Contrary to the prevalent view that cognitive functions are localized in the brain, many students of learning doubted that memory is localized. In fact, until the middle of the 20th century, many psychologists doubted that memory is a discrete function, independent of perception, language, or movement. One reason for the persistent doubt is that memory storage involves many different parts of the brain. We now appreciate, however, that these regions are not all equally important. There are several fundamentally different types of memory, and certain regions of the brain are much more important for encoding some types of memory than for others.

During the past several decades, researchers have made significant progress in the analysis and understanding of learning and memory. In this chapter, we focus on studies of normal human memory behavior, its perturbations following brain lesions due to injury or surgery, and measurements of brain activity during learning and memory recall using functional magnetic resonance imaging (fMRI) and extracellular electrophysiological recordings. These studies have yielded three major insights.

First, there are several forms of learning and memory. Each form of learning and memory has distinctive cognitive and computational properties and is supported by different brain systems. Second, memory involves encoding, storage, retrieval, and consolidation. Finally, imperfections and errors in remembering can provide clues about the nature and function of learning and memory and the fundamental role that memory plays in guiding behavior and planning for the future.

Memory can be classified along two dimensions: (1) the time course of storage and (2) the nature of the information stored. In this chapter, we consider the time course of storage. In the next two chapters, we focus on the cellular, molecular, and circuit-based mechanisms of different forms of learning and memory, based largely on studies of animal models.

Short-Term and Long-Term Memory Involve Different Neural Systems

Short-Term Memory Maintains Transient Representations of Information Relevant to Immediate Goals

When we reflect on the nature of memory, we usually think of the long-term memory that William James referred to as "memory proper" or "secondary memory." That is, we think of memory as "the knowledge of a former state of mind after it has already once dropped from consciousness." This knowledge depends on the formation of a memory trace that is durable, in which the representation persists even when its content has been out of conscious awareness for a long period.

Not all forms of memory, however, constitute "former states of mind." In fact, the ability to store information depends on a form of short-term memory, called working memory, which maintains current, albeit transient, representations of goal-relevant knowledge. In humans, working memory consists of at least two subsystems—one for verbal information and another for visuospatial information. The functioning of these two subsystems is coordinated by a third system called the *executive control processes*. Executive control processes are thought to allocate attentional resources to the verbal and visuospatial subsystems and to monitor, manipulate, and update stored representations.

We use the verbal subsystem when we attempt to keep speech-based (phonological) information in conscious awareness, as when we mentally rehearse a password before entering it. The verbal subsystem consists of two interactive components: a store that represents phonological knowledge and a rehearsal mechanism that keeps these representations active while we need them. Phonological storage depends on posterior parietal cortices, and rehearsal partially depends on articulatory processes in Broca's area.

The visuospatial subsystem of working memory retains mental images of visual objects and of the location of objects in space. The rehearsal of spatial and object information is thought to involve modulation of this information in the parietal, inferior temporal, and occipital cortices by the frontal and premotor cortices.

Single-cell recordings in nonhuman primates indicate that, over a period of seconds, some prefrontal neurons maintain spatial representations, others maintain object representations, and still others represent the integration of spatial and object knowledge. Although neurons concerned with working memory of objects tend to lie in the ventrolateral prefrontal cortex and those concerned with spatial knowledge tend to lie in the dorsolateral prefrontal cortex, all three classes of neurons are found in both prefrontal subregions (Figure 52–1).

Thus, working memory involves activation of representations of information stored in specialized cortical regions that vary based on the content of the information, as well as activation of general control mechanisms in prefrontal cortex. Prefrontal control signals in working memory are further dependent on interaction with the striatum and ascending dopaminergic inputs from the midbrain.
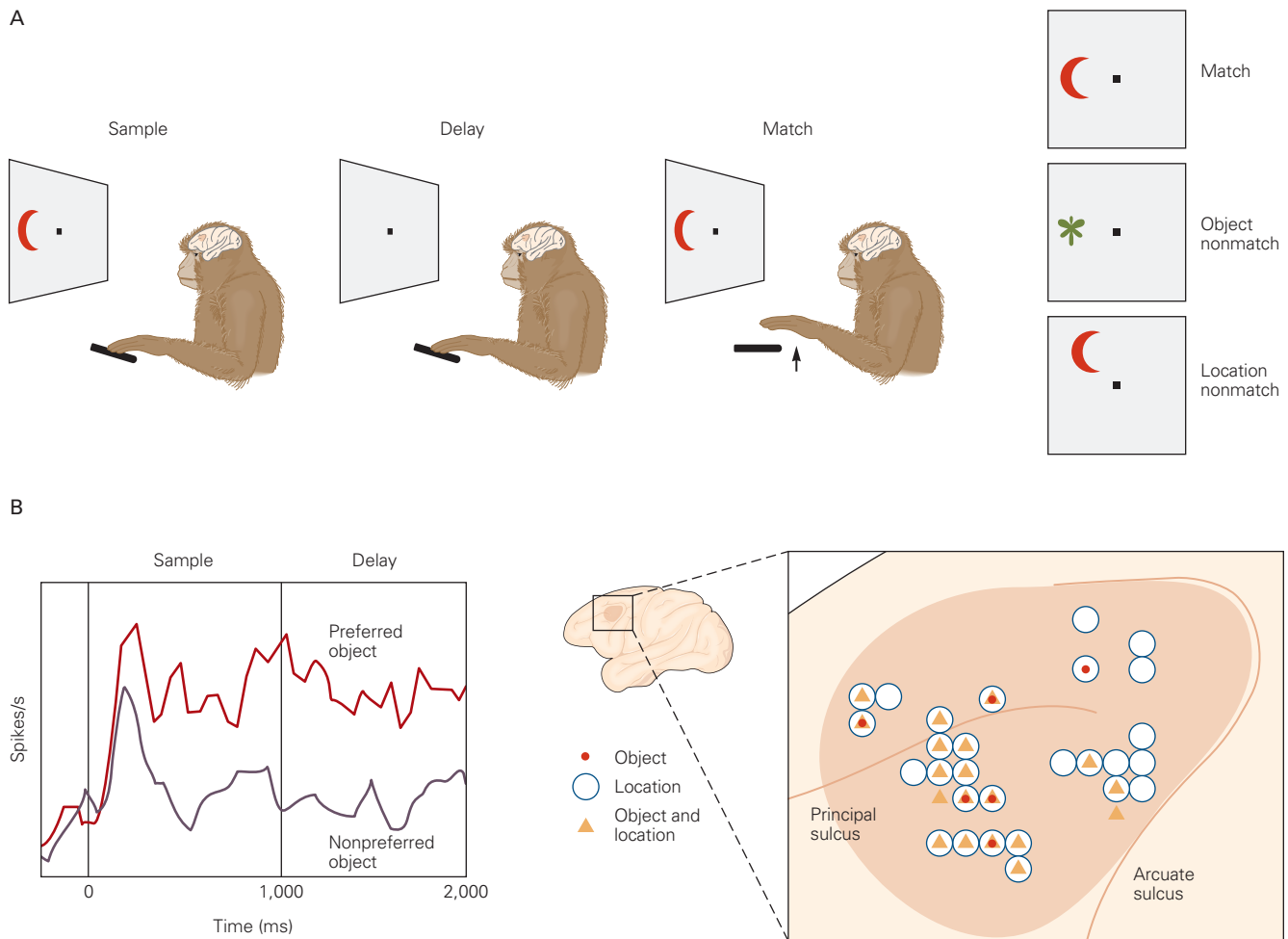
Figure 52–1 The prefrontal cortex maintains a working memory. (Adapted, with permission, from Rainer, Asaad, and Miller 1998.)

A. The role of prefrontal cortex in maintaining information in working memory is often assessed in monkeys using electrophysiological methods in conjunction with a delayed-match-to-sample (DMS) task. In this type of task, each trial begins when the monkey grabs a response lever and visually fixates a small target at the center of a computer screen. An initial visual stimulus (the sample) is briefly presented and must be held in working memory until the next stimulus (the match) appears. In the task illustrated here, the monkey was required to remember the sample ("what") and its location ("where") and release the lever only in response to stimuli that matched on both dimensions.

B. Neural firing rates in the lateral prefrontal cortex of a monkey during the delay period are often maintained above baseline and represent responses to the type of stimulus (what), the location (where), and the integration of the two (what and where). As shown, at left is the activity of a prefrontal neuron in response to a preferred object (to which the neuron responds robustly) and to a nonpreferred object (to which the neuron responds minimally). Activity is robust both when the monkey looks at the preferred object (sample) and during the delay. In the sketch at right, the symbols represent recording sites where neurons maintained each type of information (what, where, and what and where). Typically, several types of neurons were found at one site; hence, many symbols overlap and some symbols indicate more than one neuron.

Information Stored in Short-Term Memory Is Selectively Transferred to Long-Term Memory

In the mid-1950s, startling new evidence about the neural basis of long-term memory emerged from the study of patients who had undergone bilateral removal of the hippocampus and neighboring regions in the medial temporal lobe as treatment for epilepsy. The first and best-studied case was a patient called H.M. studied by the psychologist Brenda Milner and the surgeon William Scoville. (After H.M. died on December 2, 2008, his full name, Henry Molaison, was revealed to the world.)

H.M. had suffered for a number of years from untreatable temporal lobe epilepsy caused by brain

damage sustained at age 7 years in a bicycle accident. As an adult, his seizures rendered him unable to work or lead a normal life, and at the age of 27, he underwent surgery. Scoville removed the brain regions thought to be responsible for the seizures, including the hippocampal formation, the amygdala, and parts of the multimodal association area of the temporal cortex bilaterally (Figure 52–2). After the surgery, H.M.'s seizures were better controlled, but he was left with a devastating memory deficit (or amnesia). What was so remarkable about H.M.'s deficit was its specificity.

He still had normal working memory, for seconds or minutes, indicating that the medial temporal lobe is not necessary for transient memory. He also had long-term memory for events that had occurred before the operation. For example, he remembered his name, the job he had held, and childhood events. In addition, he retained a command of language, including his vocabulary, indicating that semantic memory—factual knowledge about people, places, and things—was preserved. His IQ remained unchanged, in the range of bright-normal.

What H.M. now lacked, and lacked dramatically, was the ability to transfer new information into long-term memory, a deficit termed anterograde amnesia. He was unable to retain for lengthy periods information about people, places, or objects that he had just encountered. Asked to remember a new telephone number, H.M. could repeat it immediately for seconds to minutes because of his intact working memory. But when distracted, even briefly, he forgot the number. H.M. could not recognize people he met after surgery, even when he met them again and again. For several years, he saw Milner every month, yet each time she entered the room, he reacted as though he had never seen her before. H.M. is not unique. All patients with extensive bilateral lesions of the limbic association areas of the medial temporal lobe show similar long-term memory deficits.

H.M. is a historic case because his deficit provided the first clear link between memory and the medial temporal lobe, including the hippocampus. Subsequent studies by Larry Squire and others of patients with brain damage more limited to the hippocampus confirmed its central role in memory. The observation that H.M. and others with medial temporal lobe damage had a profound deficit in the formation of new memories while the retrieval of old memories remained largely intact suggested that memories must be transferred over time from the hippocampus and medial temporal lobe to other brain structures. These studies gave rise to four central questions that continue to drive memory research to this day: First,

what is the functional role of the medial temporal lobe memory system? Second, what are the roles of different subregions within this system? Third, how do these subregions work together with other brain circuits to support different forms of memory? Fourth, where are hippocampal-dependent memories ultimately stored?

The Medial Temporal Lobe Is Critical for Episodic Long-Term Memory

A crucial finding about H.M. was that formation of long-term memory was impaired only for certain types of information. H.M. and other patients with damage to the medial temporal lobe were able to form and retain certain types of durable memories just as well as healthy subjects.

For example, H.M. learned to draw the outlines of a star while looking at the star and his hand in a mirror (Figure 52–3). Like healthy subjects learning to remap hand–eye coordination, H.M. initially made many mistakes, but after several days of training, his performance was error-free and comparable to that of healthy subjects. Nevertheless, he did not consciously remember having performed the task.

Long-term memory formation in amnesic patients is not limited to motor skills. These patients retain simple reflexive learning, including habituation, sensitization, and some forms of conditioning (to be discussed later in this chapter). Furthermore, they are able to improve their performance on certain perceptual and conceptual tasks. For example, they do well with a form of memory called priming, in which perception of a word or object or access to the meaning of a word or object is improved by prior exposure. Thus, when shown only the first few letters of previously studied words, a subject with amnesia is able to generate the same number of studied words as normal subjects, even though the amnesic patient has no conscious memory of having recently encountered the words (Figure 52–4).

This pattern of selectively impaired performance in patients with amnesia raised questions about how to classify these different forms of memory: What are the key features that distinguish between memories that survive medial temporal lobe damage and those that do not? Early theories by Squire and colleagues suggested that a critical factor may be conscious awareness—damage to the medial temporal lobe appears to impair forms of memory that can be accessed consciously and can be reported on or expressed in words, while leaving intact forms of memory that cannot. For this reason, memories that depend on the medial temporal
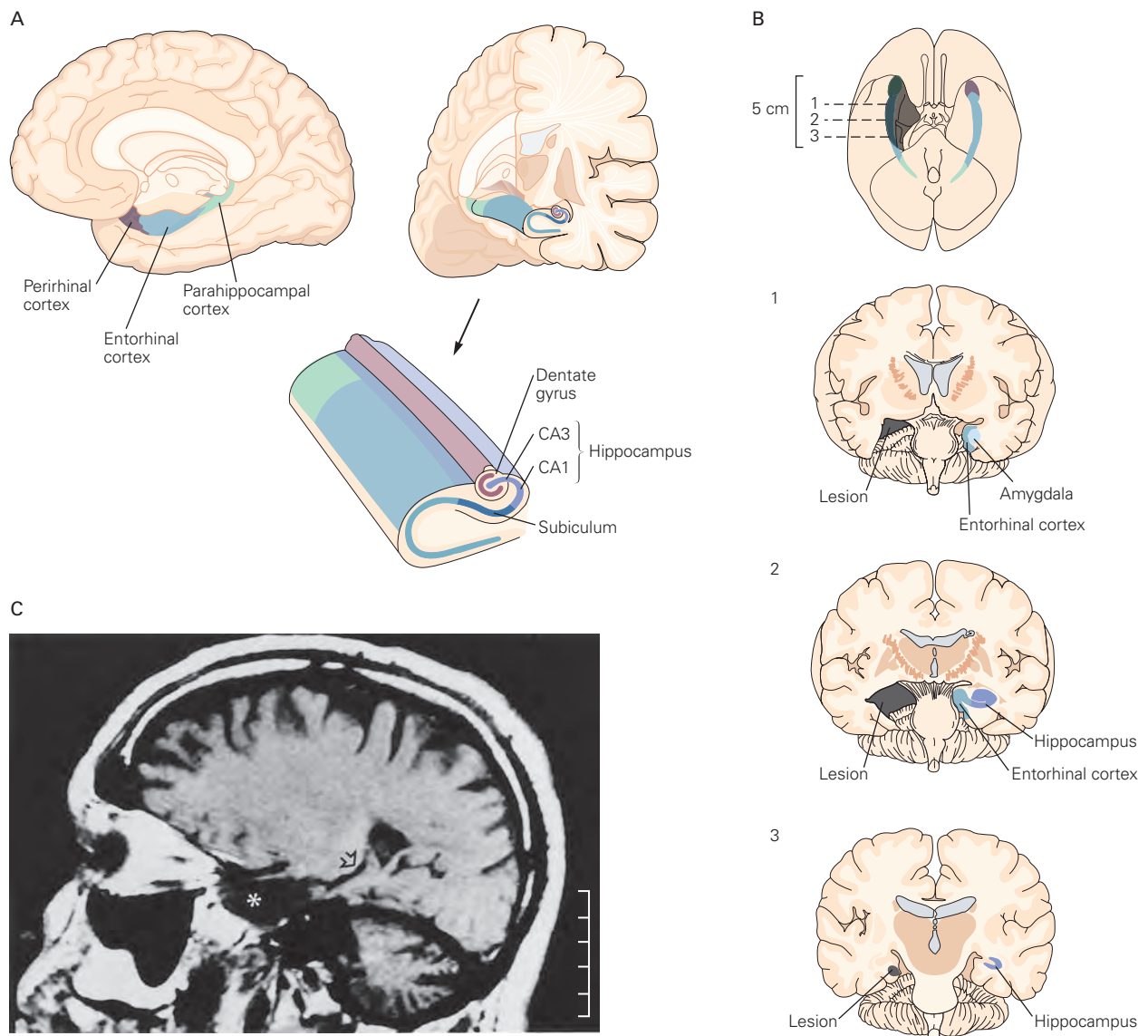
Figure 52–2 The medial temporal lobe and memory storage.

A. The key components of the medial temporal lobe important for memory storage.

B. The areas of temporal lobe resected (**gray shading**) in the patient known as H.M., viewed from the ventral surface of the brain (left hemisphere is on the right side of the image). Surgery was a bilateral, single-stage procedure, but to illustrate the structures that were removed from the left hemisphere (right side of the image), the left hemisphere is shown here intact. The longitudinal extent of the lesion is shown in a ventral view of the brain (top). Cross sections 1 through 3 show

the estimated extent of areas of the brain removed from H.M. (Adapted, with permission, from Corkin et al. 1997.)

C. Magnetic resonance image (MRI) scan of a parasagittal section from the left side of H.M.'s brain. The calibration bar at the right of the panel has 1-cm increments. The **asterisk** in the central area of the scan indicates the resected portion of the anterior temporal lobes. The nearby **arrowhead** points to the remaining portion of the intraventricular portion of the hippocampal formation. Approximately 2 cm of preserved hippocampal formation is visible bilaterally. Note also the substantial degeneration in the enlarged folial spaces of the cerebellum. (Adapted, with permission, from Corkin et al. 1997.)
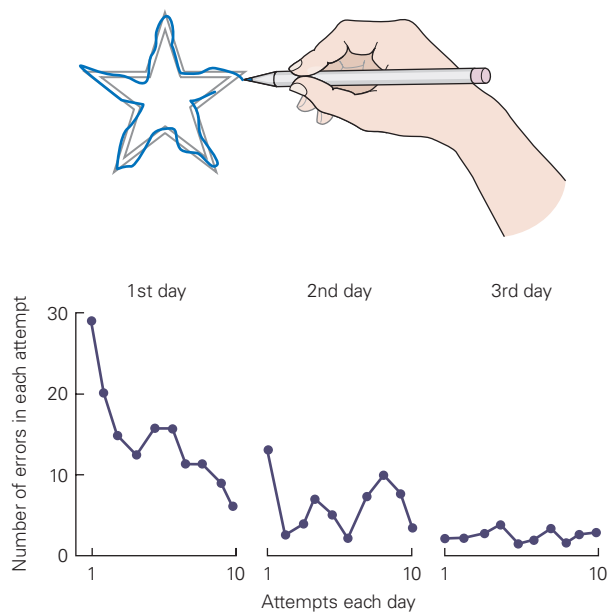
Figure 52–3 The amnesic patient H.M. could learn skilled movements. He was taught to trace between two outlines of a star while viewing his hand in a mirror. The graph plots the number of times, during each attempt, that he strayed outside the outlines as he drew the star. As with healthy subjects, H.M. improved considerably with repeated attempts despite the fact that he had no recollection of performing the task. (Reproduced, with permission, from Blakemore 1977.)

lobe are often referred to as *explicit* (or *declarative*) memory. Explicit memory can be further classified into episodic memory (the memory of personal experiences or autobiographical memory) and semantic memory (memory for facts). *Episodic memory* refers to our ability to remember rich details of moments in time, including information about what happened, when, and where. For example, episodic memory is used to recall that we saw the first flowers of spring yesterday or that we heard Beethoven's "Moonlight Sonata" several months ago. *Semantic memory* is used to recall the meanings of words or concepts, among other facts.

Cognitive psychologists found a similar distinction between different forms of memory in healthy subjects by using tasks that differ in how memories are expressed. One type is a nonconscious form of memory that is evident in the performance of a task. This form of memory is often referred to as *implicit* memory (also referred to as *nondeclarative* or *procedural* memory). Implicit memory is typically manifested in an automatic manner, with little conscious processing on the part of the subject. Different forms give rise to

priming, skill learning, habit memory, and conditioning (Figure 52–5). Explicit memory is considered to be highly flexible; multiple pieces of information can be associated under different circumstances. Implicit memory, however, is tightly connected to the original conditions under which the learning occurred.

The terms "explicit memory" and "implicit memory" are used to describe two broad forms of memory that differ in their hallmark behavioral characteristics and in their neural underpinnings. These forms of memory can be acquired in parallel. For example, one might form an explicit memory of how good a bakery smelled upon entering it yesterday, while at the same time, one might develop an automatic conditioned response of increased salivation upon viewing a picture of the bakery. Moreover, we now believe that these forms of memory, while distinct, normally interact to support behavior, although the precise
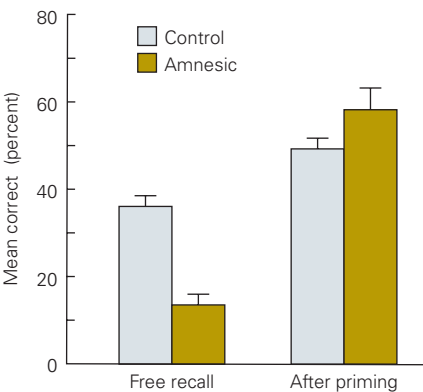

Figure 52–4 Amnesic subjects differ in their ability to recall words under two conditions. Subjects were presented with common words and then asked to recall the words. Amnesic patients did not do well on this test during free recall. However, when subjects were given the first three letters of a word that had been presented and instructed to form the first word that came to mind (word completion), the amnesic subjects performed as well as normal subjects. The baseline guessing rate in the word completion condition for words not previously presented was 9%. (Adapted from Squire 1987.)

Figure 52–5 Long-term memory is commonly classified as either explicit (the memory is reported verbally) or implicit (the memory is expressed through behavior without conscious awareness).
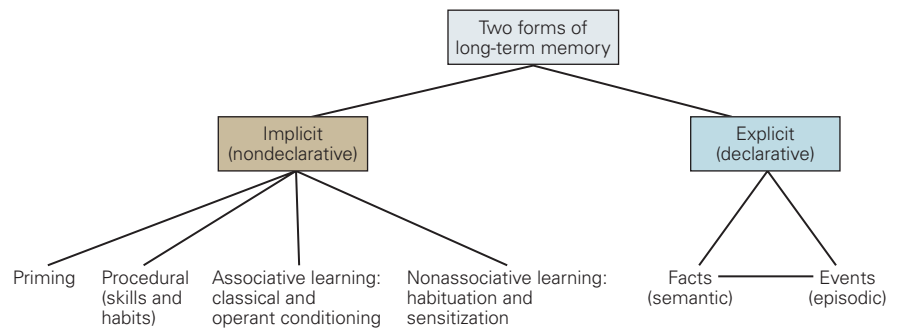
nature and extent of their interactions are a topic of ongoing investigation.

There are also ongoing debates about the role of conscious awareness in memory and about whether it is indeed a necessary feature of memories supported by the medial temporal lobe. These debates are driven by a growing body of work showing that the same medial temporal circuits necessary for explicit memory are also necessary for some forms of implicit memory (as described below). Indeed, although episodic memory is typically assessed by asking subjects to report the content of their memory, it remains unknown whether conscious accessibility is an integral feature of the memories themselves. Nonetheless, the distinction between implicit and explicit memory played an important historical role in differentiating forms of memory and still offers a productive framework for considering the neural bases of memory. Thus, we use the terms "explicit memory" and "implicit memory" here to distinguish these two forms of memory and the classes of subjective experience and behaviors that they are based on. In the following sections, we focus on episodic memory, which has been the target of a great deal of cognitive neuroscience research in both amnesic patients and healthy individuals.

Episodic Memory Processing Involves Encoding, Storage, Retrieval, and Consolidation

Episodic memory has been studied extensively and offers a window into understanding how the brain builds, stores, and retrieves details about episodes in our lives. We now know that the brain does not have a single long-term store of episodic memories. Instead, the storage of any item of knowledge is widely distributed among many brain regions that process different aspects of the content of the memory and can be accessed independently (by visual, verbal, or other sensory clues). Second, episodic memory is mediated by at least four related but distinct types of processing: encoding, storage, consolidation, and retrieval.

Encoding is the process by which new information is initially acquired and processed during the formation of a new memory. The extent of this processing is critically important for determining how well the learned material will be remembered. For a memory to persist and be well remembered, the incoming information must undergo what the psychologists Fergus Craik and Robert Lockhart called "deep" encoding. This is accomplished by attending to the information and associating it with memories that were already established. Memory encoding is also stronger when one is motivated to remember, whether because the information has particular emotional or behavioral relevance (eg, a memory for a particularly delicious meal on an enjoyable first date) or whether the information itself is neutral but is associated with something meaningful (eg, remembering the location of that restaurant).

Storage refers to the neural mechanisms and sites by which the newly acquired information is retained as a lasting memory over time. One of the remarkable features about long-term storage is that it seems to have an almost unlimited capacity. In contrast, working memory storage is very limited; psychologists believe that human working memory can hold only a few pieces of information at any one time.

Consolidation is the process that transforms temporarily stored and still labile information into a more stable form. As we shall learn in the next two chapters, consolidation involves expression of genes and protein synthesis that give rise to structural changes at synapses.

Finally, *retrieval* is the process by which stored information is recalled. It involves bringing back to mind different kinds of information that are stored in different sites. Retrieval of memory is much like perception; it is a constructive process and therefore subject to distortion much as perception is subject to illusions (Box 52–1). When a memory is retrieved, it becomes active again, providing an opportunity for an old memory to be encoded again. Because retrieval is constructive, re-encoding of a retrieved memory can differ from the original memory. For example,

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Box 52–1 Episodic Memories Are Subject to Change During Recall

How accurate is episodic memory? This question was explored by the psychologist Frederic Bartlett in a series of studies in the 1930s in which subjects were asked to read stories and then retell them. The recalled stories were shorter and more coherent than the original stories, reflecting reconstruction and condensation of the original.

The subjects were unaware that they were editing the original stories and often felt more certain about the edited parts than about the unedited parts of the retold stories. They were not confabulating; they were merely interpreting the original material so that it made sense on recall.

Observations such as these demonstrate that episodic memory is malleable. Moreover, the fact that people incorporate later edits into their original memories leads us to believe that episodic memory is a constructive process in the sense that individuals perceive the environment from the standpoint of a specific point in space as well as a specific point in their own history. Much like sensory perception, episodic memory is not a passive recording of the external world but an active process in which incoming bottom-up sensory information is shaped by top-down signals, representing prior experience, along the afferent pathways. Likewise, once information is stored, recall is not an exact copy of the information stored. Past experiences are used in the present as cues that help the brain reconstruct a past event. During recall, we use a variety of cognitive strategies, including comparison, inference, shrewd guessing, and supposition, to generate a memory that seems coherent to us, that is consistent with other memories, and that is consistent with our "memory of the memory."

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re-encoding can include information from the old memory together with the new context in which it was retrieved. This re-encoding allows memories of separate moments in time to be connected in memory, but it also opens the door to errors in memory, as discussed later in the chapter.

Retrieval of information is most efficient when a retrieval cue reminds individuals of the episodic nature of the events linking the elements of the encoded experience. For example, in a classic behavioral experiment, Craig Barclay and colleagues asked some subjects to encode sentences such as "The man lifted the piano." On a later retrieval test, "something heavy" was a more effective cue for recalling piano than "something with a nice sound." Other subjects, however, encoded the sentence "The man tuned the piano." For them, "something with a nice sound" was a more effective retrieval cue for piano than "something heavy" as it reflected better the initial experience. Retrieval, particularly of explicit memories, also is partially dependent on working memory.

**Episodic Memory Involves Interactions Between the Medial Temporal Lobe and Association Cortices**

Although studies of amnesic patients during the past few decades have refined our understanding of various types of memory, medial temporal lobe damage affects all four operations of memory—encoding, storage, consolidation, and retrieval—and thus it is often difficult to discern how the medial temporal lobe contributes to each. fMRI allows us to scan brain activity in the process of building new memories or retrieving existing memories, and thus to identify specific regions that are active during different processes (Chapter 6).

A common method for studying encoding with fMRI is the *subsequent memory paradigm*. In a typical subsequent memory task, a human subject views a series of stimuli (eg, words or pictures) one at a time while being scanned with fMRI, often while engaged in a cover task (eg, determining whether the pictures are in color or black and white). A subject's memory for the stimuli is then tested outside of the scanner, allowing the researchers to sort all the encoding events into those that were later remembered compared to those that were later forgotten. fMRI scans show that remembered items, compared with forgotten items, are associated with greater activity in the hippocampus during encoding. This difference is also evident in simultaneous activity in other parts of the brain, including prefrontal, retrosplenial, and parietal cortices. Often, the activity of these regions covaries on a moment-to-moment basis with the activity in the hippocampus during memory encoding, suggesting that these regions are functionally connected (Figure 52–6).

These fMRI findings, together with findings from patients with amnesia, provide strong support for an

Figure 52–6 In the study illustrated here, neural activity during encoding of visual events (presentation of words) was measured using functional magnetic resonance imaging (fMRI). Subsequently, recall of the studied words was tested, and each word was classified as either remembered or forgotten. The scans taken during encoding were then sorted into two groups: those made during encoding of words that were later remembered and those made during encoding of words that were later forgotten. The activity in regions of the left prefrontal cortex and medial temporal lobe was greater during the encoding of words later remembered than those later forgotten (locations denoted by **white arrows**). At right are the observed fMRI responses in these regions for words later remembered and those later forgotten. (Adapted, with permission, from Wagner et al. 1998.)
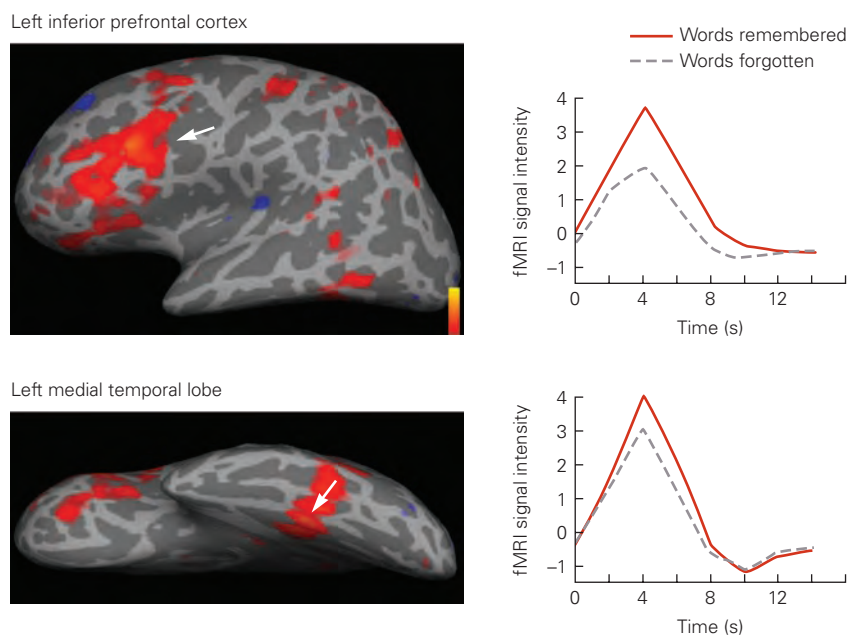
important role of the hippocampus in encoding episodic memories. The fMRI findings also extend the findings from amnesic patients, showing that successful formation of episodic memories depends on interaction between frontoparietal networks and the medial temporal lobe. However, as the medial temporal lobe is a large structure, a key goal is to understand the role of its different subregions. Such information is being provided by higher-resolution fMRI studies that use more powerful brain scanning technologies. These studies reveal that distinct subregions within and outside the hippocampus contribute to different aspects of memory encoding. Thus, whereas some cortical areas surrounding the hippocampus are particularly important for object recognition (perirhinal cortex), others are important for encoding spatial context (parahippocampal cortex). These cortical regions provide strong (but indirect) inputs to the hippocampus proper, which is thought to bind together spatial and object information, forming a unified memory.

Interaction between the medial temporal lobe and widely separated cortical regions is also central in memory consolidation and retrieval. It was initially thought that the hippocampus was not important for retrieval, since patient H.M., whose medial temporal lobe was surgically removed, could still recall childhood memories. In fact, early observations suggested that H.M. could recall many of the experiences of his life up until several years before his operation. These observations of H.M. and other amnesic patients with damage to the medial temporal lobe suggested that old

memories must be ultimately stored in various other cortical regions through interaction with the medial temporal lobe. However, even though patients with hippocampal damage like H.M. have some ability to recall older memories, there is evidence that the extent of memory recall may be impaired in these patients. Current thinking suggests that there is a distributed circuit for consolidation and retrieval involving several brain regions, with the hippocampus playing an essential role in the binding of associations during both encoding and retrieval. The cortical regions serve as the long-term repository of the separate elements of information that constitute a memory and in the controlled retrieval and reactivation of the content of the memory itself.

As with studies of encoding, studies of retrieval of episodic knowledge have implicated specific regions of association cortex, frontoparietal networks, and the medial temporal lobe. The retrieval of contextual or event details associated with an episodic memory also involves activity in the hippocampus, with medial temporal lobe retrieval processes facilitating the activation of neocortical representations that were present during encoding.

fMRI scans have a fairly limited time resolution due to the relatively slow time course of changes in blood flow associated with brain activity. To achieve higher temporal resolution of brain activity, researchers can record electrical activity from the human brain using extracellular electrodes. Such recordings are rare and possible only in human patients who are already

undergoing brain surgery for medical reasons, such as severe epilepsy, when electrode implantation is used to localize the site of seizure generation. In one study, intracranial electroencephalography (iEEG) signals were measured using subdural electrodes placed in the medial temporal lobe and other areas of cortex. A subject first learned associations between pairs of words and then had to retrieve memories of those associations. The retrieval of memories was associated with neural activity in the hippocampus, coupled with neural activity in temporal association cortex, a region involved in language and multisensory integration. This coupled neural activity was associated with a reactivation of cortical patterns that were initially observed when participants first memorized word pairs. This finding provides a link between the neural activity observed in the hippocampus during initial encoding of a memory and the later coupled activity in the temporal association cortex during retrieval. Related observations of reactivation of encoding patterns during retrieval have been reported in numerous human functional imaging studies, documenting the ubiquity of such effects. As with encoding of episodic memory, retrieval involves a complex interaction between the medial temporal lobe and distributed cortical regions, including frontoparietal networks and other high-level association areas.

Episodic Memory Contributes to Imagination and Goal-Directed Behavior

Memory enables us to use our past experience to predict future events, thus promoting adaptive behavior. Like retrieval of memories, imagination of future events involves construction of details from memory. The first report of a possible connection between memory and imagination came from the case study of patient K.C., as reported by Endel Tulving in 1985. Patient K.C. displayed typical and devastating amnesia as a result of damage to his hippocampus and medial temporal lobe. Similar to patient H.M., he had a complete lack of episodic memory while language and nonepisodic functions were unimpaired. Tulving's studies revealed further that such brain damage was associated with the loss of the ability to imagine events in the future. When asked what he would be doing the next day, K.C. was unable to provide details.

The importance of the hippocampus in imagining future events is also seen with fMRI studies. Such studies examined brain activity of healthy individuals, comparing activity when subjects were asked to remember an event from the past (eg, think of your birthday last year) with activity when they imagined

events in the future (eg, imagine a beach vacation next summer). The subjects were asked to report any vivid details of the event that came to mind. The MRI scans showed a striking overlap in the network of brain regions that were active during memory retrieval and imagination of future events. This network included the hippocampus, prefrontal cortex, posterior cingulate cortex, retrosplenial cortex, and lateral parietal and temporal areas (Figure 52–7).

Further evidence supporting the view that episodic memory and hippocampal function are necessary for planning future behavior comes from a study on human performance of a spatial navigation task using virtual reality simulations. High-resolution fMRI and multivoxel pattern analysis (Chapter 6) showed that activity in the hippocampus was related to simulation of navigation goals. Moreover, hippocampal activity during planning covaried with goal-related activity in prefrontal, medial temporal, and medial parietal cortex (Figure 52–8).

Episodic memory encoding and storage are also influenced by the adaptive value of events. Alison Adcock and colleagues showed that the anticipation of a potential reward can enhance memory by eliciting coordinated activity between the medial temporal lobe and midbrain regions that are rich in dopamine neurons. Reward can also retroactively enhance memories. When human participants navigate a maze for a reward, they have better memory for neutral events that happened right before the reward. The ability to retroactively shape episodic memory based on outcomes is important because the relevance of a specific episode may only become known after the fact. Together with the role of episodic memory in constructing the retrieval of past events and in imagining and simulating future events, the findings on reward support the view that a major function of episodic memory is to guide adaptive behaviors.

The Hippocampus Supports Episodic Memory by Building Relational Associations

In addition to the broad role of the hippocampus in episodic memory, future thinking, and goal-directed behavior, studies of rodents first pointed to a role for the hippocampus in spatial navigation (Chapter 54), findings that were later supported by studies of nonhuman primates and humans. In rodents, single neurons in the hippocampus encode specific spatial information, and lesions of the hippocampus interfere with the animal's memory for spatial location. Functional imaging of the brain in healthy humans shows that activity increases in the right hippocampus when spatial information is recalled and in the left hippocampus when words,