CHAPTER ONE

Types of Memory and Brain Regions of Interest

Learning Objectives

- To understand each of the memory types.
- To list the brain regions that have been associated with memory.
- To describe the effects of removing the medial temporal lobes.
- To pinpoint the visual sensory regions in the brain.
- To identify the control regions in the brain.

Memory enables us to have skills, to communicate with others, to make intelligent decisions, to remember our loved ones, and to know who we are. Although human memory has been studied for over two centuries (Aristotle, 350 BCE), the **cognitive neuroscience** of memory has only been studied for the last two decades. Section 1.1 of this chapter gives a brief overview of the field of cognitive neuroscience. Cognitive neuroscientists employ techniques that non-invasively track the functioning human brain. Section 1.2 details the fourteen different types of memory. In section 1.3, an overview of human brain anatomy is provided. Commonly known anatomic distinctions such as the frontal lobe, the parietal lobe, the temporal lobe, and the occipital lobe are reviewed and then more detailed anatomy is discussed. Section 1.4 highlights the importance of the medial temporal lobe in memory, which was discovered in the 1950s when this region was surgically removed from one unfortunate individual. In section 1.5, an overview of brain sensory regions is provided, such as the regions associated with visual perception and auditory perception. When a person remembers detailed information, such as the room they stayed in on their last vacation, the corresponding sensory regions of their brain are reactivated. In section 1.6, the regions of the brain that control memory retrieval are considered, which include part of the frontal cortex, the parietal cortex, and the medial temporal lobe. The final section, 1.7, provides an overview of the organization of this book. This book identifies the brain regions associated with different types of memory and details how activity in these regions changes over time. After the current evidence on the cognitive neuroscience of memory has been reviewed, the final chapter discusses the future of memory research. In the last decade, there have been many advances in understanding the brain mechanisms underlying human memory, but there is much to learn and the next decade promises to be even more exciting.

1.1 Cognitive Neuroscience

Cognitive psychology is the study of *human* mental processes such as perception, attention, imagery, memory, language, and decision making. Cognitive psychologists dissect these general processes into more specific processes by identifying behavioral measures that differ between these processes, such as accuracy or reaction time (see Chapter 2). **Behavioral neuroscience** is the study of the brain mechanisms underlying behavior in *animals* (see Chapter 10). Behavioral neuroscientists use invasive methods that can only be used with non-human animals, but they are ultimately interested in how their findings contribute to the understanding of brain processing in humans. As shown in Figure 1.1, cognitive neuroscience lies at the intersection of cognitive psychology and behavioral neuroscience. Cognitive neuroscience is the study of the brain mechanisms underlying human mental processing. Before delving into the brain regions that have been associated with memory, the specific types of memory need to be defined.

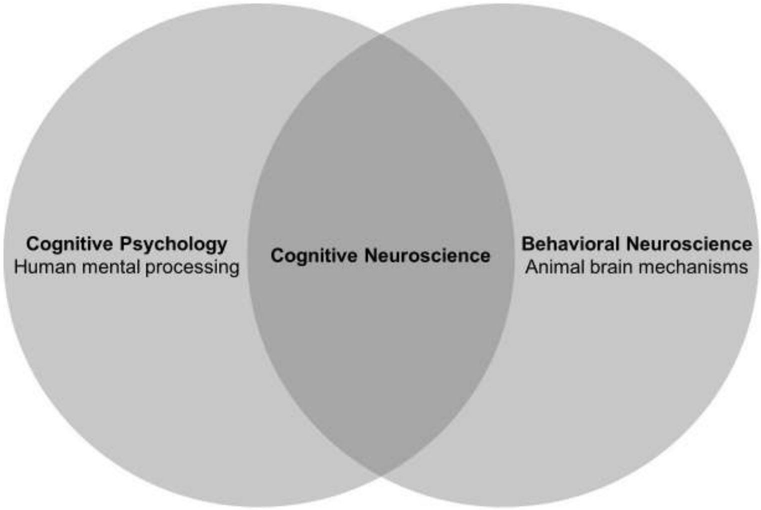

Figure 1.1 The relationships between the fields of cognitive psychology, cognitive neuroscience, and behavioral neuroscience.

1.2 Memory Types

In everyday life, the term *memory* typically refers to consciously retrieving previously experienced information, such as where someone left their sunglasses before leaving home on a sunny day. However, many different types of memory are investigated in cognitive neuroscience. To put the scientific findings that are detailed in this book in the proper framework, it is necessary to understand each type of memory and how it is related to the other types of memory.

Figure 1.2 shows the different types of memory and how they are related to one another. The number of memory types may appear daunting, but there are major distinctions that divide these into six pairs of memory types (with each pair of memory types listed at the same vertical level in the figure). The fact that nearly all memory types are in pairs indicates that scientists in the field of memory favor dichotomies. A brief description of each memory type, and how it is distinct from its paired type, will be provided in this section. A more thorough description of each memory type will be provided in the relevant sections of the book.

The first pair of memory types is **explicit memory** and **implicit memory**, which refer to conscious memory and nonconscious

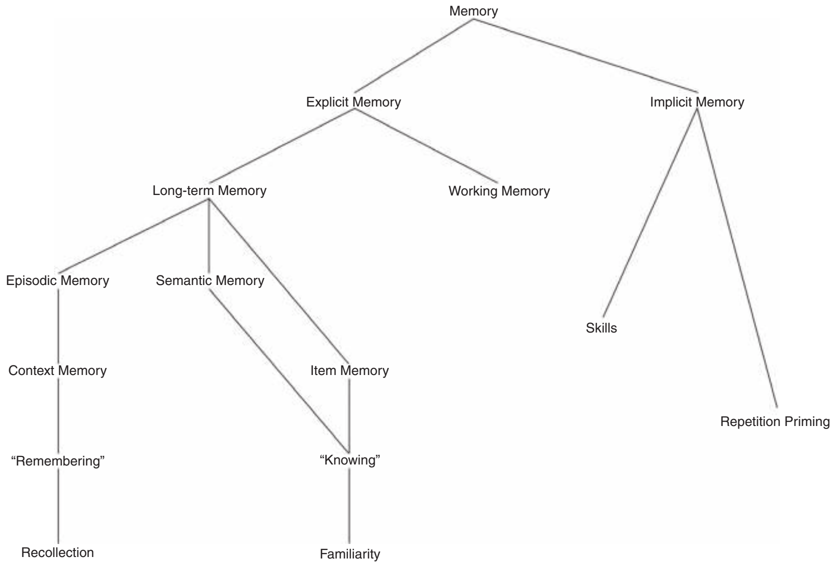

Figure 1.2 Organization of memory types.

memory, respectively. That is, all forms of explicit memory are associated with conscious experience/awareness of the previously experienced information, whereas all forms of implicit memory are associated with a lack of conscious experience/awareness of the previously experienced information. There are many types of explicit memory, which are described below. Skills constitute one type of implicit memory. After a skill is learned, performance of that skill reflects nonconscious memory. For example, after a person learns to ride a bike, they don't think about rotating the pedals, steering, braking, or balancing. Instead, their conscious experience is dominated by where they want to ride or whatever else they happen to be thinking about. **Repetition priming** is another category of implicit memory that refers to more efficient or fluent processing of an item when it is repeated. For example, when a television commercial is repeated, that information is processed more efficiently (and when the item from the commercial is seen again while shopping, implicit memory presumably increases the chance that it will be purchased). Skill learning can be assumed to be based on repetition priming (i.e., more efficient processing after a lot of practice), which illustrates that these types of implicit memory are not independent.

The rest of the memory types are kinds of explicit memory. The second pair of memory types is **long-term memory** and **working memory**. Working memory is also referred to as **short-term memory**. A typical explicit memory experiment will be detailed first to help make the distinction between long-term memory and working memory. During the study phase of both long-term memory and working memory paradigms, items such as words or objects are presented. After the study phase, there is a delay period that can last a variable amount of time. During the test phase, old items from the study phase and new items are presented, and participants make an "old" or "new" judgment for each item, which is referred to as **old–new recognition**. Accurate memory is indicated by a greater proportion of "old" responses to old items than "old" responses to new items. Long-term memory and working memory differ with regard to whether or not information is kept in mind during the delay period. In long-term memory experiments, there are typically many items in the study phase and the delay period is relatively long (e.g., minutes to hours – hence the name of this memory type). Participants do not actively maintain information from the study phase in their mind during the delay period. In working memory experiments, there are typically a few items in the study phase, the delay period is in seconds, and participants are instructed to actively maintain information from the study phase in their mind (which is working during the delay period, and hence the name of this memory type). Although explicit memory refers to both long-term memory and working memory, explicit memory is often used to refer to only long-term memory. In this book, the terms will be used according to the definitions provided in this section.

The third pair of memory types is **episodic memory** and **semantic memory**. Episodic memory refers to the detailed retrieval of a previous episode, such as what occurred, where it occurred, and when it occurred. For example, when a person remembers the last time they saw their parents, this is an example of an episodic memory. Semantic memory refers to retrieval of factual information that is learned over a long period of time, typically years, such as the definition of a word. Semantic memories do not involve any memory for the previous learning episode. For instance, the definition of the word 'sailboat' simply comes to mind without having to think back to when its meaning was learned. If any information is retrieved from the previous experience, this would constitute an episodic memory rather than a semantic memory. As mentioned above, cognitive neuroscience long-term memory experiments generally consist of a study phase, a delay phase, and a test phase. Although semantic memory is a type of long-term memory, it is typically acquired over a period of years. This makes semantic memory unique and related to language processing (see Chapter 8). As such, unless otherwise specified, when the term long-term memory is used in this book, it will refer to all the types of long-term memory except semantic memory.

The fourth pair of memory types is **context memory** and **item memory**. These are straightforward terms that refer to different kinds of memory that operate during context memory experiments. During the study phase of such experiments, items are presented in one of two contexts, such as on the left or right side of the screen or in red or green. During the test phase, old items and new items are presented and participants make an "old"–"new" recognition judgment for each item, and for items classified as "old" they also make a "context 1" or "context 2" judgment (e.g., "left" or "right"). It is notable that the second judgment is based on **recall** of previous contextual information rather than recognition, which is almost always the case for context memory judgments. Recall refers to retrieval of information based on an associated memory cue (e.g., recalling the context of an old item). Item memory refers to accurate recognition of old items versus new items, while context memory refers to accurate retrieval of context information. Context memory is also referred to as **source memory**, as a particular context can also be considered a source of information. In addition, **associative memory**, which refers to memory for an association between two items, is similar to context memory in that one item can be considered the context for the other item.

The fifth pair of memory types is **"remembering"** and **"knowing**." "Remembering" refers to the subjective experience corresponding to detailed retrieval, while "knowing" refers to the subjective experience corresponding to the lack of detailed retrieval. The quotes around these terms and other behavioral responses that reflect subjective experience (e.g., "old" and "new") will be used throughout this book. "Remembering" corresponds to the subjective mental experience of retrieving details from the previous experience, such as someone retrieving where they parked their car in a parking lot. If any details are recalled from a previous experience, this constitutes "remembering". "Knowing" is defined by the lack of memory for details from a previous experience, such as when someone is confident they have seen someone before but not where or when they saw them. "Remembering" is typically assumed to be related to context memory, as it is thought to occur whenever contextual information is retrieved. "Knowing" is typically assumed to be related to item memory and semantic memory, which is why these memory types are connected in the figure.

The sixth and last pair of memory types is **recollection** and **familiarity**. The terms recollection and familiarity can refer to mathematical models of these two kinds of memory (Slotnick & Dodson, 2005; Wixted, 2007) but more commonly refer to all the forms of detailed memory (i.e., episodic memory, context memory, and "remembering") and non-detailed memory (i.e., semantic memory, item memory, and "knowing"), respectively. It may be useful to think of context memory and item memory as measures of task performance, "remembering" and "knowing" as measures of subjective experience, and recollection and familiarity as general terms that describe strong memory and weak memory, respectively.

In one classic paper by Endel Tulving, a world-renowned cognitive psychologist and cognitive neuroscientist, it was hypothesized that there was a distinction between "remembering" and "knowing" (Tulving, 1985). This hypothesis stemmed from scientific evidence, as it was based, in part, on a patient with a brain lesion who had no detailed memory of the past (i.e., he could not "remember") but could define words. Tulving's hypothesis was also based on **introspection**, as this was

Box 1.1: The power of introspection

William James, who has been referred to as the father of American psychology, defined introspection as "the looking into our own minds and reporting what we there discover" (James, 1890, p. 185). Basically, introspection means the examination of your own mental processes. Introspection has proven to be invaluable in cognitive psychology and cognitive neuroscience and can be used to predict which type(s) of memory operate during a particular task. Introspection can also be used to identify which kind(s) of memory may be associated with a particular event. To illustrate, item memory is a form of long-term memory that is commonly assumed to reflect "knowing"/familiarity (see Figure 1.2). However, item memory can also be detailed, which means this event type can also be associated with "remembering"/recollection (and illustrates that the dichotomies in Figure 1.2 are not fixed). Despite the potential power of introspection, it can lead to problems. It is based on the experience of the person who is introspecting and can devalue the experience of others or experimental findings. Thus, in practice, predicting the type(s) of memory involved during a particular task or event involves a balance between introspection, the insight of others, and data.

a novel proposal and it is clear throughout the paper that his arguments were based on personal reflection as well as evidence. As discussed in Box 1.1, introspection is a powerful way for scientists to understand mental processing. Tulving ran **behavioral experiments** to test the hypothesis that "remember" responses and "know" responses were distinct. During one experiment, words were presented during the study phase, and then during the test phase old words and new words were presented and participants made "old"–"new" recognition judgments. For old items correctly classified as "old," participants also made a "remember"–"know" judgment and a confidence-rating judgment (ranging from 1 to 3 corresponding to low confidence, intermediate confidence, and high confidence). As shown in Figure 1.3, the probability of "remember" responses increased with increasing confidence, while the probability of "know" responses was maximal at the intermediate confidence rating. These distinct response profiles provide behavioral evidence in support of Tulving's hypothesis that "remembering" and "knowing" are distinct types of memory. A large body of research has subsequently accumulated showing that "remembering" and "knowing" are also associated with distinct regions of the brain (see Chapter 3).

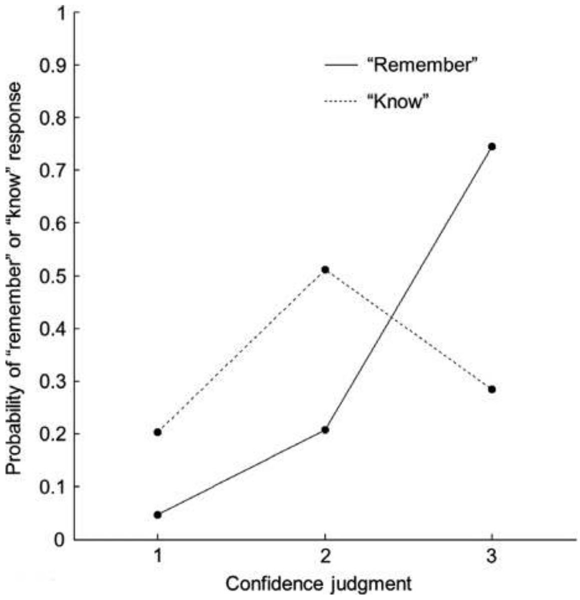

Figure 1.3 Probability of "remember" or "know" responses as a function of confidence judgements (key at the top right). Generated using data from Tulving (1985).

1.3 Brain Anatomy

The brain is composed of the occipital lobe, the temporal lobe, the parietal lobe, and the frontal lobe. Each lobe has gray matter on the cortical surface, which primarily consists of cell bodies, and white matter below the surface, which primarily consists of cell axons that connect different cortical regions. The occipital lobe is associated with visual processing, the temporal lobe is associated with visual processing and language processing, the parietal lobe is associated with visual processing and attention, and the frontal lobe is associated with many cognitive processes. Over half of the human brain is associated with visual processing. This illustrates that we are visual animals and is also the reason that the vast majority of memory studies use visual items as stimuli (e.g., written words or pictures of objects).

Figure 1.4 shows the regions of the brain that are of relevance to memory, which include the occipital cortex, the temporal cortex, the parietal cortex, the dorsolateral prefrontal cortex, and the medial temporal lobe. The cortex is folded with gyri protruding out (shown in light gray) and sulci folding in (shown in dark gray). Figure 1.4A shows

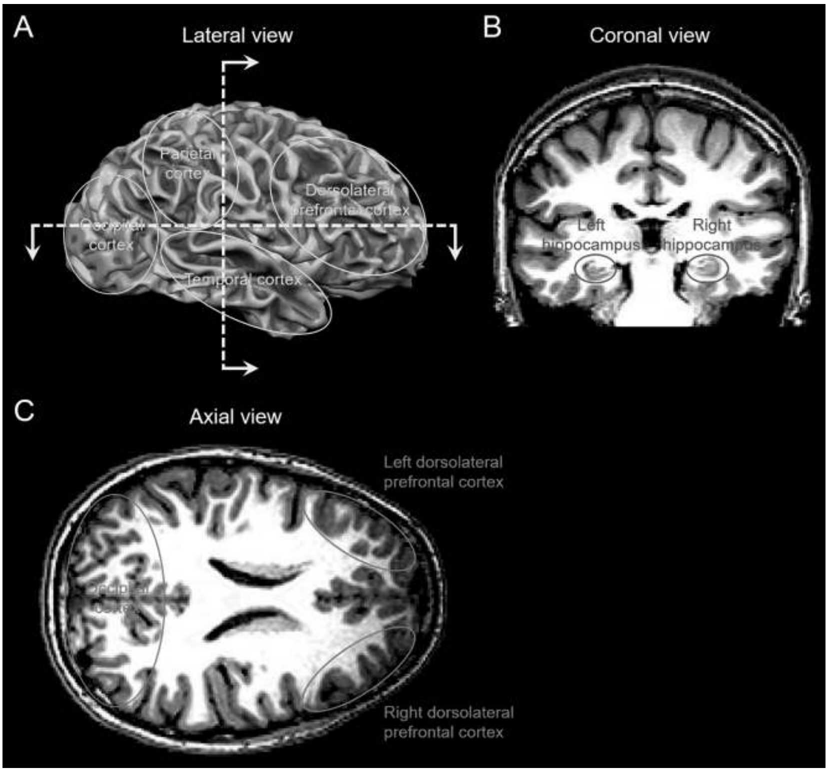

Figure 1.4 Brain regions associated with memory. Each region is shown within red ovals and labeled. (A) Lateral view of the right hemisphere oriented with the occipital pole to the left. Cortical surface gyri and sulci in this figure and all subsequent figures are shown in light and dark gray. (B) Coronal view corresponding to the position in the lateral view indicated by the dashed vertical line. (C) Axial view corresponding to the position in the lateral view indicated by the dashed horizontal line. (A black and white version of this figure will appear in some formats. For the color version, please refer to the plate section.)

a **lateral view**, as if viewing the brain from the side with the most posterior/back of the brain (i.e., the **occipital pole**) to the left. The terms **superior view** and **inferior view** refer to viewing the brain from directly above (i.e., a bird's-eye view) and viewing the brain from directly below (i.e., a worm's-eye view), respectively. Figure 1.4B shows a **coronal view**, as if viewing a thin slice of brain that is approximately parallel to the face (indicated by the vertical dashed line in Figure 1.4A). Figure 1.4C shows an **axial view**, as if viewing a thin slice of brain that is approximately parallel to the ears and nose (indicated by the horizontal dashed line in

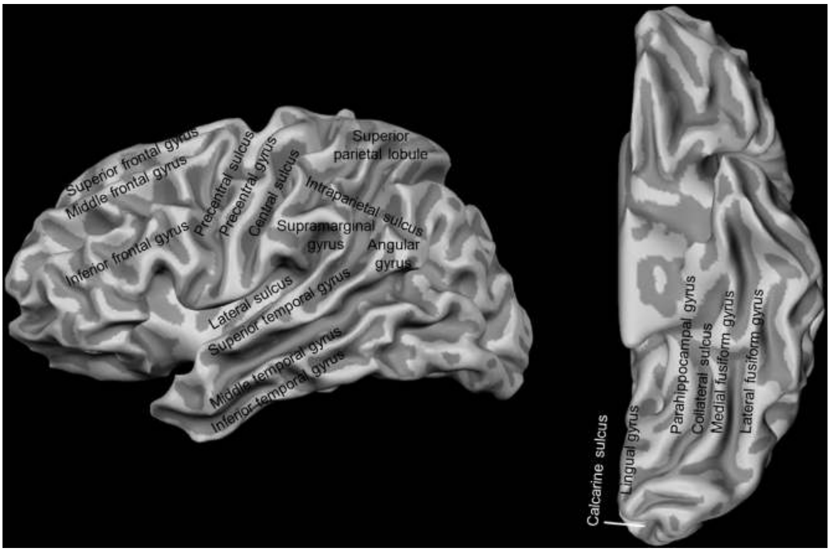

Figure 1.5 Gyri and sulci in brain regions of interest. Left, lateral view of the left hemisphere (occipital pole to the right). Right, inferior view of the left hemisphere (occipital pole at the bottom).

Figure 1.4A) with the occipital pole to the left. The **medial temporal lobe** of each hemisphere consists of the hippocampus (labeled in Figure 1.4B) and the immediately surrounding cortex. The **dorsolateral prefrontal cortex** (shown in Figures 1.4A and 1.4C) is a large part of the frontal cortex that consists of the dorsal and lateral surface that is anterior to the motor processing regions, which are in the posterior frontal cortex (described in the next paragraph). Cognitive neuroscience brain activation results are usually shown on a cortical surface (such as Figure 1.4A) and/or on a slice through the cortex (such as Figures 1.4B and 1.4C).

In scientific articles, such as the recommended readings at the end of each chapter in this book, a brain activation is almost always localized to a specific gyrus or sulcus. Figure 1.5 shows the names of gyri and sulci that are of particular relevance in the field of memory. Only the left hemisphere is shown, as both hemispheres have the same organization. Many of the names are straightforward such as the superior frontal gyrus, the middle frontal gyrus, and the inferior frontal gyrus, which refer to their respective spatial locations (i.e., the upper, middle, and lower parts of the frontal lobe). Note that the superior frontal sulcus is between the superior frontal gyrus and the middle frontal gyrus, and the inferior