

# CHAPTER

# 6

## LEARNING, MEMORY, AND FORGETTING

### INTRODUCTION

This chapter and the next two are concerned with human memory. All three chapters deal with intact human memory, but Chapter 7 also considers amnesic patients. Traditional laboratory-based research is the focus of this chapter, with more naturalistic research being discussed in Chapter 8. As we will see, there are important links among these different types of research. Many theoretical issues are relevant to brain-damaged and healthy individuals whether tested in the laboratory or in the field.

Theories of memory generally consider both the architecture of the memory system and the processes operating within that structure. Architecture refers to the way in which the memory system is organised and processes refer to the activities occurring within the memory system.

Learning and memory involve a series of stages. Processes occurring during the presentation of the learning material are known as “encoding” and involve many of the processes involved in perception. This is the first stage. As a result of encoding, some information is stored within the memory system. Thus, storage is the second stage. The third (and final) stage is retrieval, which involves recovering or extracting stored information from the memory system.

We have emphasised the distinctions between architecture and process and among encoding, storage, and retrieval. However, we cannot have architecture without process, or retrieval without previous encoding and storage.

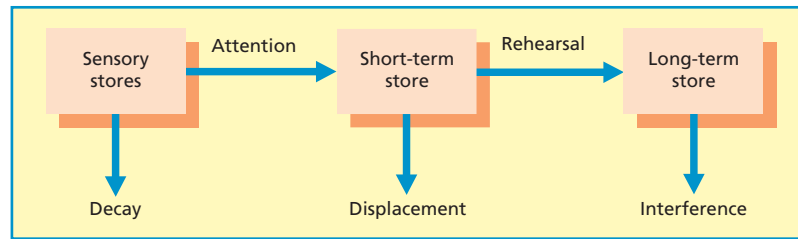
### ARCHITECTURE OF MEMORY

Throughout most of the history of memory research, it has been assumed that there is an important distinction between short-term memory and long-term memory. It seems reasonable that the processes involved in briefly remembering a telephone number are very different from those involved in long-term memory for theories and research in psychology. This traditional view is at the heart of multi-store models, which are discussed initially. In recent times, however, some theorists have argued in favour of unitary-store models in which the distinction between short-term and long-term memory is much less clear-cut than in the traditional approach. We will consider unitary-store models shortly.

#### Multi-store model

Several memory theorists (e.g., Atkinson & Shiffrin, 1968) have described the basic architecture of the memory system. We can identify a multi-store approach based on the common features of their theories. Three types of memory store were proposed:

- Sensory stores, each holding information very briefly and being modality specific (limited to one sensory modality).
- Short-term store of very limited capacity.
- Long-term store of essentially unlimited capacity holding information over very long periods of time.



**Figure 6.1** The multi-store model of memory.

The basic multi-store model is shown in Figure 6.1. Environmental stimulation is initially received by the sensory stores. These stores are modality-specific (e.g., vision, hearing). Information is held very briefly in the sensory stores, with some being attended to and processed further by the short-term store. Some information processed in the short-term store is transferred to the long-term store. Long-term storage of information often depends on rehearsal. There is a direct relationship between the amount of rehearsal in the short-term store and the strength of the stored memory trace. There is much overlap between the areas of attention and memory. Broadbent's (1958) theory of attention (see Chapter 5) was the main influence on the multi-store approach to memory. For example, Broadbent's buffer store resembles the notion of a sensory store.

### Sensory stores

The visual store is often known as the iconic store. In Sperling's (1960) classic work on this store, he presented a visual array containing three rows of four letters each for 50 ms. Participants could usually report only 4–5 letters, but claimed to have seen many more. Sperling assumed this happened because visual information had faded before most of it could be reported. He tested this by asking participants to recall only *part* of the information presented. Sperling's results supported his assumption, with part recall being good provided that the information to be recalled was cued very soon after the offset of the visual display.

Sperling's (1960) findings suggested that information in iconic memory decays within

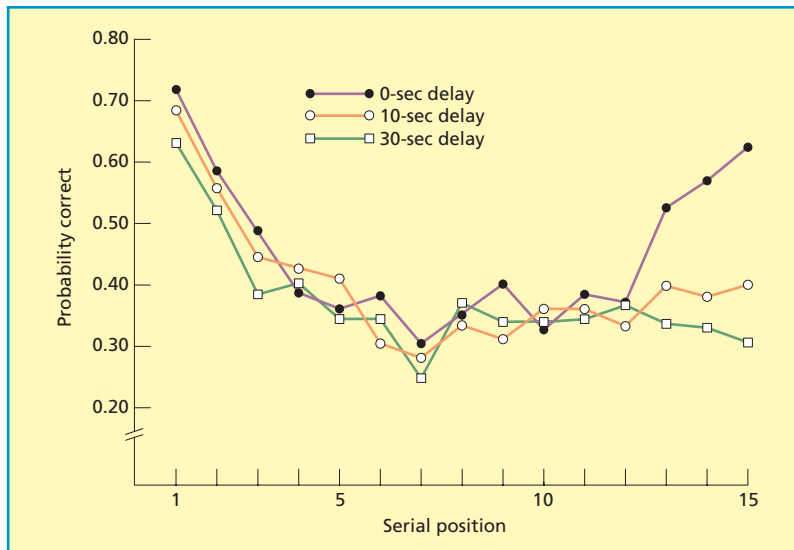
about 0.5 seconds, but this may well be an underestimate. Landman, Spekreijse, and Lamme (2003) pointed out that the requirement to verbally identify and recall items in the part-recall condition may have interfered with performance. They imposed simpler response demands on participants (i.e., is a second stimulus the same as the first one?) and found that iconic memory lasted for up to about 1600 ms (see Figure 4.12).

Iconic storage is very useful for two reasons. First, the mechanisms responsible for visual perception always operate on the icon rather than directly on the visual environment. Second, information remains in iconic memory for upwards of 500 ms, and we can shift our attention to aspects of the information within iconic memory in approximately 55 ms (Lachter, Forster, & Ruthruff, 2004; see Chapter 5). This helps to ensure we attend to important information.

The transient auditory store is known as the **echoic store**. In everyday life, you may sometimes have been asked a question while your mind was on something else. Perhaps you replied, "What did you say?", just before realising that you do know what had been said. This "playback" facility depends on the echoic store. Estimates of the duration of information in the echoic store are typically within the range of 2–4 seconds (Treisman, 1964).

### KEY TERM

**echoic store:** a sensory store in which auditory information is briefly held.



**Figure 6.2** Free recall as a function of serial position and duration of the interpolated task. Adapted from Glanzer and Cunitz (1966).

### Short- and long-term stores

The capacity of short-term memory is very limited. Consider digit span: participants listen to a random series of digits and then repeat them back immediately in the correct order. Other span measures are letter span and word span. The maximum number of units (e.g., digits) recalled without error is usually “seven plus or minus two” (Miller, 1956). However, there are two qualifications concerning that finding. First, Miller (1956) argued that the capacity of short-term memory should be assessed by the number of **chunks** (integrated pieces or units of information). For example, “IBM” is one chunk for those familiar with the company name International Business Machines but three chunks for everyone else. The capacity of short-term memory is often seven chunks rather than seven items. However, Simon (1974) found that the span in chunks was less with larger chunks (e.g., eight-word phrases) than with smaller chunks (e.g., one-syllable words).

Second, Cowan (2000, p. 88) argued that estimates of short-term memory capacity are often inflated because participants’ performance depends in part on rehearsal and on long-term memory. When these additional factors are largely eliminated, the capacity of short-term

memory is typically only about four chunks. For example, Cowan et al. (2005) used the running memory task – a series of digits ended at an unpredictable point, with the participants’ task being to recall the items from the end of the list. The digits were presented very rapidly to prevent rehearsal, and the mean number of items recalled was 3.87.

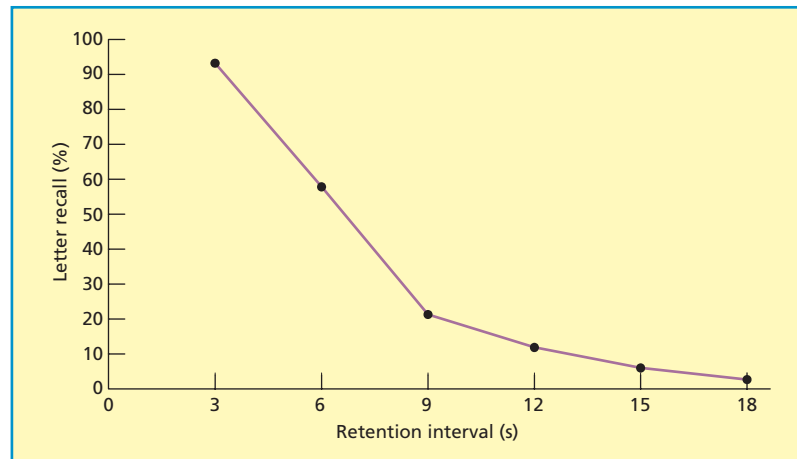
The **recency effect** in free recall (recalling the items in any order) refers to the finding that the last few items in a list are usually much better remembered in immediate recall than those from the middle of the list. Counting backwards for 10 seconds between the end of list presentation and start of recall mainly affects the recency effect (Glanzer & Cunitz, 1966; see Figure 6.2). The two or three words susceptible to the recency effect may be in the short-term store at the end of list presentation and so especially vulnerable. However, Bjork

### KEY TERMS

**chunk:** a stored unit formed from integrating smaller pieces of information.

**recency effect:** the finding that the last few items in a list are much better remembered than other items in immediate free recall.

**Figure 6.3** Forgetting over time in short-term memory. Data from Peterson and Peterson (1959).



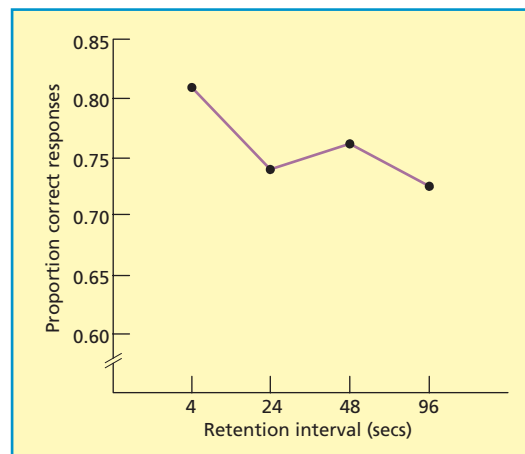
and Whitten (1974) found that there was still a recency effect when participants counted backwards for 12 seconds after each item in the list was presented. According to Atkinson and Shiffrin (1968), this should have eliminated the recency effect.

The above findings can be explained by analogy to looking along a row of telephone poles. The closer poles are more distinct than the ones farther away, just as the most recent list words are more discriminable than the others (Glenberg, 1987).

Peterson and Peterson (1959) studied the duration of short-term memory by using the task of remembering a three-letter stimulus while counting backwards by threes followed by recall in the correct order. Memory performance reduced to about 50% after 6 seconds and forgetting was almost complete after 18 seconds (see Figure 6.3), presumably because unrehearsed information disappears rapidly from short-term memory through decay (see Nairne, 2002, for a review). In contrast, it is often argued that forgetting from long-term memory involves different mechanisms. In particular, there is much cue-dependent forgetting, in which the memory traces are still in the memory system but are inaccessible (see later discussion).

Nairne, Whiteman, and Kelley (1999) argued that the rate of forgetting observed by Peterson and Peterson (1959) was especially rapid for

two reasons. First, they used all the letters of the alphabet repeatedly, which may have caused considerable interference. Second, the memory task was difficult in that participants had to remember the items themselves and the presentation order. Nairne et al. presented different words on each trial to reduce interference, and tested memory only for order information and not for the words themselves. Even though there was a rehearsal-prevention task (reading aloud digits presented on a screen) during the retention interval, there was remarkably little forgetting even over 96 seconds (see Figure 6.4).



**Figure 6.4** Proportion of correct responses as a function of retention interval. Data from Nairne et al. (1999).

This finding casts doubt on the notion that decay causes forgetting in short-term memory. However, reading digits aloud may not have totally prevented rehearsal.

Finally, we turn to the strongest evidence that short-term and long-term memory are distinct. If short-term and long-term memory are separate, we might expect to find some patients with impaired long-term memory but intact short-term memory and others showing the opposite pattern. This would produce a double dissociation. The findings are generally supportive. Patients with amnesia (discussed in Chapter 7) have severe impairments of many aspects of long-term memory, but typically have no problem with short-term memory (Spiers, Maguire, & Burgess, 2001). Amnesic patients have damage to the medial temporal lobe, including the hippocampus (see Chapter 7), which primarily disrupts long-term memory (see Chapter 7).

A few brain-damaged patients have severely impaired short-term memory but intact long-term memory. For example, KF had no problems with long-term learning and recall but had a very small digit span (Shallice & Warrington, 1970). Subsequent research indicated that his short-term memory problems focused mainly on recall of letters, words, or digits rather than meaningful sounds or visual stimuli (e.g., Shallice & Warrington, 1974). Such patients typically have damage to the parietal and temporal lobes (Vallar & Papagno, 2002).

### Evaluation

The multi-store approach has various strengths. The conceptual distinction between three kinds of memory store (sensory store, short-term store, and long-term store) makes sense. These memory stores differ in several ways:

- temporal duration
- storage capacity
- forgetting mechanism(s)
- effects of brain damage

Finally, many subsequent theories of human memory have built on the foundations of the multi-store model, as we will see later in this chapter.

However, the multi-store model possesses several serious limitations. First, it is very oversimplified. It was assumed that the short-term and long-term stores are both *unitary*, i.e., each store always operates in a single, uniform way. As we will see shortly, Baddeley and Hitch (1974) proposed replacing the concept of a single short-term store with a working memory system consisting of *three* different components. That is a more realistic approach. In similar fashion, there are several long-term memory systems (see Chapter 7).

Second, it is assumed that the short-term store acts as a gateway between the sensory stores and long-term memory (see Figure 6.1). However, the information processed in the short-term store has already made contact with information stored in long-term memory (Logie, 1999). For example, consider the phonological similarity effect: immediate recall of visually presented words in the correct order is worse when they are phonologically similar (sounding similar) (e.g., Larsen, Baddeley, & Andrade, 2000). Thus, information about the sounds of words stored in long-term memory affects processing in short-term memory.

Third, Atkinson and Shiffrin (1968) assumed that information in short-term memory represents the “contents of consciousness”. This implies that only information processed consciously can be stored in long-term memory. However, learning without conscious awareness of what has been learned (implicit learning) appears to exist (see later in the chapter).

Fourth, multi-store theorists assumed that most information is transferred to long-term memory via rehearsal. However, the role of rehearsal in our everyday lives is very limited. More generally, multi-store theorists focused too much on structural aspects of memory rather than on memory processes.

### Unitary-store models

In recent years, various theorists have argued that the entire multi-store approach is misguided and should be replaced by a unitary-store model (see Jonides, Lewis, Nee, Lustig, Berman, &

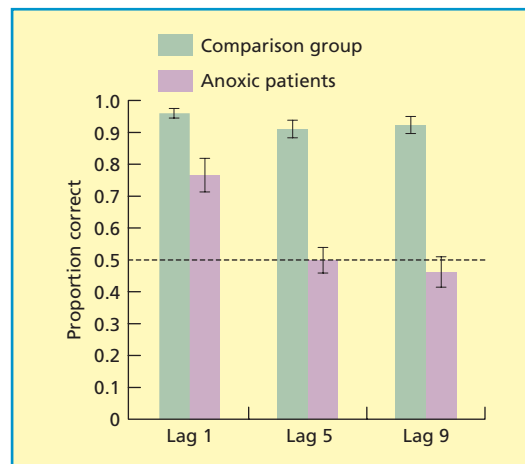
Moore, 2008, for a review). Unitary-store models assume that, “STM [short-term memory] consists of temporary activations of LTM [long-term memory] representations or of representations of items that were recently perceived” (Jonides et al., 2008, p. 198). Such activations will often occur when certain representations are the focus of attention.

Unitary-store models would seem to have great difficulty in explaining the consistent finding that amnesic patients have essentially intact short-term memory in spite of having severe problems with long-term memory. Jonides et al. (2008) argued that amnesic patients have special problems in forming novel relations (e.g., between items and their context) in both short-term and long-term memory. Amnesic patients apparently have no problems with short-term memory because short-term memory tasks typically do not require relational memory. This leads to a key prediction: amnesic patients should have impaired short-term memory performance on tasks requiring relational memory.

According to Jonides et al. (2008), the hippocampus and surrounding medial temporal lobes (typically damaged in amnesic patients) play a crucial role in forming novel relations (sometimes called binding) (see Chapter 7). Multi-store theorists assume that these structures are much more involved in long-term memory than in short-term memory. However, it follows from unitary-store models that the hippocampus and medial temporal lobes would be involved if a short-term memory task required forming novel relations.

### Evidence

Evidence supporting the unitary-store approach was reported by Hannula, Tranel, and Cohen (2006). They studied patients who had become amnesic as the result of an anoxic episode (involving deficient oxygen supply). In one experiment, scenes were presented for 20 seconds. Some scenes were repeated exactly, whereas others were repeated with one object having been moved spatially. Participants decided whether each scene had been seen previously. It was assumed that short-term memory was involved



**Figure 6.5** Proportion of correct responses for healthy controls (comparison group) and amnesics (anoxic patients). The dashed line represents chance performance. From Hannula et al. (2006) with permission from Society of Neuroscience.

when a given scene was repeated in its original or slightly modified form immediately after its initial presentation (Lag 1) but that long-term memory was involved at longer lags.

The findings are shown in Figure 6.5. Amnesic patients performed much worse than healthy controls in short-term memory (Lag 1) and the performance difference between the two groups was even larger in long-term memory. The crucial issue is whether performance at Lag 1 was *only* due to short-term memory. The finding that amnesics’ performance fell to chance level at longer lags suggests that they may well have relied almost exclusively on short-term memory at Lag 1. However, the finding that controls’ performance changed little over lags suggests that they formed strong long-term relational memories, and these long-term memories may well account for their superior performance at Lag 1.

Further support for the unitary-store approach was reported by Hannula and Ranganath (2008). They presented four objects in various locations and instructed participants to rotate the display mentally. Participants were then presented with a second display, and decided whether the second display matched or failed to match their mental representation of the rotated display. This task involved relational memory. The

key finding was that the amount of activation in the anterior and posterior regions of the left hippocampus predicted relational memory performance.

Shrager, Levy, Hopkins, and Squire (2008) pointed out that a crucial issue is whether memory performance at short retention intervals actually depends on short-term memory rather than long-term memory. They argued that a distinguishing feature of short-term memory is that it involves active maintenance of information throughout the retention interval. Tasks that mostly depend on short-term memory are vulnerable to distraction during the retention interval because distraction disrupts active maintenance. Shrager et al. divided their memory tasks into those susceptible to distraction in healthy controls and those that were not. Amnesic patients with medial temporal lobe lesions had essentially normal levels of performance on distraction-sensitive memory tasks but were significantly impaired on distraction-insensitive memory tasks. Shrager et al. concluded that short-term memory processes are intact in amnesic patients. Amnesic patients only show impaired performance on so-called “short-term memory tasks” when those tasks actually depend substantially on long-term memory.

### Evaluation

The unitary-store approach has made memory researchers think deeply about the relationship between short-term and long-term memory. There are good reasons for accepting the notion that activation of part of long-term memory plays an important role in short-term memory. According to the unitary-store approach (but not the multi-store approach), amnesic patients can exhibit impaired short-term memory under some circumstances. Some recent evidence (e.g., Hannula et al., 2006) supports the prediction of the unitary-store approach. Functional neuro-imaging evidence (e.g., Hannula & Ranganath, 2008) also provides limited support for the unitary-store approach.

What are the limitations of the unitary-store approach? First, it is oversimplified to argue that short-term memory is *only* activated

by long-term memory. We can manipulate activated long-term memory in flexible ways and such manipulations go well beyond simply activating some fraction of long-term memory. Two examples of ways in which we can manipulate information in short-term memory are backward digit recall (recalling digits in the opposite order to the presentation order) and generating novel visual images (Logie & van der Meulen, 2009). Second, there is no convincing evidence that amnesic patients have impaired performance on relational memory tasks dependent primarily on short-term memory. It seems likely that amnesic patients only perform poorly on “short-term memory” tasks that depend to a large extent on long-term memory (Shrager et al., 2008). Third, there is no other evidence that decisively favours the unitary-store approach over the multiple-store approach. However, the search for such evidence only recently started in earnest.

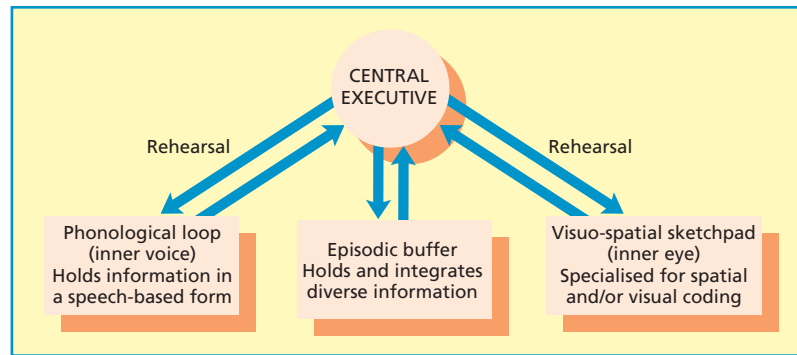
## WORKING MEMORY

Baddeley and Hitch (1974) and Baddeley (1986) replaced the concept of the short-term store with that of working memory. Since then, the conceptualisation of the working memory system has become increasingly complex. According to Baddeley (2001) and Repovš and Baddeley (2006), the working memory system has four components (see Figure 6.6):

- A modality-free **central executive** resembling attention.
- A **phonological loop** holding information in a phonological (speech-based) form.

### KEY TERMS

**central executive:** a modality-free, limited capacity, component of **working memory**.  
**phonological loop:** a component of **working memory**, in which speech-based information is held and subvocal articulation occurs.



**Figure 6.6** The major components of Baddeley's working memory system. Figure adapted from Baddeley (2001).

- A **visuo-spatial sketchpad** specialised for spatial and visual coding.
- An **episodic buffer**, which is a temporary storage system that can hold and integrate information from the phonological loop, the visuo-spatial sketchpad, and long-term memory. This component (added 25 years after the others) is discussed later.

The most important component is the central executive. It has limited capacity, resembles attention, and deals with any cognitively demanding task. The phonological loop and the visuo-spatial sketchpad are slave systems used by the central executive for specific purposes. The phonological loop preserves the order in which words are presented, and the visuo-spatial sketchpad stores and manipulates spatial and visual information. All three components have limited capacity and are relatively independent of each other. Two assumptions follow:

- (1) If two tasks use the same component, they cannot be performed successfully together.
- (2) If two tasks use different components, it should be possible to perform them as well together as separately.

Numerous dual-task studies have been carried out on the basis of these assumptions. For example, Robbins et al. (1996) considered the involvement of the three original components of working memory in the selection of chess moves by weaker and stronger players. The players selected continuation moves from

various chess positions while also performing one of the following tasks:

- *Repetitive tapping*: this was the control condition.
- *Random number generation*: this involved the central executive.
- *Pressing keys on a keypad in a clockwise fashion*: this used the visuo-spatial sketchpad.
- *Rapid repetition of the word "see-saw"*: this is **articulatory suppression** and uses the phonological loop.

Robbins et al. (1996) found that selecting chess moves involved the central executive and the visuo-spatial sketchpad but not the phonological loop (see Figure 6.7). The effects of the various additional tasks were similar on stronger and weaker players, suggesting that

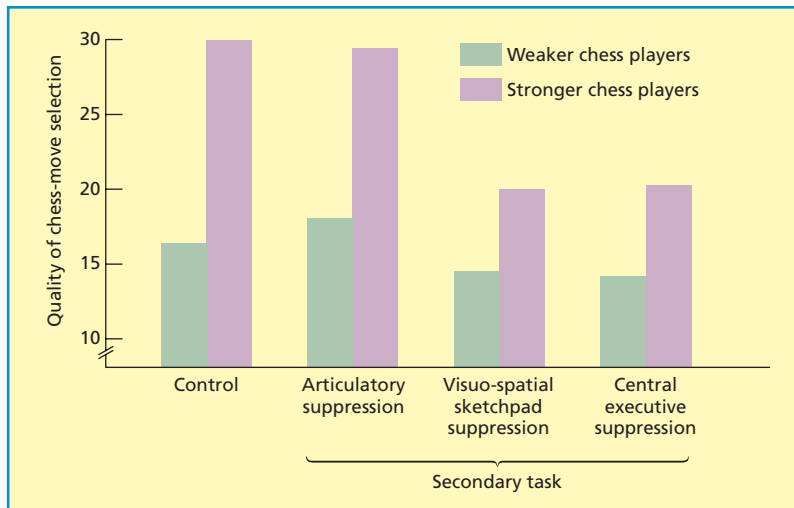
## KEY TERMS

**visuo-spatial sketchpad**: a component of **working memory** that is involved in visual and spatial processing of information.

**episodic buffer**: a component of **working memory** that is used to integrate and to store briefly information from the **phonological loop**, the **visuo-spatial sketchpad**, and **long-term memory**.

**articulatory suppression**: rapid repetition of some simple sound (e.g., "the, the, the"), which uses the articulatory control process of the **phonological loop**.





**Figure 6.7** Effects of secondary tasks on quality of chess-move selection in stronger and weaker players. Adapted from Robbins et al. (1996).



According to Robbins et al. (1996), selecting good chess moves requires use of the central executive and the visuo-spatial sketchpad, but not of the phonological loop.

both groups used the working memory system in the same way.

### Phonological loop

Most early research on the phonological loop focused on the notion that verbal rehearsal (i.e., saying words over and over to oneself) is of central importance. Two phenomena providing support for this view are the phonological similarity effect and the word-length effect. The **phonological similarity effect** is found

when a short list of visually presented words is recalled immediately in the correct order. Recall performance is worse when the words are phonologically similar (i.e., having similar sounds) than when they are phonologically dissimilar. For example, FEE, HE, KNEE, LEE, ME, and SHE form a list of phonologically similar words, whereas BAY, HOE, IT, ODD, SHY, and UP form a list of phonologically dissimilar words. Larsen, Baddeley, and Andrade (2000) used those word lists, finding that recall of the words in order was 25% worse with the phonologically similar list. This phonological similarity effect occurred because participants used speech-based rehearsal processes within the phonological loop.

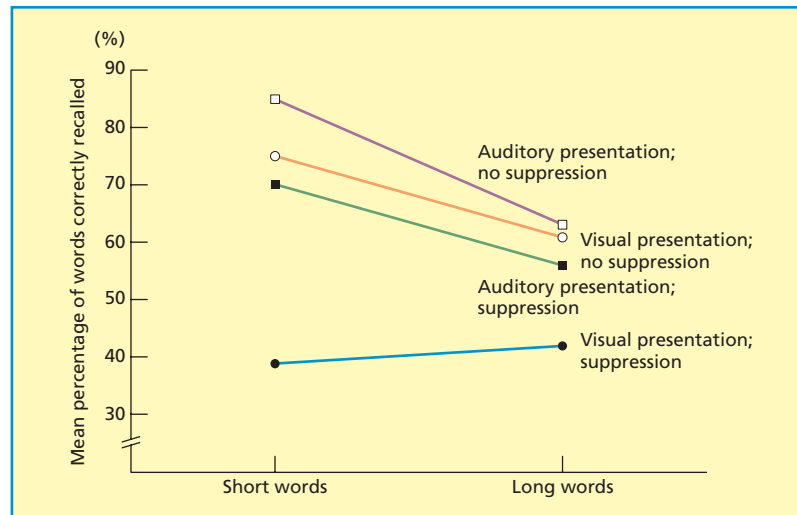
The **word-length effect** is based on memory span (the number of words or other items recalled immediately in the correct order). It is defined by the finding that memory span is lower for words taking a long time to say than for

### KEY TERMS

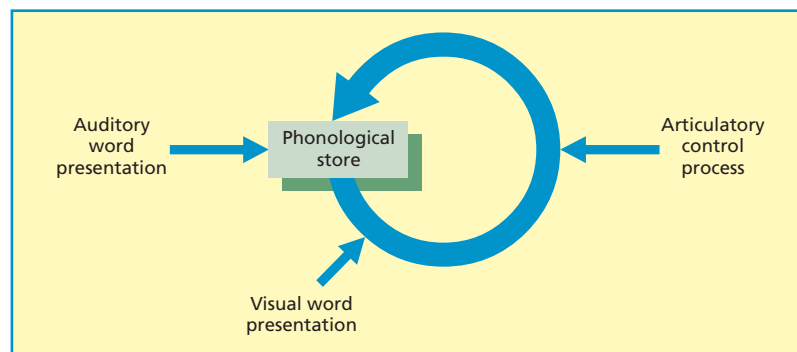
**phonological similarity effect:** the finding that serial recall of visually presented words is worse when the words are phonologically similar rather than phonologically dissimilar.

**word-length effect:** the finding that word span is greater for short words than for long words.

**Figure 6.8** Immediate word recall as a function of modality of presentation (visual vs. auditory), presence versus absence of articulatory suppression, and word length. Adapted from Baddeley et al. (1975).



**Figure 6.9** Phonological loop system as envisaged by Baddeley (1990).



those taking less time. Baddeley, Thomson, and Buchanan (1975) found that participants recalled as many words presented visually as they could read out loud in 2 seconds. This suggested that the capacity of the phonological loop is determined by temporal duration like a tape loop. Service (2000) argued that these findings depend on phonological complexity rather than on temporal duration. Reassuringly, Mueller, Seymour, Kieras, and Meyer (2003) found with very carefully chosen words that memory span depended on the articulatory duration of words rather than their phonological complexity.

In another experiment, Baddeley et al. (1975) obtained more direct evidence that the word-length effect depends on the phonological loop. The number of visually presented words (out of five) that could be recalled was assessed.

Some participants were given the articulatory suppression task of repeating the digits 1 to 8 while performing the main task. The argument was that the articulatory suppression task would involve the phonological loop and so prevent it being used on the word-span task. As predicted, articulatory suppression eliminated the word-length effect (see Figure 6.8), suggesting it depends on the phonological loop.

As so often in psychology, reality is more complex than was originally thought. Note that the research discussed so far involved the *visual* presentation of words. Baddeley et al. (1975) obtained the usual word-length effect when there was auditory presentation of word lists. Puzzlingly, however, there was still a word-length effect with auditorily presented words even when articulatory suppression was used (see Figure 6.8). This led

Baddeley (1986, 1990; see Figure 6.9) to argue that the phonological loop has two components:

- A passive phonological store directly concerned with speech perception.
- An articulatory process linked to speech production that gives access to the phonological store.

According to this account, words presented auditorily are processed differently from those presented visually. Auditory presentation of words produces *direct* access to the phonological store regardless of whether the articulatory control process is used. In contrast, visual presentation of words only permits *indirect* access to the phonological store through subvocal articulation.

The above account makes sense of many findings. Suppose the word-length effect observed by Baddeley et al. (1975) depends on the rate of articulatory rehearsal (see Figure 6.8). Articulatory suppression eliminates the word-length effect with visual presentation because access to the phonological store is prevented. However, it does *not* affect the word-length effect with auditory presentation because information about the words enters the phonological store directly.

Progress has been made in identifying the brain areas associated with the two components of the phonological loop. Some brain-damaged patients have very poor memory for auditory-verbal material but essentially normal speech production, indicating they have a damaged phonological store but an intact articulatory control process. These patients typically have damage to the left inferior parietal cortex (Vallar & Papagno, 1995). Other brain-damaged patients have an intact phonological store but a damaged articulatory control process shown by a lack of evidence for rehearsal. Such patients generally have damage to the left inferior frontal cortex.

Similar brain areas have been identified in functional neuroimaging studies on healthy volunteers. Henson, Burgess, and Frith (2000) found that a left inferior parietal area was associated with the phonological store, whereas left prefrontal cortex was associated with rehearsal.

Logie, Venneri, Della Sala, Redpath, and Marshall (2003) gave their participants the task of recalling letter sequences presented auditorily in the correct order. All participants were instructed to use subvocal rehearsal to ensure the involvement of the rehearsal component of the phonological loop. The left inferior parietal gyrus and the inferior and middle frontal gyri were activated.

### Evaluation

Baddeley's theory accounts for the word-length effects and for the effects of articulatory suppression. In addition, evidence from brain-damaged patients and from functional neuroimaging studies with healthy participants indicates the existence of a phonological store and an articulatory control process located in different brain regions. Our understanding of the phonological loop is greater than that for the other components of the working memory system.

What is the value of the phonological loop? According to Baddeley, Gathercole, and Papagno (1998, p. 158), "The function of the phonological loop is not to remember familiar words but to learn new words." Supporting evidence was reported by Papagno, Valentine, and Baddeley (1991). Native Italian speakers learned pairs of Italian words and pairs of Italian–Russian words. Articulatory suppression (which reduces use of the phonological loop) greatly slowed the learning of foreign vocabulary but had little effect on the learning of pairs of Italian words.

Several studies have considered the relationship between children's vocabulary development and their performance on verbal short-term memory tasks involving the phonological loop. The capacity of the phonological loop generally predicts vocabulary size (e.g., Majerus, Poncelet, Elsen, & van der Linden, 2006). Such evidence is consistent with the notion that the phonological loop plays a role in the learning of vocabulary. However, much of the evidence is correlational – it is also possible that having a large vocabulary increases the effective capacity of the phonological loop.

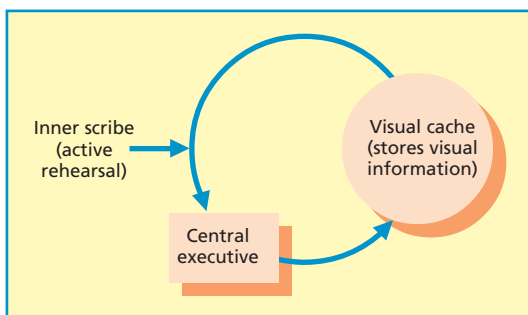
Trojano and Grossi (1995) studied SC, a patient with extremely poor phonological functioning. SC showed reasonable learning

ability in most situations but was unable to learn auditorily presented word–nonword pairs. Presumably SC's poorly functioning phonological loop prevented the learning of the phonologically unfamiliar nonwords.

### Visuo-spatial sketchpad

The visuo-spatial sketchpad is used for the temporary storage and manipulation of visual patterns and spatial movement. It is used in many situations in everyday life (e.g., finding the route when walking; playing computer games). Logie, Baddeley, Mane, Donchin, and Sheptak (1989) studied performance on a complex computer game called Space Fortress, which involves manoeuvring a space ship around a computer screen. Early in training, performance on Space Fortress was severely impaired when participants had to perform a secondary visuo-spatial task. After 25 hours' training, the adverse effects on the computer game of carrying out a visuo-spatial task at the same time were greatly reduced, being limited to those aspects directly involving perceptuo-motor control. Thus, the visuo-spatial sketchpad was used throughout training on Space Fortress, but its involvement decreased with practice.

The most important issue is whether there is a *single* system combining visual and spatial processing or whether there are partially or completely *separate* visual and spatial systems. According to Logie (1995; see Figure 6.10), the visuo-spatial sketchpad consists of two components:



**Figure 6.10** The visuo-spatial sketchpad or working memory as envisaged by Logie. Adapted from Logie (1995), Baddeley, Mane, Donchin, and Sheptak.

- **Visual cache:** This stores information about visual form and colour.
- **Inner scribe:** This processes spatial and movement information. It is involved in the rehearsal of information in the visual cache and transfers information from the visual cache to the central executive.

Recent developments in theory and research on the visuo-spatial sketchpad are discussed by Logie and van der Meulen (2009).

Klauer and Zhao (2004) explored the issue of whether there are separate visual and spatial systems. They used two main tasks – a spatial task (memory for dot locations) and a visual task (memory for Chinese ideographs). There were also three secondary task conditions:

- A movement discrimination task (spatial interference).
- A colour discrimination task (visual interference).
- A control condition (no secondary task).

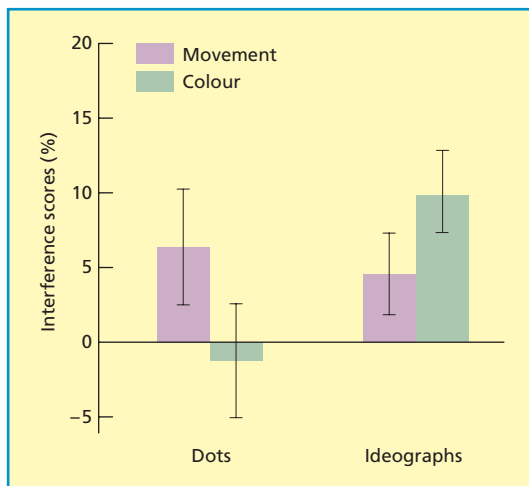
What would we expect if there are somewhat separate visual and spatial systems? First, the spatial interference task should disrupt performance more on the spatial main task than on the visual main task. Second, the visual interference task should disrupt performance more on the visual main task than on the spatial main task. Both predictions were supported (see Figure 6.11).

Additional evidence supporting the notion of separate visual and spatial systems was reported by Smith and Jonides (1997) in an ingenious study. Two visual stimuli were presented together, followed by a probe stimulus.

### KEY TERMS

**visual cache:** according to Logie, the part of the visuo-spatial sketchpad that stores information about visual form and colour.

**inner scribe:** according to Logie, the part of the **visuo-spatial sketchpad** that deals with spatial and movement information.



**Figure 6.11** Amount of interference on a spatial task (dots) and a visual task (ideographs) as a function of secondary task (spatial: movement vs. visual: colour discrimination). From Klauer and Zhao (2004), Copyright © 2000 American Psychological Association. Reproduced with permission.

Participants decided whether the probe was in the same location as one of the initial stimuli (spatial task) or had the same form (visual task). Even though the stimuli were identical in the two tasks, there were clear differences in patterns of brain activation. There was more activity in the right hemisphere during the spatial task than the visual task, but more activity in the left hemisphere during the visual task than the spatial task.

Several other studies have indicated that different brain regions are activated during visual and spatial working-memory tasks (see Sala, Rämä, & Courtney, 2003, for a review). The ventral prefrontal cortex (e.g., the inferior and middle frontal gyri) is generally activated more during visual working-memory tasks than spatial ones. In contrast, more dorsal prefrontal cortex (especially an area of the superior prefrontal sulcus) tends to be more activated during spatial working-memory tasks than visual ones. This separation between visual and spatial processing is consistent with evidence that rather separate pathways are involved in visual and spatial perceptual processing (see Chapter 2).

## Evaluation

Various kinds of evidence support the view that the visuo-spatial sketchpad consists of somewhat separate visual (visual cache) and spatial (inner scribe) components. First, there is often little interference between visual and spatial tasks performed at the same time (e.g., Klauer & Zhao, 2004). Second, functional neuroimaging data suggest that the two components of the visuo-spatial sketchpad are located in different brain regions (e.g., Sala et al., 2003; Smith & Jonides, 1997). Third, some brain-damaged patients have damage to the visual component but not to the spatial component. For example, NL found it very hard to describe details from the left side of scenes in visual imagery even though his visual perceptual system was essentially intact (Beschin, Cocchini, Della Sala, & Logie, 1997).

Many tasks require both components of the visuo-spatial sketchpad to be used in combination. It remains for the future to understand more fully how processing and information from the two components are combined and integrated on such tasks. In addition, much remains unknown about interactions between the workings of the visuo-spatial sketchpad and the episodic buffer (Baddeley, 2007).

## Central executive

The central executive (which resembles an attentional system) is the most important and versatile component of the working memory system. Every time we engage in any complex cognitive activity (e.g., reading a text; solving a problem; carrying out two tasks at the same time), we make considerable use of the central executive. It is generally assumed that the prefrontal cortex is the part of the brain most involved in the functions of the central executive. Mottaghy (2006) reviewed studies using repetitive transcranial magnetic stimulation (rTMS; see Glossary) to disrupt activity within the dorsolateral prefrontal cortex. Performance on many complex cognitive tasks was impaired by this manipulation, indicating that dorsolateral prefrontal cortex is of importance in central executive functions. However, we need to be

careful about associating the central executive too directly with prefrontal cortex. As Andrés (2003) pointed out, patients with damage to prefrontal cortex do not always show executive deficits, and some patients with no damage to prefrontal cortex nevertheless have executive deficits.

One way of trying to understand the importance of the central executive in our everyday functioning is to study brain-damaged individuals whose central executive is impaired. Such individuals suffer from **dysexecutive syndrome** (Baddeley, 1996), which involves problems with planning, organising, monitoring behaviour, and initiating behaviour. Patients with dysexecutive syndrome typically have damage within the frontal lobes at the front of the brain (adverse effects of damage to the prefrontal cortex on problem solving are discussed in Chapter 12). However, some patients seem to have damage to posterior (mainly parietal) rather than to frontal regions (e.g., Andrés, 2003). Brain-damaged patients are often tested with the Behavioural Assessment of the Dysexecutive Syndrome (BADS; Wilson, Alderman, Burgess, Emslie, & Evans, 1996). This consists of various tests assessing the ability to shift rules, to devise and implement a solution to a practical problem, to divide time effectively among various tasks, and so on. Individuals with dysexecutive syndrome as assessed by the BADS typically have great problems in holding down a job and functioning adequately in everyday life (Chamberlain, 2003).

The conceptualisation of the central executive has changed over time. As Repovš and Baddeley (2006, p. 12) admitted, it was originally “a convenient ragbag for unanswered questions related to the control of working memory and its two slave subsystems.” In the original model, the central executive was *unitary*, meaning that it functioned as a single unit. In recent years, theorists have increasingly argued that the central executive is more complex. Baddeley (1996) suggested that four of the functions of the central executive were as follows: switching of retrieval plans; timesharing in dual-task studies; selective attention to certain stimuli while ignoring others; and temporary activation

of long-term memory. These are examples of **executive processes**, which are processes that serve to organise and co-ordinate the functioning of the cognitive system to achieve current goals.

Miyake et al. (2000) identified three executive processes or functions overlapping partially with those of Baddeley (1996). They assumed these functions were related but separable:

- *Inhibition function*: This refers to “one’s ability to deliberately inhibit dominant, automatic, or prepotent responses when necessary” (p. 55). Friedman and Miyake (2004) extended the inhibition function to include resisting distractor interference. For example, consider the **Stroop task**, on which participants have to name the colours in which words are printed. In the most difficult condition, the words are conflicting colour words (e.g., the word BLUE printed in red). In this condition, performance is slowed down and there are often many errors. The inhibition function is needed to minimise the distraction effect created by the conflicting colour word. It is useful in preventing us from thinking and behaving in habitual ways when such ways are inappropriate.
- *Shifting function*: This refers to “shifting back and forth between multiple tasks, operations, or mental sets” (p. 55). It is used when you switch attention from one task to another. Suppose, for example, you are presented with a series of trials, on each of which two numbers are presented. In one

## KEY TERMS

**dysexecutive syndrome**: a condition in which damage to the frontal lobes causes impairments to the **central executive** component of **working memory**.

**executive processes**: processes that organise and co-ordinate the functioning of the cognitive system to achieve current goals.

**Stroop task**: a task in which the participant has to name the colours in which words are printed.

condition, there is task switching: on some trials you have to multiply the two numbers and on other trials you have to divide one by the other. In the other condition, there are long blocks of trials on which you always multiply the two numbers and there are other long blocks of trials on which you always divide one number by the other. Performance is slower in the task-switching condition, because attention has to be switched backwards and forwards between the two tasks. Task switching involves the shifting function, which allows us to shift attention rapidly from one task to another. This is a very useful ability in today's 24/7 world.

- *Updating function*: This refers to “updating and monitoring of working memory representations” (p. 55). It is used when you update the information you need to remember. For example, the updating function is required when participants are presented with members of various categories and have to keep track of the most recently presented member of each category. Updating is useful if you are preparing a meal consisting of several dishes or, more generally, if you are trying to cope with changing circumstances.

### Evidence

Various kinds of evidence support Miyake et al.'s (2000) identification of three executive functions. First, there are the findings from their own research. They argued that most cognitive tasks involve various processes, which makes it difficult to obtain clear evidence for any single process. Miyake et al. administered several tasks to their participants and then used latent-variable analysis. This form of analysis focuses on positive correlations among tasks as the basis for identifying the common process or function involved. Thus, for example, three tasks might all involve a common process (e.g., the shifting function) but each task might also involve additional specific processes. Latent-variable analysis provides a useful way of identifying the common process. Miyake et al.

found evidence for three separable executive functions of inhibition, shifting, and monitoring, but also discovered that these functions were positively correlated with each other.

Second, Collette et al. (2005) administered several tasks designed to assess the same three executive processes, and used positron emission tomography (PET; see Glossary) to compare brain activation associated with each process. There were two main findings. First, each executive process or function was associated with activation in a different region within the prefrontal cortex. Second, all the tasks produced activation in the right intraparietal sulcus, the left superior parietal sulcus, and the left lateral prefrontal cortex. Collette et al. suggested that the right intraparietal sulcus is involved in selective attention to relevant stimuli plus the suppression of irrelevant information; the left superior parietal sulcus is involved in switching and integration processes; and the lateral prefrontal cortex is involved in monitoring and temporal organisation.

Are there executive processes or functions not included within Miyake et al.'s (2000) theory? According to Baddeley (1996), one strong contender relates to the dual-task situation, in which people have to perform two different tasks at the same time. Executive processes are often needed to co-ordinate processing on the two tasks. Functional neuroimaging studies focusing on dual-task situations have produced somewhat variable findings (see Chapter 5). However, there is sometimes much activation in prefrontal areas (e.g., dorsolateral prefrontal cortex) when people perform two tasks at the same time but not when they perform only one of the tasks on its own (e.g., Collette et al., 2005; Johnson & Zatorre, 2006). Such findings suggest that co-ordination of two tasks can involve an executive process based mainly in the prefrontal cortex.

Further support for the notion that there is an executive process involved specifically in dual-task processing was reported by Logie, Cocchini, Della Sala, and Baddeley (2004). Patients with Alzheimer's disease were compared with healthy younger and older people

on digit recall and tracking tasks, the latter of which involved keeping a pen on a red oval that moved randomly. The Alzheimer's patients were much more sensitive than the healthy groups to dual-task demands, but did not differ in their ability to cope with single-task demands. These findings suggest that Alzheimer's patients have damage to a part of the brain involved in dual-task co-ordination. MacPherson, Della Sala, Logie, and Wilcock (2007) reported very similar findings using verbal memory and visuo-spatial memory tasks.

### Dysexecutive syndrome

Stuss and Alexander (2007) argued that the notion of a dysexecutive syndrome is flawed because it implies that brain damage to the frontal lobes typically damages *all* central executive functions of the central executive. They accepted that patients with widespread damage to the frontal lobes have a global dysexecutive syndrome. However, they claimed there are three executive processes based in different parts of the frontal lobes:

- *Task setting*: This involves planning and was defined as “the ability to set a stimulus–response relationship . . . necessary in the early stages of learning to drive a car or planning a wedding” (p. 906).
- *Monitoring*: This was defined as “the process of checking the task over time for ‘quality control’ and the adjustment of behaviour” (p. 909).
- *Energisation*: This involves sustained attention or concentration and was defined as “the process of initiation and sustaining of any response. . . . Without energisation . . . maintaining performance over prolonged periods will waver” (pp. 903–904).

All three executive processes are very general in that they are used across an enormous range of tasks. They are not really independent, because they are typically all used when you deal with a complex task. For example, if you have to give a speech in public, you would

first plan roughly what you are going to say (task setting), concentrate through the delivery of the speech (energisation), and check that what you are saying is what you intended (monitoring).

Stuss and Alexander (2007) tested their theory of executive functions on patients having fairly specific lesions within the frontal lobes. In view of the possibility that there may be reorganisation of cognitive structures and processes following brain damage, the patients were tested within a few months of suffering brain damage. A wide range of cognitive tasks was administered to different patient groups to try to ensure that the findings would generalise.



Public speaking involves all three of Stuss and Alexander's (2007) executive functions: planning what you are going to say (task setting); concentrating on delivery (energisation); and checking that what you say is as intended (monitoring).



Stuss and Alexander found evidence for the three hypothesised processes of energisation, task setting, and monitoring. They also discovered that each process was associated with a different region within the frontal cortex. Energisation involves the superior medial region of the frontal cortex, task setting involves the left lateral frontal region, and monitoring involves the right lateral frontal region. Thus, for example, patients with damage to the right lateral frontal region generally fail to detect the errors they make while performing a task and so do not adjust their performance.

Why do the processes identified by Stuss and Alexander (2007) differ from those identified by Miyake et al. (2000)? The starting point in trying to answer that question is to remember that Stuss and Alexander based their conclusions on studies with brain-damaged patients, whereas Miyake et al. studied only healthy individuals. Nearly all executive tasks involve common processes (e.g., energisation, task setting, monitoring). These common processes are positively correlated in healthy individuals and so do not emerge clearly as separate processes. However, the differences among energisation, task setting, and monitoring become much clearer when we consider patients with very specific frontal lesions. It remains for future research to show in more detail how the views of Stuss and Alexander and of Miyake et al. can be reconciled.

### Evaluation

There has been real progress in understanding the workings of the central executive. The central executive consists of various related but separable executive processes. There is accumulating evidence that inhibition, updating, shifting, and dual-task co-ordination may be four major executive processes. It has become clear that the notion of a dysexecutive syndrome is misleading in that it suggests there is a *single* pattern of impairment. Various executive processes associated with different parts of frontal cortex are involved.

Two issues require more research. First, the executive processes suggested by behavioural

and functional neuroimaging studies on healthy individuals do not correspond precisely with those suggested by studies on patients with damage to the frontal cortex. We have speculated on the reasons for this, but solid evidence is needed. Second, while we have emphasised the differences among the major executive processes or functions, there is plentiful evidence suggesting that these processes are fairly closely related to each other. The reasons for this remain somewhat unclear.

### Episodic buffer

Baddeley (2000) added a fourth component to the working memory model. This is the **episodic buffer**, in which information from various sources (the phonological loop, the visuo-spatial sketchpad, and long-term memory) can be integrated and stored briefly. According to Repovš and Baddeley (2006, p. 15), the episodic buffer, “is episodic by virtue of holding information that is integrated from a range of systems including other working memory components and long-term memory into coherent complex structures: scenes or episodes. It is a buffer in that it serves as an intermediary between subsystems with different codes, which it combines into multi-dimensional representations.”

In view of the likely processing demands involved in integrating information from different modalities, Baddeley (2000, 2007) suggested that there would be close links between the episodic buffer and the central executive. If so, we would expect to find prefrontal activation on tasks involving the episodic buffer, because there are associations between use of the central executive and prefrontal cortex.

### KEY TERM

**episodic buffer:** a component of **working memory** that is used to integrate and to store briefly information from the **phonological loop**, the **visuo-spatial sketchpad**, and **long-term memory**.

Why did Baddeley add the episodic buffer to the working memory model? The original version of the model was limited because its various components were too separate in their functioning. For example, Chincotta, Underwood, Abd Ghani, Papadopoulou, and Wresinki (1999) studied memory span for Arabic numerals and digit words, finding that participants used both verbal and visual encoding while performing the task. This suggests that participants combined information from the phonological loop *and* the visuo-spatial sketchpad. Since these two stores are separate, this combination and integration process must take place elsewhere, and the episodic buffer fits the bill.

Another finding hard to explain within the original working memory model is that, in immediate recall, people can recall about five unrelated words but up to 16 words presented in sentences (Baddeley, Vallar, & Wilson, 1987). The notion of an episodic buffer is useful, because this is where information from long-term memory could be integrated with information from the phonological loop and the visuo-spatial sketchpad.

### Evidence

Zhang et al. (2004) obtained evidence consistent with the notion that the episodic buffer is often used in conjunction with the central executive. Their participants had to recall a mixture of digits and visual locations, a task assumed to require the episodic buffer. As predicted, there was greater right prefrontal activation in this condition than one in which digits and visual locations were not mixed during presentation.

Baddeley and Wilson (2002) provided support for the notion of an episodic buffer. They pointed out that it had generally been assumed that good immediate prose recall involves the ability to store some of the relevant information in long-term memory. According to this view, amnesic patients with very impaired long-term memory should have very poor immediate prose recall. In contrast, Baddeley and Wilson argued that the ability to exhibit good immediate prose recall depends on two factors: (1) the capacity of the episodic buffer; and (2) an efficiently

functioning central executive creating and maintaining information in the buffer. According to this argument, even severely amnesic patients with practically no delayed recall of prose should have good immediate prose recall provided they have an efficient central executive. As predicted, immediate prose recall was much better in amnesics having little deficit in executive functioning than in those with a severe executive deficit.

Other studies suggest that the episodic buffer can operate independently of the central executive. Gooding, Isaac, and Mayes (2005) failed to replicate Baddeley and Wilson's (2002) findings in a similar study. Among their amnesic patients (who were less intelligent than those studied by Baddeley and Wilson), there was a non-significant correlation between immediate prose recall and measures of executive functioning. It is possible that using the central executive to maintain reasonable immediate prose recall requires high levels of intelligence. Berlingeri et al. (2008) found in patients with Alzheimer's disease that 60% of those having almost intact performance on tasks requiring the central executive nevertheless had no immediate prose recall. This finding also casts doubt on the importance of the central executive on tasks involving the episodic buffer.

Rudner, Fransson, Ingvar, Nyberg, and Ronnberg (2007) used a task involving combining representations based on sign language and on speech. This episodic buffer task was not associated with prefrontal activation, but was associated with activation in the left hippocampus. This is potentially important because the hippocampus plays a key role in binding together different kinds of information in memory (see Chapter 7). An association between use of the episodic buffer and the hippocampus was also reported by Berlingeri et al. (2008). They found among patients with Alzheimer's disease that those with most atrophy of the anterior part of the hippocampus did worst on immediate prose recall.

### Evaluation

The addition of the episodic buffer to the working memory model has proved of value. The

original three components of the model were too separate from each other and from long-term memory to account for our ability to combine different kinds of information (e.g., visual, verbal) on short-term memory tasks. The episodic buffer helps to provide the “glue” to integrate information within working memory.

Some progress has been made in tracking down the brain areas associated with the episodic buffer. The hippocampus is of central importance in binding and integrating information during learning, and so it is unsurprising that it is associated with use of the episodic buffer. The evidence suggests that use of the episodic buffer is sometimes associated with the central executive, but we do not know as yet what determines whether there is an association.

It is harder to carry out research on the episodic buffer than on the phonological loop or the visuo-spatial sketchpad. We have to use complex tasks to study the episodic buffer because it involves the complicated integration of information. In contrast, it is possible to devise relatively simple tasks to study the phonological loop or the visuo-spatial sketchpad. In addition, there are often close connections between the episodic buffer and the other components of the working memory system. That often makes it difficult to distinguish clearly between the episodic buffer and the other components.

### Overall evaluation

The working memory model has several advantages over the short-term memory store proposed by Atkinson and Shiffrin (1968). First, the working memory system is concerned with both active processing and transient storage of information, and so is involved in all complex cognitive tasks, such as language comprehension (see Chapter 10) and reasoning (see Chapter 14).

Second, the working memory model explains the partial deficits of short-term memory observed in brain-damaged patients. If brain damage affects only one of the three components of working memory, then selective deficits on short-term memory tasks would be expected.

Third, the working memory model incorporates verbal rehearsal as an optional process within the phonological loop. This is more realistic than the enormous significance of rehearsal within the multi-store model of Atkinson and Shiffrin (1968).

What are the limitations of the working memory model? First, it has proved difficult to identify the number and nature of the main executive processes associated with the central executive. For example, disagreements on the nature of executive functions have emerged from approaches based on latent-variable analyses of executive tasks (Miyake et al., 2000) and on data from brain-damaged patients (Stuss & Alexander, 2007). One reason for the lack of clarity is that most complex tasks involve the use of more than one executive process, making it hard to establish the contribution that each has made.

Second, we need more research on the relationship between the episodic buffer and the other components of the working memory system. As yet, we lack a detailed account of how the episodic buffer integrates information from the other components and from long-term memory.

## LEVELS OF PROCESSING

What determines how well we remember information over the long term? According to Craik and Lockhart (1972), what is crucial is how we process that information during learning. They argued in their levels-of-processing approach that attentional and perceptual processes at learning determine what information is stored in long-term memory. There are various levels of processing, ranging from shallow or physical analysis of a stimulus (e.g., detecting specific letters in words) to deep or semantic analysis; the greater the extent to which meaning is processed, the deeper the level of processing. They implied that processing nearly always proceeds in a serial fashion from shallow sensory levels to deeper semantic ones. However, they subsequently (Lockhart & Craik, 1990)

admitted that that was an oversimplification and that processing is often parallel.

Craik and Lockhart's (1972) main theoretical assumptions were as follows:

- The level or depth of processing of a stimulus has a large effect on its memorability.
- Deeper levels of analysis produce more elaborate, longer lasting and stronger memory traces than do shallow levels of analysis.

Craik and Lockhart (1972) disagreed with Atkinson and Shiffrin's (1968) assumption that rehearsal *always* improves long-term memory. They argued that rehearsal involving simply repeating previous analyses (**maintenance rehearsal**) does not enhance long-term memory. In fact, however, maintenance rehearsal typically has a rather small (but beneficial) effect on long-term memory (Glenberg, Smith, & Green, 1977).

## Evidence

Numerous studies support the main assumptions of the levels-of-processing approach. For example, Craik and Tulving (1975) compared recognition performance as a function of the task performed at learning:

- *Shallow graphemic task*: decide whether each word is in uppercase or lowercase letters.
- *Intermediate phonemic task*: decide whether each word rhymes with a target word.
- *Deep semantic task*: decide whether each word fits a sentence containing a blank.

Depth of processing had impressive effects on memory performance, with performance more than three times higher with deep than with shallow processing. In addition, performance was generally much better for words associated with "Yes" responses on the processing task than those associated with "No" responses. Craik and Tulving used incidental learning – the participants did not realise at the time of learning that there would be a memory test. They argued that the nature of task processing

rather than the intention to learn is crucial.

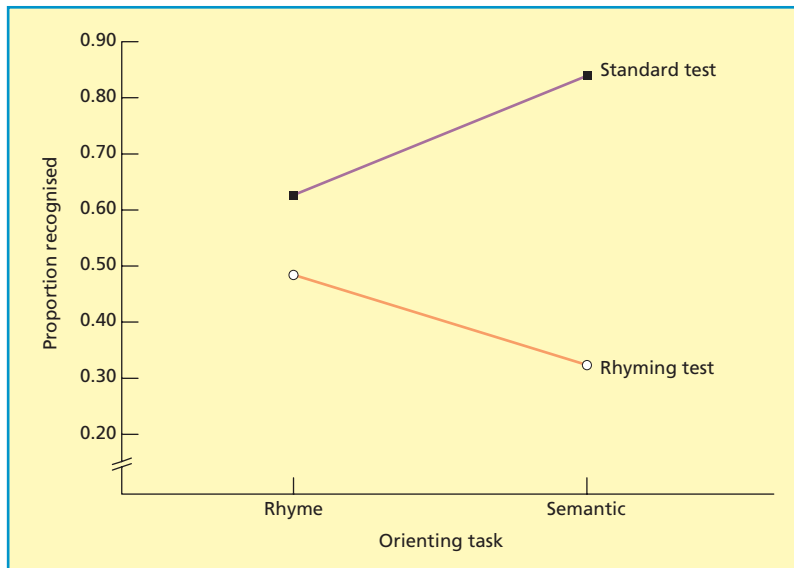
Craik and Tulving (1975) assumed that the semantic task involved deep processing and the uppercase/lowercase task involved shallow processing. However, it would be preferable to assess depth. One approach is to use brain-imaging to identify the brain regions involved in different kinds of processing. For example, Wagner, Maril, Bjork, and Schacter (2001) found there was more activation in the left inferior frontal lobe and the left lateral and medial temporal lobe during semantic than perceptual processing. However, the findings have been somewhat inconsistent. Park and Rugg (2008b) presented word pairs and asked participants to rate the extent to which they shared a semantic theme (deep processing) or sounded similar (shallow processing). Memory was better following semantic processing than phonological processing. However, successful memory performance was associated with activation in the left ventrolateral prefrontal cortex regardless of the encoding task. This finding suggests that there is no simple relationship between processing task and patterns of brain activation.

Craik and Tulving (1975) argued that elaboration of processing (i.e., the amount of processing of a particular kind) is important as well as depth of processing. Participants were presented on each trial with a word and a sentence containing a blank, and decided whether the word fitted into the blank space. Elaboration was manipulated by using simple (e.g., "She cooked the \_\_\_\_") and complex "The great bird swooped down and carried off the struggling \_\_\_\_") sentence frames. Cued recall was twice as high for words accompanying complex sentences.

Long-term memory depends on the *kind* of elaboration as well as the *amount*. Bransford, Franks, Morris, and Stein (1979) presented either minimally elaborated similes (e.g., "A mosquito

## KEY TERM

**maintenance rehearsal**: processing that involves simply repeating analyses which have already been carried out.



**Figure 6.12** Mean proportion of words recognised as a function of orienting task (semantic or rhyme) and of the type of recognition task (standard or rhyming). Data are from Morris et al. (1977), and are from positive trials only.

is like a doctor because they both draw blood”) or multiply elaborated similes (e.g., “A mosquito is like a raccoon because they both have heads, legs, jaws”). Recall was much better for the minimally elaborated similes than the multiply elaborated ones, indicating that the nature of semantic elaborations needs to be considered.

Eysenck (1979) argued that distinctive or unique memory traces are easier to retrieve than those resembling other memory traces. Eysenck and Eysenck (1980) tested this notion using nouns having irregular grapheme–phoneme correspondence (i.e., words not pronounced in line with pronunciation rules, such as “comb” with its silent “b”). In one condition, participants pronounced these nouns as if they had regular grapheme–phoneme correspondence, thus producing distinctive memory traces. Other nouns were simply pronounced normally, thus producing non-distinctive memory traces. Recognition memory was much better in the former condition, indicating the importance of distinctiveness.

Morris, Bransford, and Franks (1977) argued that stored information is remembered only if it is of *relevance* to the memory test. Participants answered semantic or shallow (rhyme) questions for lists of words. Memory was tested by a standard recognition test, in

which list and non-list words were presented, or by a rhyming recognition test. On this latter test, participants selected words that rhymed with list words: the words themselves were *not* presented. With the standard recognition test, the predicted superiority of deep over shallow processing was obtained (see Figure 6.12). However, the *opposite* result was reported with the rhyme test, which disproves the notion that deep processing always enhances long-term memory.

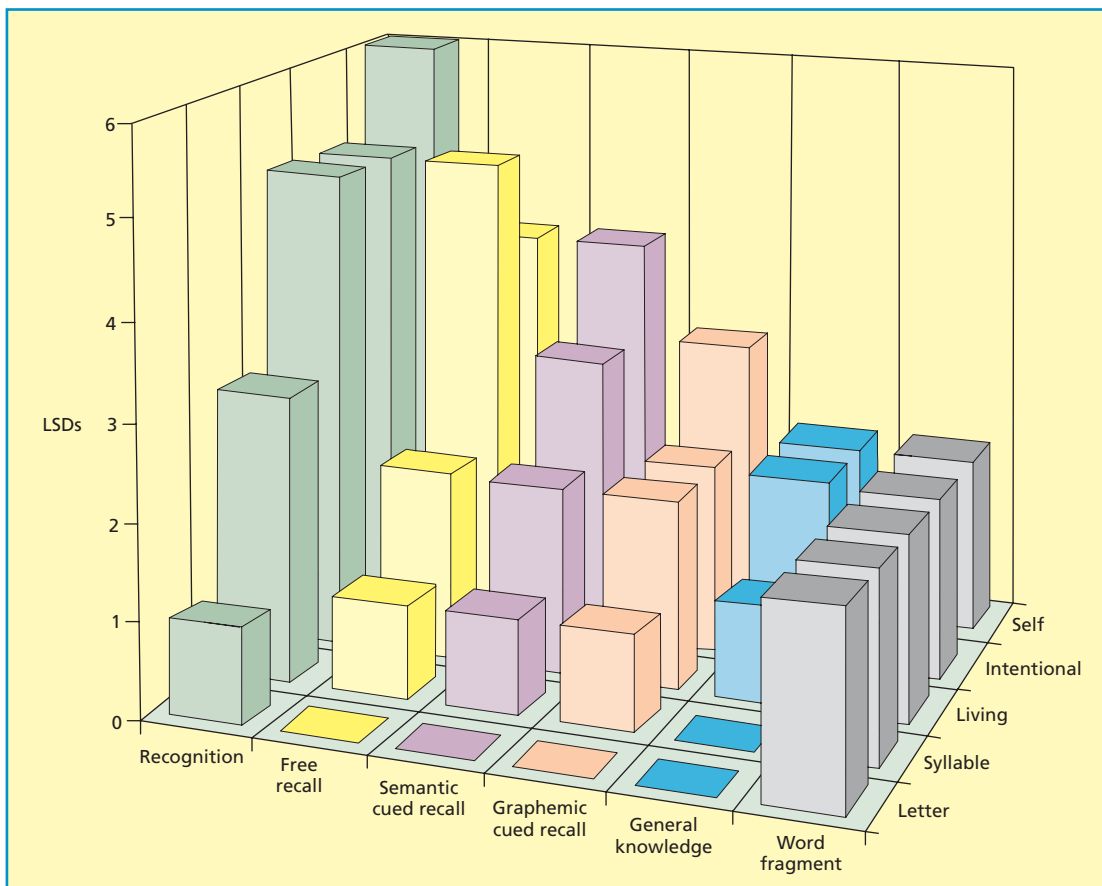
Morris et al. (1977) argued that their findings supported transfer-appropriate processing theory. According to this theory, different kinds of learning lead learners to acquire different kinds of information about a stimulus. Whether the stored information leads to subsequent retention depends on the *relevance* of that information to the memory test. For example, storing semantic information is essentially irrelevant when the memory test requires the identification of words rhyming with list words. What is required for this kind of test is shallow rhyme information. Further evidence supporting transfer-appropriate theory is discussed later in the chapter.

Nearly all the early research on levels-of-processing theory used standard memory tests (e.g., recall, recognition) involving explicit memory (conscious recollection). It is also important

to consider the effects of level of processing on implicit memory (memory not involving conscious recollection; see Chapter 7). Challis, Velichkovsky, and Craik (1996) asked participants to learn word lists under various conditions: judging whether the word was related to them (self-judgement); simple intentional learning; judging whether it referred to a living thing (living judgement); counting the number of syllables (syllable task); or counting the number of letters of a certain type (letter type). The order of these tasks reflects decreasing depth of processing. There were four explicit memory tests (recognition, free recall, semantic cued recall involving a word related in meaning to

a list word, and graphemic cued recall involving a word with similar spelling to a list word), and two implicit memory tests. One of these tests involved answering general knowledge questions in which the answers corresponded to list words, and the other involved completing word fragments (e.g., c \_ pp \_ \_).

For the four explicit memory tests, there was an overall tendency for performance to increase with increasing depth of processing, but there are some hard-to-interpret differences as well (see Figure 6.13). We turn now to the implicit memory tests. The word-fragment test failed to show any levels-of-processing effect, whereas level of processing had a significant



**Figure 6.13** Memory performance as a function of encoding conditions and retrieval conditions. The findings are presented in units of least significant differences (LSDs) relative to baseline performance, meaning that columns of differing heights are significantly different. Reprinted from Roediger (2008), based on data in Challis et al. (1996), Copyright © 1996, with permission from Elsevier.

effect on the general knowledge memory test. The general knowledge memory test is a conceptual implicit memory test based on meaning. As a result, it seems reasonable that it would be affected by level of processing, even though the effects were much smaller than with explicit memory tests. In contrast, the word-fragment test is a perceptual implicit memory test not based on meaning, which helps to explain why there was no levels-of-processing effect with this test.

In sum, levels-of-processing effects were generally greater in explicit memory than implicit memory. In addition, there is some support for the predictions of levels-of-processing theory with all memory tests other than the word-fragment test. Overall, the findings are too complex to be explained readily by levels-of-processing theory.

### Evaluation

Craik and Lockhart (1972) argued correctly that processes during learning have a major impact on subsequent long-term memory. This may sound obvious, but surprisingly little research before 1972 focused on learning processes and their effects on memory. Another strength is the central assumption that perception, attention, and memory are all closely interconnected, and that learning and remembering are by-products of perception, attention, and comprehension. In addition, the approach led to the identification of elaboration and distinctiveness of processing as important factors in learning and memory.

The levels-of-processing approach possesses several limitations. First, it is generally difficult to assess processing depth. Second, Craik and Lockhart (1972) greatly underestimated the importance of the retrieval environment in determining memory performance. As Morris et al. (1977) showed, the typical levels effect can be reversed if stored semantic information is irrelevant to the requirements of the memory test. Third, long-term memory is influenced by depth of processing, elaboration of processing, and distinctiveness of processing. However, the relative importance of

these factors (and how they are inter-related) remains unclear. Fourth, findings from amnesic patients (see Chapter 7) cannot be explained by the levels-of-processing approach. Most amnesic patients have good semantic or deep processing skills, but their long-term memory is extremely poor, probably because they have major problems with consolidation (fixing of newly learned information in long-term memory) (Craik, 2002; see Chapter 7). Fifth, Craik and Lockhart (1972) did not explain precisely *why* deep processing is so effective, and it is not clear why there is a much smaller levels-of-processing effect in implicit than in explicit memory.

## IMPLICIT LEARNING

Do you think you could learn something without being aware of what you have learned? It sounds improbable. Even if we do acquire information without any conscious awareness, it might seem somewhat pointless and wasteful – if we do not realise we have learned something, it seems unlikely that we are going to make much use of it. What we are considering here is **implicit learning**, which is, “learning without conscious awareness of having learned” (French & Cleeremans, 2002, p. xvii). Implicit learning has been contrasted with explicit learning, which involves conscious awareness of what has been learned.

Cleeremans and Jiménez (2002, p. 20) provided a fuller definition of implicit learning: “Implicit learning is the process through which we become sensitive to certain regularities in the environment (1) in the absence of intention to learn about these regularities, (2) in the absence of awareness that one is learning, and (3) in such a way that the resulting knowledge

### KEY TERM

**implicit learning:** learning complex information without the ability to provide conscious recollection of what has been learned.



Implicit learning is “learning without conscious awareness of having learned”. Bike riding is an example of implicit learning in which there is no clear conscious awareness of what has been learned.

is difficult to express.” You probably possess skills that are hard to express in words. For example, it is notoriously difficult to express what we know about riding a bicycle.

There are clear similarities between implicit learning and implicit memory, which is memory not depending on conscious recollection (see Chapter 7). You may wonder why implicit learning and implicit memory are not discussed together. There are three reasons. First, there are some differences between implicit learning and implicit memory. As Buchner and Wippich (1998) pointed out, implicit learning refers to “the [incidental] acquisition of knowledge about the structural properties of the relations between [usually more than two] objects or events.” In contrast, implicit memory refers to “situations in which effects of prior experiences can be observed despite the fact that the participants are not instructed to relate their current performance to a learning episode” (Buchner & Wippich, 1998). Second, studies of implicit learning have typically used relatively complex, novel stimulus materials, whereas most studies of implicit memory have used simple, familiar stimulus materials. Third, relatively few researchers have considered the relations between implicit learning and implicit memory.

How do the systems involved in implicit learning differ from those involved in explicit

learning and memory? Reber (1993) proposed five such characteristics (none has been established definitively):

- *Robustness*: Implicit systems are relatively unaffected by disorders (e.g., amnesia) affecting explicit systems.
- *Age independence*: Implicit learning is little influenced by age or developmental level.
- *Low variability*: There are smaller individual differences in implicit learning and memory than in explicit learning and memory.
- *IQ independence*: Performance on implicit tasks is relatively unaffected by IQ.
- *Commonality of process*: Implicit systems are common to most species.

We can identify three main types of research on implicit learning. First, there are studies to see whether healthy participants can learn fairly complex material in the absence of conscious awareness of what they have learned. According to Reber (1993), individual differences in such learning should depend relatively little on IQ. It is often assumed that implicit learning makes minimal demands on attentional resources. If so, the requirement to perform an additional attentionally-demanding task at the same time should not impair implicit learning.

Second, there are brain-imaging studies. If implicit learning depends on different cognitive processes to explicit learning, the brain areas associated with implicit learning should differ from those associated with explicit learning. More specifically, brain areas associated with conscious experience and attentional control (e.g., parts of the prefrontal cortex) should be much less activated during implicit learning than explicit learning.

Third, there are studies on brain-damaged patients, mostly involving amnesic patients having severe problems with long-term memory. Amnesic patients typically have relatively intact implicit memory even though their explicit memory is greatly impaired (see Chapter 7). If amnesic patients have intact implicit learning but impaired explicit learning, this would provide



evidence that the two types of learning are very different.

You might imagine it would be relatively easy to decide whether implicit learning has occurred – we simply ask participants to perform a complex task without instructing them to engage in deliberate learning. Afterwards, they indicate their conscious awareness of what they have learned. Implicit learning has been demonstrated if learning occurs in the absence of conscious awareness of the nature of that learning. Alas, there are several reasons why participants fail to report conscious awareness of what they have learned. For example, there is the “retrospective problem” (Shanks & St. John, 1994): participants may be consciously aware of what they are learning at the time, but have forgotten it when questioned at the end of the experiment. Shanks and St. John proposed two criteria for implicit learning to be demonstrated:

- *Information criterion:* The information participants are asked to provide on the awareness test must be the information responsible for the improved level of performance.
- *Sensitivity criterion:* “We must be able to show that our test of awareness is sensitive to all of the relevant knowledge” (p. 374). People may be consciously aware of more task-relevant knowledge than appears on an insensitive awareness test, leading us to underestimate their consciously accessible knowledge.

### Complex learning

Much early research on implicit learning involved artificial grammar learning. On this task, participants initially memorise meaningless letter strings (e.g., PVPXVPS; TSXXTVV). After that, they are told that the memorised letter strings all follow the rules of an artificial grammar, but are not told the nature of these rules. Next, the participants classify *novel* strings as grammatical or ungrammatical. Finally, they describe the rules of the artificial grammar. Participants typically perform significantly above chance level

on the classification task, but cannot describe the grammatical rules (e.g., Reber, 1967). Such findings are less impressive than they appear. As several researchers have found (e.g., Channon, Shanks, Johnstone, Vakili, Chin, & Sinclair, 2002), participants’ decisions on the grammaticality of letter strings do *not* depend on knowledge of grammatical rules. Instead, participants classify letter strings as grammatical when they share letter pairs with the letter strings memorised initially and as ungrammatical when they do not. Thus, above-chance performance depends on conscious awareness of two-letter fragments, and provides little or no evidence of implicit learning.

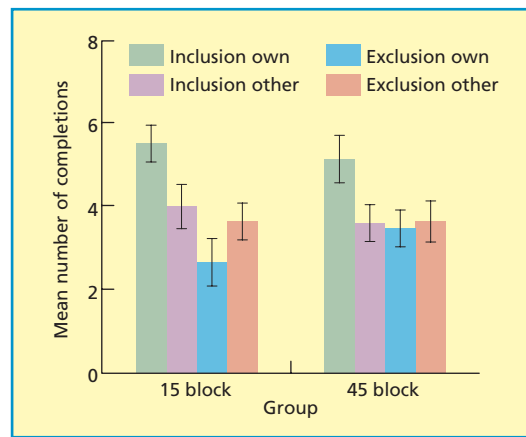
The most commonly used implicit learning task involves serial reaction time. On each trial, a stimulus appears at one out of several locations on a computer screen, and participants respond rapidly with the response key corresponding to its location. There is typically a complex, repeating sequence over trials in the various stimulus locations, but participants are not told this. Towards the end of the experiment, there is typically a block of trials conforming to a novel sequence, but this information is not given to participants. Participants speed up during the course of the experiment but respond much slower during the novel sequence (see Shanks, 2005, for a review). When questioned at the end of the experiment, participants usually show no conscious awareness that there was a repeating sequence or pattern in the stimuli presented to them.

One strength of the serial reaction time task is that the repeating sequence (which is crucial to the demonstration of implicit learning) is incidental to the explicit task of responding to the stimuli as rapidly as possible. However, we need to satisfy the information and sensitivity criteria (described above) with this task. It seems reasonable to make the awareness test very similar to the learning task, as was done by Howard and Howard (1992). An asterisk appeared in one of four locations on a screen, under each of which was a key. The task was to press the key corresponding to the position of the asterisk as rapidly as possible. Participants showed clear evidence of learning the underlying

sequence by responding faster and faster to the asterisk. However, when given the awareness test of predicting where the asterisk would appear next, their performance was at chance level. These findings suggest there was implicit learning – learning occurred in the absence of conscious awareness of what had been learned.

Contrary evidence that participants have some conscious awareness of what they have learned on a serial reaction time task was reported by Wilkinson and Shanks (2004). Participants were given either 1500 trials (15 blocks) or 4500 trials (45 blocks) on the task and showed strong evidence of sequence learning. Then they were told there was a repeated sequence in the stimuli, following which they were presented on each of 12 trials with part of the sequence under one of two conditions. In the *inclusion* condition, they guessed the next location in the sequence. In the *exclusion* condition, they were told they should avoid guessing the next location in the sequence. If sequence knowledge is wholly implicit, then performance should not differ between the inclusion and exclusion conditions because participants would be unable to control how they used their sequence knowledge. In contrast, if it is partly explicit, then participants should be able to exert intentional control over their sequence knowledge. If so, the guesses generated in the inclusion condition should be more likely to conform to the repeated sequence than those in the exclusion condition. The findings indicated that explicit knowledge was acquired on the serial reaction time task (see Figure 6.14).

Similar findings were reported by Destrebecqz et al. (2005) in another study using the serial reaction time task. The interval of time between the participant's response to one stimulus and the presentation of the next one was either 0 ms or 250 ms, it being assumed that explicit learning would be more likely with the longer interval. Participants responded progressively faster over trials with both response-to-stimulus intervals. As Wilkinson and Shanks (2004) had done, they used inclusion and exclusion conditions. Participants' responses were significantly closer



**Figure 6.14** Mean number of completions (guessed locations) corresponding to the trained sequence (own) or the untrained sequence (other) in inclusion and exclusion conditions as a function of number of trials (15 vs. 45 blocks). From Wilkinson and Shanks (2004). Copyright © 2004 American Psychological Association. Reproduced with permission.

to the training sequence in the inclusion condition than in the exclusion condition, suggesting that some explicit learning occurred, especially when the response-to-stimulus interval was long. In addition, as discussed below, brain-imaging findings from this study suggested that explicit learning occurred.

If the serial reaction time task genuinely involves implicit learning, performance on that task might well be unaffected by the requirement to perform a second, attentionally-demanding task at the same time. This prediction was tested by Shanks, Rowland, and Ranger (2005). Four different target stimuli were presented across trials, and the main task was to respond rapidly to the location at which a target was presented. Half the participants performed only this task, and the remainder also carried out the attentionally-demanding task of counting targets. Participants with the additional task performed much more slowly than those with no additional task, and also showed significantly inferior sequence learning. Thus, attentional resources were needed for effective learning of the sequence on the serial reaction time task, which casts doubt on the notion that such learning is implicit. In addition, both groups

of participants had significantly more accurate performance under inclusion than exclusion instructions, further suggesting the presence of explicit learning.

As mentioned above, Reber (1993) assumed that individual differences in intelligence have less effect on implicit learning than on explicit learning. Gebauer and Mackintosh (2007) carried out a thorough study using various implicit learning tasks (e.g., artificial grammar learning; serial reaction time). These tasks were given under standard implicit instructions or with explicit rule discovery instructions (i.e., indicating explicitly that there were rules to be discovered). The mean correlation between implicit task performance and intelligence was only +0.03, whereas it was +0.16 between explicit task performance and intelligence. This supports the hypothesis. It is especially important that intelligence (which is positively associated with performance on the great majority of cognitive tasks) failed to predict implicit learning performance.

### Brain-imaging studies

Different areas of the brain should be activated during implicit and explicit learning if they are genuinely different. Conscious awareness is associated with activation in many brain regions, but the main ones are the anterior cingulate and the dorsolateral prefrontal cortex (Dehaene & Naccache, 2001; see Chapter 16). Accordingly, these areas should be more active during explicit than implicit learning. In contrast, it has often been assumed that the striatum is associated with implicit learning (Destrebecqz et al., 2005). The **striatum** is part of the basal ganglia; it is located in the interior areas of the cerebral hemispheres and the upper region of the brainstem.

Functional neuroimaging studies have provided limited support for the above predictions. Grafton, Hazeltine, and Ivry (1995) found that explicit learning was associated with activation in the anterior cingulate, regions in the parietal cortex involved in working memory, and areas in the parietal cortex concerned with voluntary

attention. Aizenstein et al. (2004) found that there was greater activation in the prefrontal cortex and anterior cingulate during explicit rather than implicit learning. However, they did not find any clear evidence that the striatum was more activated during implicit than explicit learning.

Destrebecqz et al. (2005) pointed out that most so-called explicit or implicit learning tasks probably involve a mixture of explicit and implicit learning. As mentioned before, they used inclusion and exclusion conditions with the serial reaction time task to distinguish clearly between the explicit and implicit components of learning. Activation in the striatum was associated with the implicit component of learning, and the mesial prefrontal cortex and anterior cingulate were associated with the explicit component.

In sum, failure to discover clear differences in patterns of brain activation between explicit and implicit learning can occur because the tasks used are not pure measures of these two forms of learning. It is no coincidence that the study distinguishing most clearly between explicit and implicit learning (Destrebecqz et al., 2005) is also the one producing the greatest support for the hypothesised associations of prefrontal cortex with explicit learning and the striatum with implicit learning.

### Brain-damaged patients

As discussed in Chapter 7, amnesic patients typically perform very poorly on tests of explicit memory (involving conscious recollection) but often perform as well as healthy individuals on tests of implicit memory (on which conscious recollection is not needed). The notion that separate learning systems underlie implicit learning and explicit learning would be supported

#### KEY TERM

**striatum:** it forms part of the basal ganglia of the brain and is located in the upper part of the brainstem and the inferior part of the cerebral hemispheres.

if amnesic patients showed intact levels of implicit learning combined with impaired explicit learning. Explicit learning in amnesics is often severely impaired, but amnesics' performance on tasks allegedly involving implicit learning is variable (see Vandenberghe, Schmidt, Fery, & Cleeremans, 2006, for a review). For example, Knowlton, Ramus, and Squire (1992) found that amnesics performed as well as healthy controls on an implicit test on which participants distinguished between grammatical and ungrammatical letter strings (63% versus 67% correct, respectively). However, they performed significantly worse than the controls on an explicit test (62% versus 72%, respectively).

Meulemans and Van der Linden (2003) pointed out that amnesics' performance on Knowlton et al.'s (1992) implicit test may have depended on explicit fragment knowledge (e.g., pairs of letters found together). Accordingly, they used an artificial grammar learning task in which fragment knowledge could not influence performance on the test of implicit learning. They also used a test of explicit learning in which participants wrote down ten letter strings they regarded as grammatical. The amnesic patients performed as well as the healthy controls on implicit learning. However, their performance was much worse than that of the controls on explicit learning.

There is evidence of implicit learning in amnesic patients in studies on the serial reaction time task. The most thorough such study was carried out by Vandenberghe et al. (2006). Amnesic patients and healthy controls were given two versions of the task: (1) deterministic sequence (fixed repeating sequence); and (2) probabilistic sequence (repeating sequence with some deviations). The healthy controls showed clear evidence of learning with both sequences. The use of inclusion and exclusion instructions indicated that healthy controls showed explicit learning with the deterministic sequence but not with the probabilistic one. The amnesic patients showed limited learning of the deterministic sequence but not of the probabilistic sequence. Their performance was comparable with inclusion and exclusion instructions, indicating that this learning was implicit.

Earlier we discussed the hypothesis that the striatum is of major importance in implicit learning. Patients with Parkinson's disease (the symptoms of which include limb tremor and muscle rigidity) have damage to the striatum, and so we could predict that they would have impaired implicit learning. The evidence generally supports that prediction (see Chapter 7 for a fuller discussion). Siegert, Taylor, Weatherall, and Abernethy (2006) carried out a meta-analysis of six studies investigating the performance of patients with Parkinson's disease on the serial reaction time task. Skill learning on this task was consistently impaired in the patients relative to healthy controls. Wilkinson and Jahanshahi (2007) obtained similar findings with patients having Parkinson's disease using a different version of the serial reaction time task. In addition, they reported convincing evidence that patients' learning was implicit (i.e., lacked conscious awareness). The patients performed at chance level when trying to recognise old sequences. In addition, their knowledge was not under intentional control, as was shown by their inability to suppress the expression of what they had learned when instructed to do so.

We have seen that there is some evidence that amnesic patients have poor explicit learning combined with reasonably intact implicit learning. We would have evidence of a double dissociation (see Glossary) if patients with Parkinson's disease had poor implicit learning combined with intact explicit learning. This pattern has occasionally been reported with patients in the early stages of the disease (e.g., Saint-Cyr, Taylor, & Lang, 1988). However, Parkinson's patients generally have impaired explicit learning, especially when the learning task is fairly complex and involves organisation of the to-be-learned information (see Vingerhoets, Vermeule, & Santens, 2005, for a review).

## Evaluation

There has been a considerable amount of recent research on implicit learning involving three different approaches: behavioural studies on healthy participants; functional neuroimaging

studies on healthy participants; and studies on amnesic patients. Much of that research suggests that implicit learning should be distinguished from explicit learning. Some of the most convincing evidence has come from studies on brain-damaged patients. For example, Vanderberghe et al. (2006) found, using the serial reaction time task, that amnesic patients' learning seemed to be almost entirely at the implicit level. Other convincing evidence has come from functional neuro-imaging studies. There is accumulating evidence that explicit learning is associated with the pre-frontal cortex and the anterior cingulate, whereas implicit learning is associated with the striatum.

What are the limitations of research on implicit learning? First, it has proved hard to devise tests of awareness that can detect *all* the task-relevant knowledge of which people have conscious awareness. Second, some explicit learning is typically involved on the artificial grammar learning task and the serial reaction time task (e.g., Destrebecqz et al., 2005; Shanks et al., 2005; Wilkinson & Shanks, 2004). Third, the brain areas underlying what are claimed to be explicit and implicit learning are not always clearly different (e.g., Schendan, Searl, Melrose, & Stern, 2003).

What conclusions can we draw about implicit learning? It is too often assumed that finding that explicit learning plays some part in explaining performance on a given task means that *no* implicit learning occurred. It is very likely that the extent to which learners are consciously aware of what they are learning varies from individual to individual and from task to task. One possibility is that we have greatest conscious awareness when the representations of what we have learned are stable, distinctive, and strong, and least when those representations are unstable, non-distinctive, and weak (Kelly, 2003). All kinds of intermediate position are also possible.

Sun, Zhang, and Mathews (2009) argued that learning nearly always involves implicit and explicit aspects, and that the balance between these two types of learning changes over time. On some tasks, there is initial implicit learning based on the performance of successful actions followed by explicit learning of the rules apparently explaining why those actions are successful.

On other tasks, learners start with explicit rules and then engage in implicit learning based on observing their actions directed by those rules.

## THEORIES OF FORGETTING

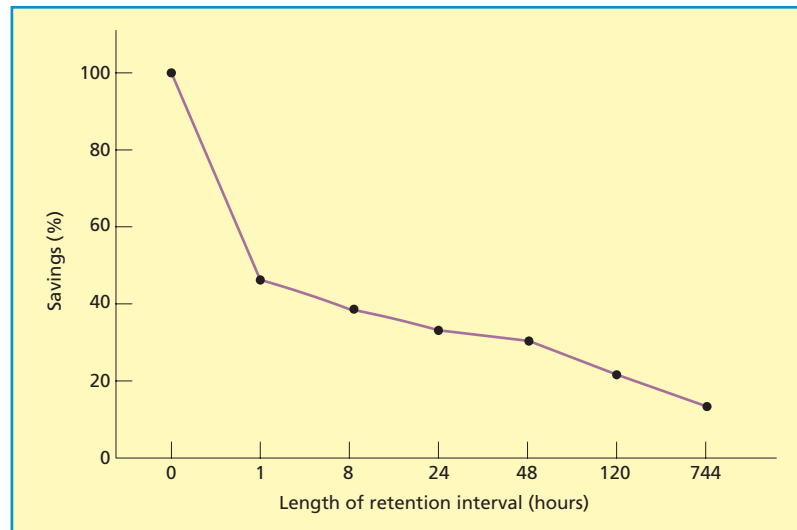
Forgetting was first studied in detail by Hermann Ebbinghaus (1885/1913). He carried out numerous studies with himself as the only participant (not a recommended approach!). Ebbinghaus initially learned a list of nonsense syllables lacking meaning. At various intervals of time, he recalled the nonsense syllables. He then re-learned the list. His basic measure of forgetting was the **savings method**, which involved seeing the reduction in the number of trials during re-learning compared to original learning. Forgetting was very rapid over the first hour after learning but slowed down considerably after that (see Figure 6.15). These findings suggest that the forgetting function is approximately logarithmic.

Rubin and Wenzel (1996) analysed the forgetting functions taken from 210 data sets involving numerous memory tests. They found (in line with Ebbinghaus (1885/1913) that a logarithmic function most consistently described the rate of forgetting (for alternative possibilities, see Wixted, 2004). The major exception was autobiographical memory, which showed slower forgetting. One of the possible consequences of a logarithmic forgetting function is Jost's (1897) law: if two memory traces differ in age but are of equal strength, the older one will decay more slowly over any given time period.

Most studies of forgetting have focused on declarative or explicit memory (see Chapter 7), which involves conscious recollection of

### KEY TERM

**savings method:** a measure of forgetting introduced by Ebbinghaus, in which the number of trials for re-learning is compared against the number for original learning.



**Figure 6.15** Forgetting over time as indexed by reduced savings. Data from Ebbinghaus (1885/1913).

previously learned information. Comparisons of forgetting rates in explicit and implicit memory (in which conscious recollection is not required) suggest that forgetting is slower in implicit memory. Tulving, Schacter, and Stark (1982) carried out a study in which participants initially learned a list of relatively rare words (e.g., “toboggan”). One hour or one week later, they received a test of explicit memory (recognition memory) or a word-fragment completion test of implicit memory. Word fragments (e.g., \_O \_O \_GA\_) were presented and participants filled in the blanks to form a word without being told that any of the words came from the list studied previously. Recognition memory was much worse after one week than one hour, whereas word-fragment completion performance was unchanged.

Dramatic evidence of long-lasting implicit memories was reported by Mitchell (2006). His participants tried to identify pictures from fragments having seen some of them before in a laboratory experiment 17 years previously. They did significantly better with the pictures seen before; thus providing strong evidence for implicit memory after all those years! In contrast, there was rather little explicit memory for the experiment 17 years earlier. A 36-year-old male participant confessed, “I’m sorry – I don’t really remember this experiment at all.”

In what follows, we will be discussing the major theories of forgetting in turn. As you read about these theories, bear in mind that they are not mutually exclusive. Thus, it is entirely possible that all the theories discussed identify some of the factors responsible for forgetting.

### Interference theory

The dominant approach to forgetting during much of the twentieth century was interference theory. According to this theory, our ability to remember what we are currently learning can be disrupted (interfered with) by previous learning (proactive interference) or by future learning (retroactive interference) (see Figure 6.16).

Interference theory dates back to Hugo Munsterberg in the nineteenth century. For many years, he kept his pocket-watch in one particular pocket. When he moved it to a different pocket, he often fumbled about in confusion when asked for the time. He had learned an association between the stimulus, “What time is it, Hugo?”, and the response of removing the watch from his pocket. Later on, the stimulus remained the same. However, a different response was now associated with it, thus causing proactive interference.

Research using methods such as those shown in Figure 6.16 revealed that proactive

Proactive interference			
Group	Learn	Learn	Test
Experimental	A-B (e.g. Cat-Tree)	A-C (e.g. Cat-Dirt)	A-C (e.g. Cat-Dirt)
Control	-	A-C (e.g. Cat-Dirt)	A-C (e.g. Cat-Dirt)
Retroactive interference			
Group	Learn	Learn	Test
Experimental	A-B (e.g. Cat-Tree)	A-C (e.g. Cat-Dirt)	A-B (e.g. Cat-Tree)
Control	A-B (e.g. Cat-Tree)	-	A-B (e.g. Cat-Tree)

Note: for both proactive and retroactive interference, the experimental group exhibits interference. On the test, only the first word is supplied, and the participants must provide the second word.

**Figure 6.16** Methods of testing for proactive and retroactive interference.

and retroactive interference are both maximal when two different responses are associated with the same stimulus and minimal when two different stimuli are involved (Underwood & Postman, 1960). Strong evidence of retroactive interference has been obtained in studies of eyewitness testimony in which memory of an event is interfered with by post-event information (see Chapter 8).

### Proactive interference

Proactive interference can be very useful when circumstances change. For example, if you have re-arranged everything in your room, it is a real advantage to forget where your belongings used to be.

Most research on proactive interference has involved declarative or explicit memory. An exception was a study by Lustig and Hasher (2001). They used a word-fragment completion task (e.g., A \_ L \_ \_ GY), on which participants wrote down the first appropriate word coming to mind. Participants previously exposed to words almost fitting the fragments (e.g., ANALOGY) showed evidence of proactive interference.

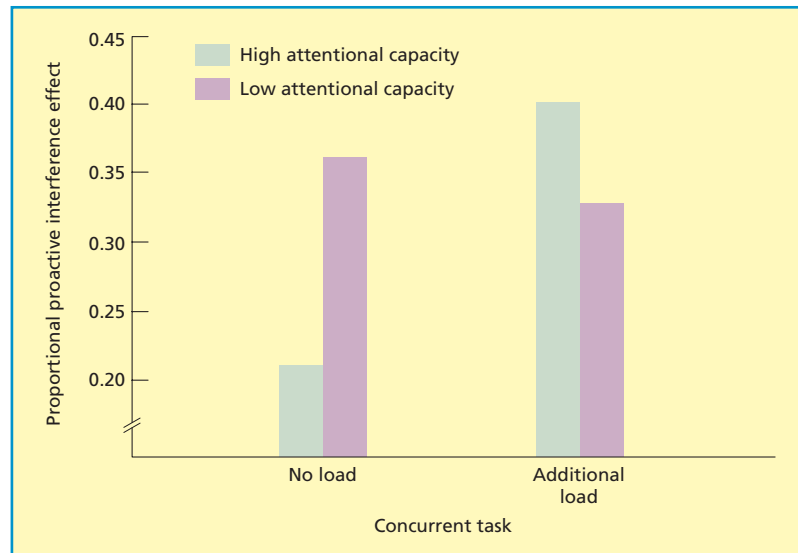
Jacoby, Debner, and Hay (2001) argued that proactive interference might occur for two reasons. First, it might be due to problems in

retrieving the correct response (discriminability). Second, it might be due to the great strength of the incorrect response learned initially (bias or habit). Thus, we might show proactive interference because the correct response is very weak or because the incorrect response is very strong. Jacoby et al. found consistently that proactive interference was due more to strength of the incorrect first response than to discriminability.

At one time, it was assumed that individuals *passively* allow themselves to suffer from interference. Suppose you learn something but find your ability to remember it is impaired by proactive interference from something learned previously. It would make sense to adopt active strategies to minimise any interference effect. Kane and Engle (2000) argued that individuals with high working-memory capacity (correlated with intelligence) would be better able to resist proactive interference than those with low capacity. However, even they would be unable to resist proactive interference if performing an attentionally demanding task at the same time as the learning task. As predicted, the high-capacity participants with no additional task showed the least proactive interference (see Figure 6.17).

The notion that people use active control processes to reduce proactive interference has

**Figure 6.17** Amount of proactive interference as a function of attentional capacity (low vs. high) and concurrent task (no vs. additional load). Data from Kane and Engle (2000).



been tested in several studies using the Recent Probes task. A small set of items (target set) is presented, followed by a recognition probe. The task is to decide whether the probe is a member of the target set. On critical trials, the probe is *not* a member of the current target set but was a member of the target set used on the previous trial. There is clear evidence of proactive interference on these trials in the form of lengthened reaction times and increased error rates.

Which brain areas are of most importance on proactive interference trials with the Recent Probes task? Nee, Jonides, and Berman (2007) found that the left ventrolateral prefrontal cortex was activated on such trials. The same brain area was also activated on a directed forgetting version of the Recent Probes task (i.e., participants were told to forget some of the target set items). This suggests that left ventrolateral prefrontal cortex may play an important role in suppressing unwanted information.

Nee et al.'s (2007) study could not show that left ventrolateral prefrontal cortex actually controls the effects of proactive interference. More direct evidence was reported by Ferdoes, Tononi, and Postle (2006). They administered transcranial magnetic stimulation (TMS; see Glossary) to left ventrolateral prefrontal cortex.

This produced a significant increase in the error rate on proactive interference trials, suggesting that this brain area is directly involved in attempts to control proactive interference.

### Retroactive interference

Numerous laboratory studies using artificial tasks such as paired-associate learning (see Figure 6.16) have produced large retroactive interference effects. Such findings do not necessarily mean that retroactive interference is important in everyday life. However, Isurin and McDonald (2001) argued that retroactive interference explains why people forget some of their first language when acquiring a second one. Bilingual participants fluent in two languages were first presented with various pictures and the corresponding words in Russian or Hebrew. Some were then presented with the same pictures and the corresponding words in the other language. Finally, they were tested for recall of the words in the first language. There was substantial retroactive interference – recall of the first-language words became progressively worse the more learning trials there were with the second-language words.

Retroactive interference is generally greatest when the new learning resembles previous learning. However, Dewar, Cowan, and Della



Sala (2007) found retroactive interference even when no new learning occurred during the retention interval. In their experiment, participants learned a list of words and were then exposed to various tasks during the retention interval before list memory was assessed. There was significant retroactive interference even when the intervening task involved detecting differences between pictures or detecting tones. Dewar et al. concluded that retroactive interference can occur in two ways: (1) expenditure of mental effort during the retention interval; or (2) learning of material similar to the original learning material. The first cause of retroactive interference probably occurs more often than the second in everyday life.

Lustig, Konkel, and Jacoby (2004) identified two possible explanations for retroactive interference in paired-associate learning. First, there may be problems with controlled processes (active searching for the correct response). Second, there may be problems with automatic processes (high accessibility of the incorrect response). They identified the roles of these two kinds of processes by assessing retroactive interference in two different ways. One way involved direct instructions (i.e., deliberately retrieve the correct responses) and the other way involved indirect instructions (i.e., rapidly produce the first response coming to mind when presented with the cue). Lustig et al. assumed that direct instructions would lead to the use of controlled and automatic processes, whereas indirect instructions would primarily lead to the use of automatic processes.

What did Lustig et al. (2004) find? First, use of direct instructions was associated with significant retroactive interference on an immediate memory test (cued recall) but not one day later. Second, the interference effect found on the immediate test depended mainly on relatively automatic processes (i.e., accessibility of the incorrect response). Third, the disappearance of retroactive interference on the test after one day was mostly due to reduced accessibility of the incorrect responses. Thus, relatively automatic processes are of major importance in retroactive interference.

## Evaluation

There is strong evidence for both proactive and retroactive interference. There has been substantial progress in understanding interference effects in recent years, mostly involving an increased focus on underlying processes. For example, automatic processes make incorrect responses accessible, and people use active control processes to minimise interference effects.

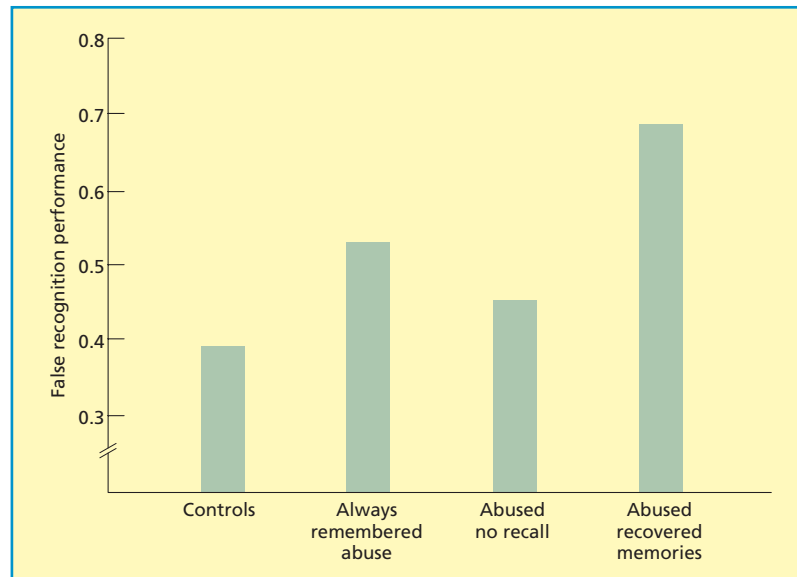
What are the limitations of interference theory? First, the emphasis has been on interference effects in declarative or explicit memory, and detailed information about interference effects in implicit memory is lacking. Second, interference theory explains why forgetting occurs but not directly why the rate of forgetting decreases over time. Third, more needs to be done to understand the brain mechanisms involved in interference and attempts to reduce interference.

## Repression

One of the best-known theories of forgetting owes its origins to the bearded Austrian psychologist Sigmund Freud (1856–1939). He claimed that very threatening or traumatic memories are often unable to gain access to conscious awareness, using the term **repression** to refer to this phenomenon. According to Freud (1915/1963, p. 86), “The essence of repression lies simply in the function of rejecting and keeping something out of consciousness.” However, Freud sometimes used the concept to refer merely to the inhibition of the capacity for emotional experience (Madison, 1956). Even though it is often believed that Freud regarded repression as unconscious, Erdelyi (2001) showed convincingly that Freud accepted that repression is sometimes an active

### KEY TERM

**repression:** motivated forgetting of traumatic or other threatening events.



**Figure 6.18** False recognition of words not presented in four groups of women with lists containing eight associates. Data from Clancy et al. (2000).

and intentional process. It is harder to test the notion of repression if it can be either unconscious or conscious.

Most evidence relating to repression is based on adult patients who have apparently recovered repressed memories of childhood sexual and/or physical abuse in adulthood. As we will see, there has been fierce controversy as to whether these recovered memories are genuine or false. Note that the controversy centres on *recovered* memories – most experts accept that continuous memories (i.e., ones constantly accessible over the years) are very likely to be genuine.

### Evidence

Clancy, Schacter, McNally, and Pitman (2000) used the Deese–Roediger–McDermott paradigm, which is known to produce false memories. Participants are given lists of semantically related words and are then found to falsely “recognise” other semantically related words not actually presented. Clancy et al. compared women with recovered memories of childhood sexual abuse with women who believed they had been sexually abused but could not recall the abuse, women who had always remem-

bered being abused, and female controls. Women reporting recovered memories showed higher levels of false recognition than any other group (see Figure 6.18), suggesting that these women might be susceptible to developing false memories.

Lief and Fetkewicz (1995) found that 80% of adult patients who admitted reporting false recovered memories had therapists who made direct suggestions that they had been the victims of childhood sexual abuse. This suggests that recovered memories recalled *inside* therapy may be more likely to be false than those recalled *outside* therapy (see box).

### Motivated forgetting

Freud, in his repression theory, focused on some aspects of motivated forgetting. However, his approach was rather narrow, with its emphasis on repression of traumatic and other distressing memories and his failure to consider the cognitive processes involved. In recent years, a broader approach to motivated forgetting has been adopted.

Motivated forgetting of traumatic or other upsetting memories could clearly fulfil a useful

### Memories of abuse recovered inside and outside therapy

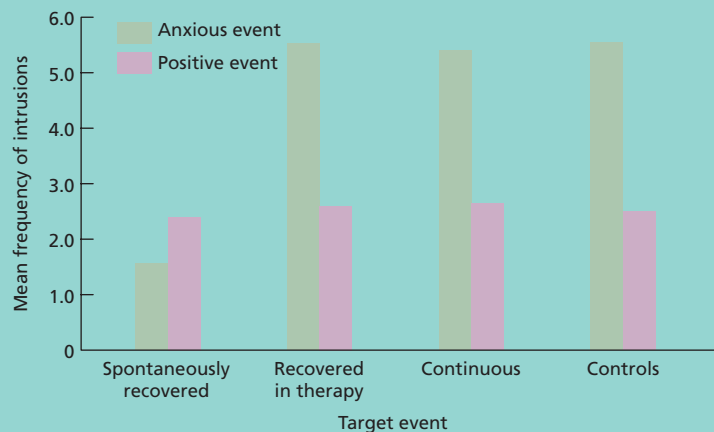
Geraerts, Schooler, Merckelbach, Jelicic, Haner, and Ambadar (2007) carried out an important study to test whether the genuineness of recovered memories depends on the context in which they were recovered. They divided adults who had suffered childhood sexual abuse into three groups: (1) those whose recovered memories had been recalled inside therapy; (2) those whose recovered memories had been recalled outside therapy; and (3) those who had continuous memories. Geraerts et al. discovered how many of these memories had corroborating evidence (e.g., someone else had also reported being abused by the same person; the perpetrator had confessed) to provide an approximate assessment of validity.

What did Geraerts et al. (2007) find? There was corroborating evidence for 45% of the individuals in the continuous memory group, for 37% of those who had recalled memories outside therapy, and for 0% of those who had recalled memories inside therapy. These findings suggest that recovered memories recalled outside therapy are much more likely to be genuine than those recalled inside therapy. In addition, those individuals whose memories were recalled outside therapy reported being much more surprised at

the existence of these memories than did those whose memories were recalled inside therapy. Presumably those whose recovered memories emerged inside therapy were unsurprised at these memories because they had previously been led to expect them by their therapist.

Geraerts et al. (2008) asked various groups of adults who claimed memories of childhood sexual abuse to recall the most positive and the most anxiety-provoking event they had experienced during the past two years. The participants were then told to try to suppress thoughts relating to these events, and to keep a diary record of any such thoughts over the following week. Adults who had recovered memories outside therapy were much better at this than control participants, those who had recovered memories inside therapy, and those who had continuous memories.

In sum, it appears that many of the traumatic memories recovered by women outside therapy are genuine. The finding that such women are especially good at suppressing emotional memories under laboratory conditions helps to explain why they were unaware of their traumatic memories for long periods of time prior to recovery.



**Figure 6.19** Mean numbers of intrusions of anxious and positive events over seven days for patients who had recovered traumatic memories outside therapy (spontaneously recovered), inside therapy (recovered in therapy), or who had had continuous traumatic memories (continuous), and non-traumatized controls. Based on data in Geraerts et al. (2008).

function. In addition, much of the information we have stored in long-term memory is outdated or irrelevant, making it useless for present purposes. For example, if you are looking for your car in a car park, there is no point in remembering where you have parked the car previously. Thus, motivated or intentional forgetting can be adaptive (e.g., by reducing proactive interference).

### Directed forgetting

**Directed forgetting** is a phenomenon involving impaired long-term memory caused by an instruction to forget some information presented for learning (see Geraerts & McNally, 2008, for a review). Directed forgetting has been studied in two ways. First, there is the item method. Several words are presented, each followed immediately by an instruction to remember or to forget it. After all the words have been presented, participants are tested for their recall or recognition of *all* the words. Memory performance on recall and recognition tests is typically worse for the to-be-forgotten words than for the to-be-remembered words.

Second, there is the list method. Here, participants receive two lists of words. After the first list has been presented, participants are told to remember or forget the words. Then the second list is presented. After that, memory is tested for the words from both lists. Recall of the words from the first list is typically impaired when participants have been told to forget those words compared to when they have been told to remember them. However, there is typically no effect when a recognition memory test is used.

*Why* does directed forgetting occur? Directed forgetting with the item method is found with both recall and recognition, suggesting that the forget instruction has its effects during learning. For example, it has often been suggested that participants may selectively rehearse remember items at the expense of forget items (Geraerts & McNally, 2008). This explanation is less applicable to the list method, because participants have had a substantial opportunity to rehearse the to-be-forgotten list

items before being instructed to forget them. The finding that directed forgetting with the list method is not found in recognition memory suggests that directed forgetting in recall involves retrieval inhibition or interference (Geraerts & McNally, 2008).

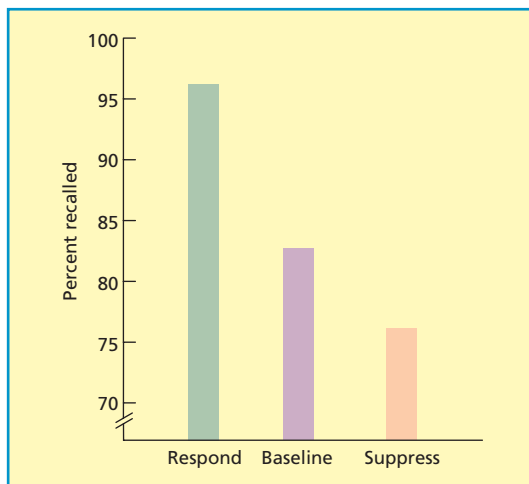
### Inhibition: executive deficit hypothesis

A limitation with much of the research is that the precise reasons *why* directed forgetting has occurred are unclear. For example, consider directed forgetting in the item-method paradigm. This could occur because to-be-forgotten items receive much less rehearsal than to-be-remembered items. However, it could also occur because of an active process designed to inhibit the storage of words in long-term memory. Wylie, Foxe, and Taylor (2007) used fMRI with the item-method paradigm to test these rival hypotheses. In crude terms, we might expect *less* brain activity for to-be-forgotten items than to-be-remembered ones if the former simply attract less processing. In contrast, we might expect *more* brain activity for to-be-forgotten items if active processes are involved. In fact, intentional forgetting when compared with intentional remembering was associated with *increased* activity in several areas (e.g., medial frontal gyrus (BA10) and cingulate gyrus (BA31)) known to be involved in executive control.

Anderson and Green (2001) developed a variant of the item method known as the think/no-think paradigm. Participants first learn a list of cue-target word pairs (e.g., Ordeal–Roach). Then they are presented with cues studied earlier (e.g., Ordeal) and instructed to think of the associated word (Roach) (respond condition) or to prevent it coming to mind (suppress condition). Some of the cues were not presented at this stage (baseline condition).

### KEY TERM

**directed forgetting:** impaired long-term memory resulting from the instruction to forget information presented for learning.



**Figure 6.20** Meta-analysis of final recall performance in the think/no-think procedure as a function of whether participants had earlier tried to recall the item (respond), suppress the item (suppress), or had had no previous reminder (baseline). Reprinted from Levy and Anderson (2008), Copyright © 2008, with permission from Elsevier.

Finally, all the cues are presented and participants provide the correct target words. Levy and Anderson (2008) carried out a meta-analysis of studies using the think/no-think paradigm. There was clear evidence of directed forgetting (see Figure 6.20). The additional finding that recall was worse in the suppress condition than in the baseline condition indicates that inhibitory processes were involved in producing directed forgetting in this paradigm.

What strategies do participants use in the suppress condition? They report using numerous strategies, including forming mental images, thinking of an alternative word or thought, or repeating the cue word (Levy & Anderson, 2008). Bergstrom, de Fockert, and Richardson-Klavehn (2009) manipulated the strategy used. Direct suppression of the to-be-forgotten words was more effective than producing alternative thoughts.

Anderson et al. (2004) focused on individual differences in memory performance using the think/no-think paradigm. Their study was designed to test the executive deficit hypothesis, according to which the ability to

suppress memories depends on individual differences in executive control abilities. Recall for word pairs was worse in the suppress condition than in the respond and baseline conditions. Of special importance, those individuals having the greatest activation in bilateral dorsolateral and ventrolateral prefrontal cortex were most successful at memory inhibition. Memory inhibition was also associated with reduced hippocampal activation – this is revealing because the hippocampus plays a key role in episodic memory (see Chapter 7). These findings suggest that successful intentional forgetting involves an executive control process in the prefrontal cortex that disengages hippocampal processing.

Additional support for the executive deficit hypothesis was reported by Bell and Anderson (in preparation). They compared individuals high and low in working memory capacity (see Chapter 10), a dimension of individual differences strongly related to executive control and intelligence. As predicted, memory suppression in the think/no-think paradigm was significantly greater in the high capacity group.

Is research using the think/no-think paradigm relevant to repression? There are encouraging signs that it is. First, Depue, Banich, and Curran (2006, 2007) had participants learn to pair unfamiliar faces with unpleasant photographs (e.g., a badly deformed infant; a car accident) using the paradigm. The findings were very similar to those of Anderson et al. (2004). There was clear evidence for suppression of unwanted memories and suppression was associated with increased activation of the lateral prefrontal cortex and reduced hippocampal activity. Second, Anderson and Kuhl (in preparation) found that individuals who had experienced several traumatic events showed superior memory inhibition abilities than those who had experienced few or none. This suggests that the ability to inhibit or suppress memories improves with practice.

### Evaluation

Directed forgetting is an important phenomenon. The hypothesis that it involves executive

control processes within the frontal lobes has received much empirical support. The extension of this hypothesis to account for individual differences in directed forgetting has also been well supported. In addition, the notion that research on directed forgetting may be of genuine relevance to an understanding of repression is important. A major implication of directed forgetting research is that suppression or repression occurs because of deliberate attempts to control awareness rather than occurring unconsciously and automatically, as suggested by Freud.

Directed forgetting is clearly one way in which forgetting occurs. However, most forgetting occurs in spite of our best efforts to remember, and so the directed forgetting approach is not of general applicability. The suppression effect in the think/no-think paradigm (baseline-suppression conditions) averages out at only 6% (see Figure 6.20), suggesting it is rather weak. However, participants spent an average of only 64 seconds trying to suppress each item, which is presumably massively less than the amount of time many individuals devote to suppressing traumatic memories. Most research on directed forgetting has used neutral and artificial learning materials, and this limits our ability to relate the findings to Freud's ideas about repression.

### Cue-dependent forgetting

Forgetting often occurs because we lack the appropriate cues (cue-dependent forgetting). For example, suppose you are struggling to think of the name of the street on which a friend of yours lives. If someone gave you a short list of possible street names, you might have no difficulty in recognising the correct one.

Tulving and Psotka (1971) showed the importance of cues. They presented between one and six word lists, with four words in six different categories in each list. After each list, participants free recalled as many words as possible (original learning). After all the lists had been presented, participants free recalled the words from all the lists (total free recall). Finally, all the category names were presented

and the participants tried again to recall all the words from all the lists (free cued recall).

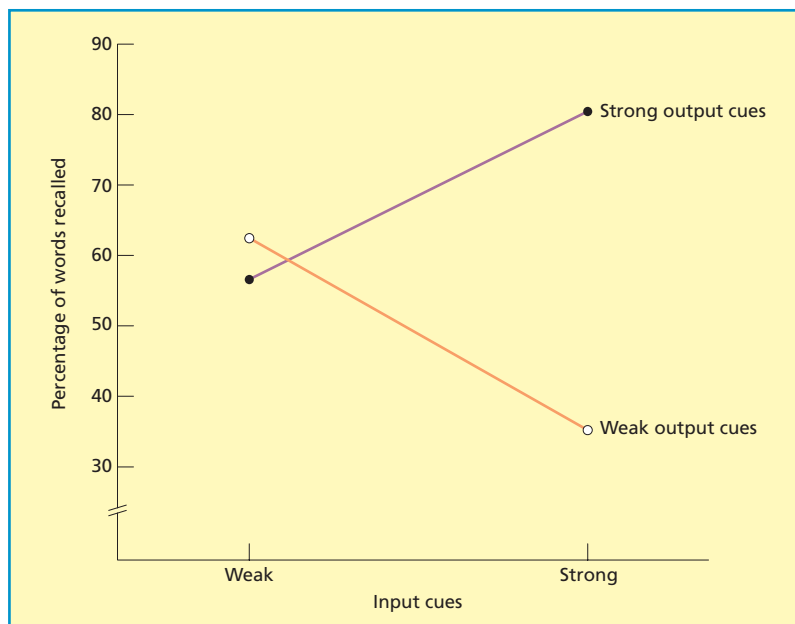
There was strong evidence for retroactive interference in total free recall, since word recall from any given list decreased as the number of other lists intervening between learning and recall increased. However, there was essentially *no* retroactive interference or forgetting when the category names were available to the participants. Thus, the forgetting observed in total free recall was basically cue-dependent forgetting (due to a lack of appropriate cues).

Tulving (1979) developed the notion of cue-dependent forgetting in his **encoding specificity principle**: “The probability of successful retrieval of the target item is a monotonically increasing function of *informational overlap* between the information present at retrieval and the information stored in memory” (p. 408; emphasis added). If you are bewildered by that sentence, note that “monotonically increasing function” refers to a generally rising function that does not decrease at any point. Tulving also assumed that the memory trace for an item generally consists of the item itself plus information about context (e.g., the setting; current mood state). It follows that memory performance should be best when the context at test is the same as that at the time of learning.

The encoding specificity principle resembles the notion of transfer-appropriate processing (Morris et al., 1977; see earlier in chapter). The central idea behind transfer-appropriate processing is that long-term memory is best when the processing performed at the time of test closely resembles that at the time of learning. The main difference between these two notions is that transfer-appropriate processing focuses more directly on the processes involved.

### KEY TERM

**encoding specificity principle:** the notion that retrieval depends on the overlap between the information available at retrieval and the information in the memory trace.



**Figure 6.21** Mean word recall as a function of input cues (strong or weak) and output cues (strong or weak). Data from Thomson and Tulving (1970).

### Evidence

Many attempts to test the encoding specificity principle involve two learning conditions and two retrieval conditions. This allows the researcher to show that memory depends on the information in the memory trace *and* the information available in the retrieval environment. Thomson and Tulving (1970) presented pairs of words in which the first was the cue and the second was the to-be-remembered word. The cues were weakly associated with the list words (e.g., “Train–BLACK”) or strongly associated (e.g., “White–BLACK”). Some of the to-be-remembered items were tested by weak cues (e.g., “Train–?”), and others were tested by strong cues (e.g., “White–?”).

Thomson and Tulving’s (1970) findings are shown in Figure 6.21. As predicted, recall performance was best when the cues provided at recall *matched* those provided at learning. Any change in the cues reduced recall, even when the shift was from weak cues at input to strong cues at recall. Why were strong cues associated with relatively poor memory performance when learning had involved weak cues? Tulving assumed that participants found it easy to gen-

erate the to-be-remembered words to strong cues, but failed to recognise them as appropriate. However, that is not the whole story. Higham and Tam (2006) found that participants given strong cues at test after weak cues at learning found it harder to generate the target words than other participants given strong cues at test who had not previously engaged in any learning! This happened because participants given weak cues at learning had formed a mental set to generate mainly weak associates to cues.

Context is important in determining forgetting. For example, information about current mood state is often stored in the memory trace, and there is more forgetting if the mood state at the time of retrieval is different. The notion that there should be less forgetting when the mood state at learning and retrieval is the same is known as mood-state-dependent memory. There is reasonable evidence for mood-state-dependent memory (see Chapter 15). However, the effect is stronger when participants are in a positive rather than negative mood because they are motivated to alter negative moods.



Mood-state dependent memory refers to the enhanced ease in recalling events that have an emotional tone similar to our current mood. If we're feeling happy and content, we are more likely to recall pleasant memories; when depressed we are likely to retrieve unpleasant ones.

Other kinds of context are also important. Marian and Neisser (2000) studied the effects of linguistic context. Russian–English bilinguals recalled personal memories when prompted with cues presented in the Russian or English language. The participants generated Russian memories (based on experiences in a Russian-speaking context) to 64% of the cues in Russian compared to only 35% when the cues were in English.

The effects of context are often stronger in recall than recognition memory. Godden and Baddeley (1975) asked participants to learn a list of words on land or 20 feet underwater, followed by a test of free recall on land or under water. Those who had learned on land recalled more on land and those who learned underwater did better when tested underwater. Overall, recall was about 50% higher when learning and recall took place in the same environment. However, there was no effect of context when Godden and Baddeley (1980) repeated the experiment using recognition memory rather than recall.

We all know that recognition is generally better than recall. For example, we may be unable to recall the name of an acquaintance but if someone mentions their name we in-

stantly recognise it. One of the most dramatic predictions from the encoding specificity principle is that recall should sometimes be better than recognition. This should happen when the information in the recall cue overlaps more than the information in the recognition cue with the information stored in the memory trace. Muter (1978) presented participants with people's names (e.g., DOYLE, THOMAS) and asked them to circle those they "recognised as a person who was famous before 1950". They were then given recall cues in the form of brief descriptions plus first names of the famous people whose surnames had appeared on the recognition test (e.g., author of the Sherlock Holmes stories: Sir Arthur Conan \_\_\_\_; Welsh poet: Dylan \_\_\_\_). Participants recognised only 29% of the names but recalled 42% of them.

Brain-imaging evidence supporting the encoding specificity principle and transfer-appropriate processing was reported by Park and Rugg (2008a). Participants were presented with pictures and words and then on a subsequent recognition test each item was tested with a congruent cue (word–word and picture–picture conditions) or an incongruent cue (word–picture and picture–word conditions). As predicted by the encoding specificity principle, memory performance was better in the congruent than in the incongruent conditions.

Park and Rugg (2008) carried out a further analysis based on brain activity at learning for items subsequently recognised. According to transfer-appropriate processing, it is more important for successful recognition for words to be processed at learning in a "word-like" way if they are tested by picture cues than by word cues. In similar fashion, successful recognition of pictures should depend more on "picture-like" processing at study if they are tested by pictures cues than by word cues. Both predictions were supported, suggesting that long-term memory is best when the processing at the time of learning is similar to that at the time of retrieval.

Rugg, Johnson, Park, and Uncapher (2008) reported similar findings supporting transfer-



appropriate processing. However, they pointed out that the similarity in patterns of brain activation at learning and retrieval was never very great. This probably happened because only some of the processing at the time of learning directly influenced what information was stored. In addition, only some of the processing at retrieval directly determined what was retrieved.

### Evaluation

The overlap between the information stored in the memory trace and that available at the time of retrieval often plays an important role in determining whether retrieval occurs. Recent neuroimaging evidence supports both the encoding specificity principle and transfer-appropriate processing. The emphasis placed on the role of contextual information in retrieval is also valuable. As we have seen, several different kinds of context (e.g., external cues; internal mood states; linguistic context) influence memory performance.

What are the limitations of Tulving's approach? First, it is most directly applicable to relatively simple memory tasks. Tulving assumed that the information at the time of test is compared in a simple and direct way with the information stored in memory to assess informational overlap. That is probably often the case, as when we effortlessly recall autobiographical memories when in the same place as the original event (Berntsen & Hall, 2004). However, if you tried to answer the question, "What did you do six days ago?", you would probably use complex problem-solving strategies not included within the encoding specificity principle.

Second, the encoding specificity principle is based on the assumption that retrieval occurs fairly automatically. However, that is not always the case. Herron and Wilding (2006) found that active processes can be involved in retrieval. People found it easier to recollect episodic memories relating to when and where an event occurred when they adopted the appropriate mental set or frame of mind beforehand. Adopting this mental set was associated

with increased brain activity in the right frontal cortex.

Third, there is a danger of circularity (Eysenck, 1978). Memory is said to depend on "informational overlap", but this is rarely measured. It is tempting to infer the amount of informational overlap from the level of memory performance, which is circular reasoning.

Fourth, as Eysenck (1979) pointed out, what matters is not only the informational overlap between retrieval information and stored information but also the extent to which retrieval information allows us to *discriminate* the correct responses from the incorrect ones. Consider the following thought experiment (Nairne, 2002b). Participants read aloud the following list of words: write, right, rite, rite, write, right. They are then asked to recall the word in the third serial position. We increase the informational overlap for some participants by providing them with the sound of the item in the third position. This increased informational overlap is totally unhelpful because it does not allow participants to discriminate the correct spelling of the sound from the wrong ones.

Fifth, Tulving assumed that context influences recall and recognition in the same way. However, the effects of context are often greater on recall than on recognition memory (e.g., Godden & Baddeley, 1975, 1980).

### Consolidation

None of the theories considered so far provides a wholly convincing account of forgetting over time. They identify factors causing forgetting, but do not indicate clearly why forgetting is greater shortly after learning than later on. Wixted (2004a, 2005) argued that the secret of forgetting may lie in consolidation theory. **Consolidation** is a process lasting for a long

#### KEY TERM

**consolidation:** a process lasting several hours or more which fixes information in **long-term memory**.

time (possibly years) that fixes information in long-term memory. More specifically, it is assumed that the hippocampus plays a vital role in the consolidation of memories (especially episodic memories for specific events and episodes), with many memories being stored ultimately in various parts of the neocortex, including the temporal lobes. A key assumption is that recently formed memories still being consolidated are especially vulnerable to interference and forgetting. Thus, “New memories are clear but fragile and old ones are faded but robust” (Wixted, 2004a, p. 265).

According to some versions of consolidation theory (e.g., Eichenbaum, 2001), the process of consolidation involves two major phases. The first phase occurs over a period of hours and centres on the hippocampus. The second phase takes place over a period of time ranging from days to years and involves interactions between the hippocampal region, adjacent entorhinal cortex and the neocortex. This second phase only applies to episodic memories and semantic memories (stored knowledge about the world). It is assumed that such memories are stored in the lateral neocortex of the temporal and other lobes.

Consolidation theory is relevant to two of the oldest laws of forgetting (Wixted, 2004b). First, there is Jost’s (1897) law (mentioned earlier), according to which the older of two memories of the same strength will decay slower. According to the theory, the explanation is that the older memory has undergone more consolidation and so is less vulnerable. Second, there is Ribot’s (1882) law, according to which the adverse effects of brain injury on memory are greater on newly formed memories than older ones. This is temporally graded retrograde amnesia. It can be explained on the basis that newly formed memories are most vulnerable to disruption because they are at an early stage of consolidation.

### Evidence

Several lines of evidence support consolidation theory. First, consider the form of the forgetting

curve. A decreasing rate of forgetting over time since learning follows from the notion that recent memories are vulnerable due to an ongoing process of consolidation. Consolidation theory also provides an explanation of Jost’s law.

Second, there is research on Ribot’s law, which claims that brain damage adversely affects recently-formed memories more than older ones. Such research focuses on patients with **retrograde amnesia**, which involves impaired memory for events occurring before the onset of the amnesia. Many of these patients have suffered damage to the hippocampus as the result of an accident, and this may have a permanently adverse effect on consolidation processes. As predicted by consolidation theory, numerous patients with retrograde amnesia show greatest forgetting for those memories formed very shortly before the onset of amnesia (Manns, Hopkins, & Squire, 2003). However, retrograde amnesia can in extreme cases extend for periods of up to 40 years (Cipolotti et al., 2001).

Third, consolidation theory predicts that newly-formed memories are more susceptible to retroactive interference than are older memories. On the face of it, the evidence is inconsistent. The amount of retroactive interference generally does not depend on whether the interfering material is presented early or late in the retention interval (see Wixted, 2005, for a review). However, the great majority of studies have only considered specific retroactive interference (i.e., two responses associated with the same stimulus). Consolidation theory actually claims that newly-formed memories are more susceptible to interference from *any* subsequent learning. When the interfering material is dissimilar, there is often more retroactive interference when it is presented early in the retention interval (Wixted, 2004a).

### KEY TERM

**retrograde amnesia:** impaired memory for events occurring before the onset of amnesia.

Fourth, consider the effects of alcohol on memory. People who drink excessive amounts of alcohol sometimes suffer from “blackout”, an almost total loss of memory for all events occurring while they were conscious but very drunk. These blackouts probably indicate a failure to consolidate memories formed while intoxicated. An interesting (and somewhat surprising) finding is that memories formed shortly *before* alcohol consumption are often better remembered than those formed by individuals who do not subsequently drink alcohol (Bruce & Pihl, 1997). Alcohol probably prevents the formation of new memories that would interfere with the consolidation process of the memories formed just before alcohol consumption. Thus, alcohol protects previously formed memories from disruption.

Fifth, Haist, Gore, and Mao (2001) obtained support for the assumption that consolidation consists of two phases. Participants identified faces of people famous in the 1980s or 1990s. Selective activation of the hippocampus for famous faces relative to non-famous ones was only found for those famous in the 1990s. In contrast (and also as predicted), there was greater activation in the entorhinal cortex connected to widespread cortical areas for famous faces from the 1980s than from the 1990s.

### Evaluation

Consolidation theory has various successes to its credit. First, it explains *why* the rate of

forgetting decreases over time. Second, consolidation theory successfully predicts that retrograde amnesia is greater for recently formed memories and that retroactive interference effects are greatest shortly after learning. Third, consolidation theory identifies the brain areas most associated with the two phases of consolidation.

What are the limitations of consolidation theory? First, we lack strong evidence that consolidation processes are responsible for all the effects attributed to them. For example, there are various possible reasons why newly formed memories are more easily disrupted than older ones. Second, consolidation theory indicates in a *general* way why newly formed memory traces are especially susceptible to interference effects, but not the more *specific* finding that retroactive interference is greatest when two different responses are associated with the same stimulus. Third, forgetting can involve several factors other than consolidation. For example, forgetting is greater when there is little informational overlap between the memory trace and the retrieval environment (i.e., encoding specificity principle), but this finding cannot be explained within consolidation theory. Fourth, consolidation theory ignores cognitive processes influencing forgetting. For example, as we have seen, the extent to which forgetting due to proactive interference occurs depends on individual differences in the ability to inhibit or suppress the interfering information.

## CHAPTER SUMMARY

- **Architecture of memory**  
According to the multi-store model, there are separate sensory, short-term, and long-term stores. Much evidence (e.g., from amnesic patients) provides general support for the model, but it is clearly oversimplified. According to the unitary-store model, short-term memory is the temporarily activated part of long-term memory. There is support for this model in the finding that amnesics’ performance on some “short-term memory” tasks is impaired. However, it is likely that long-term memory plays an important role in determining performance on such tasks.

- **Working memory**  
Baddeley replaced the unitary short-term store with a working memory system consisting of an attention-like central executive, a phonological loop holding speech-based information, and a visuo-spatial sketchpad specialised for spatial and visual coding. More recently, Baddeley has added a fourth component (episodic buffer) that integrates and holds information from various sources. The phonological loop and visuo-spatial sketchpad are both two-component systems, one for storage and one for processing. The central executive has various functions, including inhibition, shifting, updating, and dual-task co-ordination. Some brain-damaged patients are said to suffer from dysexecutive syndrome, but detailed analysis indicates that different brain regions are associated with the functions of task setting, monitoring, and energisation.
- **Levels of processing**  
 Craik and Lockhart (1972) focused on learning processes in their levels-of-processing theory. They identified depth of processing (the extent to which meaning is processed), elaboration of processing, and distinctiveness of processing as key determinants of long-term memory. Insufficient attention was paid to the relationship between processes at learning and those at retrieval. In addition, the theory isn't explanatory, it is hard to assess processing depth, and shallow processing can lead to very good long-term memory.
- **Implicit learning**  
 Much evidence supports the distinction between implicit and explicit learning, and amnesic patients often show intact implicit learning but impaired explicit learning. In addition, the brain areas activated during explicit learning (e.g., prefrontal cortex) differ from those activated during implicit learning (e.g., striatum). However, it has proved hard to show that claimed demonstrations of implicit learning satisfy the information and sensitivity criteria. It is likely that the distinction between implicit and explicit learning is oversimplified, and that more complex theoretical formulations are required.
- **Theories of forgetting**  
 Strong proactive and retroactive interference effects have been found inside and outside the laboratory. People use active control processes to minimise proactive interference. Much retroactive interference depends on automatic processes making the incorrect responses accessible. Most evidence on Freud's repression theory is based on adults claiming recovered memories of childhood abuse. Such memories when recalled outside therapy are more likely to be genuine than those recalled inside therapy. There is convincing evidence for directed forgetting, with executive control processes within the prefrontal cortex playing a major role. Forgetting is often cue-dependent, and the cues can be external or internal. However, decreased forgetting over time is hard to explain in cue-dependent terms. Consolidation theory provides an explanation for the form of the forgetting curve, and for reduced forgetting rates when learning is followed by alcohol.

**FURTHER READING**

- Baddeley, A.D. (2007). *Working memory: Thought and action*. Oxford: Oxford University Press. Alan Baddeley, who has made massive contributions to our understanding of working memory, has written an excellent overview of current knowledge in the area.
- Baddeley, A.D., Eysenck, M.W., & Anderson, M.C. (2009). *Memory*. Hove, UK: Psychology Press. Several chapters in this book provide additional coverage of the topics discussed in this chapter (especially forgetting).
- Jonides, J., Lewis, R.L., Nee, D.E., Lustig, C.A., Berman, M.G., & Moore, K.S. (2008). The mind and brain of short-term memory. *Annual Review of Psychology*, 59, 193–224. This chapter discusses short-term memory at length, and includes a discussion of the multi-store and unitary-store models.
- Repovš, G., & Baddeley, A. (2006). The multi-component model of working memory: Explorations in experimental cognitive psychology. *Neuroscience*, 139, 5–21. This article provides a very useful overview of the working memory model, including a discussion of some of the most important experiment findings.
- Roediger, H.L. (2008). Relativity of remembering: Why the laws of memory vanished. *Annual Review of Psychology*, 59, 225–254. This chapter shows very clearly that learning and memory are more complex and involve more factors than is generally assumed to be the case.
- Shanks, D.R. (2005). Implicit learning. In K. Lamberts & R. Goldstone (eds.), *Handbook of cognition*. London: Sage. David Shanks puts forward a strong case for being critical of most of the evidence allegedly demonstrating the existence of implicit learning.
- Wixted, J.T. (2004). The psychology and neuroscience of forgetting. *Annual Review of Psychology*, 55, 235–269. A convincing case is made that neuroscience has much to contribute to our understanding of forgetting.

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# CHAPTER

# 7

## LONG-TERM MEMORY SYSTEMS

### INTRODUCTION

We have an amazing variety of information stored in long-term memory. For example, long-term memory can contain details of our last summer holiday, the fact that Paris is the capital of France, information about how to ride a bicycle or play the piano, and so on. Much of this information is stored in the form of schemas or organised packets of knowledge, and is used extensively during language comprehension. The relationship between schematic knowledge and language comprehension is discussed in Chapter 10.

In view of the variety of information in long-term memory, Atkinson and Shiffrin's (1968) notion that there is a single long-term memory store seems improbable (see Chapter 6). As we will see, it is generally accepted that there are several major long-term memory systems. For example, Schacter and Tulving (1994) argued that there are four major long-term memory systems (episodic memory, semantic memory, the perceptual representation system, and procedural memory), and their approach will be discussed. However, there has been some controversy about the precise number and nature of long-term memory systems.

What do we mean by a memory system? According to Schacter and Tulving (1994) and Schacter, Wagner, and Buckner (2000), we can use three criteria to identify a memory system:

(1) *Class inclusion operations*: Any given memory system handles various kinds of

information within a given class or domain. For example, semantic memory is concerned with general knowledge of different kinds.

- (2) *Properties and relations*: The properties of a memory system, “include types of information that fall within its domain, rules by which the system operates, neural substrates, and functions of the system (what the system is ‘for’)” (Schacter et al., 2000, p. 629).
- (3) *Convergent dissociations*: Any given memory system should differ clearly in various ways from other memory systems.

### Amnesia

Convincing evidence that there are several long-term memory systems comes from the study of brain-damaged patients with amnesia. Such patients have problems with long-term memory, but if you are a movie fan you may have mistaken ideas about the nature of amnesia (Baxendale, 2004). In the movies, serious head injuries typically cause characters to forget the past while still being fully able to engage in new learning. In the real world, however, new learning is generally greatly impaired. In the movies, amnesic individuals often suffer a profound loss of identity or their personality changes completely. For example, consider the film *Overboard* (1987). In that film, Goldie Hawn falls from her yacht, and immediately switches from being a rich, spoilt socialite into a loving mother. Such personality shifts are extremely rare. Most bizarrely,

### The famous case HM

HM was the most-studied amnesic patient of all time. He suffered from very severe epilepsy starting at the age of ten. This eventually led to surgery by William Beecher Scoville, involving removal of the medial temporal lobes including the hippocampus. HM had his operation on 23 August 1953, and since then he “forgets the events of his daily life as fast as they occur” (Scoville & Milner, 1957). More dramatically, Corkin (1984, p. 255) reported many years after the operation that HM, “does not know where he lives, who cares for him, or where he ate his last meal... In 1982 he did not recognise a picture of himself that had been taken on his fortieth birthday in 1966.” When shown faces of individuals who had become famous after the onset of his amnesia, HM could only identify John Kennedy and Ronald Reagan. In spite of everything, HM still had a sense of humour. When Suzanne Corkin asked him how he tried to remember things, he replied, “Well, that I don’t know ‘cause I don’t remember [laugh] what I tried” (Corkin, 2002, p. 158).

It would be easy to imagine that all HM’s memory capacities were destroyed by surgery. In fact, what was most striking (and of greatest theoretical importance) was that he retained the ability to form many kinds of long-term memory as well as having good short-term mem-

ory (e.g., on immediate span tasks; Wickelgren, 1968). For example, HM showed reasonable learning on a mirror-tracing task (drawing objects seen only in reflection), and he retained some of this learning for one year (Corkin, 1968). He also showed learning on the pursuit rotor, which involves manual tracking of a moving target. HM showed normal performance on a perceptual identification task in which he had to identify words presented very briefly. He identified more words previously studied than words not previously studied, thus showing evidence for long-term memory.

Some reports indicated that his language skills were reasonably well preserved. However, Mackay, James, Taylor, and Marian (2007) reported that he was dramatically worse than healthy controls at language tasks such as detecting grammatical errors or answering questions about who did what to whom in sentences.

HM died on 2 December 2008 at the age of 82. He was known only as HM to protect his privacy, but after his death it was revealed that his real name was Henry Gustav Molaison.

Researchers have focused on the patterns of intact and impaired memory performance shown by HM and other amnesic patients. The theoretical insights they have produced will be considered in detail in this chapter.

the rule of thumb in the movies is that the best cure for amnesia caused by severe head injury is to suffer another massive blow to the head!

We turn now to the real world. Amnesic patients are sometimes said to suffer from the “amnesic syndrome” consisting of the following features:

- **Anterograde amnesia:** a marked impairment in the ability to remember new information learned after the onset of amnesia. HM is a famous example of anterograde amnesia (see box).
- **Retrograde amnesia:** problems in remembering events occurring prior to the onset of amnesia (see Chapter 6).

- Only slightly impaired short-term memory on measures such as digit span (the ability to repeat back a random string of digits).
- Some remaining learning ability after the onset of amnesia.

The reasons why patients have become amnesic are very varied. Bilateral stroke is one

#### KEY TERM

**anterograde amnesia:** reduced ability to remember information acquired after the onset of amnesia.



factor causing amnesia, but closed head injury is the most common cause. However, patients with closed head injury often have several cognitive impairments, which makes interpreting their memory deficit hard. As a result, most experimental work has focused on patients who became amnesic because of chronic alcohol abuse (Korsakoff's syndrome; see Glossary). There are two problems with using Korsakoff patients to study amnesia. First, the amnesia usually has a gradual onset, being caused by an increasing deficiency of the vitamin thiamine associated with chronic alcoholism. That makes it hard to know whether certain past events occurred before or after the onset of amnesia. Second, brain damage in Korsakoff patients is often rather widespread. Structures within the diencephalon (e.g., the hippocampus and the amygdala) are usually damaged. There is often damage to the frontal lobes, and this can produce various cognitive deficits not specific to the memory system. It would be easier to interpret findings from Korsakoff patients if the brain damage were more limited. Other cases of amnesia typically have damage to the hippocampus and adjacent areas in the medial temporal lobes. The brain areas associated with amnesia are discussed more fully towards the end of the chapter.

Why have amnesic patients contributed substantially to our understanding of human memory? The study of amnesia provides a good *test-bed* for existing theories of healthy memory. For example, strong evidence for the distinction between short- and long-term memory comes from studies on amnesic patients (see Chapter 6). Some patients have severely impaired long-term memory but intact short-term memory, whereas a few patients show the opposite pattern. The existence of these opposite patterns forms a double dissociation (see Glossary) and is good evidence for separate short- and long-term stores.

The study of amnesic patients has also proved very valuable in leading to various theoretical developments. For example, distinctions such as the one between declarative or explicit memory and non-declarative or implicit memory (discussed in the next section) were originally proposed in part because of data collected from

amnesic patients. Furthermore, such patients have provided some of the strongest evidence supporting these distinctions.

## Declarative vs. non-declarative memory

The most important distinction between different types of long-term memory is that between declarative memory and non-declarative memory. **Declarative memory** involves conscious recollection of events and facts – it refers to memories that can be “declared” or described. Declarative memory is sometimes referred to as **explicit memory**, defined as memory that “requires conscious recollection of previous experiences” (Graf & Schacter, 1985, p. 501).

In contrast, **non-declarative memory** does not involve conscious recollection. Typically, we obtain evidence of non-declarative memory by observing changes in behaviour. For example, consider someone learning how to ride a bicycle. We would expect their cycling performance (a form of behaviour) to improve over time even though they could not consciously recollect what they had learned about cycling. Non-declarative memory is also known as **implicit memory**, which involves enhanced performance in the absence of conscious recollection.

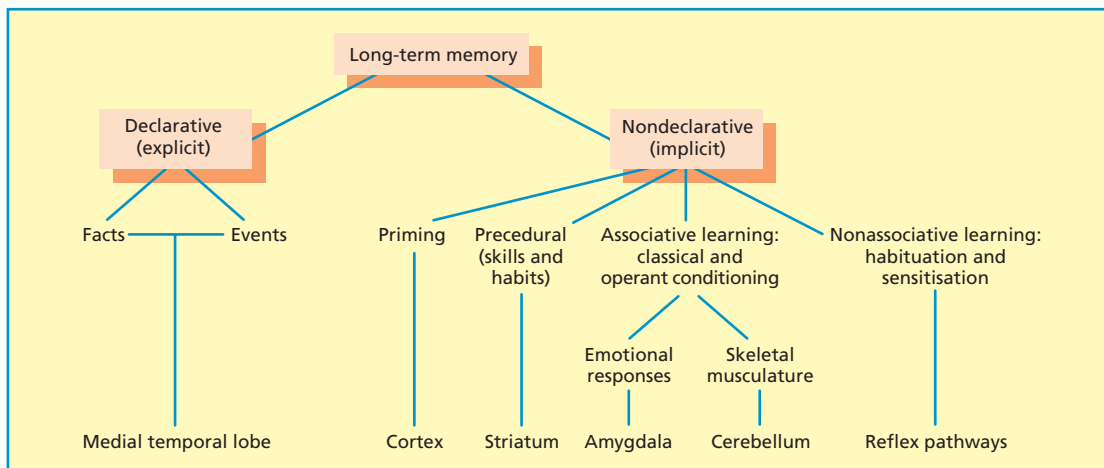
### KEY TERMS

**declarative memory:** a form of long-term memory that involves knowing that something is the case and generally involves conscious recollection; it includes memory for facts (**semantic memory**) and memory for events (**episodic memory**).

**explicit memory:** memory that involves conscious recollection of information; see **implicit memory**.

**non-declarative memory:** forms of long-term memory that influence behaviour but do not involve conscious recollection; **priming** and **procedural memory** are examples of non-declarative memory.

**implicit memory:** memory that does not depend on conscious recollection; see **explicit memory**.



**Figure 7.1** The main forms of long-term memory, all of which can be categorised as declarative (explicit) or nondeclarative (implicit). The brain regions associated with each form of long-term memory are also indicated. From Kandel, Kupferman, and Iverson (2000) with permission from McGraw Hill.

Declarative memory and non-declarative memory seem to be very different. Evidence for the distinction comes from amnesic patients. They seem to have great difficulties in forming declarative memories but their ability to form non-declarative memories is intact or nearly so. In the case of HM, he had extremely poor declarative memory for personal events occurring after the onset of amnesia and for faces of those who had become famous in recent decades (see Box on p. 252). However, he had reasonable learning ability on tasks such as mirror tracing, the pursuit rotor, and perceptual identification. What these otherwise different tasks have in common is that they all involve non-declarative memory. As we will see later in the chapter, the overwhelming majority of amnesic patients have very similar patterns of memory performance to HM.

Functional imaging evidence also supports the distinction between declarative and non-declarative memory. Schott, Richardson-Klavehn, Henson, Becker, Heinze, and Duzel (2006) found that brain activation during learning that predicted subsequent declarative memory performance occurred in the bilateral medial temporal lobe and the left prefrontal cortex. In contrast, brain activation predicting subsequent non-declarative memory performance occurred in the bilateral

extrastriate cortex, the left fusiform gyrus, and bilateral inferior prefrontal cortex, areas that are involved in stimulus identification.

Schott et al. (2005) found that different brain areas were associated with memory *retrieval* on declarative memory and non-declarative tasks. Declarative retrieval was associated with bilateral parietal and temporal and left frontal increases in activation, whereas non-declarative retrieval was associated with decreases in activation in the left fusiform gyrus and bilateral frontal and occipital regions. Thus, the brain areas associated with declarative memory and non-declarative memory are different both at the time of encoding or learning and at the time of retrieval. In addition, retrieval from declarative memory is generally associated with *increased* brain activation, whereas retrieval from non-declarative memory is associated with *decreased* brain activation.

For the rest of the chapter, we will discuss the various forms of declarative and non-declarative memory. Figure 7.1 provides a sketch map of the ground we are going to be covering.

## Declarative memory

We all have declarative or explicit memory for many different kinds of memories. For example,

we remember what we had for breakfast this morning or that “le petit déjeuner” is a French expression meaning “breakfast”. Tulving (1972) argued that these kinds of memories are very different, and he used the terms “episodic memory” and “semantic memory” to refer to the difference. **Episodic memory** involves storage (and retrieval) of specific events or episodes occurring in a given place at a given time. According to Wheeler, Stuss, and Tulving (1997, p. 333), the main distinguishing characteristic of episodic memory is, “its dependence on a special kind of awareness that all healthy human adults can identify. It is the type of awareness experienced when one thinks back to a specific moment in one’s personal past and consciously recollects some prior episode or state as it was previously experienced.”

In contrast, **semantic memory** “is the aspect of human memory that corresponds to general knowledge of objects, word meanings, facts and people, without connection to any particular time or place” (Patterson, Nestor, & Rogers, 2007, p. 976). Wheeler et al. (1997) shed further light on the distinction between semantic and episodic memory. They pointed out that semantic memory involves “knowing awareness” rather than the “self-knowing” associated with episodic memory.



Semantic memory goes beyond the meaning of words and extends to sensory attributes such as taste and colour; and to general knowledge of how society works, such as how to behave in a supermarket.

There are similarities between episodic and semantic memory. Suppose you remember meeting your friend yesterday afternoon at Starbucks. That clearly involves episodic memory, because you are remembering an event at a given time in a given place. However, semantic memory is also involved – some of what you remember depends on your general knowledge about coffee shops, what coffee tastes like, and so on.

Tulving (2002, p. 5) clarified the relationship between episodic and semantic memory: “Episodic memory... shares many features with semantic memory, out of which it grew,... but also possesses features that semantic memory does not.... Episodic memory is a recently evolved, late-developing, and early-deteriorating past-oriented memory system, more vulnerable than other memory systems to neuronal dysfunction.”

What is the relationship between episodic memory and autobiographical memory (discussed in Chapter 8)? They are similar in that both forms of memory are concerned with personal experiences from the past, and there is no clear-cut distinction between them. However, there are some differences. Much information in episodic memory is relatively trivial and is remembered for only a short period of time. In contrast, autobiographical memory stores information for long periods of time about events and experiences of some importance to the individual concerned.

## Non-declarative memory

A defining characteristic of non-declarative memory is that it is expressed by behaviour

### KEY TERMS

**episodic memory:** a form of long-term memory concerned with personal experiences or episodes that occurred in a given place at a specific time; see **semantic memory**.

**semantic memory:** a form of long-term memory consisting of general knowledge about the world, concepts, language, and so on; see **episodic memory**.

and does not involve conscious recollection. Schacter et al. (2000) identified two non-declarative memory systems: the perceptual representation system and procedural memory: the **perceptual representation system** “can be viewed as a collection of domain-specific modules that operate on perceptual information about the form and structure of words and objects” (p. 635). Of central importance within this system is **repetition priming** (often just called priming): stimulus processing occurs faster and/or more easily on the second and successive presentations of a stimulus. For example, we may *identify* a stimulus more rapidly the second time it is presented than the first time. What we have here is learning related to the *specific* stimuli used during learning. Schacter, Wig, and Stevens (2007, p. 171) provided a more technical definition: “Priming refers to an improvement or change in the identification, production, or classification of a stimulus as a result of a prior encounter with the same or a related stimulus.” The fact that repetition priming has been obtained in the visual, auditory, and touch modalities supports the notion that there is a perceptual representation system.

In contrast, **procedural memory** “refers to the learning of motor and cognitive skills, and is manifest across a wide range of situations. Learning to ride a bike and acquiring reading skills are examples of procedural memory” (Schacter et al., 2000, p. 636). The term “skill learning” has often been used to refer to what Schacter et al. defined as procedural memory. It is shown by learning that *generalises* to several stimuli other than those used during training. On the face of it, this seems quite different from the very specific learning associated with priming.

Reference back to Figure 7.1 will indicate that there are other forms of non-declarative memory: classical conditioning, operant conditioning, habituation, and sensitisation. We will refer to some of these types of memory later in the chapter as and when appropriate.

There is one final point. The distinction between declarative or explicit memory and non-declarative or implicit memory has been

highly influential and accounts for numerous findings on long-term memory. As you read through this chapter, you will see that some doubts have been raised about the distinction. Towards the end of this chapter, an alternative approach is discussed under the heading, “Beyond declarative and non-declarative memory: amnesia”. Much of that section focuses on research suggesting that the notion that amnesic patients have deficient declarative memory but intact non-declarative memory is oversimplified.

## EPISODIC VS. SEMANTIC MEMORY

If episodic and semantic memory form separate memory systems, there should be several important differences between them. We will consider three major areas of research here.

The first major area of research involves testing the ability of amnesic patients to acquire episodic and semantic memories after the onset of amnesia. In other words, the focus was on the extent of anterograde amnesia. Spiers, Maguire, and Burgess (2001) reviewed 147 cases of amnesia involving damage to the hippocampus or fornix. There was impairment of episodic memory in *all* cases, whereas many of the patients had only modest problems with semantic memory. Thus, the impact of brain damage was much greater on episodic than on semantic memory, suggesting that the two types of memory are distinctly different. Note that

### KEY TERMS

**perceptual representation system:** an implicit memory system thought to be involved in the faster processing of previously presented stimuli (e.g., **repetition priming**).

**repetition priming:** the finding that stimulus processing is faster and easier on the second and successive presentations.

**procedural memory/knowledge:** this is concerned with knowing how, and includes the ability to perform skilled actions; see **declarative memory**.

the memory problems of amnesic patients are limited to long-term memory. According to Spiers et al. (p. 359), “None of the cases was reported to have impaired short-term memory (typically tested using digit span – the immediate recall of verbally presented digits).”

We would have stronger evidence if we could find amnesic patients with very poor episodic memory but *intact* semantic memory. Such evidence was reported by Vargha-Khadem, Gadian, Watkins, Connelly, Van Paesschen, and Mishkin (1997). They studied three patients, two of whom had suffered bilateral hippocampal damage at an early age before they had had the opportunity to develop semantic memories. Beth suffered brain damage at birth, and Jon did so at the age of four. Jon suffered breathing problems which led to anoxia and caused his hippocampus to be less than half the normal size. Both of these patients had very poor episodic memory for the day’s activities, television programmes, and telephone conversations. In spite of this, Beth and Jon both attended ordinary schools, and their levels of speech and language development, literacy, and factual knowledge (e.g., vocabulary) were within the normal range.

Vargha-Khadem, Gadian, and Mishkin (2002) carried out a follow-up study on Jon at the age of 20. As a young adult, he had a high level of intelligence (IQ = 120), and his semantic memory continued to be markedly better than his episodic memory. Brandt, Gardiner, Vargha-Khadem, Baddeley, and Mishkin (2006) obtained evidence suggesting that Jon’s apparent recall of information from episodic memory actually involved the use of semantic memory. Thus, Jon’s episodic memory may be even worse than was previously assumed.

How can we explain the ability of Beth and Jon to develop fairly normal semantic memory in spite of their grossly deficient episodic memory? Vargha-Khadem et al. (1997) argued that episodic memory depends on the hippocampus, whereas semantic memory depends on the underlying entorhinal, perirhinal, and parahippocampal cortices. The brain damage suffered by Beth and Jon was centred on the hippocampus. Why do so many amnesics have

great problems with both episodic and semantic memory? The answer may be that they have damage to the hippocampus *and* to the underlying cortices. This makes sense given that the two areas are adjacent.

Some support for the above hypothesis was reported by Verfaellie, Koseff, and Alexander (2000). They studied a 40-year-old woman (PS), who, as an adult, suffered brain damage to the hippocampus but not the underlying cortices. In spite of her severe amnesia and greatly impaired episodic memory, she managed to acquire new semantic memories (e.g., identifying people who only became famous after the onset of her amnesia).

We have seen that some amnesic patients perform relatively better on tasks involving semantic memory than on those involving episodic memory. However, there is a potential problem of interpretation, because the opportunities for learning are generally greater with semantic memory (e.g., acquiring new vocabulary). Thus, one reason why these patients do especially poorly on episodic memory tasks may be because of the limited time available for learning.

The second main area of research involves amnesic patients suffering from retrograde amnesia (i.e., impaired memory for learning occurring before the onset of amnesia; see also Chapter 6). If episodic and semantic memory form different systems, we would expect to find some patients showing retrograde amnesia only for episodic or semantic memory. For example, consider KC, who suffered damage to several cortical and subcortical brain regions, including the medial temporal lobes. According to Tulving (2002, p. 13), “[KC’s] retrograde amnesia is highly asymmetrical: He cannot recollect any personally experienced events..., whereas his semantic knowledge acquired before the critical accident is still reasonably intact. His knowledge of mathematics, history, geography, and other ‘school subjects’, as well as his general knowledge of the world is not greatly different from others’ at his educational level.”

The opposite pattern was reported by Yasuda, Watanabe, and Ono (1997), who studied an amnesic patient with bilateral lesions to the

temporal lobe. She had very poor ability to remember public events, cultural items, historical figures, and some items of vocabulary from the time prior to the onset of amnesia. However, she was reasonably good at remembering personal experiences from episodic memory dating back to the pre-amnesia period.

Kapur (1999) reviewed studies on retrograde amnesia. There was clear evidence for a double dissociation: some patients showed more loss of episodic than semantic memory, whereas others showed the opposite pattern.

Which brain regions are involved in retrograde amnesia? The hippocampal complex of the medial temporal lobe (including the hippocampus proper, dentate gyrus, the perirhinal, entorhinal, and parahippocampal cortices) is of special importance. According to multiple trace theory (e.g., Moscovitch, Nadel, Winocur, Gilboa, & Rosenbaum, 2006), every time an episodic memory is retrieved, it is re-encoded. This leads to multiple episodic traces of events distributed widely throughout the hippocampal complex. Of key importance, it is assumed theoretically that detailed episodic or autobiographical memories of the past always depend on the hippocampus. Semantic memories initially depend heavily on the hippocampus, but increasingly depend on neocortex.

Multiple trace theory has received support from studies on healthy individuals as well as patients with retrograde amnesia. For example, Gilboa, Ramirez, Kohler, Westmacott, Black, and Moscovitch (2005) studied people's personal recollections of recent and very old events going back several decades. Activation of the hippocampus was associated with the vividness of their recollections rather than the age of those recollections.

There is reasonable support for predictions following from multiple trace theory. First, the severity of retrograde amnesia in episodic memory is fairly strongly related to the amount of damage to the hippocampal complex, although frontal areas are also often damaged (Moscovitch et al., 2006). Second, damage to the hippocampal complex generally has less effect on semantic memory than on episodic memory, with any

effects being limited to a period of about ten years. Third, damage to the neocortex impairs semantic memory. Westmacott, Black, Freedman, and Moscovitch (2004) studied retrograde amnesia in patients suffering from **Alzheimer's disease** (a progressive disease in which cognitive abilities including memory are gradually lost). The severity of retrograde amnesia for vocabulary and famous names in these patients increased with the progress of the disease. This suggests that the impairment in semantic memory was related to the extent of degeneration of neocortex.

The third main area of research involves functional neuroimaging. Studies in this area indicate that episodic and semantic memory involve activation of somewhat different parts of the brain. In a review, Wheeler et al. (1997) reported that the left prefrontal cortex was more active during episodic than semantic encoding. What about brain activation during retrieval? Wheeler et al. reported that the right prefrontal cortex was more active during episodic memory retrieval than during semantic memory retrieval in 25 out of 26 neuroimaging studies.

Further neuroimaging evidence was reported by Prince, Tsukiura, and Cabeza (2007). The left hippocampus was associated with episodic encoding but not with semantic memory retrieval, whereas the lateral temporal cortex was associated with semantic memory retrieval but not with episodic encoding. The greater involvement of the hippocampus with episodic than with semantic memory is consistent with the research on brain-damaged patients discussed above (Moscovitch et al., 2006). In addition, Prince et al. (2007) found within the left inferior prefrontal cortex that a posterior region was involved in semantic retrieval, a mid-region was associated with both semantic retrieval and episodic encoding, and a more anterior region was associated with episodic encoding only

## KEY TERM

**Alzheimer's disease:** a condition involving progressive loss of memory and mental abilities.

when semantic retrieval was also involved. These various findings suggested that, “episodic and semantic memory depend on different but closely interacting memory systems” (Prince et al., 2007, p. 150).

## Evaluation

There is convincing evidence for separate episodic and semantic memory systems. The relevant evidence is of various kinds, and includes studies of anterograde and retrograde amnesia as well as numerous neuroimaging studies.

It should be emphasised that the episodic and semantic memory systems typically *combine* in their functioning. For example, suppose you retrieve an episodic memory of having an enjoyable picnic in the countryside. To do this, you need to retrieve semantic information about the concepts (e.g., picnic; grass) contained in your episodic memory. We have just seen that Prince et al. (2007) found evidence that some of the same brain regions are associated with episodic and semantic memory. In similar fashion, Nyberg et al. (2003) found that four regions of prefrontal cortex were activated during episodic and semantic memory tasks: left fronto-polar cortex, left mid-ventrolateral prefrontal cortex, left mid-dorsolateral prefrontal cortex, and dorsal anterior cingulate cortex. Nyberg et al. also found that the same areas were activated

during various working-memory tasks, which raises the possibility that these regions of prefrontal cortex are involved in executive processing or cognitive control.

## EPISODIC MEMORY

As we saw in Chapter 6, most episodic memories exhibit substantial and progressive forgetting over time. However, there are some exceptions. For example, Bahrck, Bahrck, and Wittlinger (1975) made use of photographs from high-school yearbooks dating back many years. Ex-students showed remarkably little forgetting of information about their former classmates at retention intervals up to 25 years. Performance was 90% for recognising a name as being that of a classmate, for recognising a classmate’s photograph, and for matching a classmate’s name to his/her school photograph. Performance remained very high on the last two tests even at a retention interval of almost 50 years, but performance on the name recognition task declined.

Bahrck, Hall, and Da Costa (2008) asked American ex-college students to recall their academic grades. Distortions in recall occurred shortly after graduation but thereafter remained fairly constant over retention intervals up to 54 years. Perhaps not surprisingly, the great



Bahrck et al. (1975) found that adults were remarkably good at recognising the photographs of those with whom they had been at school almost so years later.

majority of distortions involved inflating the actual grade.

Bahrick (1984) used the term *permastore* to refer to very long-term stable memories. This term was based on *permafrost*, which is the permanently frozen subsoil found in polar regions. It seems probable that the contents of the *permastore* consist mainly of information that was very well-learned in the first place.

We turn now to a detailed consideration of how we can assess someone's episodic memory. Recognition and recall are the two main types of episodic memory test. The basic recognition-memory test involves presenting a series of items, with participants deciding whether each one was presented previously. As we will see, however, more complex forms of recognition-memory test have also been used. There are three basic forms of recall test: free recall, serial recall, and cued recall. Free recall involves producing to-be-remembered items in any order in the absence of any specific cues. Serial recall involves producing to-be-remembered items in the order in which they were presented originally. Cued recall involves producing to-be-remembered items in the presence of cues. For example, 'cat-table' might be presented at learning and the cue, 'cat-?' might be given at test.

## Recognition memory

Recognition memory can involve recollection or familiarity (e.g., Mandler, 1980). According to Diana, Yonelinas, and Ranganath (2007, p. 379), "Recollection is the process of recognising an item on the basis of the retrieval of specific contextual details, whereas familiarity is the process of recognising an item on the basis of its perceived memory strength but without retrieval of any specific details about the study episode."

We can clarify the distinction with the following anecdote. Several years ago, the first author walked past a man in Wimbledon, and was immediately confident that he recognised him. However, he simply could not think of the situation in which he had seen the man previously. After some thought (this is the kind

of thing academic psychologists think about!), he realised the man was a ticket-office clerk at Wimbledon railway station. Thus, initial recognition based on familiarity was replaced by recognition based on recollection.

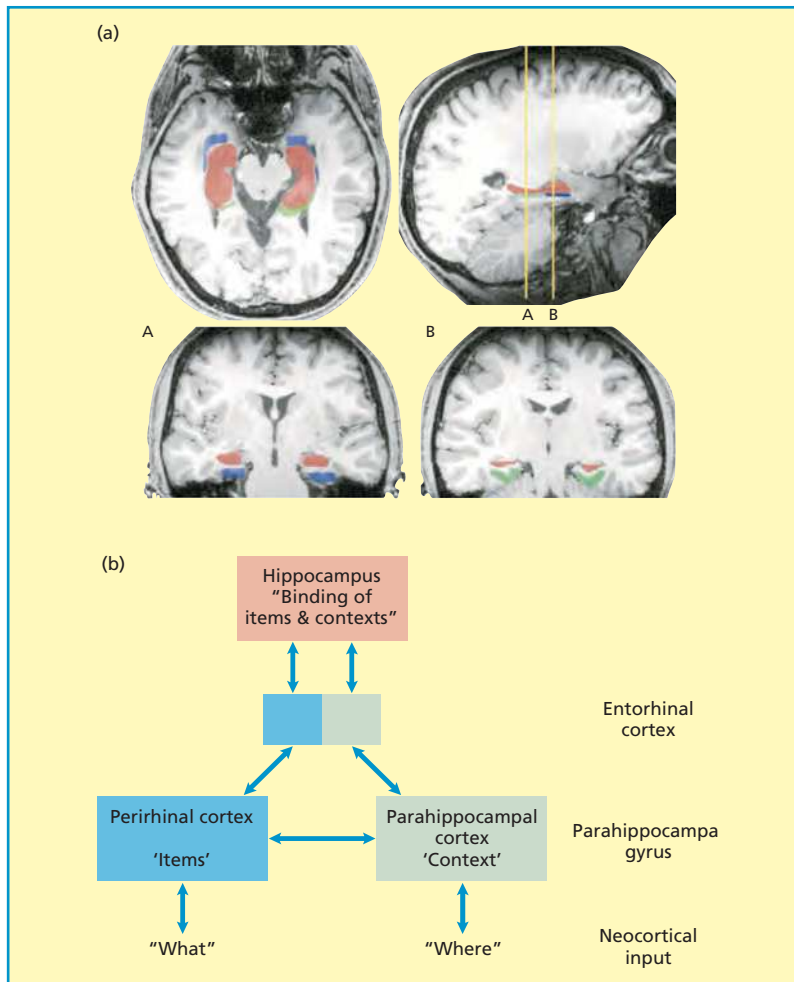
There are various ways of distinguishing between these two forms of recognition memory. Perhaps the simplest is the *remember/know* task, in which participants indicate subjectively whether their positive recognition decisions were based on recollection of contextual information (*remember* responses) or solely on familiarity (*know* responses). The crucial issue here is deciding whether recollection and familiarity involve different processes – sceptics might argue that the only real difference is that strong memory traces give rise to recollection judgements and weak memory traces give rise to familiarity judgements. Dunn (2008) is one such sceptic. He carried out a meta-analysis of 37 studies using the *remember-know* task, and found that the findings could be explained in terms of a single process based on memory strength. However, as we will see, there is much support for dual-process models.

We saw earlier that the medial temporal lobe and adjacent areas are of crucial importance in episodic memory. There is now reasonable support for a more precise account of the brain areas involved in recognition memory provided by the *binding-of-item-and-context* model (Diana et al., 2007) (see Figure 7.2):

- (1) Perirhinal cortex receives information about specific items ("what" information needed for familiarity judgements).
- (2) Parahippocampal cortex receives information about context ("where" information useful for recollection judgements).
- (3) The hippocampus receives what and where information (both of great importance to episodic memory), and binds them together to form item-context associations that permit recollection.

Functional neuroimaging studies provide support for the *binding-of-item-and-context* model. Diana et al. (2007) combined findings



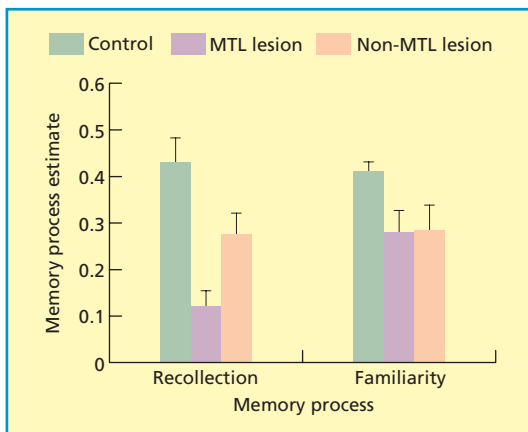


**Figure 7.2** (a) locations of the hippocampus (red), the perirhinal cortex (blue), and the parahippocampal cortex (green); (b) the binding-of-item-and-context model. Reprinted from Diana et al. (2007), Copyright © 2007, with permission from Elsevier.

from several studies of recognition memory that considered patterns of brain activation during encoding and retrieval (see Figure 7.2). As predicted, recollection was associated with more activation in parahippocampal cortex and the hippocampus than in the perirhinal cortex. In contrast, familiarity was associated with more activation in the perirhinal cortex than the parahippocampal cortex or hippocampus.

It is a reasonable prediction from the above model that amnesic patients (who nearly always have extensive hippocampal damage) should have greater problems with recognition based on recollection than recognition based on familiarity. Skinner and Fernandes (2007) carried

out a meta-analysis of recognition-memory studies involving amnesic patients with and without lesions in the medial temporal lobes (including the hippocampus). Of central interest was the memory performance of these two groups on measures of recollection and familiarity (see Figure 7.3). Both groups performed consistently worse than healthy controls. Most importantly, however, the patient group with medial temporal lobe lesions only had significantly worse performance than the other patient group with recollection and not with familiarity. This suggests that the hippocampus and adjacent regions are especially important in supporting recollection.



**Figure 7.3** Mean recollection and familiarity estimates for healthy controls, patients with medial temporal lobe (MTL) lesions, and patients with non-MTL lesions. Reprinted from Skinner and Fernandes (2007), Copyright © 2007, with permission from Elsevier.

### Recall memory

Some research on recall is discussed in Chapter 6. Here, we will focus on whether the processes involved in free recall are the same as those involved in recognition memory. In an important study, Staresina and Davachi (2006) used three memory tests: free recall, item recognition (familiarity), and associative recognition (recollection). Successful memory performance on all three tests was associated with increased activation in the left hippocampus and left ventrolateral prefrontal cortex at the time of encoding. This was most strongly the case with free recall and least strongly the case with item recognition. In addition, only successful subsequent free recall was associated with increased activation in the dorsolateral prefrontal cortex and posterior parietal cortex. The most likely explanation of this finding is that successful free recall involves forming associations (in this case between items and the colours in which they were studied), something that is not required for successful recognition memory.

What conclusions can we draw? First, the finding that similar brain areas are associated with successful free recall and recognition suggests that there are important similarities between the two types of memory test. Second,

successful free recall is associated with higher levels of brain activity in several areas at encoding and at retrieval than successful recognition memory. This suggests that free recall is in some sense more “difficult” than recognition memory. Third, Staresina and Davachi’s (2006) finding that some brain areas are associated with successful free recall but not recognition memory suggests that free recall involves processes additional to those involved in recognition memory. As indicated above, inter-item processing is the most obvious requirement specific to free recall.

### Is episodic memory constructive?

We use episodic memory to remember past events that have happened to us. You might imagine that our episodic memory system would work like a video recorder, providing us with accurate and detailed information about past events. That is *not* the case. As Schacter and Addis (2007, p. 773) pointed out, “Episodic memory is... a fundamentally constructive, rather than reproductive process that is prone to various kinds of errors and illusions.” Plentiful evidence for this constructive view of episodic memory is discussed in other chapters. In Chapter 8, we discuss research showing how the constructive nature of episodic memory leads eyewitnesses to produce distorted memories of what they have seen. In Chapter 10, we discuss the influential views of Bartlett (1932). His central assumption was that the knowledge we possess can produce systematic distortions and errors in our episodic memories, an assumption that has been supported by much subsequent research.

*Why* are we saddled with an episodic memory system that is so prone to error? Schacter and Addis (2007) identified three reasons. First, it would require an incredible amount of processing to produce a semi-permanent record of all our experiences. Second, we generally want to access the gist or essence of our past experiences; thus, we want our memories to be *discriminating* by omitting the trivial details. Third, imagining possible future events and scenarios is important

to us for various reasons (e.g., forming plans for the future). Perhaps the constructive processes involved in episodic memory are also used to imagine the future.

### Evidence

We typically remember the gist of what we have experienced previously, and our tendency to remember gist increases with age. Consider a study by Brainerd and Mojardin (1998). Children aged 6, 8, and 11 listened to sets of three sentences (e.g., “The coffee is hotter than the tea”; “The tea is hotter than the cocoa”; “The cocoa is hotter than the soup”). On the subsequent recognition test, participants decided whether the test sentences had been presented initially in precisely that form. The key condition was one in which sentences having the same meaning as original sentences were presented (e.g., “The cocoa is cooler than the tea”). False recognition on these sentences increased steadily with age.

We turn now to the hypothesis that imagining future events involves the same processes as those involved in remembering past events. On that hypothesis, individuals with very poor episodic memory (e.g., amnesic patients) should also have impaired ability to imagine future events. Hassabis, Kumaran, Vann, and Maguire (2007) asked amnesic patients and healthy controls to imagine future events (e.g., “Imagine you are lying on a white sandy beach in a beautiful tropical bay”). The amnesic patients produced imaginary experiences consisting of isolated fragments of information lacking the richness and spatial coherence of the experiences imagined by the controls.

Addis, Wong, and Schacter (2007) compared brain activity when individuals generated past and future events and then elaborated on them. There was considerable overlap in patterns of brain activity during the elaboration phase. The areas activated during elaboration of past and future events included the left anterior temporal cortex (associated with conceptual and semantic information about one’s life) and the left frontopolar cortex (associated with self-referential processing). There was some overlap

during the generation phase as well. However, there were higher levels of activity in several areas (e.g., the right frontopolar cortex; the left inferior frontal gyrus) during the generation of future than of past events. This suggests that more intensive constructive processes are required to imagine future events than to retrieve past events.

### Evaluation

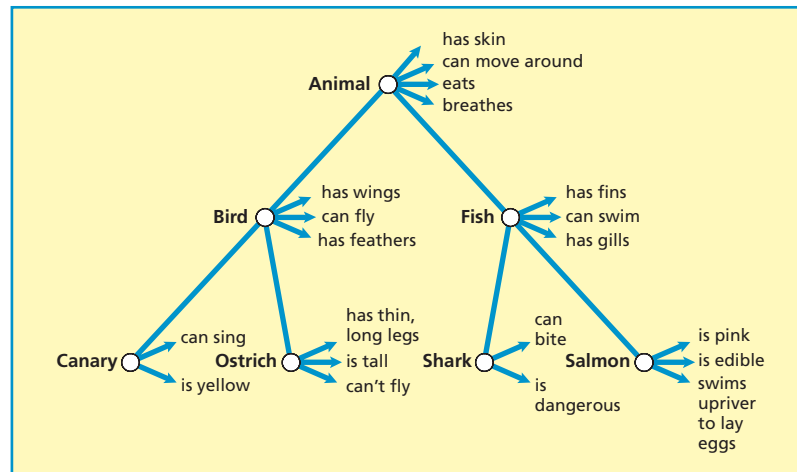
It has been assumed by many theorists, starting with Bartlett (1932), that episodic memory relies heavily on constructive processes, and there is convincing evidence to support that assumption (see Chapters 8 and 10). The further assumption by Schacter and Addis (2007) that the same constructive processes involved in episodic memory for past events are also involved in imagining the future is an exciting development. The initial findings from amnesic patients and functional neuroimaging studies are supportive. However, further research is needed to clarify the reasons why there are higher levels of brain activation when individuals imagine future events than when they recall past events.

## SEMANTIC MEMORY

Our organised general knowledge about the world is stored in semantic memory. The content of such knowledge can be extremely varied, including information about the French language, the rules of hockey, the names of capital cities, and the authors of famous books. How is information organised within semantic memory? Most is known about the organisation of **concepts**, which are mental representations of categories of objects or items. We will start by considering influential models focusing on the ways in which concepts are interconnected. After that, we will consider the storage of information about concepts within the brain.

### KEY TERM

**concepts:** mental representations of categories of objects or items.



**Figure 7.4** Collins and Quillian's (1969) hierarchical network.

## Network models

We can answer numerous simple questions about semantic memory very rapidly. For example, it takes about one second to decide a sparrow is a bird, or to think of a fruit starting with p. This great efficiency suggests that semantic memory is highly organised or structured.

The first systematic model of semantic memory was put forward by Collins and Quillian (1969). Their key assumption was that semantic memory is organised into hierarchical networks (see Figure 7.4). The major concepts (e.g., animal, bird, canary) are represented as nodes, and properties or features (e.g., has wings; is yellow) are associated with each concept. You may wonder why the property “can fly” is stored with the bird concept rather than with the canary concept. According to Collins and Quillian, those properties possessed by nearly all birds (e.g., can fly; has wings) are stored only at the bird node or concept. The underlying principle is one of cognitive economy: property information is stored as high up the hierarchy as possible to minimise the amount of information stored.

According to the model of Collins and Quillian (1969), it should be possible to decide very rapidly that the sentence, “A canary is yellow”, is true because the concept (i.e., “canary”) and the property (i.e., “is yellow”) are stored together at the same level of the

hierarchy. In contrast, the sentence, “A canary can fly”, should take longer because the concept and property are separated by one level in the hierarchy. The sentence, “A canary has skin”, should take even longer because two levels separate the concept and the property. As predicted, the time taken to respond to true sentences became progressively slower as the separation between the subject of the sentence and the property became greater.

The model is right in its claim that we often use semantic memory successfully by *inferring* the right answer. For example, the information that Leonardo da Vinci had knees is not stored directly in semantic memory. However, we know Leonardo da Vinci was a human being, and that human beings have knees, and so we confidently infer that Leonardo da Vinci had knees. This is the kind of inferential process proposed by Collins and Quillian (1969).

In spite of its successes, the model suffers from various problems. A sentence such as, “A canary is yellow”, differs from, “A canary has skin”, not only in the hierarchical distance between the concept and its property, but also in familiarity. Indeed, you have probably never encountered the sentence, “A canary has skin”, in your life before! Conrad (1972) found that hierarchical distance between the subject and the property had little effect on verification time when familiarity was controlled.



The typicality effect determines that it will take longer to decide that a penguin is a bird than that a canary is a bird. A penguin is an example of a relatively atypical member of the category to which it belongs, whereas the canary – being a more representative bird – can be verified more quickly.

There is another limitation. Consider the following statements: “A canary is a bird” and “A penguin is a bird”. On their theory, both statements should take the same length of time to verify, because they both involve moving one level in the hierarchy. In fact, however, it takes longer to decide that a penguin is a bird. Why is that so? The members of most categories vary considerably in terms of how typical or representative they are of the category to which they belong. For example, Rosch and Mervis (1975) found that oranges, apples, bananas, and peaches were rated as much more typical fruits than olives, tomatoes, coconuts, and dates. Rips, Shoben, and Smith (1973) found that verification times were faster for more typical or representative members of a category than for relatively atypical members (the **typicality effect**).

More typical members of a category possess more of the characteristics associated with that category than less typical ones. Rosch (1973) produced a series of sentences containing the word “bird”. Sample sentences were as follows: “Birds eat worms”; “I hear a bird singing”; “I watched a bird fly over the house”; and “The bird was perching on the twig”. Try replacing the word *bird* in each sentence in turn with *robin*, *eagle*, *ostrich*, and *penguin*. *Robin* fits all the sentences, but *eagle*, *ostrich*, and *penguin* fit progressively less well. Thus, penguins and

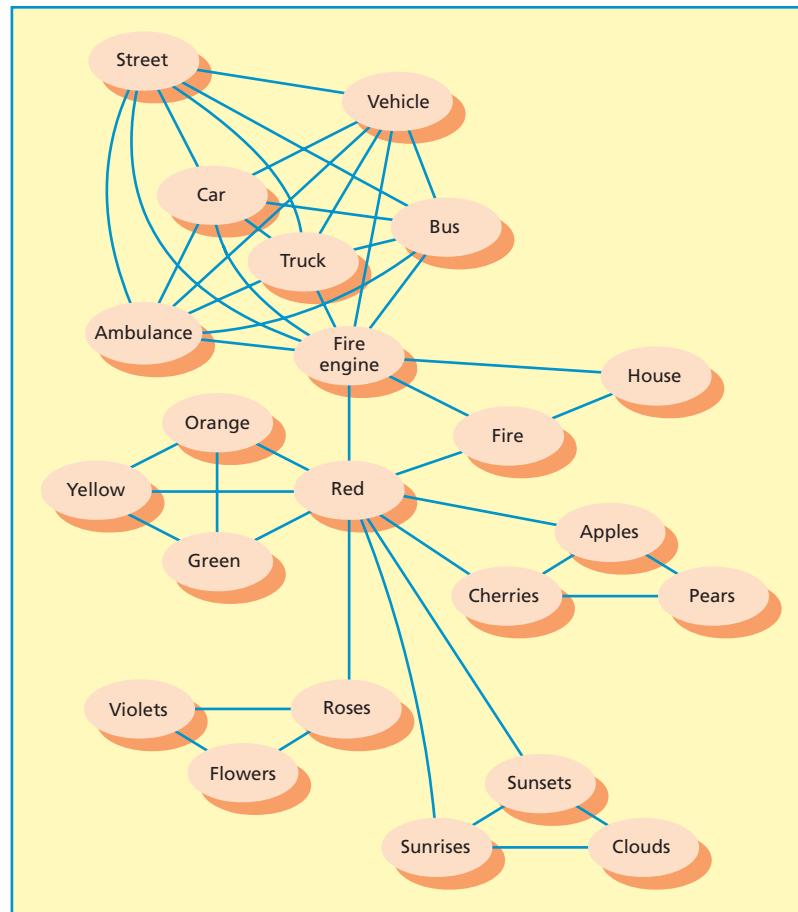
ostriches are less typical birds than eagles, which in turn are less typical than robins.

What does this tell us about the structure of semantic memory? It strongly implies that Collins and Quillian (1969) were mistaken in assuming that the concepts we use belong to rigidly defined categories. Convincing evidence that many concepts in semantic memory are fuzzy rather than neat and tidy was reported by McCloskey and Glucksberg (1978). They gave 30 people tricky questions such as, “Is a stroke a disease?” and “Is a pumpkin a fruit?” They found that 16 said a stroke is a disease, but 14 said it was not. A pumpkin was regarded as a fruit by 16 participants but not as a fruit by the remainder. More surprisingly, when McCloskey and Glucksberg tested the same participants a month later, 11 of them had changed their minds about “stroke” being a disease, and eight had altered their opinion about “pumpkin” being a fruit!

Collins and Loftus (1975) put forward a spreading activation theory. They argued that

### KEY TERM

**typicality effect:** the finding that objects can be identified faster as category members when they are typical or representative members of the category in question.



**Figure 7.5** Example of a spreading activation semantic network. From Collins and Loftus (1975). Copyright © 1975 American Psychological Association. Reproduced with permission.

the notion of logically organised hierarchies was too inflexible. They assumed instead that semantic memory is organised on the basis of semantic relatedness or semantic distance. Semantic relatedness can be measured by asking people to decide how closely related pairs of words are. Alternatively, people can list as many members as they can of a particular category. Those members produced most often are regarded as most closely related to the category.

You can see part of the organisation of semantic memory assumed by Collins and Loftus in Figure 7.5, with the length of the links between two concepts indicating their degree of semantic relatedness. Thus, for example, *red* is more closely related to *orange* than to *sunsets*.

According to spreading activation theory, whenever a person sees, hears, or thinks about a concept, the appropriate node in semantic memory is activated. This activation then spreads most strongly to other concepts closely related semantically, and more weakly to those more distant semantically. For example, activation would pass strongly and rapidly from “robin” to “bird” in the sentence, “A robin is a bird”, because “robin” and “bird” are closely related semantically. However, it would pass more weakly and slowly from “penguin” to “bird” in the sentence, “A penguin is a bird”. As a result, the model predicts the typicality effect.

Other predictions of the spreading activation model have been tested experimentally. For example, Meyer and Schvaneveldt (1976)

had participants decide as rapidly as possible whether a string of letters formed a word. In the key condition, a given word (e.g., “butter”) was immediately preceded by a semantically related word (e.g., “bread”) or by an unrelated word (e.g., “nurse”). According to the model, activation should have spread from the first word to the second only when they were semantically related and this activation should have made it easier to identify the second word. Thus, “butter” should have been identified as a word faster when preceded by “bread” than by “nurse”. Indeed, there was a facilitation (or semantic priming) effect for semantically related words.

McNamara (1992) used the same basic approach as Meyer and Schvaneveldt (1976). Suppose the first word was “red”. This was sometimes followed by a word one link away (e.g., “roses”), and sometimes by a word two links away (e.g., “flowers”). More activation should spread from the activated word to words one link away than those two links away, and so the facilitation effect should have been greater in the former case. That is what McNamara (1992) found.

Schacter, Alpert, Savage, Rauch, and Albert (1996) used the Deese–Roediger–McDermott paradigm described in Chapter 6. Participants received word lists constructed in a particular way. An initial word (e.g., “doctor”) was selected, and then several words closely associated with it (e.g., “nurse”, “sick”, “hospital”, “patient”) were selected. All these words (excluding the initial word) were presented for learning, followed by a test of recognition memory. When the initial word was presented on the recognition test, it should theoretically have been highly activated because it was so closely related to all the list words. Schacter et al. compared brain activation on the recognition test when participants falsely recognised the initial word and when they correctly recognised list words. The pattern and intensity of brain activation were very similar in both cases, indicating that there was substantial activation of the initial word, as predicted by the model.

The spreading activation model has generally proved more successful than the hierarchical

network model. An important reason is that it is a much more flexible approach. However, flexibility means that the model typically does not make very precise predictions. This makes it difficult to assess its overall adequacy.

## Organisation of concepts in the brain

It is often assumed (e.g., Bartlett, 1932; Bransford, 1979) that we have schemas (organised packets of knowledge) stored in semantic memory. For example, our schematic knowledge leads us to expect that most kitchens will have an oven, a refrigerator, a sink, cupboards, and so on. What is known about the organisation of schematic knowledge in the brain is discussed in Chapter 10.

In this section, we focus on our semantic knowledge of concepts and objects. How is that knowledge organised in the brain? One obvious possibility is that all information we possess about any given object or concept is stored in *one* location in the brain. Another possibility is that different kinds of information (features) about a given object are stored in different locations in the brain. This notion is incorporated in feature-based theories. According to such theories, “Object concepts may be represented in the brain as distributed networks of activity in the areas involved in the processing of perceptual or functional knowledge” (Canessa et al., 2008, p. 740). As we will see, both of these possibilities capture part of what is actually the case.

### Perceptual–functional theories

An influential feature-based approach was put forward by Warrington and Shallice (1984) and Farah and McClelland (1991). According to this approach, there is an important distinction between visual or perceptual features (e.g., what does the object look like?) and functional features (e.g., what is the object used for?). Our semantic knowledge of living things is mostly based on perceptual information. In contrast, our knowledge of non-living things (e.g., tools) mainly involves functional information.

An additional assumption of the perceptual–functional approach is that semantic memory contains far more information about perceptual properties of objects than of functional properties. Farah and McClelland (1991) examined the descriptors of living and non-living objects given in the dictionary. Three times more of the descriptors were classified as visual than as functional. As predicted, the ratio of visual to functional descriptors was 7.7:1 for living objects but only 1.4:1 for non-living objects.

Two major predictions follow from the perceptual–functional approach. First, brain damage should generally impair knowledge of living things more than non-living things. Brain damage is likely to destroy more information about perceptual features than functional features because more such information is stored in the first place. Second, neuroimaging should reveal that different brain areas are activated when perceptual features of an object are processed than functional features.

We turn now to a consideration of the relevant evidence. Some research has focused on brain-damaged patients who have problems with semantic memory and other research has used neuroimaging while healthy participants engage in tasks that involve semantic memory.

### Evidence

Many brain-damaged patients exhibit **category-specific deficits**, meaning they have problems with specific categories of object. For example, Warrington and Shallice (1984) studied a patient (JBR). He had much greater difficulty in identifying pictures of living than of non-living things (success rates of 6% and 90%, respectively). This pattern is common. Martin and Caramazza (2003) reviewed the evidence. More than 100 patients with a category-specific deficit for living but not for non-living things have been studied compared to approximately 25 with the opposite pattern. These findings are as predicted by perceptual–functional theories.

Why do some patients show greater impairment in recognising non-living than living things? Gainotti (2000) reviewed the evidence

from 44 patients. Of the 38 patients having a selective impairment for knowledge of living things, nearly all had damage to the anterior, medial, and inferior parts of the temporal lobes. In contrast, the six patients having a selective impairment for knowledge of man-made objects had damage in fronto-parietal areas extending further back in the brain than the areas damaged in the other group.

Support for perceptual–functional theories has also come from neuroimaging studies. Lee, Graham, Simons, Hodges, Owen, and Patterson (2002) asked healthy participants to retrieve perceptual or non-perceptual information about living or non-living objects or concepts when presented with their names. Processing of perceptual information from both living and non-living objects was associated with activation of left posterior temporal lobe regions. In contrast, processing of non-perceptual information (e.g., functional attributes) was associated with activation of left posterior inferior temporal lobe regions. Comparisons between living and non-living objects indicated that the same brain regions were activated for *both* types of concept. Thus, what determined which brain areas were activated was whether perceptual or non-perceptual information was being processed.

Similar findings were reported by Marques, Canessa, Siri, Catricala, and Cappa (2008). Participants were presented with statements about the features (e.g., form, colour, size, motion) of living and non-living objects, and patterns of brain activity were assessed while they decided whether the statements were true or false. Their findings largely agreed with those of Lee et al. (2002): “The results... highlighted that feature type rather than concept domain [living versus non-living] is the main organisational factor of the brain representation of conceptual knowledge” (Marques et al., 2008, p. 95).

### KEY TERM

**category-specific deficits:** disorders caused by brain damage in which **semantic memory** is disrupted for certain semantic categories.



### Multiple-property approach

The findings discussed so far are mostly consistent with perceptual–functional theories. However, there is increasing evidence that such theories are oversimplified. For example, many properties of living things (e.g., carnivore; lives in the desert) do not seem to be sensory or functional. In addition, the definition of functional feature has often been very broad and included an object’s uses as well as how it is manipulated. Buxbaum and Saffran (2002) have shown the importance of distinguishing between these two kinds of knowledge. Some of the patients they studied suffered from **apraxia**, a disorder involving the inability to make voluntary bodily movements. Apraxic patients with frontoparietal damage had preserved knowledge of the uses of objects but loss of knowledge about how to manipulate objects. In contrast, non-apraxic patients with damage to the temporal lobe showed the opposite pattern. Functional knowledge should probably be divided into “what for” and “how” knowledge (Canessa et al., 2008).

Canessa et al. (2008) reported functional magnetic resonance imaging (fMRI; see Glossary) findings supporting the above distinction. Healthy participants were presented with pictures of pairs of objects on each trial. They decided whether the objects were used in the same context (functional or “what for” knowledge) or involved the same manipulation pattern (action or “how” knowledge). Processing action knowledge led to activation in a left frontoparietal network, whereas processing functional knowledge activated areas within the lateral anterior infero-temporal cortex. The areas associated with these two kinds of knowledge were generally consistent with those identified by Buxbaum and Saffran (2002) in brain-damaged patients.

Cree and McRae (2003) showed that the distinction between perceptual and functional properties of objects is oversimplified. They argued that functional features should be divided into entity behaviours (what a thing does) and functional information (what humans use it for). Perceptual properties should be divided into visual (including colour), auditory,

taste, and tactile. For example, there are similarities among fruits, vegetables, and foods because sensory features associated with taste are important to all three categories.

Cree and McRae (2003) identified seven different patterns of category-specific deficits occurring following brain damage (see Table 7.1). They pointed out that no previous theory could account for all these patterns. However, their multiple-feature approach can do so. When brain damage reduces stored knowledge for one or more properties of objects, semantic memory for all categories relying strongly on those properties is impaired.

The multiple-property approach is promising for various reasons. First, it is based on a recognition that most concepts consist of several properties and that these properties determine similarities and differences among them. Second, the approach provides a reasonable account of several different patterns of deficit in conceptual knowledge observed in brain-damaged patients. Third, it is consistent with brain-imaging findings suggesting that different object properties are stored in different parts of the brain (e.g., Martin & Chao, 2001).

### Distributed-plus-hub theory vs. grounded cognition

As we have seen, there is general agreement that much of our knowledge of objects and concepts is widely distributed in the brain. Such knowledge is modality-specific (e.g., visual or auditory) and relates to perception, language, and action. This knowledge is probably stored in brain regions overlapping with those involved in perceiving, using language, and acting.

Does semantic memory also contain relatively abstract amodal representations not associated directly with any of the sensory

#### KEY TERM

**apraxia:** a neurological condition in which patients are unable to perform voluntary bodily movements.

**TABLE 7.1:** Cree and McRae's (2003) explanation of why brain-damaged patients show various patterns of deficit in their knowledge of different categories. From Smith and Kosslyn (2007). Copyright © Pearson Education, Inc. Reproduced with permission.

Deficit pattern	Shared properties
1. Multiple categories consisting of living creatures	Visual motion, visual parts, colour
2. Multiple categories of non-living things	Function, visual parts
3. Fruits and vegetables	Colour, function, taste, smell
4. Fruits and vegetables with living creatures	Colour
5. Fruits and vegetables with non-living things	Sound, colour
6. Inanimate foods with living things (especially fruits and vegetables)	Function, taste, smell
7. Musical instruments with living things	Function

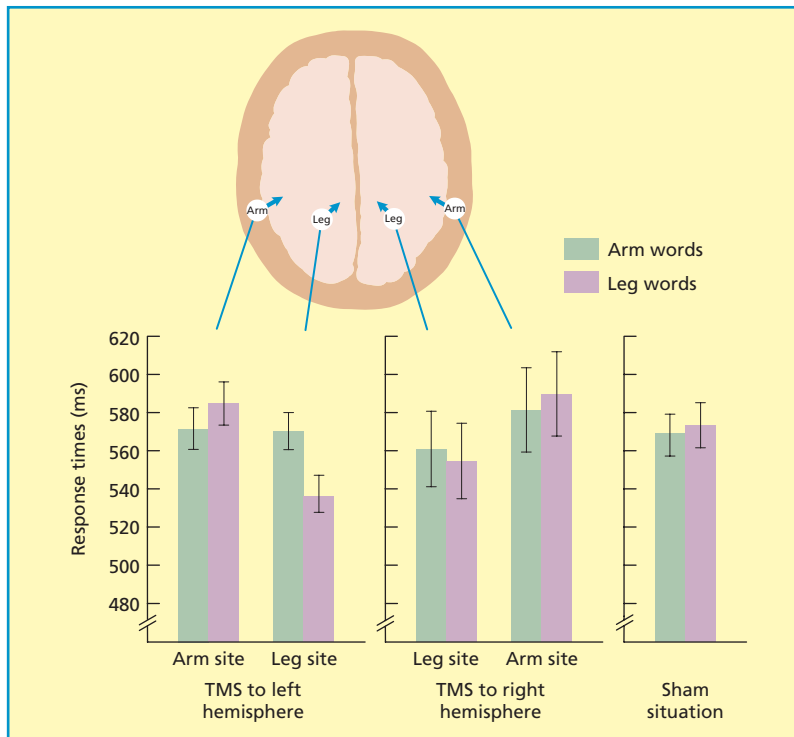
modalities? There has been much recent controversy on this issue. Barsalou (2008) argued that the answer is, “No”. He argued in favour of theories of grounded cognition which, “reject the standard view that amodal symbols represent knowledge in semantic memory... [they] focus on the roles of simulation in cognition... Simulation is the re-enactment of perceptual, motor, and introspective states acquired during experience (p. 618).

According to the distributed-plus-hub theory (Patterson et al., 2007; Rogers et al., 2004), the answer is, “Yes”. There is a hub for each concept or object in addition to distributed modality-specific information. Each hub is a unified conceptual representation that “supports the interactive activation of [distributed] representations in all modalities” (Patterson et al., 2007, p. 977). According to Patterson et al., concept hubs are stored in the anterior temporal lobes. Why do we have hubs? First, they provide an efficient way of integrating our knowledge of any given concept. Second, they make it easier for us to detect semantic similarities across concepts differing greatly in their modality-specific attributes. As Patterson et al. pointed out, scallops and prawns are conceptually related even though they have different shapes, colours, shell structures, forms of movement, names, and so on.

### Evidence

As predicted by theories of grounded cognition, modality-specific information is very important in our processing of concepts. Consider a study by Hauk, Johnsrude, and Pulvermüller (2004). Tongue, finger, and foot movements produced different patterns of activation along the motor strip. When they presented participants with words such as “lick”, “pick”, and “kick”, these verbs activated parts of the motor strip overlapping with (or very close to) the corresponding part of the motor strip. Thus, for example, the word “lick” activated areas associated with tongue movements.

The findings of Hauk et al. (2004) show that the motor system is *associated* with the processing of action words. However, these findings do not necessarily mean that the motor and premotor cortex *influence* the processing of action words. More convincing evidence was reported by Pulvermüller, Hauk, Nikulin, and Ilmoniemi (2005). Participants performed a lexical decision task in which they decided whether strings of letters formed words. Different parts of the motor system were stimulated with transcranial magnetic stimulation (TMS; see Glossary) while this task was performed. The key conditions were those in which arm-related or leg-related words were presented while TMS was applied to parts of the left-hemisphere



**Figure 7.6** Top: sites to which TMS was applied. Bottom left: response times to make lexical (word vs. non-word) decisions on arm- and leg-related words when TMS was applied to the left language-dominant hemisphere. Bottom middle and right: findings from control experiments with TMS to the right hemisphere and during sham stimulation. From Pulvermüller et al. (2005). © 2005 Federation of European Neuroscience Societies. Reprinted with permission of Wiley-Blackwell.

motor strip associated with arm or leg movements. There was a facilitation effect: arm-related words were processed faster when TMS was applied to the arm site than to the leg site, and the opposite was the case with leg-related words (see Figure 7.6).

Evidence that perceptual information is involved in our use of concepts was reported by Solomon and Barsalou (2001). Participants decided whether concepts possessed certain properties. The key issue was whether verification times would be speeded up when the same property was linked to two different concepts. There was a facilitation effect *only* when the shape of the property was similar in both cases, indicating that perceptual information influenced task performance. For example, verifying that “mane” is a property of “pony” was facilitated by previously verifying “mane” for “horse” but not by verifying “mane” for “lion”.

The grounded cognition approach is clearly useful in understanding our knowledge of

concrete concepts or objects that we can see and interact with. On the face of it, the approach seems less useful when applied to abstract concepts such as “truth”, “freedom”, and “invention”. However, Barsalou and Wiemer-Hastings (2005) argued that abstract concepts can potentially be understood within the grounded cognition approach. Participants indicated the characteristic properties of various abstract concepts. Many properties referred to settings or events associated with the concept (e.g., scientists working in a laboratory for “invention”), and others referred to relevant mental states. Thus, much of the knowledge we have of abstract concepts is relatively concrete.

According to the distributed-plus-hub theory, hubs or amodal conceptual representations are stored in the anterior temporal lobes. What would happen if someone suffered brain damage to these lobes? Theoretically, this should lead to impaired performance on all tasks requiring semantic memory. Thus, performance

would be poor regardless of the modality of input (e.g., objects; words; sounds) and the modality of output (e.g., object naming; object drawing).

The above predictions have been tested using patients with semantic dementia. **Semantic dementia** involves loss of concept knowledge even though most cognitive functions are reasonably intact early in the disease. It always involves degeneration of the anterior temporal lobes. As predicted by the distributed-plus-hub theory, patients with semantic dementia perform very poorly on tests of semantic memory across all semantic categories regardless of the modalities of input and output (see Patterson et al., 2007, for a review). Patients with semantic dementia are unable to name objects when relevant pictures are presented or when they are given a description of the object (e.g., “What do we call the African animal with black and white stripes?”). They are also unable to identify objects when listening to their characteristic sounds (e.g., a phone ringing; a dog barking).

Theoretically, we would expect functional neuroimaging studies to indicate strong activation in the anterior temporal lobes when healthy participants perform semantic memory tasks. In fact, most studies have found no evidence for such activation! Rogers et al. (2006) identified two likely reasons. First, most studies used fMRI, which is poor at detecting activation in the anterior frontal lobes. Second, the semantic memory tasks used in most fMRI studies have not required objects to be classified with much precision or specificity, but patients with semantic dementia have greater problems with more precise categories. Rogers et al. carried out a study on healthy participants using PET rather than fMRI. Their task involved deciding whether an object belonged to the category specified by a previous word. The category was *specific* (e.g., BMW; labrador) or more *general* (e.g., car; dog). There was activation in the anterior temporal lobes when the task involved specific categories. Thus, we finally have solid evidence of the involvement of the anterior temporal lobes in semantic memory from a functional neuroimaging study.

## Evaluation

Much progress has been made in understanding the organisation of semantic memory (see also Chapter 10). The distributed-plus-hub theory provides a more comprehensive account of semantic memory than previous theories. The evidence from brain-damaged patients with category-specific deficits indicates that different object properties are stored in different brain areas. In addition, patients with semantic dementia provide evidence for the existence of concept hubs stored in the anterior temporal lobes.

What are the limitations of distributed-plus-hub theory? First, more remains to be discovered about the information contained within concept hubs. For example, is more information stored in the hubs of very familiar concepts than of less familiar ones? Second, how do we combine or integrate concept hub information with distributed modality-specific information? It would seem that complex processes are probably involved, but we do not as yet have a clear sense of how these processes operate.

## NON-DECLARATIVE MEMORY

The essence of non-declarative memory is that it does not involve conscious recollection but instead reveals itself through behaviour. As discussed earlier, repetition priming (facilitated processing of repeated stimuli) and procedural memory (mainly skill learning) are two of the major types of non-declarative memory. There are several differences between repetition priming and procedural memory. First, priming often occurs rapidly, whereas procedural memory or skill learning is typically slow and gradual

### KEY TERM

**semantic dementia:** a condition in which there is widespread loss of information about the meanings of words and concepts but executive functioning is reasonably intact in the early stages.

(Knowlton & Foerde, 2008). Second, there is stimulus specificity. Priming is tied to specific stimuli whereas skill learning typically generalises to numerous stimuli. For example, it would not be much use if you learned how to hit backhands at tennis very well, but could only do so provided that the ball came towards you from a given direction at a given speed! Third, there is increasing evidence that different brain areas are involved in repetition priming and skill learning (Knowlton & Foerde, 2008).

If repetition priming and skill learning involve different memory systems, then there is no particular reason why individuals who are good at skill learning should be good at priming. There is often practically no correlation between performance on these two types of task. Schwartz and Hashtroudi (1991) used a word-identification task to assess priming and an inverted-text reading task to assess skill learning. There was no correlation between priming and skill learning. However, the interpretation of such findings is open to dispute. Gupta and Cohen (2002) developed a computational model based on the assumption that skill learning and priming depend on a *single* mechanism. This model accounted for zero correlations between skill learning and priming.

It is probable that priming and skill learning involve separate memory systems. However, most of the evidence is not clear-cut because the tasks assessing skill learning and repetition priming have been very different. This led Poldrack, Selco, Field, and Cohen (1999) to compare skill learning and priming within a *single* task. Participants entered five-digit numbers as rapidly as possible into a computer keypad. Priming was assessed by performance on repeated digit strings, whereas skill learning was assessed by performance on non-repeated strings. Skill learning and the increase in speed with repetition priming were both well described by a power function, leading Poldrack et al. to conclude that they both involve the same learning mechanism.

Poldrack and Gabrieli (2001) studied skill learning and repetition priming using a mirror-reading task in which words and pronounceable

non-words presented in a mirror were read as fast as possible. Activity in different areas of the brain was assessed by fMRI. The findings were reasonably clear-cut:

*[Skill] learning...was associated with increased activation in left inferior temporal, striatal, left inferior prefrontal and right cerebellar regions and with decreased activity in the left hippocampus and left cerebellum. Short-term repetition priming was associated with reduced activity in many of the regions active during mirror reading and...long-term repetition priming resulted in a virtual elimination of activity in those regions. (p. 67)*

The finding that very similar areas were involved in skill learning and priming is consistent with the hypothesis that they involve the same underlying memory system. However, evidence less supportive of that hypothesis is discussed later.

## Repetition priming

We can draw a distinction between perceptual priming and conceptual priming. **Perceptual priming** occurs when repeated presentation of a stimulus leads to facilitated processing of its perceptual features. For example, it is easier to identify a word presented in a degraded fashion if it has recently been encountered. In contrast, **conceptual priming** occurs when repeated presentation of a stimulus leads to facilitated processing of its meaning. For example, people can decide faster whether an object is living or nonliving if they have seen it recently.

### KEY TERMS

**perceptual priming:** a form of repetition priming in which repeated presentation of a stimulus facilitates perceptual processing of it.

**conceptual priming:** a form of **repetition priming** in which there is facilitated processing of stimulus meaning.



Perceptual priming occurs when repeated presentation of a stimulus leads to facilitated processing of its perceptual features. For example, it would be easier to identify words that had been eroded and had faded in the sand, if they had previously been seen when freshly etched.

Much evidence supports the distinction between perceptual and conceptual priming. Keane, Gabrieli, Mapstone, Johnson, and Corkin (1995) studied perceptual and conceptual priming in LH, a patient with bilateral brain damage within the occipital lobes. LH had an absence of perceptual priming but intact conceptual priming. In contrast, patients with Alzheimer's disease have the opposite pattern of intact perceptual priming but impaired conceptual priming (see Keane et al., 1995, for a review). According to Keane et al., the impaired conceptual priming shown by Alzheimer's patients is due to damage within the temporal and parietal lobes. The findings suggest the existence of a double dissociation (see Glossary), which provides reasonable support that different processes underlie the two types of priming.

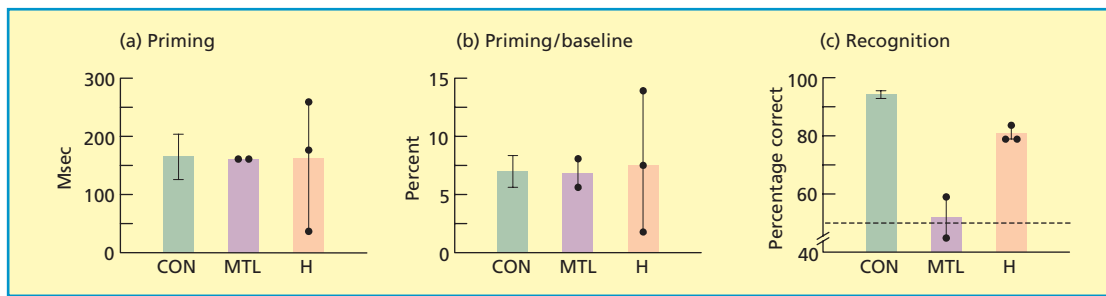
### Evidence

If repetition priming involves non-declarative memory, then amnesic patients should show intact repetition priming. This prediction has been supported many times. Cermak, Talbot, Chandler, and Wolbarst (1985) compared the performance of amnesic patients and non-amnesic alcoholics on perceptual priming. The

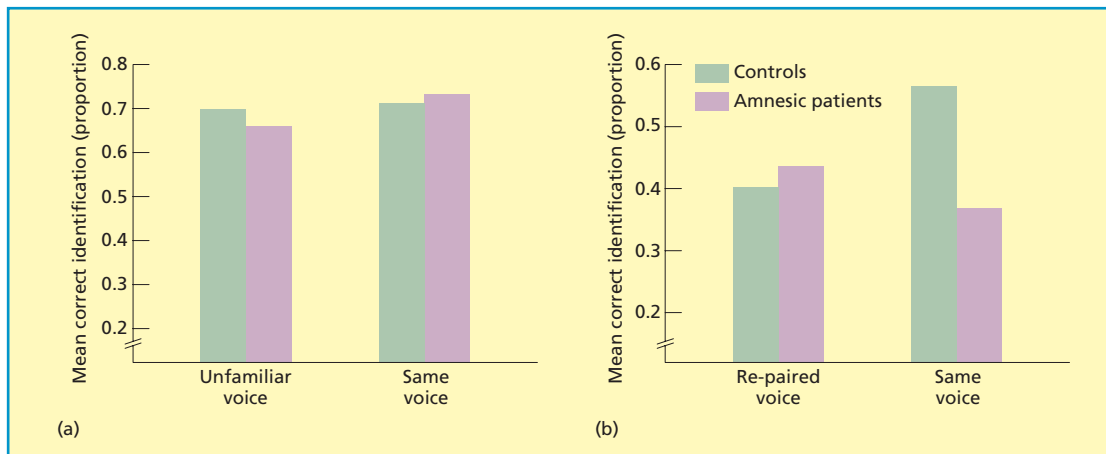
patients were presented with a list of words followed by a priming task. This task was perceptual identification, and involved presenting the words at the minimal exposure time needed to identify them. The performance of the amnesic patients resembled that of control participants, with identification times being faster for the primed list words than for the unprimed ones. Thus, the amnesic patients showed as great a perceptual priming effect as the controls. Cermak et al. also used a conventional test of recognition memory (involving episodic memory) for the list words. The amnesic patients did significantly worse than the controls on this task.

Graf, Squire, and Mandler (1984) studied a different perceptual priming effect. Word lists were presented, with the participants deciding how much they liked each word. The lists were followed by one of four memory tests. Three tests involved declarative memory (free recall, recognition memory, and cued recall), but the fourth test (word completion) involved priming. On this last test, participants were given three-letter word fragments (e.g., STR \_\_\_\_ ) and simply wrote down the first word they thought of starting with those letters (e.g., STRAP; STRIP). Priming was assessed by the extent to which the word completion corresponded to words from the list previously presented. Amnesic patients did much worse than controls on all the declarative memory tests, but the groups did not differ on the word-completion test.

Levy, Stark, and Squire (2004) studied conceptual priming and recognition memory (involving declarative memory) in amnesic patients with large lesions in the medial temporal lobe, amnesic patients with lesions limited to the hippocampus, and healthy controls. The conceptual priming task involved deciding whether words previously studied or not studied belonged to given categories. The findings were striking. All three groups showed very similar amounts of conceptual priming. However, both amnesic groups performed poorly on recognition memory (see Figure 7.7). Indeed, the amnesic patients with large lesions showed no evidence of any declarative memory at all.



**Figure 7.7** Performance of healthy controls (CON), patients with large medial temporal lobe lesions (MTL), and patients with hippocampal damage only (H) on: (a) priming in terms of reaction times; (b) priming in terms of percentage priming effect; and (c) recognition performance. From Levy et al. (2004). Reprinted with permission of Wiley-Blackwell.



**Figure 7.8** Auditory word identification for previously presented words in amnesics and controls. (a) All words originally presented in the same voice; data from Schacter and Church (1995). (b) Words originally presented in six different voices; data from Schacter et al. (1995).

The notion that priming depends on memory systems different from those involved in declarative memory would be strengthened if we could find patients having intact declarative memory but impaired priming. This would be a double dissociation, and was achieved by Gabrieli, Fleischman, Keane, Reminger, and Morell (1995). They studied a patient, MS, who had right occipital lobe lesion. MS had normal levels of performance on the declarative memory tests of recognition and cued recall but impaired performance on perceptual priming.

Further evidence that amnesics have intact perceptual priming was reported by Schacter and Church (1995). Participants initially heard

words spoken in the same voice. After that, they tried to identify the same words passed through an auditory filter; the words were spoken in the same voice or an unfamiliar voice. Amnesic patients and healthy controls both showed perceptual priming, with word-identification performance being better when the words were spoken in the same voice (see Figure 7.8a).

The findings discussed so far seem neat and tidy. However, complications arose in research by Schacter, Church, and Bolton (1995). Their study resembled that of Schacter and Church (1995) in that perceptual priming based on auditory word identification was investigated. However, it differed in that the words were

initially presented in *six* different voices. On the word-identification test, half the words were presented in the same voice and half were spoken by one of the other voices (re-paired condition). The healthy controls showed more priming for words presented in the same voice, but the amnesic patients did not (see Figure 7.8b).

How can we explain the above findings? In both the same voice and re-paired voice conditions, the participants were exposed to words and voices they had heard before. The only advantage in the same voice condition was that the pairing of word and voice was the same as before. However, only those participants who had linked or associated words and voices at the original presentation would benefit from that fact. The implication is that amnesics are poor at binding together different kinds of information even on priming tasks apparently involving non-declarative memory (see discussion later in the chapter).

What processes are involved in priming? One popular view is based on perceptual fluency: repeated presentation of a stimulus means it can be processed more efficiently using fewer resources. It follows from this view that priming should be associated with *reduced* levels of brain activity (known as neural priming). There is considerable evidence for this prediction (e.g., Poldrack & Gabrieli, 2001). The precise brain regions showing reduced activation vary somewhat depending on the task and whether perceptual or conceptual priming is being studied. Early visual areas in the occipital lobe often show reduced activity with perceptual priming, whereas the inferior frontal gyrus and left inferior temporal cortex show reduced activity with conceptual priming (see Schacter et al., 2007, for a review).

The finding that repetition of a stimulus causes priming and reduced brain activity does not show there is a *causal* link between patterns of brain activation and priming. More direct evidence was reported by Wig, Grafton, Demos, and Kelley (2005). They studied conceptual priming using a task in which participants classified objects as living or nonliving. Wig et al. tested the involvement of the left inferior

frontal gyrus in conceptual priming by delivering transcranial magnetic stimulation to that area. The subsequent classification of objects that had been accompanied by TMS showed an absence of both conceptual and neural priming. These findings suggest that the left inferior temporal cortex plays a causal role in producing conceptual priming.

### Evaluation

There are important similarities and differences between perceptual and conceptual priming. They are similar in that most amnesic patients typically show essentially intact perceptual and conceptual priming, suggesting that both types of priming involve non-declarative memory. However, the finding of a double dissociation in which some patients are much better at perceptual than at conceptual priming, whereas others show the opposite pattern, suggests there are some important differences between them. The consistent finding that repetition priming is associated with reduced brain activation suggests that people become more efficient at processing repeated stimuli. Recent research has supported the hypothesis that there is a causal link between patterns of brain activation and priming performance.

Future research needs to establish more clearly that reduced brain activation during repetition priming is causally related to enhanced priming. There is also a need to identify more precisely the different processes involved in perceptual and conceptual priming.

### Procedural memory or skill learning

What exactly is skill learning? According to Poldrack et al. (1999, p. 208), “Skill learning refers to the gradual improvement of performance with practice that generalises to a range of stimuli within a domain of processing.” Motor skills are important in everyday life. For example, they are needed in word processing, writing, and playing a musical instrument.

Foerde and Poldrack (2009) identified numerous types of skill learning or procedural



memory, including the following: motor skill learning; sequence learning, mirror tracing; perceptual skill learning; mirror reading; probabilistic classification learning; and artificial grammar learning. Some of these forms of skill learning are discussed at length in Chapter 6.

Here, we will address the issue of whether the above tasks involve non-declarative or procedural memory, and thus involve different memory systems from those underlying episodic and semantic memory. This issue has been addressed in various ways. However, we will mostly consider research on skill learning in amnesic patients. The rationale for doing this is simple: if amnesic patients have essentially intact skill learning but severely impaired declarative memory that would provide evidence that different memory systems are involved.

We will shortly turn to the relevant evidence. Before doing so, however, we need to consider an important issue. It is easy to imagine that some tasks involve only non-declarative or procedural memory, whereas others involve declarative memory. In fact, matters are rarely that simple (see Chapter 6). For example, consider the probabilistic classification task. Participants predict whether the weather will be sunny or rainy on the basis of various cues. Reber, Knowlton, and Squire (1996) found that amnesics learned this task as rapidly as healthy controls, suggesting that the task involves procedural memory.

Foerde, Knowlton, and Poldrack (2006) obtained evidence suggesting that learning on the probabilistic classification task can depend on either procedural or declarative memory. Participants performed the task on its own or with a demanding secondary task. Performance was similar in the two conditions. However, important differences emerged between the conditions when the fMRI data were considered. Task performance in the dual-task condition correlated with activity in the striatum (part of the basal ganglia), a part of the brain associated with procedural learning and memory. In contrast, task performance in the single-task performance correlated with activity in the medial temporal lobe, an area associated with

declarative memory. Thus, the involvement of procedural and declarative memory on the probabilistic classification task seemed to depend on the precise conditions under which the task was performed.

### Evidence

Amnesics often have normal (or nearly normal) rates of skill learning across numerous tasks. Spiers et al. (2001), in a review discussed earlier, considered the memory performance of numerous amnesic patients. They concluded as follows: “None of the cases was reported to...be impaired on tasks which involved learning skills or habits, priming, simple classical conditioning and simple category learning” (p. 359).

Corkin (1968) reported that the amnesic patient HM (see p. 252) was able to learn mirror drawing, in which the pen used in drawing a figure is observed in a mirror rather than directly. He also showed learning on the pursuit rotor, which involves manual tracking of a moving target. HM’s rate of learning was slower than that of healthy individuals on the pursuit rotor. In contrast, Cermak, Lewis, Butters, and Goodglass (1973) found that amnesic patients learned the pursuit rotor as rapidly as healthy participants. However, the amnesic patients were slower than healthy individuals at learning a finger maze.

Tranel, Damasio, Damasio, and Brandt (1994) found in a study on 28 amnesic patients that all showed comparable learning on the pursuit rotor to healthy controls. Of particular note was a patient, Boswell, who had unusually extensive brain damage to areas (e.g., medial and lateral temporal lobes) strongly associated with declarative memory. In spite of this, his learning on the pursuit rotor and retention over a two-year period were both at the same level as healthy controls.

The typical form of the serial reaction time task involves presenting visual targets in one of four horizontal locations, with the participants pressing the closest key as rapidly as possible (see Chapter 6). The sequence of targets is sometimes repeated over 10 or 12 trials, and skill learning is shown by improved performance on these repeated sequences. Nissen, Willingham,

and Hartman (1989) found that amnesic patients and healthy controls showed comparable performance on the serial reaction time task during learning and also on a second test one week later. Vandenberghe et al. (2006) obtained more complex findings. They had a deterministic condition in which there was a repeating sequence and a probabilistic condition in which there was a repeating sequence but with some deviations. Amnesic patients failed to show skill learning in the probabilistic condition, but exhibited some implicit learning in the deterministic condition. Thus, amnesic patients do not always show reasonable levels of skill learning.

Mirror tracing involves tracing a figure with a stylus, with the figure to be traced being seen reflected in a mirror. Performance on this task improves with practice in healthy participants, and the same is true of amnesic patients (e.g., Milner, 1962). The rate of learning is often similar in both groups.

In mirror reading we can distinguish between *general* improvement in speed of reading produced by practice and more *specific* improvement produced by re-reading the same groups of words or sentences. Cohen and Squire (1980) reported general and specific improvement in reading mirror-reversed script in amnesics, and there was evidence of improvement even after a delay of three months. Martone, Butters, Payne, Becker, and Sax (1984) also obtained evidence of general and specific improvement in amnesics.

Cavaco, Anderson, Allen, Castro-Caldas, and Damasio (2004) pointed out that most tasks used to assess skill learning in amnesics require learning far removed from that occurring in everyday life. Accordingly, Cavaco et al. used five skill-learning tasks requiring skills similar to those needed in the real world. For example, there was a weaving task and a control stick task requiring movements similar to those involved in operating machinery. Amnesic patients showed comparable rates of learning to those of healthy individuals on all five tasks, in spite of having significantly impaired declarative memory for the tasks assessed by recall and recognition tests.

In sum, amnesic patients show reasonably good skill or procedural learning and memory

in spite of very poor declarative memory. That provides reasonable evidence that there are major differences between the two forms of memory. Shortly, we will consider evidence indicating that the brain areas associated with procedural memory differ from those associated with declarative memory. However, we must not think of declarative and procedural memory as being entirely separate. Brown and Robertson (2007) gave participants a procedural learning task (the serial reaction time task) and a declarative learning task (free recall of a word list). Procedural memory was disrupted when declarative learning occurred during the retention interval. In a second experiment, declarative memory was disrupted when procedural learning occurred during the retention interval. Thus, there can be *interactions* between the two memory systems.

## BEYOND DECLARATIVE AND NON-DECLARATIVE MEMORY: AMNESIA

Most memory researchers have argued that there is a very important distinction between declarative/explicit memory and non-declarative/implicit memory. As we have seen, this distinction has proved very useful in accounting for most of the findings (especially those from amnesic patients). However, there are good grounds for arguing that we need to move beyond that distinction. We will focus our discussion on amnesia, but research on healthy individuals also suggests that the distinction between declarative and non-declarative memory is limited (see Reder, Park, & Kieffaber, 2009, for a review).

According to the traditional viewpoint, amnesic patients should have intact performance on declarative memory tasks and impaired performance on non-declarative tasks. There is an alternative viewpoint that has attracted increasing interest (e.g., Reder et al., 2009; Ryan, Althoff, Whitlow, & Cohen, 2000; Schacter et al., 1995). According to Reder et al. (2009, p. 24), “The critical feature that distinguishes

tasks that are impaired from those that are spared under amnesia hinges on whether the task requires the formation of an association (or binding) between the two concepts.” We will briefly consider research relevant to adjudicating between these two viewpoints. Before we do so, note that the binding-of-item-and-context model (Diana et al., 2007; discussed earlier in the chapter) identifies the hippocampus as of central importance in the binding process. The relevance of that model here is that amnesic patients typically have extensive damage to the hippocampus.

## Evidence

Earlier in the chapter we discussed a study by Schacter et al. (1995) on perceptual priming. Amnesic patients and healthy controls identified words passed through an auditory filter having previously heard them spoken by the same voice or one out of five different voices. The measure of perceptual priming was the extent to which participants were better at identifying words spoken in the same voice than those spoken in a different voice. Since six different voices were used altogether, successful perceptual priming required binding or associating the voices with the words when the words were presented initially. In spite of the fact that Schacter et al. used a non-declarative memory task, amnesic patients showed no better performance for words presented in the same voice than in a different voice (see Figure 7.8b). This finding is inconsistent with the traditional viewpoint but is as predicted by the binding hypothesis.

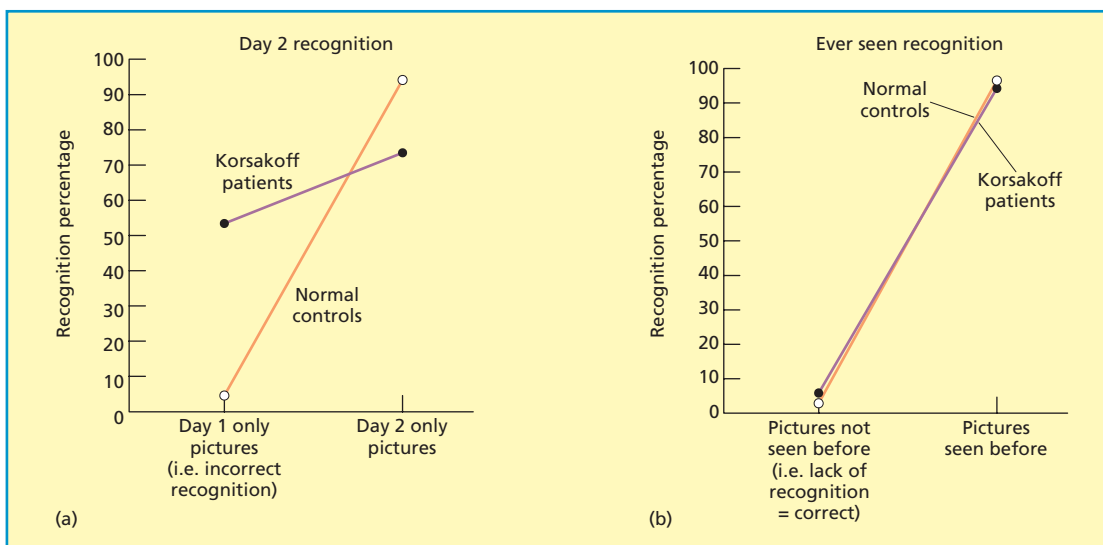
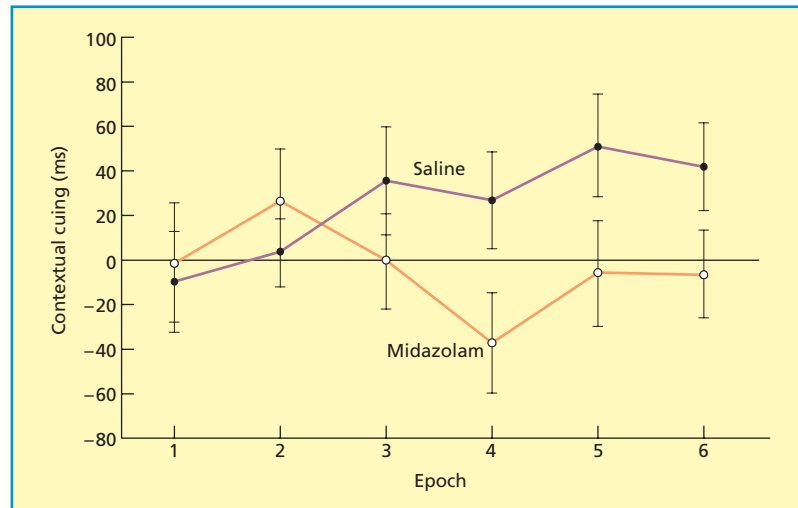
More evidence that amnesic patients sometimes have deficient implicit memory was reported by Chun and Phelps (1999). Amnesic patients and healthy controls carried out a visual search task in which the target was a rotated T and the distractors were rotated Ls. Half the displays were new and the remainder were old or repeated. There were two main findings with the healthy controls. First, their performance improved progressively throughout the experiment (skill learning). Second, they improved significantly

more with practice on the old displays than on the new ones. This involved implicit learning, because they had no ability to discriminate old displays from new ones on a recognition test. The amnesic patients showed general improvement with practice, and thus some implicit learning. However, there was no difference between their performance on new and old displays. This failure of implicit learning probably occurred because the amnesic patients could not bind the arrangement of the distractors to the location of the target in old displays.

There have been some failures to replicate the above findings (see Reder et al., 2009, for a review), perhaps because amnesic patients differ so much in their precise brain damage and memory impairments. Park, Quinlan, Thornton, and Reder (2004) argued that a useful approach is to use drugs that mimic the effects of amnesia. They administered midazolam, a benzodiazepine that impairs performance on explicit memory tasks but not implicit tasks (e.g., repetition priming). They carried out a study very similar to that of Chun and Phelps (1999), and obtained similar findings. Their key result was that healthy individuals given midazolam failed to perform better on old displays than new ones, in contrast to individuals given a placebo (saline) (see Figure 7.9). Thus, midazolam-induced amnesia impairs implicit learning because it disrupts binding with old displays.

A study by Huppert and Piercy (1976) on declarative memory supports the binding hypothesis. They presented large numbers of pictures on day 1 and on day 2. Some of those presented on day 2 had been presented on day 1 and others had not. Ten minutes after the day-2 presentation, there was a recognition-memory test, on which participants decided which pictures had been presented on day 2. Successful performance on this test required binding of picture and temporal context at the time of learning. Healthy controls performed much better than amnesic patients in correctly identifying day-2 pictures and rejecting pictures presented only on day 1 (see Figure 7.10a). Thus, amnesic patients were at a great disadvantage when binding was necessary for memory.

**Figure 7.9** The difference between visual search performance with old and new displays (i.e., contextual cueing effect) as a function of condition (Midazolam vs. placebo/saline) and stage of practice (epochs). From Park et al. (2004), Copyright © 2004 National Academy of Sciences, USA. Reprinted with permission.



**Figure 7.10** Recognition memory for pictures in Korsakoff patients and normal controls. Data from Huppert and Piercy (1976).

Huppert and Piercy (1976) also used a familiarity-based recognition memory test. Participants decided whether they had ever seen the pictures before. Here, no prior binding of picture and temporal context was necessary. On this test, the amnesic patients and healthy controls performed the task extremely well (see Figure 7.10b). Thus, as predicted by the binding hypothesis, amnesic patients can perform

declarative memory tasks successfully provided that binding is not required.

### Evaluation

Since declarative memory tasks generally require the formation of associations and non-declarative memory tasks do not, it is often hard to decide which viewpoint is preferable. However, there

is increasing support for the binding hypothesis. More specifically, we now have studies showing that amnesic patients sometimes fail to show non-declarative/implicit memory when binding of information (e.g., stimulus + context) is required (e.g., Chun & Phelps, 1999; Schacter et al., 1995). In addition, amnesic patients sometimes show essentially intact declarative/explicit memory when binding of information is not required (e.g., Huppert & Piercy, 1976).

What is needed for the future? First, we need more research in which the predictions based on the traditional viewpoint differ from those based on the binding hypothesis. Second, we should look for tasks that differ more clearly in their requirements for binding than most of those used hitherto. Third, it is important to specify more precisely what is involved in the binding process.

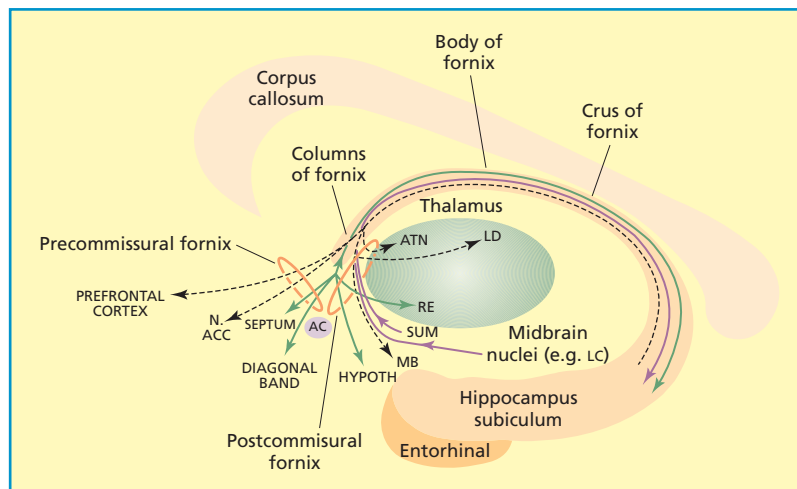
## LONG-TERM MEMORY AND THE BRAIN

Our understanding of long-term memory has been greatly enhanced by functional imaging studies and research on brain-damaged patients. It is clear that encoding and retrieval in long-term memory involve several processes and are more complex than was previously thought. In this section, we will briefly consider how

different brain regions contribute to long-term memory, with an emphasis on the *major* brain areas associated with each memory system. As we will see, each memory system is associated with different brain areas. This strengthens the argument that the various memory systems are indeed somewhat separate. In what follows, we will discuss some of the evidence. The role of the anterior temporal lobes in semantic memory (e.g., Patterson et al., 2007), early visual areas in the occipital lobe in perceptual priming (Schacter et al., 2007), and left inferior temporal cortex in conceptual priming (e.g., Wig et al., 2005) were discussed earlier in the chapter.

### Medial temporal lobe and medial diencephalon

The medial temporal lobe including the hippocampal formation is of crucial importance in anterograde amnesia and in declarative memory generally. However, we have a problem because chronic alcoholics who develop Korsakoff's syndrome have brain damage to the diencephalon including the mamillary bodies and various thalamic nuclei (see Figure 7.11). Aggleton (2008) argued persuasively that temporal lobe amnesia and diencephalic amnesia both reflect damage to the same integrated brain system involving the temporal lobes and the medial diencephalon. Aggleton pointed out



**Figure 7.11** The main interconnected brain areas involved in amnesia: AC = anterior commissure; ATN = anterior thalamic nuclei; HYPOTH = hypothalamus; LC = locus coeruleus; LD = thalamic nucleus lateralis dorsalis; MB = mammillary bodies; RE = nucleus reuniens; SUM = supramammillary nucleus. From Aggleton (2008).

that the anterior thalamic nuclei and the mammillary bodies differ from the rest of the medial diencephalon in that they both receive direct inputs from the hippocampal formation via the fornix (see Figure 7.11). Thus, these areas are likely to be of major importance within the hypothesised integrated system. Aggleton and Brown (1999) proposed that an “extended hippocampal system” consisting of the hippocampus, fornix, mammillary bodies, and the anterior thalamic nuclei is crucial for episodic memory.

There is much support for the notion of an extended hippocampal system. Harding, Halliday, Caine, and Kril (2000) studied the brains of alcoholics with Korsakoff’s syndrome and those of alcoholics without amnesia. The only consistent difference between the two groups was that the Korsakoff patients had degeneration of the anterior thalamic nuclei. There is also evidence for the importance of the fornix. Patients with benign brain tumours who suffer atrophy of the fornix as a consequence consistently exhibit clear signs of anterograde amnesia (Gilboa et al., 2006).

We have focused on anterograde amnesia in this section. However, the hippocampal formation and medial temporal lobe are also very important in retrograde amnesia (Moscovitch et al., 2006). In addition, the hippocampus (and the prefrontal cortex) are of central importance in autobiographical memory (Cabeza & St. Jacques, 2007; see Chapter 8).

### Striatum and cerebellum

Which brain areas are involved in skill learning or procedural memory? Different types of skill learning involve different brain areas depending on characteristics of the task (e.g., auditory versus visual input). However, two brain areas are most closely associated with procedural memory: the striatum (part of the basal ganglia) in particular but also the cerebellum. The evidence implicating those brain areas comes from studies on brain-damaged patients and from neuroimaging research.

Much research has made use of brain-damaged patients suffering from Parkinson’s disease, which is associated with damage to the

striatum. **Parkinson’s disease** is a progressive disorder characterised by tremor of the limbs, muscle rigidity, and mask-like facial expression. Siegert, Taylor, Weatherall, and Abernethy (2006) reported a meta-analysis of learning on the serial reaction time task (discussed above) by patients with Parkinson’s disease (see Chapter 6). Skill learning by Parkinson’s patients was consistently slower than that by healthy controls.

Strong evidence that the basal ganglia are important in skill learning was reported by Brown, Jahanshahi, Limousin-Dowsey, Thomas, Quinn, and Rothwell (2003). They studied patients with Parkinson’s disease who had had posteroventral pallidotomy, a surgical form of treatment that disrupts the output of the basal ganglia to the frontal cortex. These patients showed no implicit learning at all on the serial reaction time task.

Not all the evidence indicates that Parkinson’s patients show deficient procedural learning and memory. Osman, Wilkinson, Beigi, Castaneda, and Jahanshahi (2008) reviewed several studies in which Parkinson’s patients performed well on procedural learning tasks. In their own experiment, participants had to learn about and control a complex system (e.g., water-tank system). Patients with Parkinson’s disease showed the same level of procedural learning as healthy controls on this task, which suggests that the striatum is not needed for all forms of procedural learning and memory.

Neuroimaging studies have produced somewhat variable findings (see Kelly & Garavan, 2005, for a review). However, practice in skill learning is often associated with decreased activation in the prefrontal cortex but increased activation in the basal ganglia. It is likely that the decreased activation in the prefrontal cortex occurs because attentional and control processes

#### KEY TERM

**Parkinson’s disease:** it is a progressive disorder involving damage to the basal ganglia; the symptoms include rigidity of the muscles, limb tremor, and mask-like facial expression.

are important early in learning but become less so with extensive practice. Debaere et al. (2004) found, during acquisition of a skill requiring coordination of hand movements, that there were decreases in activation within the right dorsolateral prefrontal cortex, the right premotor cortex, and the bilateral superior parietal cortex. At the same time, there were increases in activation within the cerebellum and basal ganglia.

In sum, the striatum (and to a lesser extent the cerebellum) are important in procedural learning and memory. However, we must avoid oversimplifying a complex reality. The neuroimaging findings indicate clearly that several other areas (e.g., the prefrontal cortex; the posterior parietal cortex) are also involved.

### Prefrontal cortex

As discussed in Chapter 5, the prefrontal cortex is extremely important in most (or all) executive processes involving attentional control. As we have seen in this chapter, it is also of significance in long-term memory. Two relatively small regions on the lateral or outer surface of the frontal lobes are of special importance: the dorsolateral prefrontal cortex (roughly BA9 and B46) and the ventrolateral prefrontal cortex (roughly BA45 and BA47) (see Figure 1.4).

#### Dorsolateral prefrontal cortex

What is the role of dorsolateral prefrontal cortex in declarative memory? One idea is that this area is involved in relational encoding (forming links between items or between an item and its context). Murray and Ranganath (2007) carried out a study in which unrelated word pairs were presented. In one condition, the task involved a comparison between the two words (relational encoding) and in the other it did not (item-specific encoding). Activation of the dorsolateral prefrontal cortex was greater during relational than item-specific encoding. More importantly, the amount of dorsolateral activity at encoding predicted successful performance on a recognition test of relational memory.

Another possible role of dorsolateral prefrontal cortex in memory is to evaluate the

relevance of retrieved information to current task requirements (known as post-retrieval monitoring). The more information that is retrieved, the more likely the individual will engage in monitoring. Achim and Lepage (2005) manipulated the amount of information likely to be retrieved in two recognition-memory tests. As predicted, activity within the dorsolateral prefrontal cortex was greater when there was more demand for post-retrieval monitoring.

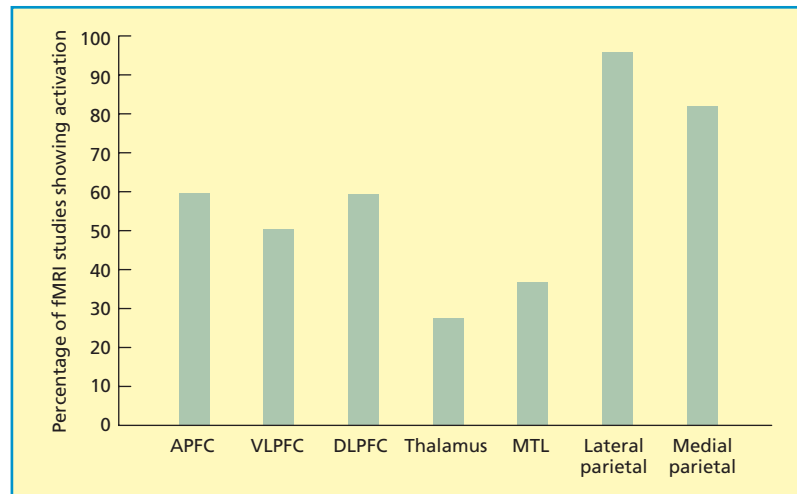
In sum, dorsolateral prefrontal cortex plays a role at encoding and at retrieval. First, it is involved in relational encoding at the time of learning. Second, it is involved in post-retrieval monitoring at the time of retrieval. In general terms, dorsolateral prefrontal cortex is often activated when encoding and/or retrieval is relatively complex.

#### Ventrolateral prefrontal cortex

Badre and Wagner (2007) discussed a two-process account of the involvement of the ventrolateral prefrontal cortex in declarative memory. There is a controlled retrieval process used to activate goal-relevant knowledge. There is also a post-retrieval selection process that deals with competition between memory representations active at the same time.

Evidence that both of the above processes involve the ventrolateral prefrontal cortex was reported by Badre, Poldrack, Pare-Blagoev, Insler, and Wagner (2005). A cue word and two or four target words were presented on each trial, and the task was to decide which target word was semantically related to the cue word. It was assumed that the controlled retrieval process would be involved when the target word was only weakly associated with the cue (e.g., cue = candle; target word = halo). It was also assumed that the post-retrieval selection process would be needed when one of the incorrect target words was non-semantically associated with the cue word (e.g., cue = ivy; incorrect target word = league). As predicted, there was increased activation within the ventrolateral prefrontal cortex when the task required the use of controlled retrieval or post-retrieval selection.

**Figure 7.12** Percentages of fMRI studies of episodic memory showing activation in various brain regions. APFC = anterior prefrontal cortex; VLPFC = ventrolateral prefrontal cortex; DLPFC = dorsolateral prefrontal cortex; MTL = medial temporal lobe. Reprinted from Simons et al. (2008), Copyright © 2008, with permission from Elsevier.



Kuhl, Kahn, Dudukovic, and Wagner (2008) studied the post-retrieval selection process. There was activation of the right ventrolateral prefrontal cortex and the anterior cingulate when memories that had previously been selected against were successfully retrieved. It was assumed that an effective post-retrieval selection process was needed to permit previously selected-against memories to be retrieved.

### Parietal lobes

What is the involvement of the parietal lobes in long-term memory? Simons et al. (2008) carried out a meta-analysis of functional neuroimaging studies on episodic memory in which brain activation was assessed during successful recollection of the context in which events had occurred. Lateral and medial areas within the parietal lobes were more consistently activated than any other areas in the entire brain (see Figure 7.12).

The picture seems to be very different when we consider patients with damage to the parietal lobes. For the most part, these patients do not seem to have severe episodic memory deficits (see Cabeza, 2008, for a review). However, some deficits have been found in such patients. In one study (Berryhill, Phuong, Picasso, Cabeza, & Olson, 2007), patients with ventral parietal damage freely recalled events from their own

lives. The memories recalled were less vivid and contained less detail than those of healthy controls. However, the same patients performed normally when they were probed for specific details of their memories.

Cabeza (2008) explained this and other findings in his dual attentional processes hypothesis. According to this hypothesis, ventral parietal cortex is associated with bottom-up attentional processes captured by the retrieval output. These attentional processes were damaged in the patients studied by Berryhill et al. (2007). In contrast, dorsal parietal cortex is associated with top-down attentional processes influenced by retrieval goals. The hypothesis is supported by two findings (see Cabeza, 2008, for a review):

- (1) There is greater ventral parietal activation when memory performance is high due to greater capture of bottom-up attention by relevant stimuli.
- (2) There is greater dorsal parietal activation when memory performance is low due to greater demands on top-down attention.

### Evaluation

Considerable progress has been made in understanding the involvement of different brain areas in the major memory systems. The findings



from cognitive neuroscience are generally consistent with those from cognitive psychology. As a result, we have an increasingly clear overall picture of how memory works.

What are the limitations of research in this area? First, the findings from brain-damaged patients and from functional neuroimaging sometimes seem inconsistent. Thus, for example, the importance of the parietal cortex in human memory seems greater in neuroimaging studies than in studies on brain-damaged patients.

Second, even when we have established that a given brain area is important with respect to some memory system, its role is not always very

clear. A brain area might be important because it is needed for initial encoding, for subsequent storage of information, for control of memory-relevant processes, or for retrieval of stored information. Finding that a given brain area is activated during a particular memory task does not immediately indicate *why* it is activated.

Third, a major task for the future is to understand how different brain areas interact and combine during learning and memory. Learning and memory undoubtedly depend upon networks consisting of several brain regions, but as yet we know relatively little about the structure or functioning of such networks.

## CHAPTER SUMMARY

- Introduction

There are several long-term memory systems. However, the crucial distinction is between declarative and non-declarative memory. Strong evidence for that distinction comes from amnesic patients having severely impaired declarative memory but almost intact non-declarative memory and from functional neuroimaging. Declarative memory can be divided into episodic and semantic memory. Non-declarative memory can be divided into repetition priming and procedural memory or skill learning.

- Episodic vs. semantic memory

Virtually all amnesic patients have severe problems with forming new episodic memories but many have only modest problems in forming new semantic memories. Some amnesic patients have retrograde amnesia mainly for episodic memory, whereas others have retrograde amnesia mainly for semantic memory. Damage to the hippocampal complex has less effect on semantic memory than on episodic memory, whereas damage to the neocortex impairs semantic memory. Functional neuroimaging also indicates that different brain areas are associated with episodic and semantic memory.

- Episodic memory

There is an important distinction between familiarity and recollection in recognition memory. According to the binding-of-item-and-context model, familiarity judgements depend on perirhinal cortex, whereas recollection depends on binding what and where information in the hippocampus. Free recall involves similar brain areas to recognition memory. However, it is associated with higher levels of brain activity, and it also involves some brain areas not needed for recognition memory. Episodic memory is basically constructive rather than reproductive, and so we remember the gist or essence of our past experiences. We use the constructive processes associated with episodic memory to imagine future events.

- **Semantic memory**  
Collins and Quillian (1969) argued that semantic memory is organised into hierarchical networks with concept properties stored as high up the hierarchy as possible. This inflexible approach was superseded by spreading activation theory, in which activation of one concept causes activation to spread to semantically related concepts. Perceptual–functional theories assume that the visual or perceptual features of an object are stored in different locations from its functional features. Such theories are oversimplified. The distributed-plus-hub theory provides the most comprehensive approach to semantic memory. There are hubs (unified abstract conceptual representations) for concepts as well as distributed modality-specific information. Evidence from patients with semantic dementia indicates that these hubs are stored in the anterior temporal lobes.
- **Non-declarative memory**  
Amnesic patients typically have intact repetition priming but impaired declarative memory, whereas a few patients with other disorders show the opposite pattern. Priming is associated with perceptual fluency and increased neural efficiency. Amnesic patients generally (but not always) have high levels of procedural learning and memory. This is the case whether standard motor-skill tasks are used or tasks requiring skills similar to those needed in the real world.
- **Beyond declarative and non-declarative memory: amnesia**  
Several theorists have argued that the distinction between declarative and non-declarative memory is oversimplified and is inadequate to explain the memory deficits of amnesic patients. According to an alternative viewpoint, amnesic patients are deficient at binding or forming associations of all kinds. The evidence mostly supports this binding hypothesis over the traditional viewpoint that amnesic patients are deficient at declarative or explicit memory.
- **Long-term memory and the brain**  
Research on amnesic patients has shown that an extended hippocampal system is crucial for episodic memory. Skill learning or procedural memory involves the striatum and the cerebellum. Patients with Parkinson's disease have damage to the striatum and are generally impaired at procedural learning. Neuroimaging studies suggest that the prefrontal cortex is often involved in the early stages of procedural learning and the striatum at later stages. The dorsolateral prefrontal cortex is involved in relational encoding and post-retrieval monitoring. The ventrolateral prefrontal cortex is involved in controlled retrieval and a process dealing with competing memory representations. The parietal cortex is involved in various attentional processes of relevance to learning and memory.

## FURTHER READING

- Baddeley, A.D., Eysenck, M.W., & Anderson, M.C. (2009). *Memory*. Hove, UK: Psychology Press. Several chapters (especially 5, 6, and 11) are of direct relevance to the topics covered in this chapter.

- Foerde, K., & Poldrack, R.A. (2009). Procedural learning in humans. In *Encyclopedia of neuroscience*. New York: Elsevier. This chapter gives an excellent overview of theory and research on procedural learning and procedural memory.
- Patterson, K., Nestor, P.J., & Rogers, T.T. (2007). Where do you know what you know? The representation of semantic knowledge in the human brain. *Nature Reviews Neuroscience*, 8, 976–987. The authors provide a succinct overview of our current understanding of how semantic memory is organised within the brain.
- Reder, L.M., Park, H., & Kieffaber, P.D. (2009). Memory systems do not divide on consciousness: Re-interpreting memory in terms of activation and binding. *Psychological Bulletin*, 135, 23–49. The distinction between explicit/declarative and implicit/non-declarative memory systems is evaluated in the light of the evidence and an alternative theoretical perspective is proposed.
- Schacter, D.L., & Addis, D.R. (2007). The cognitive neuroscience of constructive memory: Remembering the past and imagining the future. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 362, 773–786. Interesting new perspectives on episodic memory are offered in this article by Schacter and Addis.
- Schacter, D.L., Wig, G.S., & Stevens, W.D. (2007). Reductions in cortical activity during priming. *Current Opinion in Neurobiology*, 17, 171–176. Schacter and his co-authors discuss the main mechanisms underlying priming.