

14

Declarative Memory

- **Subcategories of Declarative Memory 353**
- **The Role of the Medial Temporal Lobes in Declarative Memory 354**
- **The Role of the Frontal Lobes in Declarative Memory 365**
- **The Role of the Parietal and Posterior Midline Regions in Declarative Memory 373**
- **The Role of Sensory Cortices in Declarative Memory 376**

Introduction

Declarative memory refers to remembering personal events, cultural history, semantic information, and other facts that we can be explicitly aware of and thus report, or “declare,” either verbally or nonverbally (as when pressing a button in a test paradigm). Even though non-human primates and other animals are incapable of verbal reports, what is taken to be the equivalent of human declarative memories can be reported nonverbally; thus monkeys can indicate mental content by bar presses, eye movements, or other gestures, and rodents effectively report what they do or do not remember by their behavioral choices in mazes or other paradigms. As emphasized in the discussion of H.M. and other amnesic subjects in the previous chapter, declarative memory in humans is critically dependent on the integrity of the medial temporal lobes. Indeed, the link between declarative memory and medial temporal lobe function is so strong that this brain region is sometimes taken to define declarative memory. Thus, when verbal reports are not available (as in the case of young children and non-human animals), memory tasks are often classified as declarative if there is evidence that they are sensitive to medial temporal lobe lesions. Although the medial temporal lobes are necessary for normal declarative memory, much of the evidence described here shows that this region is not by itself a sufficient basis for its operation. Declarative memory involves many other brain regions, including the prefrontal cortex, lateral and medial parietal regions, and the occipito-temporal cortices. This chapter reviews the functions of both the medial temporal lobes and the additional regions that support the encoding, consolidation, and retrieval of declarative memories, and considers the various ways that investigators have tried to rationalize the complex interactions among these regions that result in functioning declarative memory.

Subcategories of Declarative Memory

Working at the University of Toronto in the early 1970s, psychologist Endel Tulving introduced a distinction between two basic forms of declarative

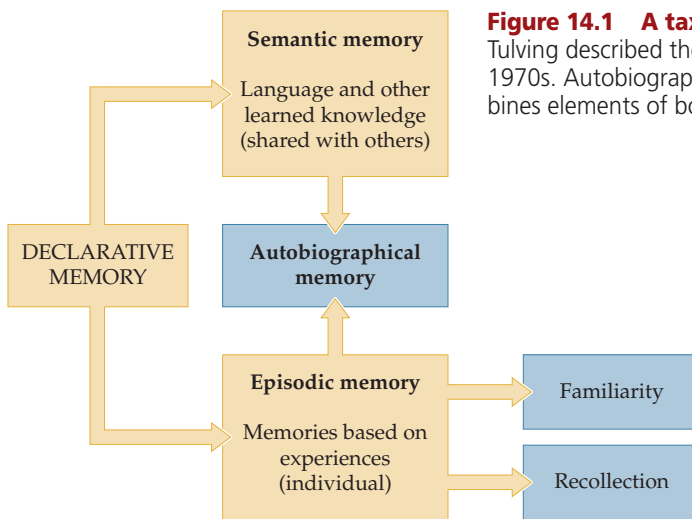


Figure 14.1 A taxonomy of declarative memory functions. Psychologist Endel Tulving described the distinction between episodic and semantic memory in the early 1970s. Autobiographical memory—an individual’s memory of his or her own life—combines elements of both forms of memory. Episodic memory has further subdivisions.

memory that he named *episodic* and *semantic* (Figure 14.1). **Episodic memory** refers to memory of events that an individual has experienced personally in a specific place and at a particular time; in contrast, **semantic memory** refers to knowledge about the world that individuals share with other members of their culture, including the knowledge of a native language and facts learned in school. For example, remembering being in your living room listening to reggae music last Sunday evening is an episodic memory, whereas knowing that reggae is a popular style of Jamaican music characterized by syncopated rhythm

and lyrics that often entail social protest is a semantic memory.

In the laboratory, episodic memory is sometimes defined as memories created during the experiment, such as memory of a list of words participants were asked to study; semantic memory, on the other hand, is defined as information that the participants had stored before the experiment started (Box 14A). In life, episodic and semantic memories interact and to some degree overlap. In fact, memory for the events of our own lives, called **autobiographical memory**, is a complex mixture of episodic and semantic memories. For example, the semantic knowledge that the river Seine runs through Paris, that the Louvre is a famous museum in that city, and that long lines are frequent at famous museums may affect our reconstruction of episodic memories of a particular day actually spent in Paris. Complicating this distinction further, things learned in school can also be remembered as episodes (e.g., the day in French class when Paris was the topic of discussion).

Episodic memory is typically subdivided into two further categories, *recollection* and *familiarity*. **Recollection** refers to memories of a past event that include specific associations and contextual details, whereas **familiarity** refers to the sense that we experienced an event at some point in the past, even though no specific associations or contextual details come to mind. An example of familiarity without recollection is seeing a person’s face and knowing that we have seen that person before, but being unable to remember any specific previous encounter or information about the person, such as their name. Again, these distinctions are somewhat fuzzy, and it has been argued that familiarity is more closely related to semantic memory or even to priming than it is to episodic memory.

The Role of the Medial Temporal Lobes in Declarative Memory

Given the dramatic effects of medial temporal lobe damage in human and non-human animals described in the last chapter, there is no doubt that the medial temporal lobes play a fundamental role in declarative memory. However, memory processing in this region and the specific contributions of various medial temporal lobe components to declarative memory and its subcategories are not well understood. Several different theories have been proposed regarding the role of this brain region (the hippocampus in particular) in declarative memory.

■ BOX 14A Declarative Memory Tests for Humans

Tests of episodic memory can be divided into recall or recognition types based on the nature of the cues or information provided.

In *recall tests*, participants are provided with a partial description of the targets (i.e., the information to be retrieved) and are then asked to generate the targets. For example, in a *word list free-recall test* participants may be asked to generate all the words on a list that was presented at the beginning of the experiment.

In *recognition tests*, participants are provided with targets intermixed with nontargets and are asked to distinguish the targets. Recognition does not require the generation of targets as such, but depends on the ability to discriminate targets (studied, or “old” items) and nontargets (nonstudied, or “new” items). Thus there are four possible outcomes in a recognition test: target items may be classified correctly as old (“hits”) or incorrectly as new (“misses”); and nontarget items may be classified correctly as new (“correct rejections”) or incorrectly as old (“false alarms”). If a subject responds “old” to all trials, he or she maximizes the number of hits but at the expense of increasing the number of false alarms. Thus, in order to evaluate memory

performance, the experimenter must consider both correct and incorrect responses, so memory researchers use a *corrected recognition score* calculated by subtracting false alarms from hits.

Different episodic memory tests discriminate according to the type of information targeted. When we remember past events, we usually remember not only what happened (*item information*) but also where, when, and how it happened (*context information*). Although item and context information tend to be intermixed in natural retrieval situations, in the laboratory it is possible to examine each kind of information separately. Thus, in *item memory tests* participants are asked to retrieve the core elements or content of an event, such as the words in a list. In *context memory tests*, however, subjects are asked to retrieve the context associated with each item. For example, participants might be asked if a particular word presented during the study phase was on the left side or the right side of the screen (*spatial memory*); if the word was included in the first or the second list of words (*temporal order memory*) or if a male or a female speaker presented the word (*source memory*). Context memory tests are primarily sensitive to recollection, whereas item

memory tests entail both recollection and familiarity. Both lesion studies and functional neuroimaging suggest that context memory is more dependent on hippocampal and prefrontal cortex functions than item memory.

Semantic memory tests include measures of the meaning of words (e.g., an elephant is an animal), factual knowledge (e.g., elephants are native to Africa and Asia), and the properties of objects (e.g., elephants are large and have trunks). As with episodic memory tests, semantic memory tests involve recall (e.g., *What is the capital of Turkey?*) or recognition (e.g., *Is Ankara the capital of Turkey?*). Studies with brain-damaged patients often test the ability to generate words that start with a certain letter or belong to a certain category (*verbal fluency tests*), the ability to define the meaning of difficult words (*vocabulary tests*), or the ability to name objects presented visually (*picture-naming tests*). Visual semantic memory can be further tested by asking participants to recognize photos of celebrities or famous buildings, and spatial semantic information can be tested by asking subjects to estimate the relative locations of cities in a country, or to draw a map of a well-known neighborhood or of their house.

Cognitive map theory

The **cognitive map theory** was originally proposed in 1978 by John O’Keefe at University College London and Lynn Nadel at the University of Arizona. In their view, the hippocampus mediates memory for spatial relations among objects in the environment. The strongest evidence for this idea is the existence of **place cells** in the rodent hippocampus (**Figure 14.2A**). These neurons become active only when the animal is in a particular spatial location in its local environment. The existence of place cells in the human hippocampus is less clear, but studies in which epileptic patients with implanted electrodes played a “taxi driver” computer game that involved driving passengers to target locations within a virtual town suggests that they do (**Figure 14.2B**). As in rats, some neurons of the hippocampus were active only when the “taxi” passed through a specific locale.

The fact that cells in the hippocampus fire when patients drive a virtual taxi through specific locations reinforces studies by Eleanor Maguire and collaborators at the University College London that reveal taxi drivers to have significant changes in the gross anatomy of this region of the brain. The investigators found that in London cab drivers with years of experience, the size of

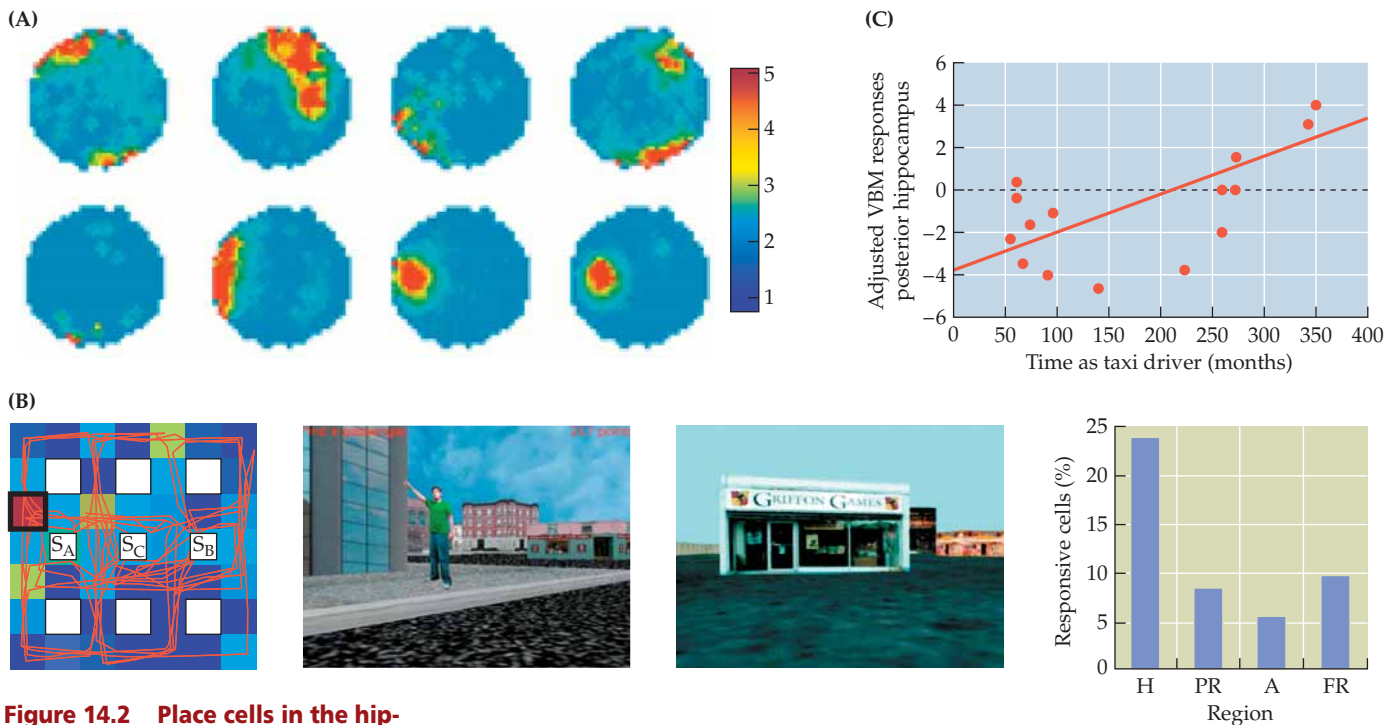


Figure 14.2 Place cells in the hippocampus. (A) In the rat, place cells fire when the animal is in a specific location of an open circular cage. The color code in this illustration shows the firing pattern of eight different place cells, with red indicating intense activity. Note that each cell being recorded from is active only when the rat is in a particular position in its environment (shown here as if looking down on the circular arena the animal is exploring). The color scale shows cell firing rate in Hz. (B) A neuron in the human hippocampus was active only when the subject was in a specific location (red square) of a virtual town (red lines indicate the trajectory of the “taxi”). Lettered squares are store locations, and white squares are nontarget buildings. Although most place cells in humans were found in the hippocampus (H), some were also found in the parahippocampal region (PR), the amygdala (A), and the frontal lobes (FR). (C) In this study, the size of the posterior hippocampus in London taxi drivers was found to be positively correlated with the number of years the subject had worked in this profession. (B from Ekstrom et al. 2003; C after Maguire 2000.)

the posterior hippocampus was significantly larger than in controls. Moreover, this effect was positively correlated with the number of years the subjects had worked as cab drivers (Figure 14.2C). Although these findings in a single such study must be interpreted with caution, they suggest that the circuitry in hippocampus gradually increases in complexity as a function of navigational experience.

Relational memory theory

Rather than contest the substantial evidence that the hippocampus is involved in spatial aspects of declarative memory, Howard Eichenbaum at Boston University and Neal Cohen at the University of Illinois proposed a more general theory of hippocampal function. Their theory, put forth in the early 1990s, incorporates spatial memory but also attempts to explain the role of the hippocampus in other aspects of declarative memory. According to this **relational memory theory**, the hippocampus does not mediate a representation of space as such (Figure 14.3A), but rather a *memory space*, in which relationships are coded by the conjunction of overlapping cues (Figure 14.3B). Consistent with this idea, there is evidence that place cells in rodents do not represent a global topology of the environment, but the *spatial relationships among subsets of cues*. Furthermore, the firing of place cells is also affected by nonspatial variables, such as the speed with which the rat moves and the presence of particular stimuli or rewards in environment. Thus the relational memory theory holds that the hippocampus actually mediates associations among spatial cues, temporal cues, rewards, and perhaps other factors as well.

An example of how the hippocampus is involved in remembering overlapping associations is seen in a study that tested rats using an odor association task (Box 14B). By hiding treats such as Fruit Loops cereal in cups of differently odorized sand, rats were trained to prefer odor A over odor B, odor B over odor C, and so on. The trained rats later showed that they remembered not only each paired relationship (e.g., $A > B$, $B > C$), but also more complex rela-

BOX 14B Investigating Declarative Memory in Non-Human Animals

The most obvious challenge to investigating declarative memory in non-human animals is that they cannot follow verbal instructions or “declare” their memories verbally. However, there are ways of measuring declarative memory in such circumstances.

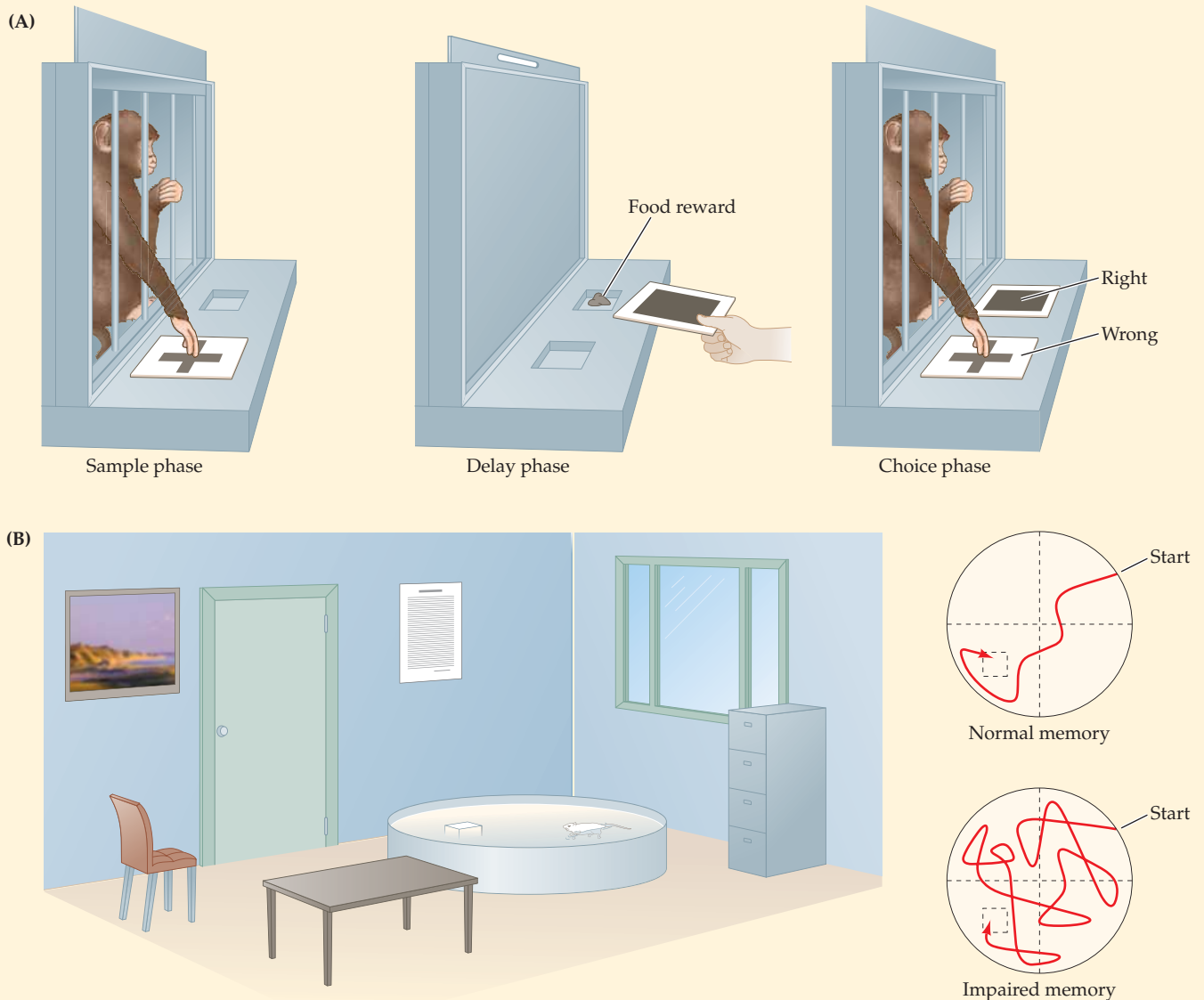
One such method used in studies on non-human primates is known as a *delayed nonmatch-to-sample task* (Figure A). A typical trial in this paradigm has three phases. During the *sample phase*, a monkey is shown a single stimulus

(e.g., a white cross) above a well containing a food reward; during the *delay phase*, a door is lowered so the monkey can no longer see the stimulus and reward; and during the *choice phase*, the monkey is presented with the previously rewarded stimulus (the white cross) along with a new stimulus (e.g., a black rectangle). This time the animal must select the new (nonmatching) stimulus in order to obtain the reward. (There is also a matching version of this task, discussed in Box 16A, but monkeys learn the non-

matching rule faster because they have a natural tendency to manipulate novel objects.) Using nonmatch-to-sample tasks, David Gaffan at Oxford University and Mortimer Mishkin at the National Institutes of Health

(Continued on next page)

(A) Delayed nonmatch-to-sample task. Declarative memory is indexed by the ability to choose the novel stimulus. (B) The Morris water maze. Declarative memory is indexed by the ability to find the hidden platform.



BOX 14B (continued)

showed that lesions of the medial temporal lobe severely impair memory in monkeys, thus providing the first animal model of the human amnesic syndrome described in Chapter 13.

Such studies can also be done using rodents—a particularly important advance because the use of rodents allows us to examine the genetic basis of behavior in these animals. The most popular “declarative” memory task for rodents is the *Morris water maze*, pioneered by Richard Morris and his

group at the University of Edinburgh. The animal’s task is to swim to a small platform hidden just beneath the surface in a circular tank filled with murky water, which then provides a safe haven (Figure B). Once the animal has learned where to find the platform, the experimenter can assess memory by measuring how long the rat takes to find the platform again, or how much time it spends within the quadrant that contains the platform compared to the other three quadrants

of the tank. Given that the murky water means the animal’s view of the tank is the same in all directions, remembered cues from objects in the room (e.g., windows, a large wall clock) are presumably used to locate the platform.

The Morris water maze measures spatial memory; however, it is also possible to measure nonspatial forms of declarative memory in rodents in paradigms such as the odor association task described in the text and Figure 14.4.

tionships among the elements of the pairs ($A > B > C > D > E$; **Figure 14.4**). In contrast, animals with lesions that disrupted the output of the hippocampus could remember the individual paired relationships they were trained on, but could not express memories of the overlapping relationships.

Episodic memory theory

Whereas the cognitive map and relational memory theories were originally inspired by research with non-human animals, a further issue in humans is

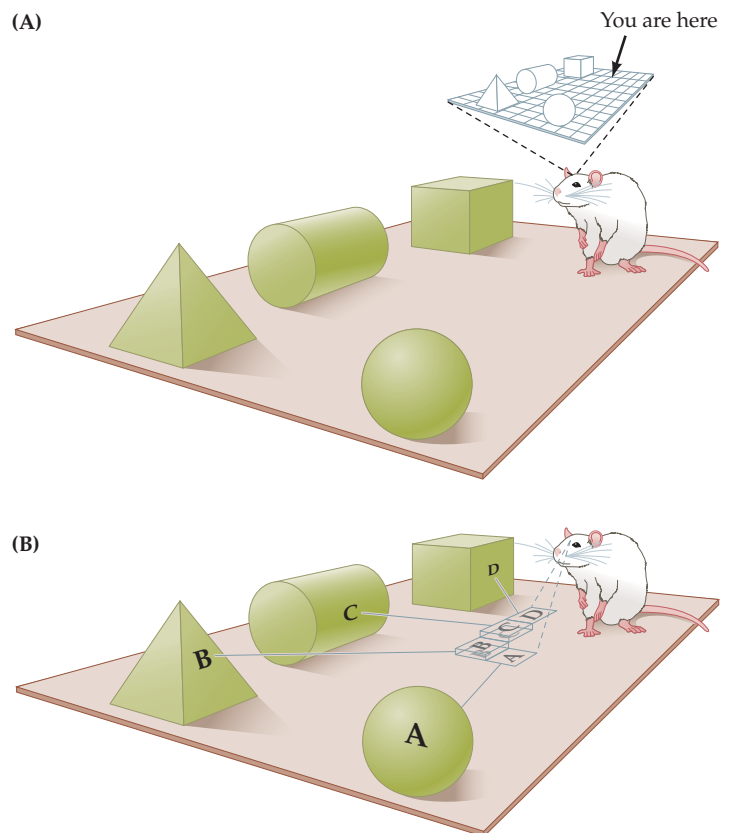


Figure 14.3 Comparing the cognitive map and relational memory theories of hippocampal function.

(A) According to cognitive map theory, the hippocampus holds a spatial map of the environment. (B) According to relational memory theory, the hippocampus stores a set of overlapping associations (A/B , B/C , etc.) that are not necessarily or even primarily spatial. (After Eichenbaum et al. 1999.)

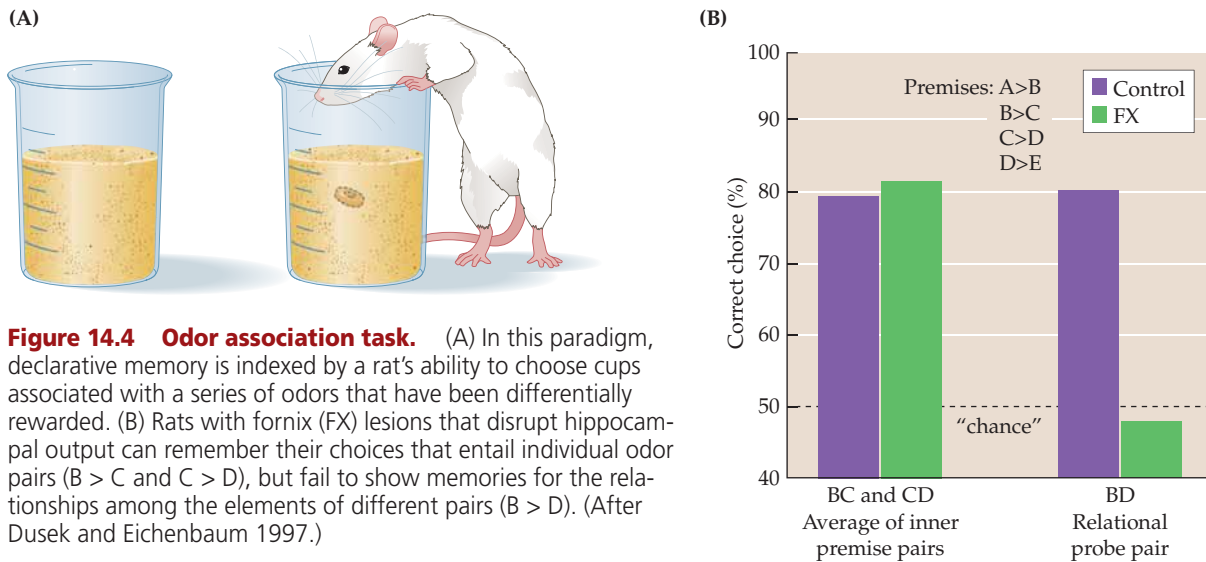


Figure 14.4 Odor association task. (A) In this paradigm, declarative memory is indexed by a rat's ability to choose cups associated with a series of odors that have been differentially rewarded. (B) Rats with fornix (FX) lesions that disrupt hippocampal output can remember their choices that entail individual odor pairs ($B > C$ and $C > D$), but fail to show memories for the relationships among the elements of different pairs ($B > D$). (After Dusek and Eichenbaum 1997.)

whether the hippocampus contributes equally to episodic and to semantic memory. According to the **episodic memory theory**, supported by Endel Tulving, Morris Moscovitch, and other researchers, the hippocampus is critical for episodic memory but is not required for semantic memory.

The episodic memory theory is supported by several pieces of evidence. First, retrograde memory deficits following hippocampal damage are more pronounced for episodic than for semantic information. An example is K.C., an amnesic patient investigated by Tulving and other memory researchers at the University of Toronto. K.C. had a motorcycle accident in which he sustained damage to several brain regions, including the hippocampus (**Figure 14.5**). As with patient H.M., K.C.'s intellectual abilities were well preserved: he is able to read, write and play chess at much the same level as before his accident. However, both his anterograde and retrograde episodic memory are severely impaired.

Unlike H.M., K.C.'s retrograde amnesia covers his whole life, and for all intents and purposes he cannot remember any personal history. In contrast, his memory for semantic information acquired before the accident is intact. He has a good vocabulary, and his knowledge of subjects such as mathematics, history, and geography is not greatly different than that of others with his educational background. Thus, medial temporal lobe damage can in at least some cases impair retrograde episodic memory while sparing retrograde semantic memory. It could be argued that K.C.'s general knowledge was acquired earlier than the episodic memories tested and hence was more consolidated and less dependent on the hippocampus (see Chapter 13). However, K.C. can readily retrieve semantic information he acquired while working as a machinist, such as the meaning of technical terms like *spiral mandrel* and *keyway shank*, whereas he fails to remember events that happened in the factory during the same time period.

A second line of evidence supporting the episodic memory theory is that anterograde memory deficits following hippocampal damage can spare new

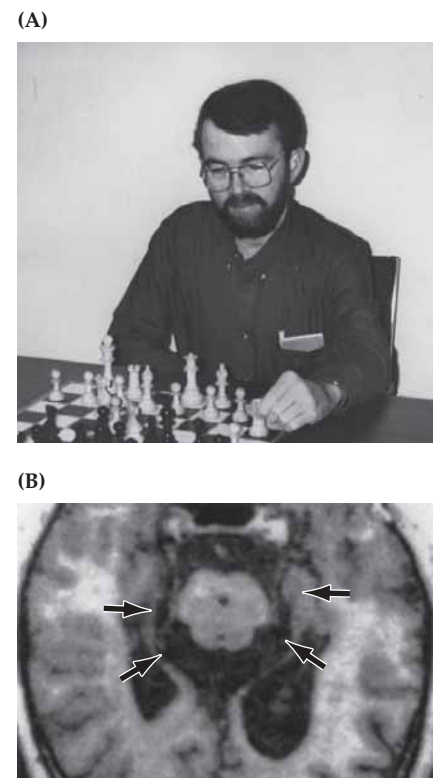
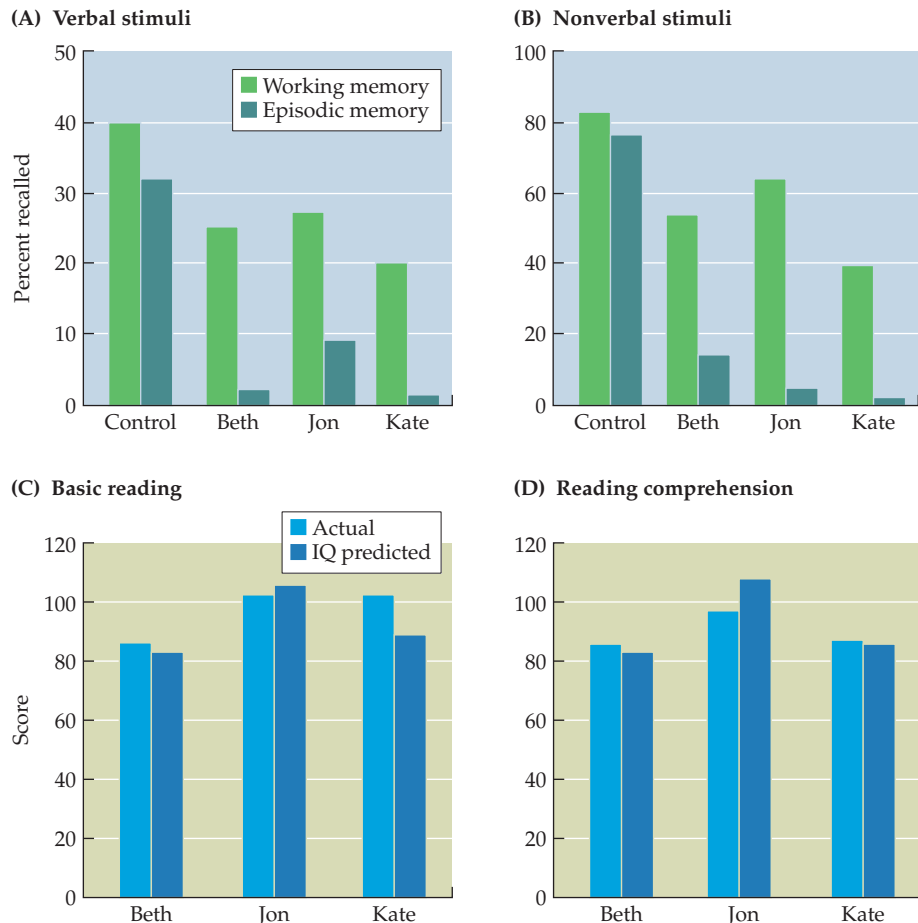


Figure 14.5 Amnesic patient K.C. (A) K.C.'s ability to play chess was not affected by his brain lesions. (B) Sagittal MRI slice showing K.C.'s bilateral hippocampal and parahippocampal damage. (A from Tulving 2002; B from Rosenbaum et al. 2000.)

Figure 14.6 Hippocampal lesions in young children can result in developmental amnesia.

(A,B) Compared to control subjects, developmental amnesic children Beth, Jon, and Kate are impaired in episodic but not in working memory for both verbal and nonverbal stimuli. (C,D) The three children show normal reading ability, as indicated by similar actual and expected scores on the basis of their IQs. (After Vargha-Khadem et al. 1997.)



semantic learning to certain degree. Several studies have shown that adult patients with anterograde amnesia (including K.C.) can in fact learn new vocabulary and facts, albeit slowly. Preserved semantic learning also is seen in children who suffer selective hippocampal lesions due to anoxic accidents at an early age, usually through complications at birth. Faraneh Vargha-Khadem and her collaborators at University College London have shown that these cases of **developmental amnesia** have severe difficulties in remembering personal occurrences and perform poorly on tests of episodic memory (**Figure 14.6A,B**). Nonetheless, they make normal or near-normal progress in school, and acquire semantic knowledge about the world more or less normally (**Figure 14.6C,D**).

Finally, a double dissociation supports this distinction of hippocampal function in declarative memory within the temporal lobes. Whereas hippocampal lesions affect episodic more than semantic memory, left-lateralized damage to anterior temporal cortex tends to affect semantic more than episodic memory. The latter pattern is displayed by patients with the progressive disorder known as **semantic dementia** (**Figure 14.7A**). An example is A.M., a patient investigated by Kim Graham and John Hodges at Cambridge University. A.M. first sought medical attention because he had difficulty finding the right words to name things (*anomia*). Otherwise his speech was fluent. His episodic memory was also good, and he could relate—albeit with severe difficulty finding the right words—the details of recent holidays and golfing achievements. Neuropsychological testing showed a dissociation between semantic and episodic memory deficits: A.M. was severely impaired in

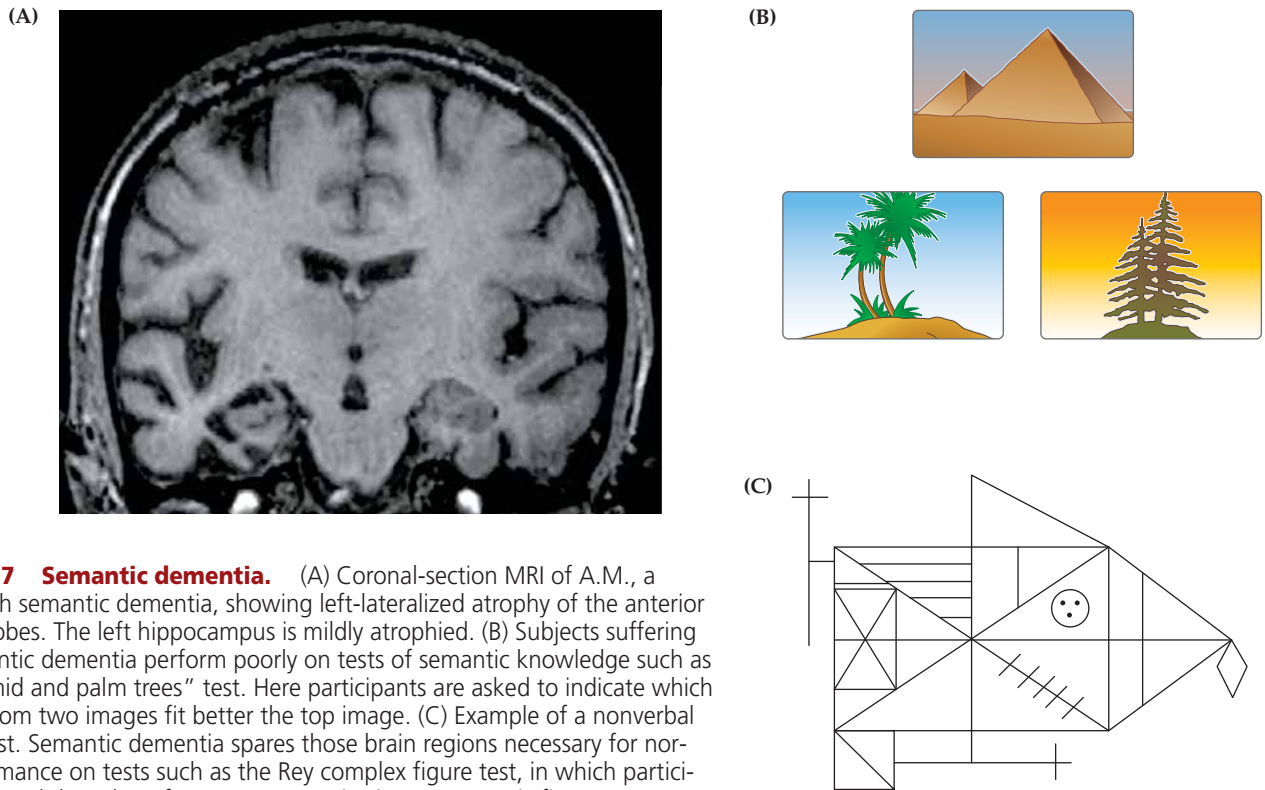


Figure 14.7 Semantic dementia. (A) Coronal-section MRI of A.M., a patient with semantic dementia, showing left-lateralized atrophy of the anterior temporal lobes. The left hippocampus is mildly atrophied. (B) Subjects suffering from semantic dementia perform poorly on tests of semantic knowledge such as the “pyramid and palm trees” test. Here participants are asked to indicate which of the bottom two images fit better the top image. (C) Example of a nonverbal episodic test. Semantic dementia spares those brain regions necessary for normal performance on tests such as the Rey complex figure test, in which participants copy and then draw from memory an intricate geometric figure.

semantic knowledge tests (e.g., the “pyramid and palm trees” test shown in **Figure 14.7B**) but performed normally on nonverbal episodic memory tasks (e.g., the Rey complex figure test, **Figure 14.7C**). Thus, whereas amnesic patients with hippocampal lesions may be impaired in episodic but not in semantic memory, semantic dementia patients with left anterior temporal damage tend to be impaired in semantic more than in episodic memory.

Evidence supporting both relational and episodic memory theories

Evidence linking the hippocampus to recollection is consistent with both the relational and the episodic memory theories. *Recollection* involves relational memory and is the prototypical form of episodic memory; thus a number of investigators have sought to show that the hippocampus is more concerned with processing recollection than in providing a sense of familiarity.

Several methods have been used to distinguish recollection from familiarity. In one method, participants are asked to use introspection to distinguish between recognition responses based on recollection (“remember” responses) and those based on familiarity (“know” responses). Supporting the validity of both the relational and episodic memory theories, fMRI studies show that “remember” responses elicit greater hippocampal activity than “know” responses (**Figure 14.8A**).

Another method is to measure participants’ ability to encode and retrieve specific associations between items, or between items and contexts. For instance, another fMRI study found that the left hippocampus was associated with both successful encoding and successful retrieval of semantic and perceptual associations (**Figure 14.8B**). Finally, estimates of recollection and familiarity can be calculated on the basis of the proportion of hits and false alarms. A study that used this method to assess memory for odors in rats found that

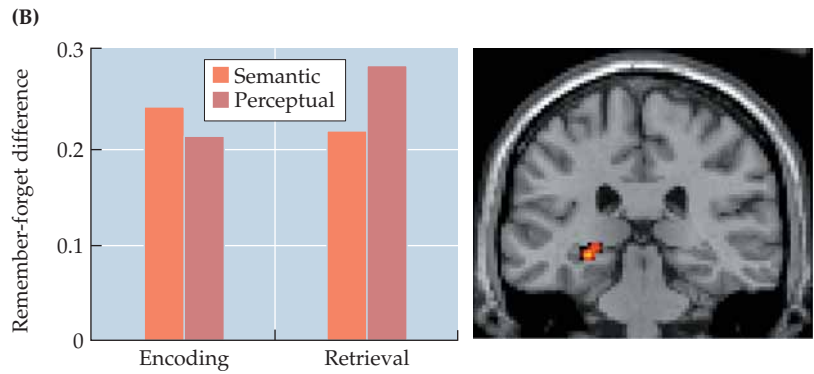
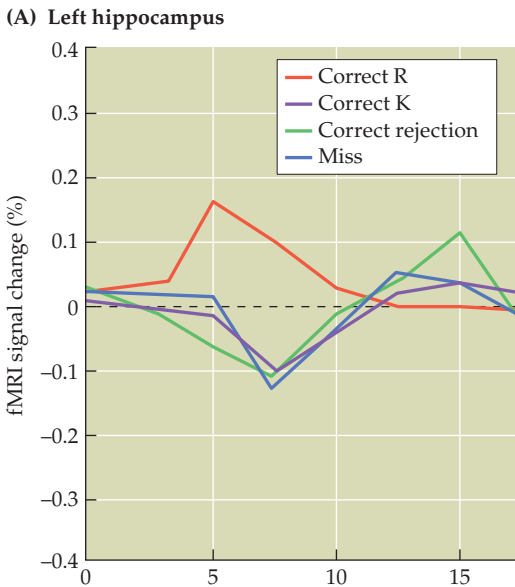
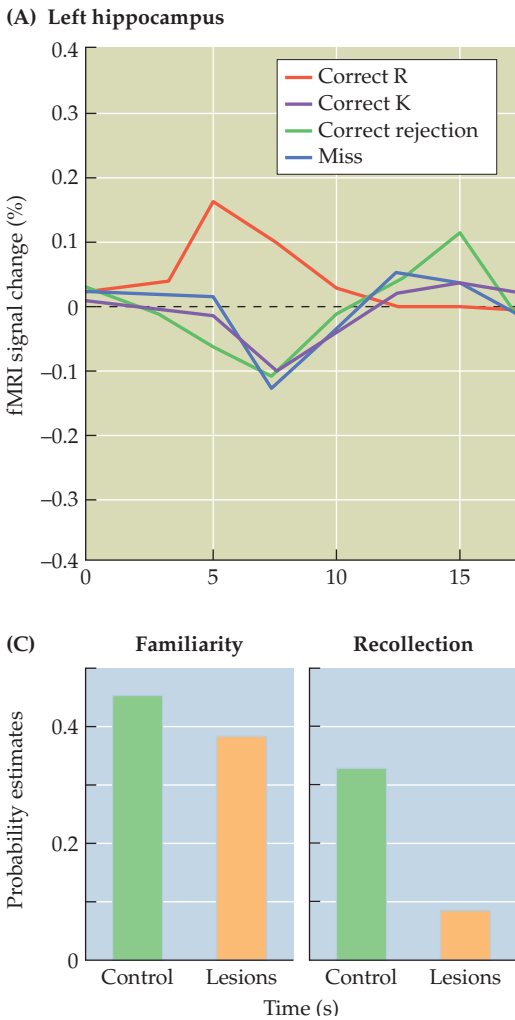


Figure 14.8 Evidence for a greater hippocampal role in recollection than in familiarity. (A) In this study, the hippocampus in participants was activated during recognition responses based on recollection (“remember”; R responses) but not during recognition responses based on familiarity (“know”; K responses). (B) During both encoding and retrieval, activity in the left hippocampus was associated with successful memory for both semantic and perceptual associations. (C) Compared to controls, rats with selective hippocampal lesions are impaired in recollection but not in familiarity. (A after Eldridge et al. 2000; B after Prince et al. 2005; C after Yonelinas et al. 2002.)

selective hippocampal lesions impaired recollection but not familiarity estimates (Figure 14.8C). In sum, several lines of evidence indicate a strong link between the hippocampus and recollection, implying a key role for this structure in episodic memory.

Declarative memory theory

The **declarative memory theory** supported by Larry Squire and his collaborators at the University of California at San Diego argues that the hippocampus mediates *all* declarative memories, regardless of whether they are spatial or nonspatial, relational or nonrelational, episodic or semantic. Supporting this view, studies of patients with hippocampal lesions have shown that some amnesic individuals are impaired to about the same extent in item- and context-memory tasks. Furthermore, several functional neuroimaging studies have shown that, under certain conditions, the hippocampus is similarly activated in normal subjects carrying out these tasks. The reasons why these studies failed to observe the differences reported in other patient and functional neuroimaging studies remain uncertain, emphasizing the difficulty of decisively delineating medial temporal lobe functions with the research methods currently available.

Integrating theories of hippocampal memory function

Given that all four of these theories about hippocampal functions—cognitive map, relational, episodic, and declarative memory—are supported by substantial evidence, a reasonable view at present is that all of them are correct in some measure. Thus, rather than seeing these ideas as competitors, it makes sense to integrate them. For example, the cognitive map and relational memory theories could be integrated by assuming that they apply to different regions of the hippocampus. Indeed, it been suggested that spatial memory functions are more pronounced in the *right* hippocampus, whereas general relational functions are more the province of the *left* hippocampus. Another proposal is that spatial memory functions depend primarily on *posterior* hip-

pocampal regions, whereas general relational memory functions depend primarily on *anterior* hippocampal regions.

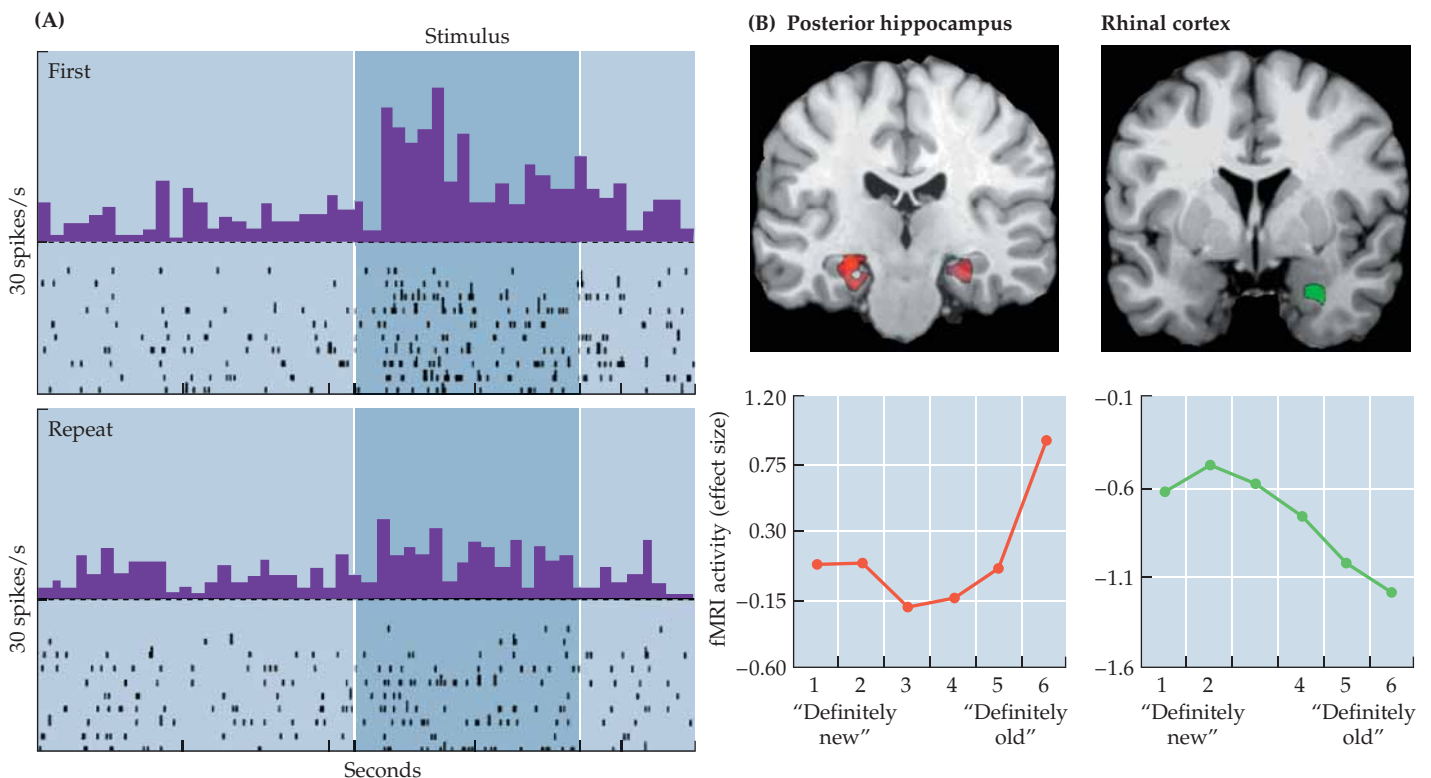
Moreover, the relational memory and episodic theories are already closely related. As noted already, both views are consistent with evidence linking the hippocampus to recollection. These two theories could be further integrated with the declarative memory theory by postulating that the distinctions between relational and item memory and between episodic and semantic memory are not clear-cut but a continuum, as indeed seems likely.

Distinguishing the functions of different medial temporal lobe subregions

An issue of obvious importance is how hippocampal functions—however one interprets them—are related to the functions of other structures in the medial temporal lobes, the surrounding perirhinal and parahippocampal cortices in particular (see Box 13B). Several ideas about functional differences between the hippocampus and the other medial temporal lobe structures have been proposed.

According to a **hippocampal-perirhinal theory** put forward by Malcolm Brown and John Aggleton at Bristol University, England, the hippocampus processes information relatively slowly and is associational and spatial, whereas the *perirhinal cortex* processes information more rapidly and is item-based. In this conception, neurons in the hippocampus signal information about spatial positions or associations between items (i.e., recollection), whereas neurons in the perirhinal cortex signal information about the novelty of individual items (i.e., familiarity). Consistent with the latter hypothesis, single-cell recordings in experimental animals have shown that perirhinal neurons do indeed show a stronger response when an item is first presented than when the same item is shown again (Figure 14.9A). Functional neuroimaging

Figure 14.9 Evidence for complementary hippocampal and perirhinal systems. (A) Neurons in the perirhinal cortex show a strong response when an item is first presented but not when the item is repeated. (B) Functional MRIs show that activity in the hippocampus increases sharply for items recognized as “definitely old,” whereas activity in rhinal cortex decreases gradually as items become more familiar. (A from Xiang and Brown 1998; B from Daselaar et al. 2006.)



studies also suggest that the hippocampus and the perirhinal cortex make different contributions to recollection. For example, the hippocampus shows a sharp increase in activity when participants are sure they have encountered an item before (“definitely old”), consistent with its putative role in recollection. Activity in perirhinal cortex, on the other hand, decreases gradually as items are regarded as more and more familiar, consistent with a greater role in familiarity than recollection (Figure 14.9B). It is unclear, however, whether the decrease in perirhinal activity measured with fMRI reflects the reduction in firing rate measured with single-cell recording studies seen in Figure 14.9A.

As discussed Chapter 15, a reduction in neural response as a function of repetition has also been proposed as a mechanism for priming (see also the discussion of habituation in Chapter 13). Also pertinent to this and other theories about different regional functions in the medial temporal lobe are the different connections of the hippocampus and perirhinal cortex to the thalamus. Whereas the hippocampus is connected to the anterior nucleus of the thalamus via the fornix and the mammillary bodies (see Box 13B), the perirhinal cortex are connected to the medial dorsal nucleus of the thalamus. It seems likely, then, that these thalamic regions also play some role in declarative memory.

A different conception is the **item-in-context theory** proposed by Howard Eichenbaum at Boston University in collaboration with Andrew Yonelinas and Charan Ranganath at the University of California at Davis. They proposed that the perirhinal cortex and associated lateral entorhinal cortex are concerned with *memory for items*, whereas the parahippocampal cortex and associated medial entorhinal cortex are involved in *memory for context*. In this view, the hippocampus interacts with *both* regions and is thus involved in memory for the *item in context* (Figure 14.10).

This three-process theory has several strengths. First, it accounts for evidence linking the perirhinal cortex to familiarity and the hippocampus to recollection. Second, the distinction between perirhinal and parahippocampal

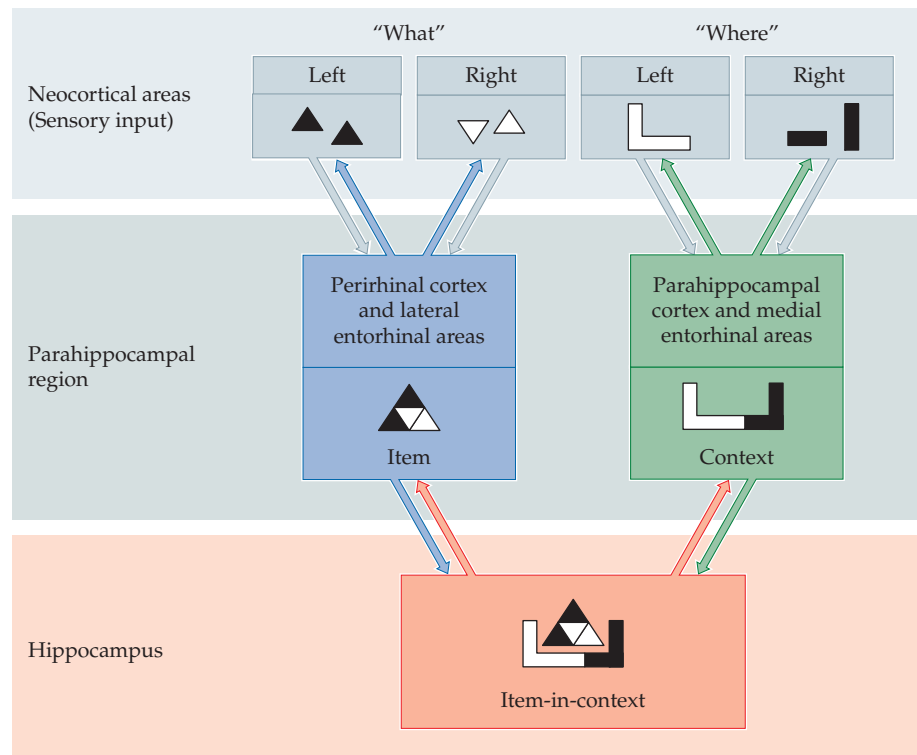


Figure 14.10 The item-in-context theory of medial temporal lobe memory functions. The perirhinal cortex and associated lateral entorhinal cortex are taken to be concerned with memory for items, whereas the parahippocampal cortex and associated medial entorhinal cortex are involved in memory for context. In this theory, the hippocampus interacts with both regions to produce item-in-context memories. (After Eichenbaum et al. 2007.)

functions fits well with anatomical, lesion, and functional neuroimaging evidence. The perirhinal cortex receives most of its visual input from the ventral (“what”) pathway, whereas the parahippocampal cortex receives most of its visual input from the dorsal (“where”) pathway (see Figure 14.10 and Chapter 4). In monkeys, perirhinal lesions tend to impair object memory rather than spatial memory, whereas parahippocampal lesions yield the opposite pattern. In humans, functional neuroimaging studies have repeatedly shown that a parahippocampal region known as *parahippocampal place area* is consistently activated during perception and memory of spatial layouts. Finally, the notion of item-in-context memory accommodates both the role of the hippocampus in spatial memory (the cognitive map theory) and its more general role in context memory and recollection (the relational and episodic theories). Despite these strengths, however, this newer model has not yet been well tested.

In sum, there are several theories about the relative contributions of the hippocampus and other medial temporal lobe regions to declarative memory. All the theories linking the hippocampus and associated structures in the medial temporal lobe to spatial memory, relational memory, and episodic memory are supported by empirical evidence and are likely to be at least partially correct. A full-fledged theory of declarative memory, however, will need to consider not only medial temporal lobe functions but also the role of other brain regions, the frontal lobes in particular.

The Role of the Frontal Lobes in Declarative Memory

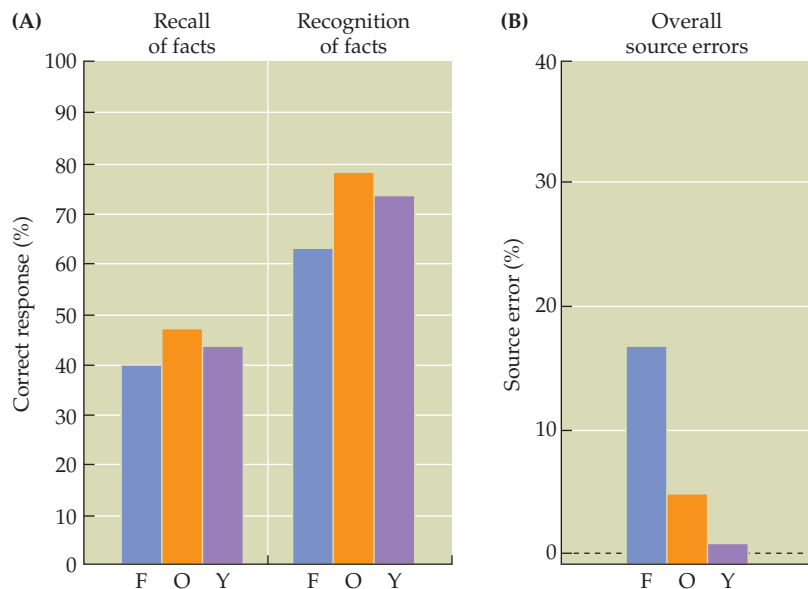
Effects of frontal lobe damage

Whereas medial temporal lobe lesions are associated with a devastating amnesic syndrome, frontal lesions typically cause only mild declarative memory deficits, and only in certain tasks. In general, the effects of frontal damage on declarative memory appear to be a function of the strategic demands of the task. In the case of episodic memory, for example, recall and context memory tests, which are more dependent on strategic control processes (see Box 14A), are more affected by frontal lesions than recognition memory tests are. The importance of frontal regions in context memory has been known for some time.

In 1971, Brenda Milner reported that patients with frontal lobe damage were more impaired in temporal-order memory (a form of context memory) than on simple recognition memory tests. This finding was later supported by parallel studies in monkeys, and in humans was extended to other forms of context memory, such as memory for source of information. For example, in one study, patients with frontal lobe damage, age-matched controls, and younger controls were presented a series of facts that previous testing indicated they had not known prior to the study; after a delay, their memory for these facts was tested. When a test question was answered correctly, participants were asked whether they had learned the fact during the experiment or whether they had known it all along (the latter being an incorrect answer). Although the three groups performed at about the same level in recall and recognition, frontally damaged patients made many more errors in identifying the source of the memory than the two control groups (**Figure 14.11**).

Declarative memory deficits following brain lesions may reflect difficulties during encoding, difficulties during retrieval, or both. Thus, one of the great advantages of using functional neuroimaging to investigate declarative memory is that it provides separate measures of encoding and retrieval. The next two sections review functional neuroimaging studies investigating each of these two phases of declarative memory.

Figure 14.11 Recall, recognition, and source memory in patients with frontal lobe damage. Patients were compared with age-matched controls and with younger control subjects. (A) Performance on tests of fact recall and recognition was similar across all three groups. (B) Source memory was significantly impaired in patients with frontal lobe damage. F = frontal lobe damage patients; O = age-matched controls; Y = young controls. (After Janowsky et al. 1989.)



Functional neuroimaging of episodic encoding and semantic retrieval

The rationale for considering episodic encoding and semantic retrieval together is that these two processes are closely related; they are often considered to be two sides of the same coin. For example, thinking about the meaning of a piece of information (semantic retrieval) normally leads to the storage of this information in episodic memory (episodic encoding). Conversely, the attempt to learn new information (episodic encoding) usually involves semantic processing (semantic retrieval). It is therefore not surprising that in functional neuroimaging studies, episodic encoding and semantic retrieval tasks activate many of the same brain regions.

The most prominent of these shared regions is the left inferior frontal gyrus. In the 1990s, the first functional neuroimaging study of episodic encoding found that the left inferior frontal gyrus showed greater activity when participants processed the meaning of words than when they processed their orthography (e.g., does the word contain the letter *o*?) (Figure 14.12A). Given that subsequent memory for words was much better for semantic than for perceptual processing (the *levels of processing* effect mentioned in Chapter 2), these researchers attributed the left prefrontal activation not only to semantic retrieval but also to episodic encoding. The role of left inferior frontal gyrus in successful episodic encoding was later confirmed by Anthony Wagner (then at Harvard University) and his collaborators using the *subsequent memory paradigm* (Box 14C). As illustrated in Figure 14.12B, the left inferior frontal gyrus showed greater encoding activity for words that were subsequently remembered than for words that were subsequently forgotten. Greater activity for subsequently remembered than forgotten words (the “difference in memory” or Dm effects described in Box 14C) was also found in the left medial temporal lobe region. In general, the Dm effects in the left inferior frontal gyrus tended to occur in the left hemisphere for verbal stimuli, and bilaterally for visual stimuli.

As already mentioned, the role of left inferior frontal gyrus in encoding is likely to reflect semantic processing. However, not all parts of this gyrus mediate semantic processing. In fact, studies with *aphasic* patients (patients with language deficits; see Chapter 21) and studies of working memory using

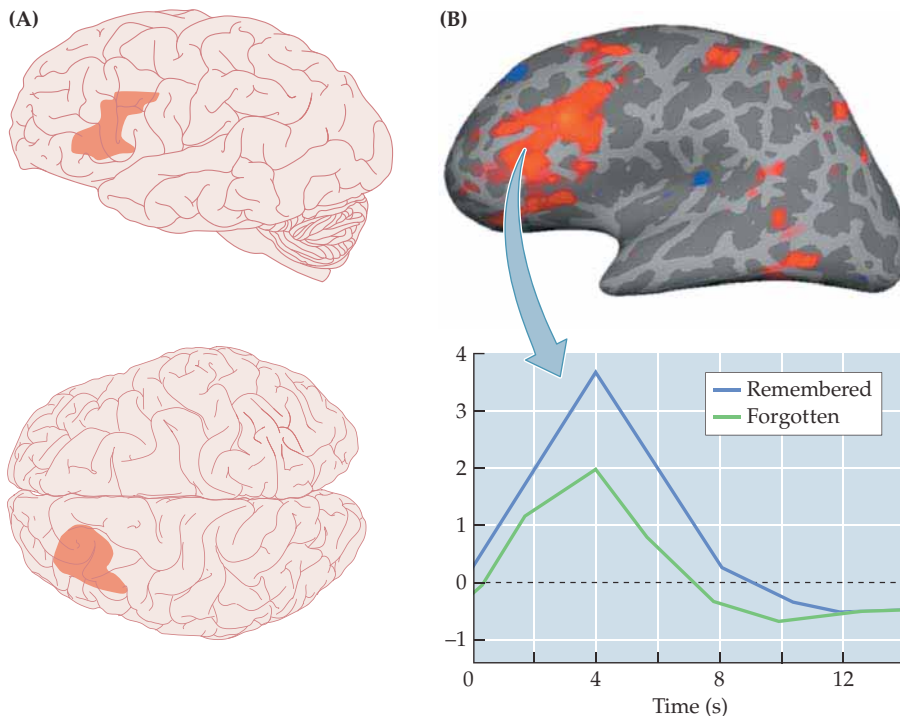


Figure 14.12 Frontal lobe activity during encoding of declarative information. (A) Greater left ventrolateral prefrontal activity is seen for words encoded during a semantic task (here, attending to whether the words referred to living or nonliving things) than during a perceptual processing task (attending to whether the words contained the letter “a”). (B) Greater encoding activity is seen in the left inferior frontal gyrus for words that were subsequently remembered than for words that were subsequently forgotten. This is the difference-in-memory, or Dm effect. (A after Kapur et al. 1994; B after Paller et al. 2002.)

functional neuroimaging (see Chapter 16) have linked the posterior part of the left inferior frontal gyrus, known as *Broca’s area*, to phonological processing. (Another view, discussed in Chapter 16, suggests that the general function of Broca’s area is to provide inhibitory control processes.) This functional subdivision of the left inferior frontal gyrus has been confirmed by fMRI studies that manipulated and compared semantic (meaning) to phonological (sound) processing. These studies have shown that the anterior part of the left inferior frontal gyrus (Brodmann areas 45/47) is more activated during semantic processing, whereas the posterior portion of this gyrus (areas 44/46) is more activated during phonological processing (Figure 14.13).

Dm effects, in contrast, are usually found in the *inferior* frontal gyrus (ventrolateral prefrontal cortex; Figure 14.14A) but rarely in the *middle* frontal

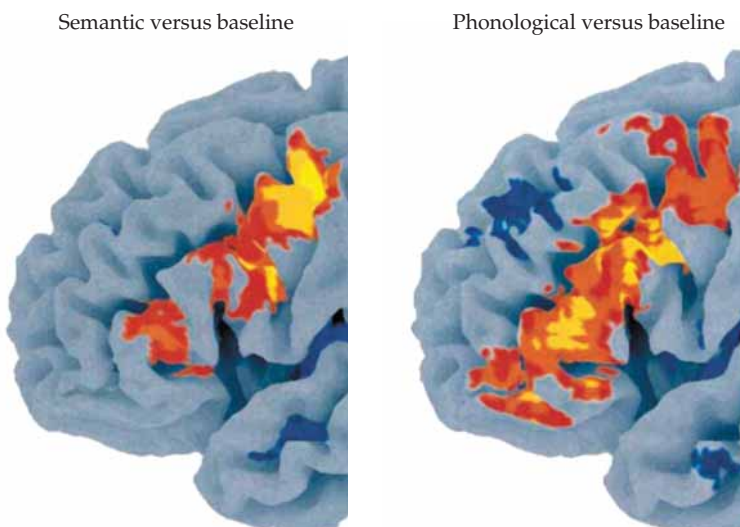


Figure 14.13 Word processing in Broca’s area. Semantic processing of words activates both anterior and posterior regions of the left inferior frontal gyrus, whereas phonological processing of words activates mainly the posterior region. (From McDermott et al. 2003.)

BOX 14C Functional Neuroimaging Methods to Study Episodic Memory

As described in Chapter 3, functional neuroimaging provides a powerful method to investigate the neural correlates of cognitive functions. With respect to episodic memory, these methods are especially useful in that they can distinguish between memory encoding and retrieval. When studying brain-damaged patients who are impaired in episodic memory, it is difficult or impossible to know whether the impairment reflects encoding deficits, retrieval deficits, or both. Functional neuroimaging studies of normal subjects, however, have identified differences in the involvement of several brain regions in encoding versus retrieval.

In working to isolate activity specifically associated with successful encoding or retrieval operations, the event-related potential (ERP) designs described in Chapter 3 are well suited to this purpose because they allow a direct comparison between successful and unsuccessful trials during encoding and/or retrieval. When applied to encoding, this method is known as the *subsequent memory paradigm* and involves four steps (Figure A, left panel).

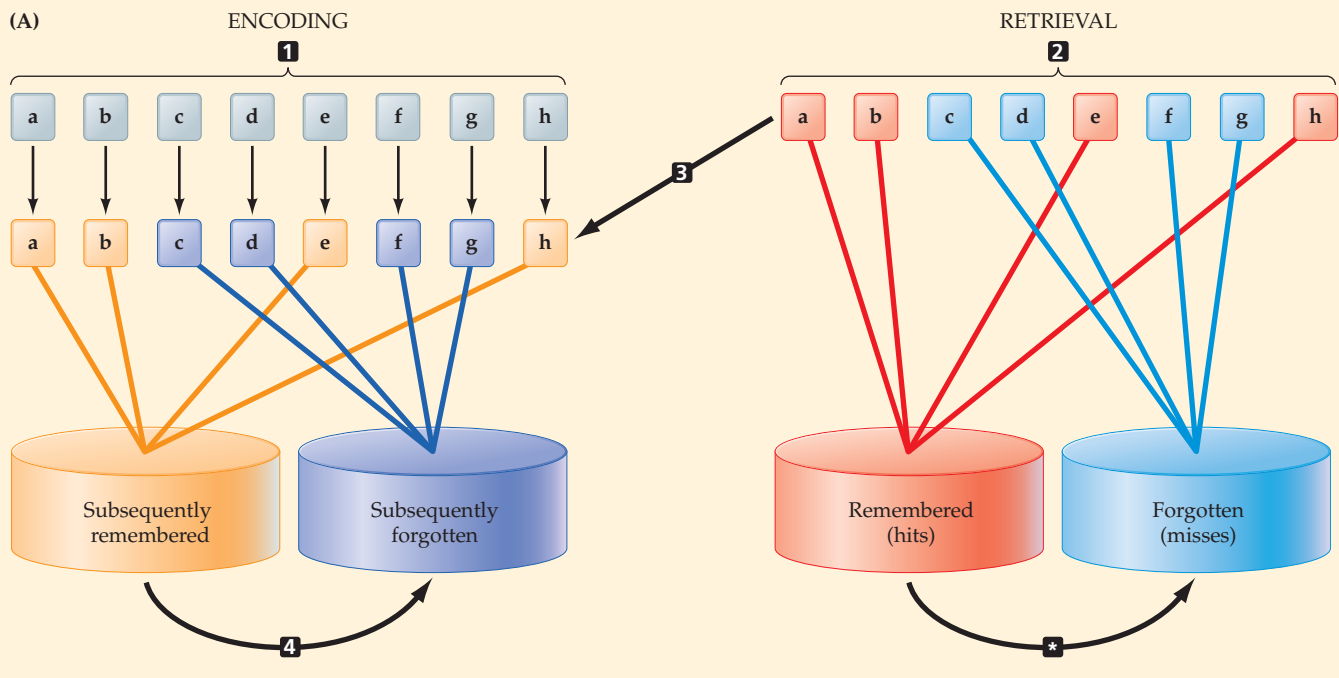
In Step 1, participants study a series of items (*a, b, c...*) while their brain activity is recorded. Step 2 requires that they perform encoding trials, remembering some of the studied items and forgetting others. On the basis of retrieval performance, in Step 3 the encoding trials are coded as subsequently remembered or subsequently forgotten; activity during these two types of encoding trials is compared in Step 4. Greater activity for subsequently remembered than forgotten trials is assumed to reflect successful encoding processes, and is known as *subsequent memory effects* or **difference-in-memory (Dm) effects**.

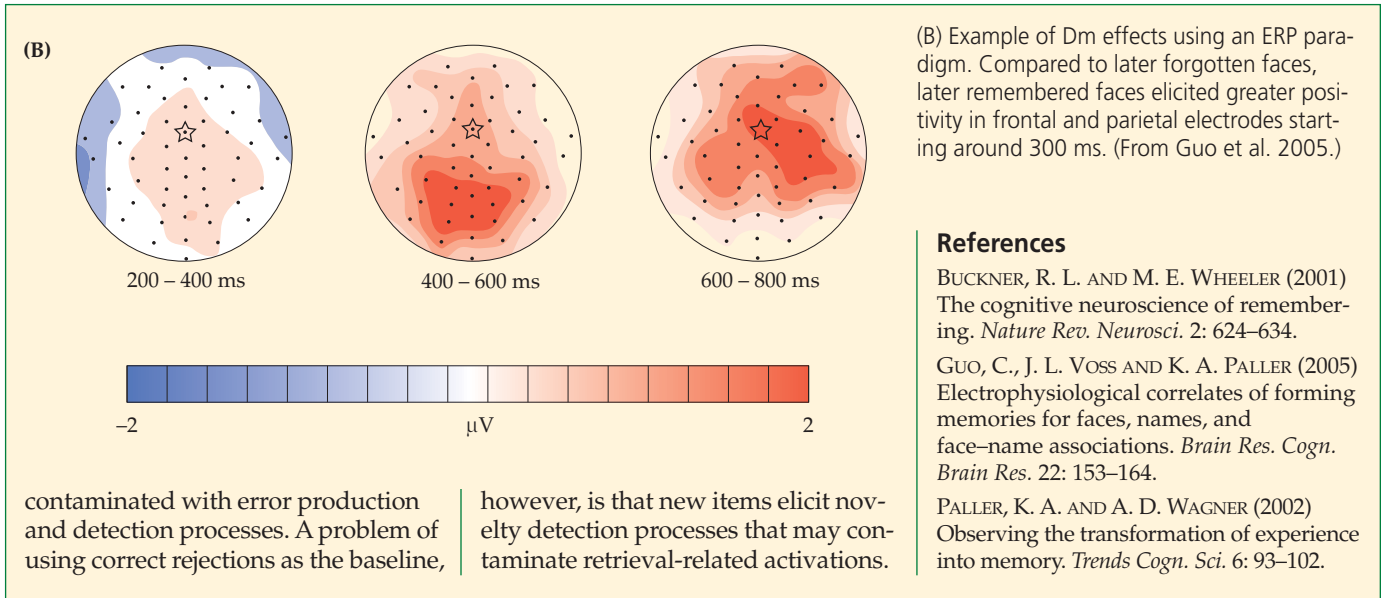
Although only recently adapted to fMRI studies, the subsequent memory paradigm has been used in ERP studies since the early 1980s by Kenneth Paller (now at Northwestern University) and other researchers. In ERP studies, Dm effects tend to be seen over frontoparietal scalp regions. Although the neural generators of scalp ERPs are uncertain, this method has the ad-

vantage of providing fine temporal resolution. As an example, Figure B, which measures Dm effects during the encoding of faces, shows that ERPs for later-remembered and forgotten faces start to diverge around 300 ms after stimulus onset, a distinction that persists until about 800 ms. This time window provides a useful limit on speculation about the cognitive processes supporting successful face encoding.

As illustrated by the right panel in Figure A, successful versus unsuccessful trials (i.e., hits versus misses) can also be compared during retrieval. An alternative approach to isolating activity associated with retrieval success is to compare hits to correct rejections of new items. An important advantage of the hit versus miss contrast is that the same set of items is compared as in the subsequent memory paradigm (e.g., *a, b, e, h...* versus *c, d, f, g...* in Figure A). An advantage of the hit versus correct rejection comparison is that it is based on correct responses, and hence not

(A) Methods for comparing successful and unsuccessful trials during encoding and retrieval.





gyrus (dorsolateral prefrontal cortex). This pattern may reflect the simple nature of stimuli used in Dm studies, which may not require the organizing functions attributed to dorsolateral prefrontal regions. To investigate this idea, a recent fMRI study scanned participants while they were reordering or

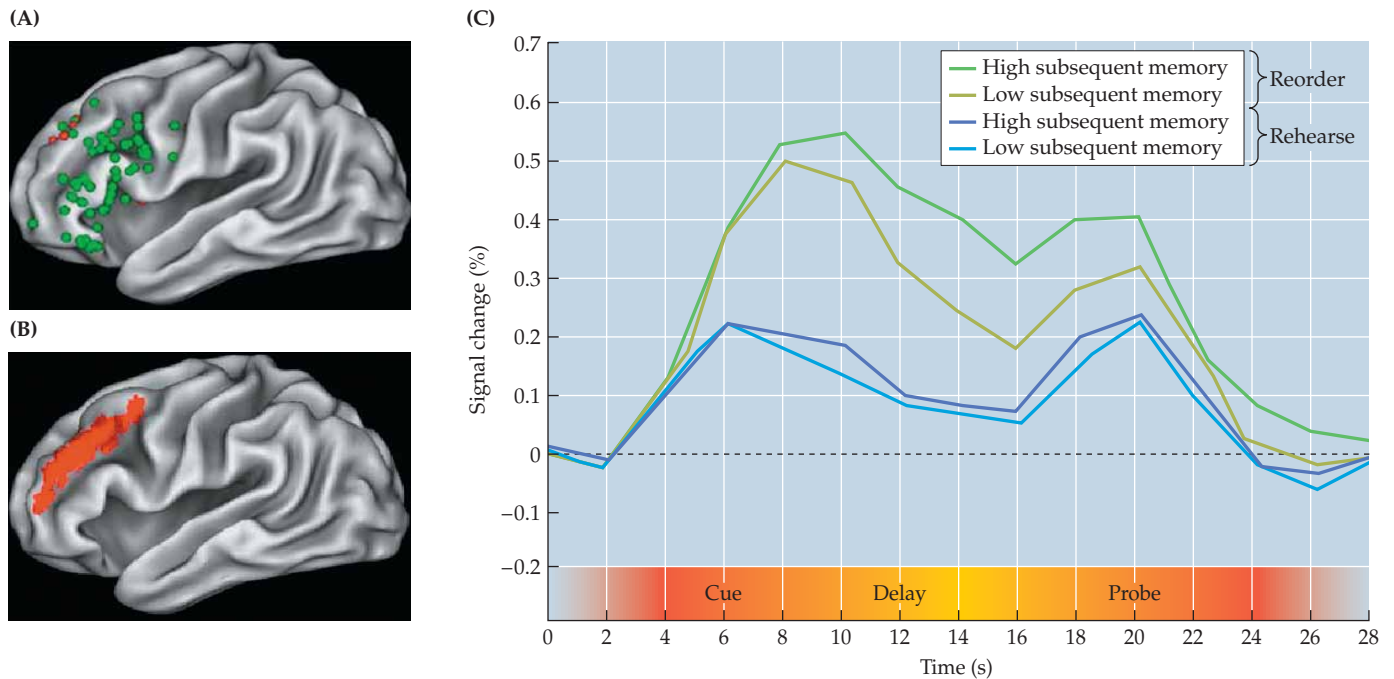


Figure 14.14 Dm effects in the inferior vs. middle frontal gyri. (A) Greater activity for subsequently remembered than forgotten items (the Dm effect) is typically found in the inferior frontal gyrus (green dots), but rarely in the middle frontal gyrus (red dots). (B) When the encoding task requires organizing information within working memory, the middle frontal gyrus (shown in red) shows significant Dm effects. (C) This region showed a significant Dm effect during the delay period of a working memory task when participants reordered words during this period, but not when they just rehearsed them. (After Blumenfeld and Ranganath 2006.)

rehearsing words in working memory; the participants' memory was later tested for the words outside the scanner. As shown in **Figure 14.14B,C**, the left dorsolateral prefrontal region showed a significant Dm effect, but only for the reorder condition. This finding suggests that the dorsolateral prefrontal region contributes to successful episodic encoding through its role in organizing information within working memory.

In sum, episodic encoding and semantic retrieval are associated with activation of the left inferior frontal gyrus. Dm effects, on the other hand, are usually left-lateralized for verbal stimuli and bilateral for pictorial stimuli. The anterior part of the left inferior frontal gyrus has been associated to semantic processing, and the posterior part with phonological processing. Finally, dorsolateral prefrontal regions may also show Dm effects when stimuli are more complex and require organization of the information in working memory to facilitate subsequent memory retrieval.

Episodic memory retrieval

Consider trying to remember what you had for breakfast the day before yesterday. The train of thought elicited by this challenge might go something like this:

Hmm... the day before yesterday I had a class in the morning and I didn't have much time for breakfast. I think I just grabbed something in the kitchen. I made coffee, which I always have in the morning, and I probably had a piece of toast. No... I didn't have toast because I was in a hurry. Now, I remember... I spread peanut butter on a slice of bread and ate it while I drank some coffee and browsed through a clothing catalog. I drank the rest of the coffee in the car...

This example illustrates typical components of episodic memory retrieval. A **retrieval cue** (the question about breakfast) triggers a **memory search** that narrows the focus to a particular time and place (the day before yesterday, in the kitchen), which leads to the **recovery** of increasingly specific stored memory traces (*coffee, toast, peanut butter, browsing a clothing catalog*). The information recovered is evaluated by a **monitoring process** that can reject inappropriate memories (e.g., *toast*), leading to further refinement. While these various processes are being performed, attention remains focused on a particular place and time in the past. This sustained mental state, which is assumed to be qualitatively different from the mental states associated with other cognitive processes such as semantic memory retrieval, is known as **episodic retrieval mode**, or simply **retrieval mode**.

To investigate the neural correlates of the components of episodic retrieval, researchers have manipulated different variables in neuroimaging studies. One important variable is the amount of valid information recovered, or **retrieval success**. Retrieval success can be measured by comparing conditions in which studied items are remembered well or poorly; by comparing recognition of old and new items; or by comparing correct and incorrect recognition ("hits" versus "misses"; see Box 14C). Brain regions in which activity increases as a function of retrieval success are likely to be involved in recovery processes, or in processes that maintain recovered information in working memory. In contrast, brain regions that are more active when recovery is low, which indexes **retrieval effort**, are likely to be involved in more demanding search or monitoring processes. Retrieval mode is assumed to reflect a *qualitative* aspect of episodic retrieval, and hence to be relatively immune to variations in retrieval success or effort. Thus, regions that show similar activity for old and new items, such as anterior right prefrontal regions, have been associated with the retrieval mode.

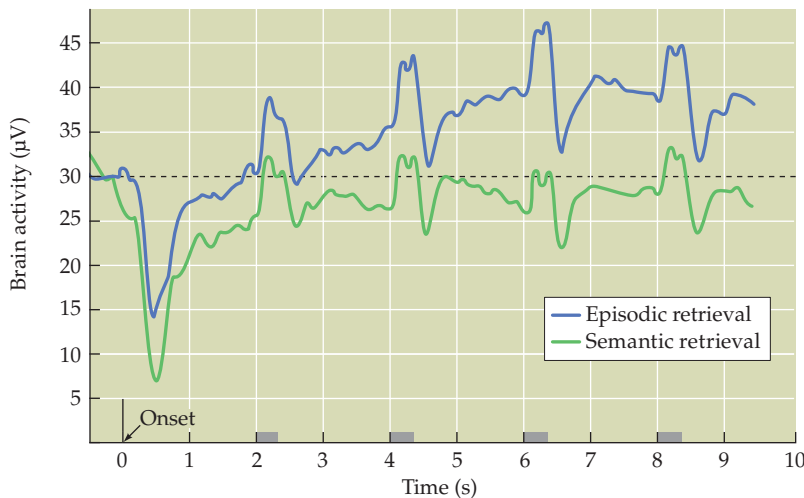
Retrieval processes also differ in their temporal characteristics. In a typical episodic retrieval test that includes several items from the same past event

(e.g., a study list), recovery and monitoring processes are assumed to vary from trial to trial, and to dissipate during the intertrial interval. Retrieval mode, however, is assumed to be sustained throughout the task, including the interval between the trials. One way of distinguishing sustained from transient activations is to use the hybrid block/event-related designs described in Chapter 3.

The first hybrid-design study of episodic retrieval measured slow and fast changes on scalp electrical activity. As illustrated in **Figure 14.15A**, electrical activity over right frontopolar regions showed not only transient changes associated with the retrieval of each item (every 2 seconds), but a slower, positive-going drift across the whole retrieval block (10 seconds). This right-lateralized drift occurred for episodic but not for semantic retrieval, consistent with the notion of episodic retrieval mode. Subsequent fMRI studies using hybrid designs confirmed that right anterior prefrontal regions show sustained activity during episodic retrieval (**Figure 14.15B**). This sustained right anterior prefrontal activation thus links this region to involvement in the retrieval mode.

Turning to transient prefrontal activations detected with event-related fMRI designs, transient activation in the left hemisphere has been associated with recollection, whereas transient activity in the right hemisphere is better associated with familiarity. For example, a study investigating the “remember/know” paradigm (see previous discussion) found that left dorsolateral prefrontal cortex was more strongly activated for recollection-based than for

(A) Right frontopolar electrode



(B) Right frontopolar cortex

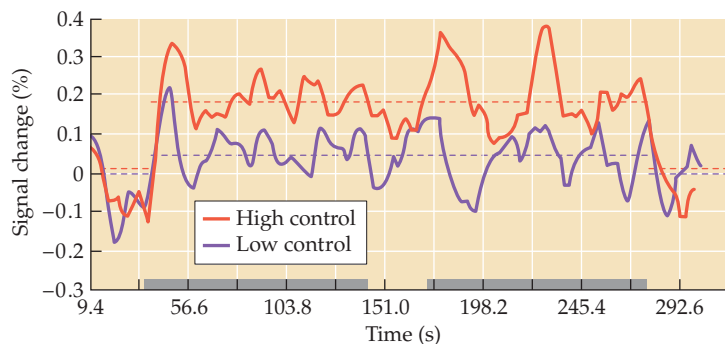
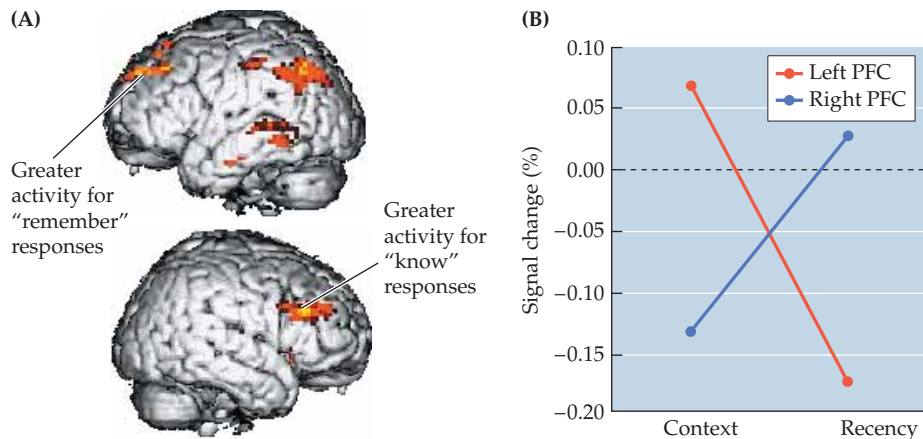


Figure 14.15 Evidence of sustained activity in right frontopolar cortex associated with retrieval. (A) Electrical activity in a right frontopolar electrode during a 10-second block consisting of the block instruction (onset, indicated by the arrow) and four items presented at 2-second intervals (gray bars). In addition to transient item-related activity every 2 seconds, there is a slow, positive-direction drift that lasts throughout the entire block. (B) Similar finding in a hybrid blocked/event-related fMRI study. The right frontopolar cortex showed sustained activity during an episodic retrieval task. Dashed lines indicate average activity and show differences during the block (gray bars) but not during the interblock intervals. (A after Düzel et al. 1999; B after Velanova et al. 2003.)

Figure 14.16 Transient prefrontal activation differentially associated with recollection and familiarity.

(A) Left prefrontal cortex shows greater activity for “remember” responses (recollection) than for “know” responses (familiarity), whereas right prefrontal cortex shows the opposite effect. (B) A context memory task (recollection) engaged left dorsolateral regions more than right dorsolateral regions, whereas a recency task (familiarity) yielded the opposite pattern. (A from Henson et al. 1999; B after Dobbins et al. 2003).



familiarity-based recognition responses; the right dorsolateral prefrontal cortex showed the opposite pattern (Figure 14.16A). A similar dissociation was found in a study that compared a context memory task that was dependent on recollection to a recency discrimination task assumed to be more dependent on familiarity (Figure 14.16B). Besides differentiating recollection versus familiarity, these double dissociations fit well with other distinctions. For instance, Marcia Johnson and collaborators have proposed that left prefrontal regions mediate **systematic processes** (such as detailed, deliberate analyses of activated information), and that right prefrontal regions mediate **heuristic processes** (such as simple contrasts between the activated information and a decision criterion).

In addition to its role in familiarity, the right dorsolateral prefrontal cortex has been associated with monitoring processes during retrieval. This idea is supported by functional neuroimaging evidence showing this region to be activated during more demanding retrieval conditions (Box 14D). For example, in a study in which participants made recognition memory decisions followed by confidence ratings, right dorsolateral prefrontal activity was greater for low- than for high-confidence recognition responses (Figure 14.17A). The link between right dorsolateral prefrontal cortex and monitoring is also supported by brain-lesion evidence. Daniel Schacter’s group at Harvard reported a patient (patient B.G.) with a large right dorsolateral prefrontal lesion who showed a severe deficit in rejecting nonstudied distractors among the studied items in a recognition test. As illustrated in Figure 14.17B, B.G. produced an abnormally high proportion of “old” responses to nonstudied items (“false alarms”), many of which he classified as “remember” rather than “know.” This sort of impairment suggests a monitoring deficit, although since the study used only behavioral methods, it is impossible to determine if impairments reflect encoding or retrieval deficits.

In short, retrieval of episodic memories has been associated with both sustained and transient activations of the prefrontal cortex. Sustained activation has been linked to the qualitative mental state accompanying episodic retrieval (i.e., retrieval mode), and tends to occur in right anterior prefrontal regions. In contrast, transient activation of the left dorsolateral regions has been associated more specifically with recollection or the attempt to recollect, whereas transient activation in right dorsolateral regions is more strongly associated with familiarity or monitoring. The role of left prefrontal cortex in recollection and right prefrontal in familiarity is also supported by lesion evidence. Although left prefrontal lesions do not usually impair semantic memo-

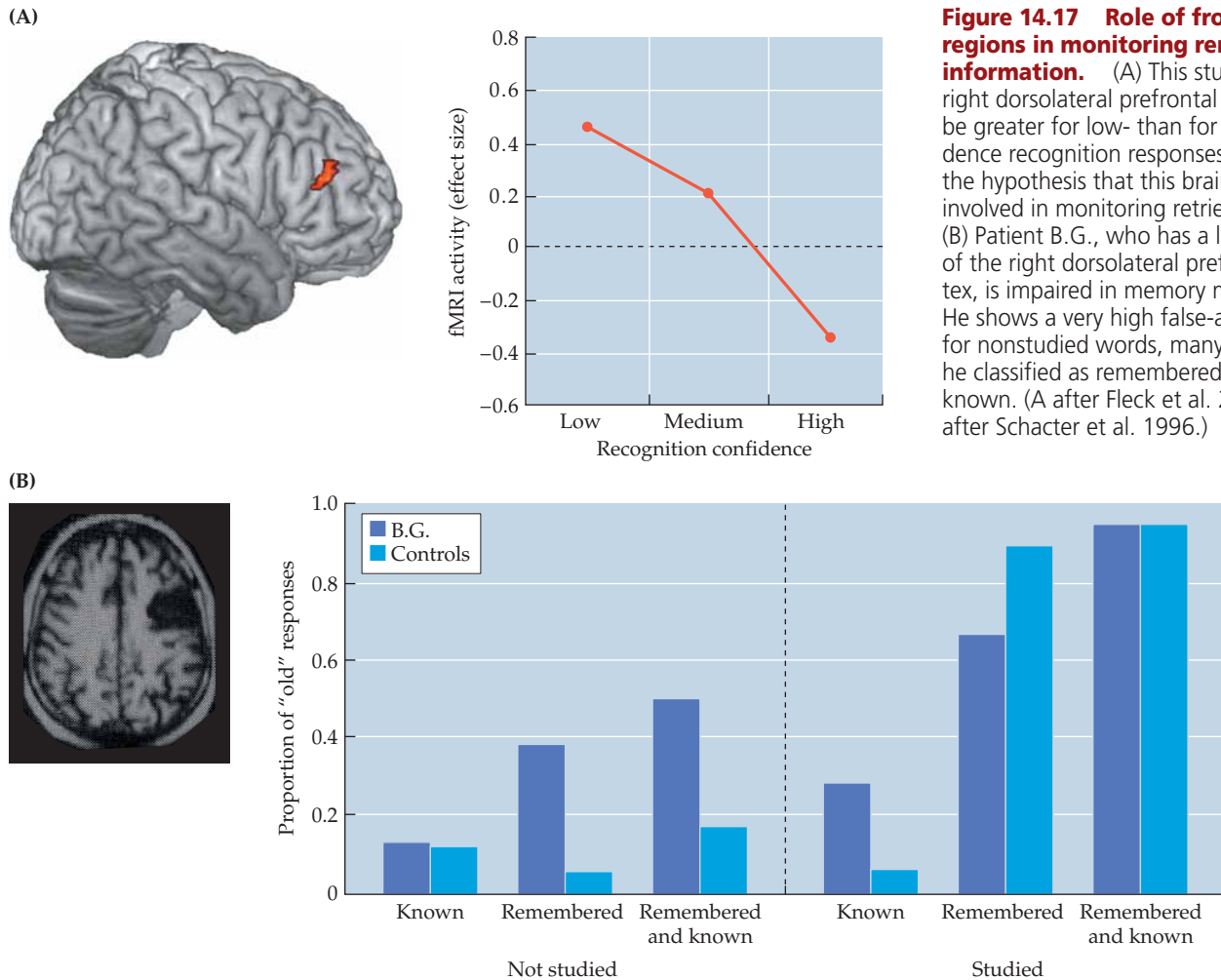


Figure 14.17 Role of frontal brain regions in monitoring remembered information. (A) This study showed right dorsolateral prefrontal activity to be greater for low- than for high-confidence recognition responses, supporting the hypothesis that this brain region is involved in monitoring retrieval output. (B) Patient B.G., who has a large lesion of the right dorsolateral prefrontal cortex, is impaired in memory monitoring. He shows a very high false-alarm rate for nonstudied words, many of which he classified as remembered rather than known. (A after Fleck et al. 2006; B after Schacter et al. 1996.)

ry retrieval, the apparent inconsistency with functional neuroimaging findings may be explained by some degree of functional reorganization following brain damage. Thus, the evidence to date generally supports an important role for the frontal cortices in declarative memory.

The Role of the Parietal and Posterior Midline Regions in Declarative Memory

In addition to the medial temporal and prefrontal regions, episodic memory retrieval has also been associated with parietal regions. The contribution of parietal regions was first revealed by ERP studies (see Box 14D), and later confirmed by PET and fMRI. The functional imaging studies identified not only lateral posterior parietal regions, but several posterior midline regions as well, including the precuneus, the posterior cingulate cortices, and the retrosplenial cortices. A hypothesis about the role of the precuneus in episodic retrieval was proposed by Paul Fletcher (now at Cambridge University), who suggested that this region is involved in visual imagery. This idea could account for the neuroimaging evidence that the precuneus is more active during the retrieval of words that elicit a visual image (e.g., *house*, *dog*) than ones that don't (e.g., *true*, *false*). However, the precuneus is also active in conditions with no obvious visual imagery component. In general, activity in the precuneus and other pos-

■ BOX 14D ERP Studies of Episodic Retrieval

Studies of episodic memory retrieval using event-related potentials have identified three consistent differences between recalling old and new items. First, some 300–500 milliseconds after a stimulus has been presented, new items tend to elicit greater negative voltage over mid-frontal regions than old items do. This *frontal negativity (FN) effect* has been called **FN400 effect** to distinguish it from the central parietal N400 effect typically associated with semantic processing (see Chapter 21). The FN400 effect responds similarly to studied items and to new items that appear familiar, and to both deeply and shallowly encoded items (see figure). Because of these and other findings, the FN400 effect has been attributed to familiarity.

Second, 400–800 milliseconds after the stimulus, old items tend to elicit more positive voltage over parietal electrodes than new items do. This effect is typically left-lateralized for verbal materials, and is known as the **left-parietal effect**. This phenomenon tends to be more pronounced when higher (more complex) levels of recollection are required. For example, the effect tends to be greater for deeply encoded items than for shallowly encoded items (see figure); for words judged as “remembered” rather than “known”; and for words accompanied by successful rather than unsuccessful source retrieval. The source of

the left-parietal effect is most likely the left posterior parietal region in that it is typically activated during PET and fMRI studies of episodic retrieval and is strongly associated with retrieval success.

Finally, at 600–1200 milliseconds poststimulus, old items sometimes elicit a more positive response over right frontal regions than do new items; this is known as the **right-frontal effect**. The right-frontal effect is usually apparent during tasks that entail demanding source memory decisions and is assumed to reflect postretrieval operations. This idea fits the extended time-course of the right-frontal effect, and is consistent with functional neuroimaging and lesion

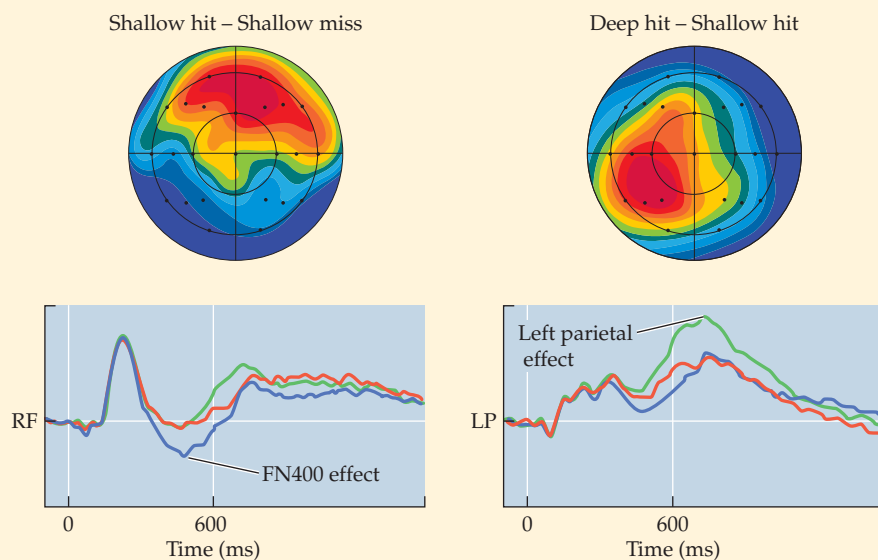
evidence linking the right prefrontal cortex to monitoring.

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ERP waveforms during recognition of new words and words studied under deep or shallow encoding conditions. The left panel illustrates the FN400 effect associated with familiarity; the right panel (deep = shallow) shows the left-parietal effect associated with recollection (deep > shallow). RF = right frontal electrode; LP = left parietal electrode. (From Rugg and Yonelinas 2003.)

terior midline and lateral parietal regions increases as a function of retrieval success. These regions usually show greater activity during correct recognition of old items (“hits”) than for correct recognition of new items (“misses”).

An aspect of the role of the lateral posterior parietal and posterior midline regions in episodic retrieval is the contrast with their role during encoding. During retrieval, these regions are typically activated with respect to the baseline levels, and tend to show more activity for successful than for unsuccessful

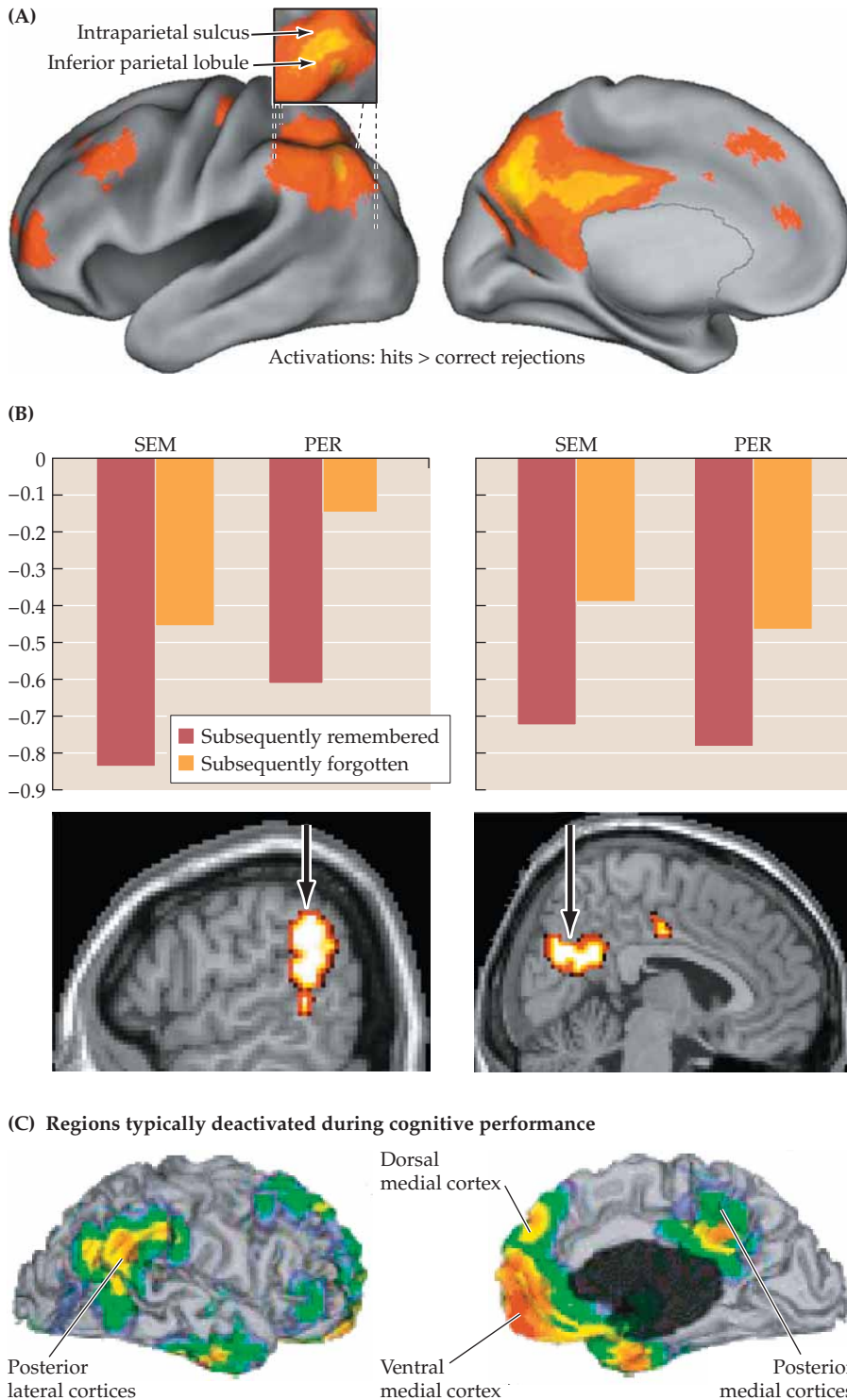


Figure 14.18 Posterior parietal and dorsal midline activity during declarative memory tasks.

(A) Brain regions that typically show greater activity for correct recognition of old items (“hits”) than for correct recognition of new items (“correct rejections”). (B) These same regions are deactivated during encoding, and to a greater extent for items that are subsequently remembered than for items that are subsequently forgotten. (C) Posterior parietal and posterior midline regions are part of a set of brain areas that are typically deactivated during demanding cognitive tasks, possibly because they support processes during resting conscious state, or default mode.

(A after Wagner et al. 2005; B after Daselaar et al. 2004; C after Gusnard and Raichle 2001.)

ful trials (Figure 14.18A). During encoding, however, these regions are usually deactivated with respect to the baseline, and tend to show *less* activity for successful than for unsuccessful trials (i.e., a “reverse Dm” effect; Figure 14.18B). The finding that these regions are deactivated during encoding makes some sense in light of the fact these same regions are part of a group of regions that are typically deactivated during cognitive performance (Figure 14.18C).

According to Marcus Raichle and his collaborators at Washington University, these typically deactivated brain areas are involved in processes that occur normally during resting but nonetheless conscious brain states, which these researchers have called the **default mode**. In their view, the default mode must be “turned off” during cognitive performance. Episodic retrieval seems to be an exception to the rule, because it is associated with activation rather than deactivation of these regions. One hypothesis is that episodic retrieval is part of the default mode of the brain, and hence disengagement of these regions during episodic retrieval tasks is not required. Although much more work will be needed to sort out these speculations, these regions do show a dissociation between encoding and retrieval, which constrains possible accounts of their functions.

The Role of Sensory Cortices in Declarative Memory

As described in Chapter 13, most memory researchers believe that memory traces, or *engrams*, are stored in or near the cortical regions originally involved in processing each aspect of a complex event (i.e., visual information is stored in visual cortex, auditory information in auditory cortex, and so on). More abstract memory representations such as concepts are thought to be stored in association areas of the ventral and lateral temporal cortices. Thus an important question regarding the role of occipital and temporal cortices in declarative memory is how such knowledge is organized. This issue is discussed in the chapters on vision (Chapter 5) and on the neural correlates of language (Chapter 21).

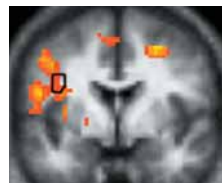
(A) Encoding

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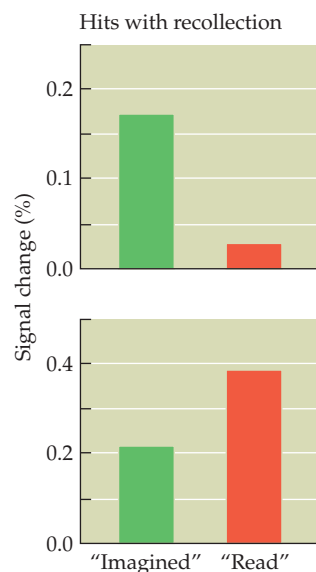
Parahippocampal

Read > Image

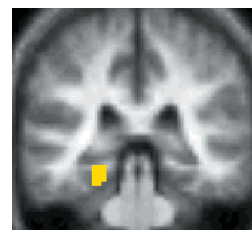


Premotor/prefrontal

(B) Retrieval



Parahippocampal



Premotor/prefrontal



False alarms

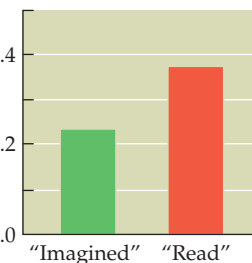
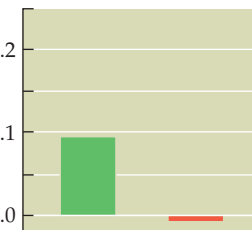


Figure 14.19 Recapitulation during retrieval of episodic memories.

(A) During encoding, a parahippocampal region was more active in the “image” than in the “read” condition, whereas a left premotor/prefrontal region showed the reverse pattern. (B) During retrieval, these two regions were both activated when participants correctly or incorrectly assigned words to these conditions. (After Kahn et al. 2004.)

The idea that memory traces are stored in the regions originally involved in encoding an event predicts that those same regions should be reactivated when the memory of that event is retrieved, in some sense *recapitulating* the original experience. Functional neuroimaging data have generally supported this idea. In one such study, Lars Nyberg at Umeå University, Sweden, and his collaborators at the University of Toronto had participants memorize visually presented words (e.g., *dog, drill*), some of which were presented alone and some of which were accompanied by a matching sound (e.g., a barking sound or the whirring of a drill). Later the subjects were scanned while retrieving the words. The words accompanied by sounds during the initial exposure elicited greater auditory cortex activity than those presented alone, implying that recapitulation is indeed elicited when multiple aspects of the original event are presented.

Complementing these findings, fMRI studies carried out by Randy Buckner (now at Harvard University) and John Gabrieli (now at MIT) and their collaborators showed greater visual cortex activity for written words that were encoded as pictures than for words presented alone. In another fMRI study, participants encoded words by making mental images (image encoding) or by thinking about the sound of words (read encoding). The parahippocampal region was more active in the image- than in the read-encoding condition, whereas a left premotor/prefrontal region showed the reverse pattern (**Figure 14.19A**). During retrieval, these two regions were activated when participants correctly or incorrectly assigned words to these conditions (**Figure 14.19B**). The fact that these regions are activated during incorrect source assignments suggests further that the reactivation during retrieval of encoding regions does not necessarily reflect stored memory traces. Again, some further effort will be required to sort out this interesting issue.

Summary

1. Declarative memory functions are strongly associated with the neural processing in the medial temporal lobes, and also with regions of the frontal and parietal lobes, as well as with sensory regions throughout the brain.
2. Within the medial temporal lobes, the key structure is the hippocampus. The functions of the hippocampus in declarative memory are not fully settled, but normal hippocampal operation is clearly important for encoding spatial, relational, and episodic memories. Other medial temporal structures, adjacent to the hippocampus and richly connected to it, are also critical for the normal operation of declarative memory.
3. Whereas the hippocampus appears to be particularly important for successfully establishing memory for items in a context, the perirhinal cortices influence both memory for items as such and memory of context.
4. With respect to the frontal lobes, different regions of the prefrontal cortex have been specifically implicated in the retrieval of different types of declarative memory. Thus episodic retrieval is associated with neural activity in anterior prefrontal regions, recollection with activity in the left dorsolateral prefrontal regions, and familiarity/monitoring with activation of the right dorsolateral prefrontal regions.
5. Other frontal lobe regions are active in semantic retrieval, and these are strongly linked to the language areas in the left inferior frontal gyrus. Posterior lateral parietal and posterior midline regions are also involved in episodic retrieval, but are usually deactivated during episodic encoding.
6. The primary sensory and sensory association cortices, which are the presumed loci of the stored memory traces that entail perceptual qualities, appear to be reactivated during retrieval as a function of the quality of the information that was stored during encoding. Accordingly, sensory regions of the brain are also necessary for the storage and retrieval of many sorts of declarative memories.
7. More abstract information involves still other regions of the brain. The interaction of many different brain regions is needed to successfully encode, store, and retrieve the memories that we and other animals are explicitly aware of and can in one way or another report to ourselves and to others.

Additional Reading

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