brain activity and cognitive task performance provide causal information or merely correlational information? Explain your answer.
- 2.7 Suppose that you are interested in learning about the brain areas involved in memory processing. You are specifically interested in testing whether the retrieval of accurate and false memories relies on the same underlying processes in brain functioning. Describe a study using one of the brain recording techniques described in this chapter that would test this question.

Thinking About Research

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

1. How did this study use recordings of brain activity to test a theoretical description of a cognitive process?
2. What was the primary manipulated variable in this experiment? (Hint: Review the Research Methodologies section in Chapter 1 for help in answering this question.)
3. Do you think the researchers would have achieved similar results if they had used EEG instead of fMRI in this study? Why or why not?
4. Why was it important for the researchers to show that the participants were equally accurate in identifying when the syllable appeared and when the specific words appeared in interpreting the brain activity results?

Study Reference

Cona, G., Chiossi, F., Di Tomasso, S., Pellegrino, G., Piccione, F., Bisiacchi, P., & Arcara, G. S. (2020). Theta and alpha oscillations as signatures of internal and external attention to delayed intentions: A magnetoencephalography (MEG) study. *NeuroImage*, 205, 116295. <https://pubmed.ncbi.nlm.nih.gov/31629832/>

Purpose of the study: The researchers' goal was to map brain activity in two tasks that differed in the type of attention the tasks required. One task required internal attention and the other task required external attention. Brain electrical activity was recorded using the MEG technique. The researchers predicted that the brain activity patterns would differ across the two tasks due to the different kinds of attention they relied on.

Method of the study: Participants were 21 healthy young adults. The participants were asked to complete a lexical decision task, where letter strings were presented for word/non-word judgments. This task was performed on its own and also performed with additional tasks. One of the additional tasks involved pressing a separate key when the syllable "pra" was present in any of the letter strings. This task requires external attention to scan for this syllable within the stimuli. The other additional task involved pressing a separate key when three specific words were presented with a different key to be pressed for each word. This task used internal attention to monitor for and notice the specific words and then remember which corresponding key to press. Participants completed the tasks while positioned in an MEG device to record brain activity during the tasks. The recorded activity was then mapped onto an MRI of the participants' brains to determine the location of the activity.

Results of the study: The brain activity results revealed a different pattern of activity for the external and internal attention tasks. Specifically, when compared with blocks of trials where the lexical decision task was completed on its own, the external attention task was consistent with a reduction in activity over time on each trial, whereas the internal attention task was consistent with increases in activity over time on each trial. In addition, no performance difference was found across the two tasks—participants were equally likely in the two tasks to complete the correct responses to the specific words and the syllable they were given for the additional tasks.

Conclusions of the study: From the recordings of brain activity seen in this study, the researchers concluded that tasks that differ in the type of required attention produce different brain activity patterns, such that tasks using internal attention (keeping a task in their immediate memory) are associated with an increase in a specific type of brain activity, but tasks using external attention (monitoring stimuli for a specific feature, like a syllable) are associated with a decrease in a different type of brain activity.

Chapter Review

- **How do cognitive researchers make use of information about brain structure and activity in their research studies?**

A variety of brain activity recording techniques are used by cognitive neuroscientists to better understand how brain activity is tied to cognition. All rely in some way on neuron activity, with some (single-cell recordings, EEG) measuring the electrical signals from neurons and others (PET, fMRI) recording images of neuron activity in larger areas of the brain. Knowledge of the specific areas of the brain involved in a task can be gained through these techniques. In addition, current knowledge of brain structure helps guide researchers in knowing which brain areas to focus on in their recordings.

- **How do case studies of individuals with cognitive deficits inform us about the connection between cognition and brain function?**

Individuals who have suffered a brain lesion can help us connect cognitive deficits to specific areas of the brain. By examining the area(s) of the lesion and which cognitive deficits the individuals have, researchers can make hypotheses about the primary function of different areas of the brain. Much of the early knowledge of localization of function in the brain came from such clinical case studies.

- **What techniques do researchers use to examine brain structures and functions?**

A number of techniques reviewed in this chapter can be used by researchers to examine brain activity under different conditions and for different groups of people. Some techniques measure electrical activity of neurons, either directly from a single neuron or group of neurons or from the surface of the head for different cortical areas. Other techniques use imaging to examine blood flow to active areas of the brain to measure differences in activity across conditions.

- **What can be learned about cognition through measurements of neural activity in the brain?**

As in clinical case studies, cognitive neuroscience researchers can connect specific brain areas with cognitive abilities. However, measurements of brain activity also allow researchers to provide better tests of hypotheses about brain function because experiments can be conducted with brain activity as the dependent measures.

Chapter Quiz

- Which brain recording technique(s) is (are) often limited to laboratory animals because it (they) requires the insertion of a recording needle into the brain?
 - fNIRS
 - EEG/ERP
 - fMRI
 - single-cell recording
 - both (a) and (b)
- Which brain recording technique(s) measures a change in blood flow to different areas of the brain?
 - PET scan
 - EEG/ERP
 - fMRI
 - single-cell recording
 - both (a) and (b)
- What is meant by localization and lateralization of brain function?
- Describe some disadvantages of using clinical case studies to connect brain function and cognition.
- From Phineas Gage, researchers learned that the _____ lobe of the brain is important for reasoning abilities and control of emotion.
 - frontal
 - parietal
 - temporal
 - occipital
- In which lobe of the brain is visual information primarily processed?
 - frontal
 - parietal
 - temporal
 - occipital
- In what ways is the single-cell recording technique different from other brain recording techniques?
- How do brain recording techniques allow for experiments that cannot be done with clinical case study patients?
- When EEG recordings are connected to the timing of the presentation of a stimulus, it is called _____.
- The MEG technique provides better _____ than EEG.

11. The _____ brain imaging technique is noninvasive, portable, and is often used together with other brain recording techniques.
12. Which recording techniques can also be used to excite or inhibit brain activity?

Key Terms

Amnesia

Aphasia

Axon

Dendrites

Electroencephalography (EEG)

Event-related potential (ERP)

Functional magnetic resonance imaging (fMRI)

Functional near-infrared spectroscopy (fNIRS)

Hippocampus

Lateralization

Localization

Magnetic resonance imaging (MRI)

Magnetoencephalography (MEG)

Neuron

Neurotransmitters

Plasticity

Positron emission tomography (PET)

Single-cell recording

Synapse

Transcranial direct current stimulation (tDCS)

Transcranial magnetic stimulation (TMS)