SOME QUESTIONS WE WILL CONSIDER

- What is the best way to store information in long-term memory? (180)
- What are some techniques we can use to help us get information out of long-term memory when we need it? (187)
- How is it possible that a lifetime of experiences and accumulated knowledge can be stored in neurons? (193)
- How can the results of memory research be used to create more effective study techniques? (202)

In my students' "top 10" list of what they use memory for (Chapter 5, page 121), we saw that remembering material for exams was at the top of the list. Although uses for memory extend far beyond studying for exams, thinking about studying is a good way to begin our discussion of some of the things we need to explain about long-term memory (LTM).

When you study, one of your goals is to get information into LTM. We saw in Chapter 5, when we described Rachel ordering pizza, that the process of acquiring information and transferring it into LTM is called **encoding**. Notice that the term *encoding* is similar to the term *coding* that we discussed in relation to STM and LTM in Chapter 6. Some authors use these terms interchangeably. We have used the term *coding* to refer to the *form* in which information is represented. For example, a word can be coded visually or by its sound or by its meaning. We will use the term *encoding* to refer to the *process* used to get information into LTM. For example, a word can be encoded by repeating it over and over, by thinking of other words that rhyme with it, or by using it in a sentence. One of the main messages in this chapter is that some methods of encoding are more effective than others.

Imagine that you've just finished studying for an exam and are pretty sure that you have encoded the material that is likely to be on the exam into your LTM. But the moment of truth occurs when you are in the exam and you have to remember some of this information to answer a question. This remembering involves accessing some of the information that you've encoded and transferring it from LTM into working memory to become consciously aware of it. This process of transferring information from LTM to working memory is called **retrieval**. It is, of course, essential to your success on the exam, because even if information is in LTM, it doesn't help you answer the exam question if you can't retrieve it. One of the main factors that determines whether you can retrieve information from LTM is the way that information was encoded when you learned it. In the next section, we will focus on how information is encoded into LTM. We will then consider retrieval and how it relates to encoding.

Encoding: Getting Information Into Long-Term Memory

There are a number of ways of getting information into long-term memory, some of which are more effective than others. One example is provided by different ways of rehearsing information. Consider, for example, holding a phone number in your memory by repeating it over and over. If you do this without any consideration of meaning or making connections with other information, you are engaging in **maintenance rehearsal**. Typically, this type of rehearsal results in poor memory, so you don't remember the number when you want to call it again later.

But what if, instead of mindlessly repeating the phone number, you find a way to relate it to something meaningful. As it turns out, the first three numbers are the same as your phone number, and the last four just happen to be the year you were born! Coincidence as this may be, it provides an example of being able to remember the number by considering meaning or making connections to other information. When you do that, you are engaging in **elaborative rehearsal**. Typically, this type of rehearsal results in better memory than maintenance rehearsal.

This contrast between maintenance rehearsal and elaborative rehearsal is one example of how encoding can influence the ability to retrieve memories. We will now consider a number of other examples, many of which show that better memory is associated with encoding that is based on meaning and making connections.

LEVELS OF PROCESSING THEORY

An early idea linking the type of encoding to retrieval, proposed by Fergus Craik and Robert Lockhart (1972), is called **levels of processing theory**. According to levels of processing theory, memory depends on the depth of processing that an item receives. **Depth of processing** distinguishes between *shallow processing* and *deep processing.* Shallow processing involves little attention to meaning, as when a phone number is repeated over and over or attention is focused on a word's physical features such as whether it is printed in lowercase or capital letters. **Deep processing** involves close attention, focusing on an item's meaning and relating it to something else. According to levels of processing theory, deep processing results in better memory than shallow processing.

In an experiment testing memory following different levels of processing, Craik and Endel Tulving (1975) presented words to subjects and asked them three different types of questions:

1. A question about the physical features of the word. For example, subjects see the word *bird* and are asked whether it is printed in capital letters (**Figure 7.1a**).
2. A question about rhyming. For example, subjects see the word *train* and are asked if it rhymes with the word *pain.*
3. A fill-in-the-blanks question. For example, subjects see the word *car* and are asked if it fits into the sentence "He saw a _______ on the street."

The three types of questions were designed to create different levels of processing: (1) physical features = shallow processing; (2) rhyming = deeper processing; (3) fill in the blanks = deepest processing. After subjects responded to these three types of questions, they were given a memory test to see how well they recalled the words. The results, shown in **Figure 7.1b**, indicate that deeper processing is associated with better memory.

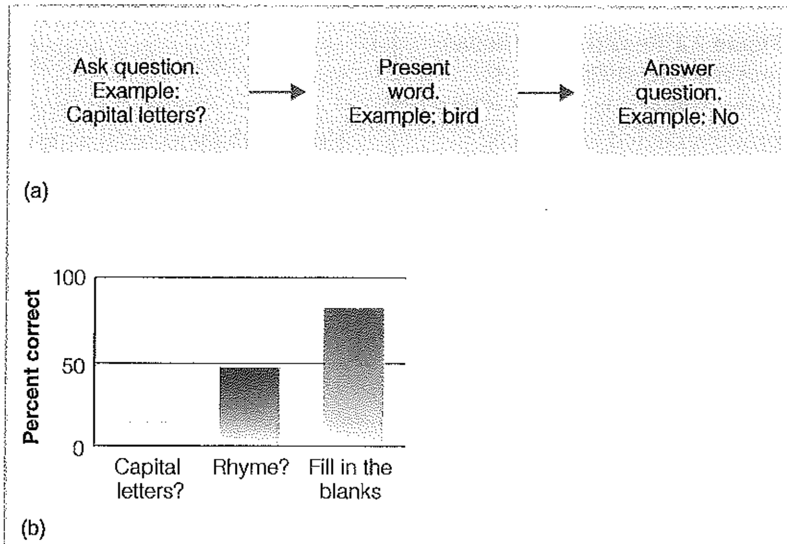

Figure 7.1 (a) Sequence of events in Craik and Tulving's (1975) experiment. (b) Results of this experiment. Deeper processing (fill-in-the-blanks question) is associated with better memory.

The idea of levels of processing motivated a great deal of research but became less popular when it became apparent that it was difficult to define exactly what depth of processing is. For example, how do we know that Craik and Tulving's fill-in-the-blanks task results in deeper processing than the rhyming task? You might say that deeper processing for the fill-in-the-blanks task is indicated by Craik and Tulving's finding that this task results in better memory. But this is an example of circular reasoning: Defining a procedure as deeper because it results in better memory and then using that procedure to show that deeper processing results in better memory doesn't really prove anything. What is needed is a way to define depth of processing that is independent of the memory test, but such a definition does not exist.

Even though the term *levels of processing* is rarely used by present-day memory researchers, the basic idea behind levels of processing theory—that memory retrieval is affected by how items are encoded—is still widely accepted, and a great deal of research has demonstrated this relationship. For example, research at about the same time that levels of processing theory was proposed showed that forming images can improve memory for word pairs.

FORMING VISUAL IMAGES

Gordon Bower and David Winzenz (1970) decided to test whether using visual imagery—"images in the head" that connect words visually—can create connections that enhance memory. They used a procedure called **paired-associate learning,** in which a list of word pairs is presented. Later, the first word of each pair is presented, and the subject's task is to remember the word it was paired with.

Bower and Winzenz presented a list of 15 pairs of nouns, such as *boat–tree,* to subjects for 5 seconds each. One group was told to silently repeat the pairs as they were presented, and another group was told to form a mental picture in which the two items were interacting. When subjects were later given the first word and asked to recall the second one for each pair, the subjects who had created images remembered more than twice as many words as the subjects who had just repeated the word pairs (**Figure 7.2**).

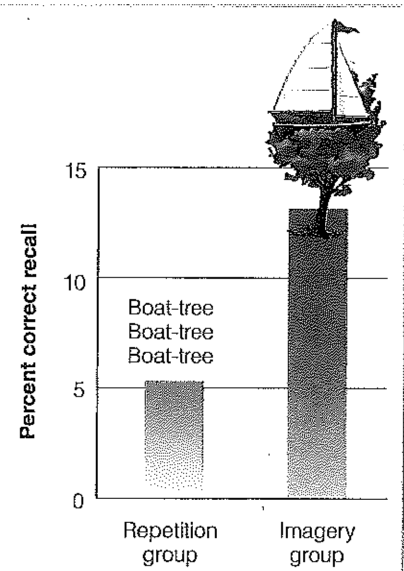

Figure 7.2 Results of the Bower and Winzenz (1970) experiment. Subjects in the repetition group repeated word pairs. Subjects in the imagery group formed images representing the pairs. © Cengage Learning

LINKING WORDS TO YOURSELF

Another example of how memory is improved by encoding is the **self-reference effect**: Memory is better if you are asked to relate a word to yourself. T. B. Rogers and coworkers (1977) demonstrated this by using the same procedure Craik and Tulving had used in their depth-of-processing experiment. The design of Rogers's experiment is shown in **Figure 7.3a**. Subjects read a question for 3 seconds and then saw a word. They answered "yes" if the word was the answer to the question and "no" if it wasn't. In the example in **Figure 7.3a**, the question is "Describes you?" Subjects would respond "yes" to the word *shy* if they saw themselves as shy. Here are examples of all four types of questions, along with a sample word:

1. Question: "Printed in small case?" (Physical characteristics of word) Word: *happy*
2. Question: "Rhymes with *happy*?" (Rhyming) Word: *snappy*
3. Question: "Means the same as *happy*?" (Meaning) Word: *upbeat*
4. Question: "Describes you?" (Self-reference) Word: *happy*

When Rogers then tested his subjects' recall, he obtained the results shown in **Figure 7.3b** for words that resulted in a "yes" response. Subjects were more likely to remember words that they had rated as describing themselves.

Why are subjects more likely to remember words they connect to themselves? One possible explanation is that the words become linked to something the subjects know well—themselves. Generally, statements that result in richer, more detailed representations in a person's mind result in better memory.

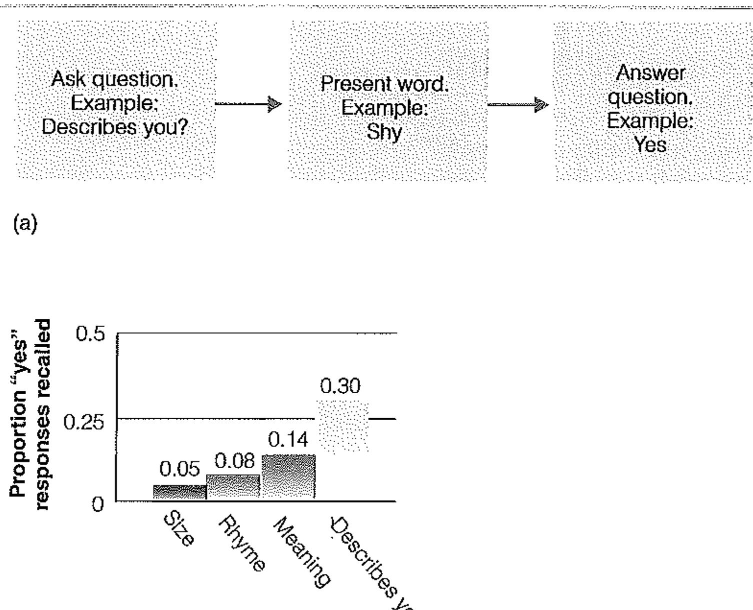

Figure 7.3 (a) Sequence of events in Rogers et al.'s (1977) self-reference experiment. This is the same as the design of Craik and Tulving's (1975) experiment shown in **Figure 7.1**, but the questions refer to the person being tested. (b) Results of the experiment. *(Source: Based on T. B. Rogers, N. A. Kuiper, & W. S. Kirker, Self-reference and the encoding of personal information,* Journal of Personality and Social Psychology, 35, *677–688, 1977.)*

GENERATING INFORMATION

Generating material yourself, rather than passively receiving it, enhances learning and retention. Norman Slameka and Peter Graf (1978) demonstrated this effect, called the **generation effect**, by having subjects study a list of word pairs in two different ways:

1. *Read group*: Read these pairs of related words. king–crown; horse–saddle; lamp–shade; etc.
2. *Generate group*: Fill in the blank with a word that is related to the first word. king–cr ______; horse–sa ______; lamp–sh ______; etc.

After either reading the pairs of words (read group) or generating the list of word pairs based on the word and first two letters of the second word (generate group), subjects were presented with the first word in each pair and were told to indicate the word that went with it. Subjects who had *generated* the second word in each pair were able to reproduce 28 percent more word pairs than subjects who had just *read* the word pairs. You might guess that this finding has some important implications for studying for exams. We will return to this idea later in the chapter.

ORGANIZING INFORMATION

Folders on your computer's desktop, computerized library catalogs, and tabs that separate different subjects in your notebook are all designed to organize information so it can be accessed more efficiently. The memory system also uses organization to access information. This has been shown in a number of ways.

DEMONSTRATION

READING A LIST

Get paper and pen ready. Read the following words, then cover them and write down as many as you can.

apple, desk, shoe, sofa, plum, chair, cherry, coat, lamp, pants, grape, hat, melon, table, gloves

STOP! Cover the words and write down the ones you remember, before reading further.

Look at the list you created and notice whether similar items (for example, *apple, plum, cherry; shoe, coat, pants*) are grouped together. If they are, your result is similar to the result of research that shows that subjects spontaneously organize items as they recall them (Jenkins & Russell, 1952). One reason for this result is that remembering words in a particular category may serve as a **retrieval cue**—a word or other stimulus that helps a person remember information stored in memory. In this case, a word in a particular category, such as fruits, serves as a retrieval cue for other words in that category. So, remembering the word *apple* is a retrieval cue for other fruits, such as *grape* or *plum*, and therefore creates a recall list that is more organized than the original list that you read.

If words presented randomly become organized in the mind, what happens when words are presented in an organized way during encoding? Gordon Bower and coworkers (1969) answered this question by presenting material to be learned in an "organizational tree," which organized a number of words according to categories. For example, one tree organized the names of different minerals by grouping together precious stones, rare metals, and so on (Figure 7.4).

One group of subjects studied four separate trees for minerals, animals, clothing, and transportation for 1 minute each and were then asked to recall as many words as they could from all four trees. In the recall test, subjects tended to organize their

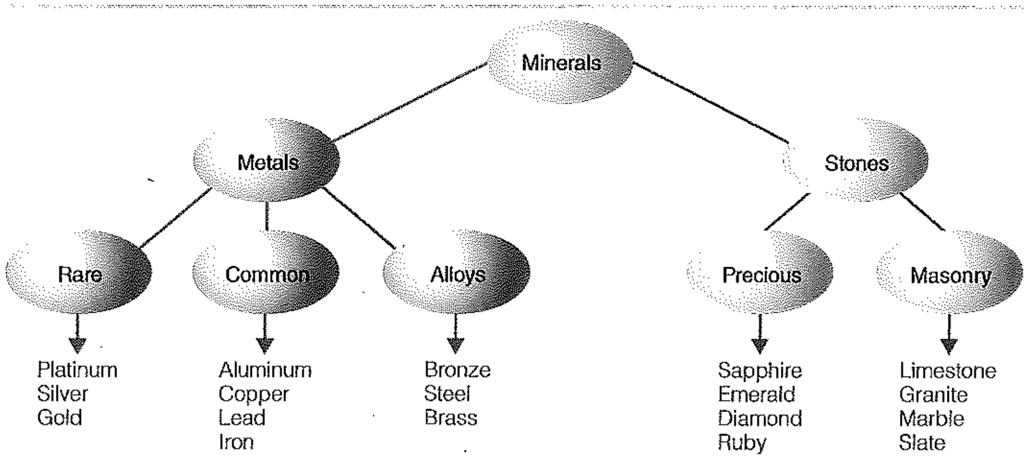

Figure 7.4 The organized "tree" for minerals used in Bower et al.'s (1969) experiment on the effect of organization on memory. *(Source: G. H. Bower et al., Hierarchical retrieval schemes in recall of categorized word lists,* Journal of Verbal Learning and Verbal Behavior, *8, 323–343, Figure 1. Copyright © 1969 Elsevier Ltd. Republished with permission.)*

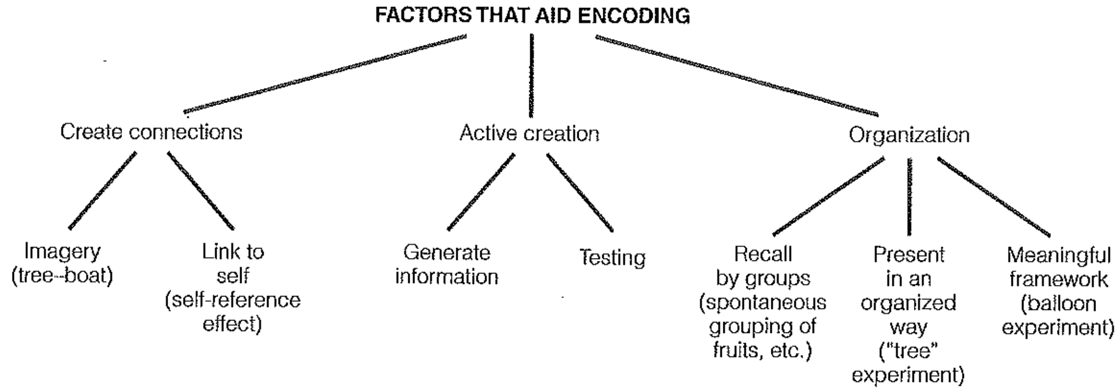

Figure 7.5 An organized tree for some of the material about encoding presented in this section of the chapter. © Cengage Learning

responses in the same way the trees were organized, first saying "minerals," then "metals," then "common," and so on. Subjects in this group recalled an average of 73 words from all four trees.

Another group of subjects also saw four trees, but the words were randomized, so that each tree contained a random assortment of minerals, animals, clothing, and transportation. These subjects were able to remember only 21 words from all four trees. Thus, organizing material to be remembered results in substantially better recall. Perhaps this is something to keep in mind when creating study materials for an exam. You might, for example, find it useful to organize material you are studying for your cognitive psychology exam in trees like the one in **Figure 7.5**.

If presenting material in an organized way improves memory, we might expect that *preventing* organization from happening would *reduce* the ability to remember. This effect was illustrated by John Bransford and Marcia Johnson (1972), who asked their subjects to read the following passage:

> If the balloons popped, the sound wouldn't be able to carry since everything would be too far away from the correct floor. A closed window would also prevent the sound from carrying, since most buildings tend to be well insulated. Since the whole operation depends on the steady flow of electricity, a break in the middle of the wire would also cause problems. Of course, the fellow could shout, but the human voice is not loud enough to carry that far. An additional problem is that the string could break on the instrument. Then there would be no accompaniment to the message. It is clear that the best situation would involve less distance. Then there would be fewer potential problems. With face to face contact, the least number of things could go wrong. (p. 719)

What was that all about? Although each sentence makes sense, it was probably difficult to picture what was happening, based on the passage. Bransford and Johnson's subjects not only found it difficult to picture what was going on, but they also found it extremely difficult to *remember* this passage.

To make sense of this passage, look at **Figure 7.8** on page 187 and then reread the passage. When you do this, the passage makes more sense. Bransford and Johnson's (1972) subjects who saw this picture *before* they read the passage remembered twice as much from the passage as subjects who did not see the picture or subjects who saw the picture *after* they read the passage. The key here is organization. The picture provides a mental framework that helps the reader link one sentence to the next to create a meaningful story. The resulting organization makes this passage easier to comprehend and much easier to remember later. This example illustrates once again that the ability to remember material depends on how that material is programmed into the mind.

RELATING WORDS TO SURVIVAL VALUE

James Nairne (2010) proposes that we can understand how memory works by considering its function, because, through the process of evolution, memory was shaped to increase the ability to survive. The following memory demonstration is based on this idea.

DEMONSTRATION

REMEMBERING LISTS

Part 1. Cover the list below and then uncover each word one by one. Your task is to count the number of vowels in each word and then go right on to the next one. Once you get to the end of the list, cover it and follow the instructions at the end of the list.

chair

mathematics

elephant

lamp

car

elevator

thoughtful

cactus

Instructions: With the list covered, count backward by 3s from 100. When you get to 76, write down the words you remember. Do that now.

Part 2. Cover the list below and uncover each word one by one as you did in the previous part. This time, imagine that you are stranded in the grasslands of a foreign land without any basic survival materials. Rate on a scale of 1 to 5 how relevant each word below would be for finding steady supplies of food and water and protection from predators (1 = totally irrelevant; 5 = extremely relevant). When you get to the end of the list, follow the instructions.

umbrella

exercise

forgiveness

rock

hamburger

sunlight

coffee

bottle

Instructions: With the list covered, count backward by 3s from 99. When you reach 75, write down the words you remember. Do that now.

Which procedure resulted in better memory—counting the number of vowels or rating an item's survival value? When Nairne and coworkers (2007, 2008) ran experiments similar to this (involving longer lists of words), they found that linking words to survival created memory that was not only better than memory created by counting vowels but was also better than memory achieved by the "elaborative" tasks we have described such as forming visual images, linking words to oneself, and generating information. Whether this advantage is due to evolution is debated among memory researchers, but there is no question that relating words to something meaningful and potentially important like survival does enhance memory (also see Klein et al., 2011).

RETRIEVAL PRACTICE

As we will see when we consider study techniques at the end of this chapter, many students prepare for tests by rereading their notes or information they have highlighted in their text (Karpicke et al., 2009). However, recent research shows that practicing retrieval of information by making up and answering practice test questions results in better memory than rereading the information (Karpicke, 2012).

Henry Roediger and Jeffrey Karpicke (2006) demonstrated the advantages of practice testing using the experimental design in **Figure 7.6**. In the first phase of the experiment, college students read prose passages for 7 minutes followed by a 2-minute break during which they solved math problems. Then one group (the testing group) took a 7-minute recall test in which they were asked to write down as much of the passage as they could remember, in no particular order. The other group (the rereading group) were given 7 minutes to reread the material.

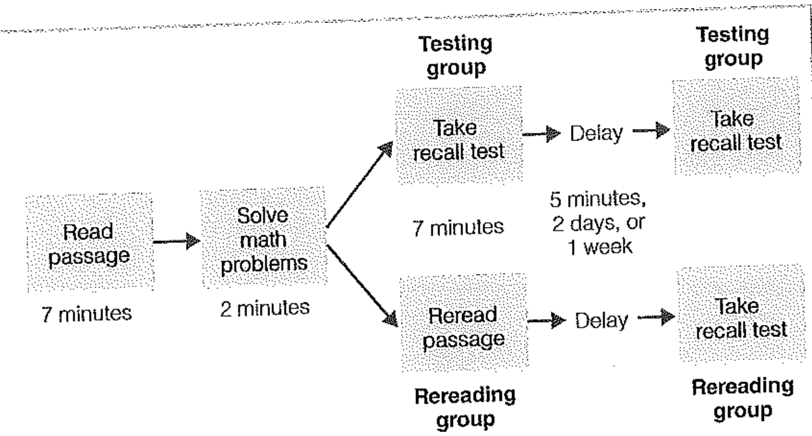

Figure 7.6 Design of the Roediger and Karpicke (2006) "testing effect" experiment. © Cengage Learning

In the second phase of the experiment, which occurred after a delay of either 5 minutes, 2 days, or 1 week, all subjects were given the recall test in which they wrote down what they remembered from the passage. The results, in **Figure 7.7**, show that there was little difference between the rereading and testing groups after the 5-minute delay but that after 1 week, the testing group's performance was much better than the rereading group's. This enhanced performance due to retrieval practice is called the **testing effect**. It has been demonstrated in a large number of experiments, both in the laboratory and in classroom settings (Karpicke et al., 2009). For example, testing resulted in better performance than rereading for eighth-grade students' performance on a history test (Carpenter et al., 2009) and for college students' performance on an exam in a brain and behavior course (McDaniel et al., 2007).

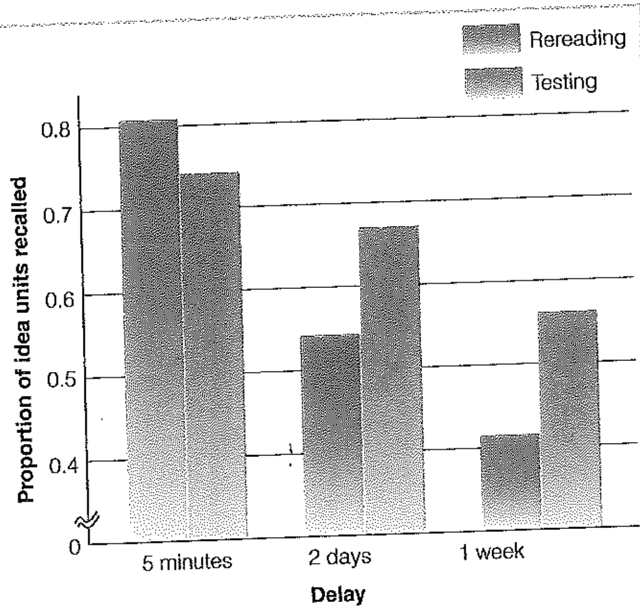

Figure 7.7 Results of the Roediger and Karpicke (2006) experiment. Note that at longer time intervals after learning, the performance of the testing group is better than the performance of the rereading group. *(Source: H. L. Roediger & J. D. Karpicke, Test-enhanced learning: Taking memory tests improves long-term retention,* Psychological Science, *17, 249–255, 2006. Reprinted by permission of SAGE Publications.)*

Table 7.1 lists all of the examples we have described of encoding methods that increase memory. What do these procedures have in common? Practicing retrieval and generating information both involve actively creating and recreating material. Similarities between the other procedures are not as obvious, but it is probably accurate to say that each, in its own way, increases the richness of representation in memory by providing connections between the material to be remembered and other material in memory. For example, when material is organized, it becomes easier to form links between items (such as *apple*, *grape*, and *plum*) in a list. What all this means is that there is a close relationship between encoding and retrieval. We will consider further evidence for this connection as we discuss retrieval in the next section.

Table 7.1: Encoding Procedures That Affect Retrieval

CONDITION	EXPERIMENT/RESULT
Forming visual images	Pairs of words are remembered better if images are formed (compared to just reading word pairs).
Linking words to yourself	Words associated with yourself are remembered better (self-reference effect).
Generating information	Memory is better if the second word of a word pair is generated by the person, compared to just being presented with the word (generation effect).
Organizing information	Studying information that is organized, as in a "tree," results in better memory. Presenting information so organization is difficult ("balloon" story) results in poor memory.
Relating words to survival value	Memory is enhanced by relating words to survival value. This works because it helps link words to something meaningful.
Practicing retrieval	Testing following learning results in better memory than rereading material after learning (testing effect).

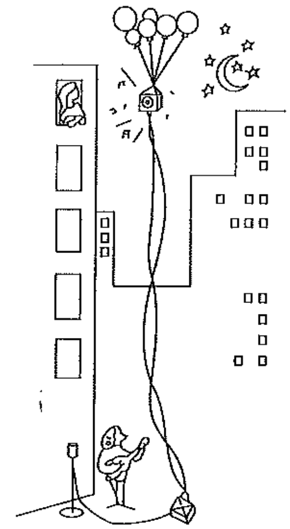

Figure 7.8 Picture used by Bransford and Johnson (1972) to illustrate the effect of organization on memory. *(Source: J. D. Bransford & M. K. Johnson, Contextual prerequisites for understanding: Some investigations of comprehension and recall,* Journal of Verbal Learning and Verbal Behavior, 11, *717–726, Figure 1. Copyright © 1972 Elsevier Ltd. Republished with permission.)*

TEST YOURSELF 7.1

1. What is encoding? Retrieval? Why is each necessary for successful memory?
2. What is the difference between elaborative rehearsal and maintenance rehearsal in terms of (a) the procedures associated with each type of rehearsal and (b) their effectiveness for creating long-term memories?
3. What is levels of processing theory? Be sure you understand depth of processing, shallow processing, and deep processing. What would levels of processing theory say about the difference between maintenance rehearsal and elaborative rehearsal?
4. What does it mean to say that levels of processing theory does not define depth of processing independently of memory?
5. Give examples of how memory for a word can be increased by (a) forming visual images, (b) linking words to yourself, (c) generating the word during acquisition, (d) organizing information, (e) rating the word in terms of survival, and (f) practicing retrieval. What do these procedures have in common?
6. What do the results of the procedures in #5 indicate about the relationship between encoding and retrieval?

Retrieval: Getting Information Out of Memory

Before material that has been encoded can be used, it must be retrieved. The process of retrieval is extremely important because many of our failures of memory are failures of retrieval—the information is "in there," but we can't get it out. For example, you've studied hard for an exam but can't come up with an answer when you're taking the exam, only to remember it later after the exam is over. Or you unexpectedly meet someone you have previously met and can't recall the person's name, but it suddenly comes to you as you are talking (or, worse, after the person leaves). In both of these examples, the information you need has been encoded, but you can't retrieve it when you need it.

RETRIEVAL CUES

When we discussed how remembering the word *apple* might serve as a retrieval cue for *grape* (page 183), we defined *retrieval cues* as words or other stimuli that help us remember information stored in our memory. As we now consider these cues in more detail, we will see that they can be provided by a number of different sources.

An experience I had as I was preparing to leave home to go to class illustrates how *location* can serve as a retrieval cue. While I was in my office at home, I made a mental note to be sure to take the DVD on amnesia to school for my cognitive psychology class. A short while later, as I was leaving the house, I had a nagging feeling that I was forgetting something, but I couldn't remember what it was. This wasn't the first time I'd had this problem, so I knew exactly what to do. I returned to my office, and as soon as I got there I remembered that I was supposed to take the DVD. Returning to the place where I had originally thought about taking the disk helped me to retrieve my original thought. My office served as a retrieval cue for remembering what I wanted to take to class.

You may have had similar experiences in which returning to a particular place stimulated memories associated with that place. The following description by one of my students illustrates retrieval of memories of childhood experiences.

> When I was 8 years old, both of my grandparents passed away. Their house was sold, and that chapter of my life was closed. Since then I can remember general things about being there as a child, but not the details. One day I decided to go for a drive. I went to my grandparents' old house and I pulled around to the alley and parked. As I sat there and stared at the house, the most amazing thing happened. I experienced a vivid recollection. All of a sudden, I was 8 years old again. I could see myself in the backyard, learning to ride a bike for the first time. I could see the inside of the house. I remembered exactly what every detail looked like. I could even remember the distinct smell. So many times I tried to remember these things, but never so vividly did I remember such detail. (Angela Paidousis)

My experience in my office and Angela's experience outside her grandparents' house are examples of retrieval cues that are provided by returning to the location where memories were initially formed. Many other things besides location can provide retrieval cues. Hearing a particular song can bring back memories for events you might not have thought about for years. Or consider smell. I once experienced a musty smell like the stairwell of my grandparents' house and was instantly transported back many decades to the experience of climbing those stairs as a child. The operation of retrieval cues has also been demonstrated in the laboratory using a technique called *cued recall.*

METHOD
CUED RECALL

We can distinguish two types of recall procedures. In **free recall**, a subject is simply asked to recall stimuli. These stimuli could be words previously presented by the experimenter or events experienced earlier in the subject's life. We have seen how this has been used in many experiments, such as the retrieval practice experiment described on page 186. In **cued recall**, the subject is presented with retrieval cues to aid in recall of the previously experienced stimuli. These cues are typically words or phrases. For example, Endel Tulving and Zena Pearlstone (1966) did an experiment in which they presented subjects with a list of words to remember. The words were drawn from specific categories such as birds (*pigeon, sparrow*), furniture (*chair, dresser*), and professions (*engineer, lawyer*), although the categories were not specifically indicated in the original list. For the memory test, subjects in the free recall group were asked to write down as many words as they could. Subjects in the cued recall group were also asked to recall the words but were provided with the names of the categories, such as "birds," "furniture," and "professions."

The results of Tulving and Pearlstone's experiment demonstrate that retrieval cues aid memory. Subjects in the free recall group recalled 40 percent of the words, whereas subjects in the cued recall group who had been provided with the names of categories recalled 75 percent of the words.

One of the most impressive demonstrations of the power of retrieval cues was provided by Timo Mantyla (1986), who presented his subjects with a list of 504 nouns, such as *banana*, *freedom*, and *tree*. During this study phase, subjects were told to write three words they associated with each noun. For example, three words for *banana* might be *yellow*, *bunches*, and *edible*. In the test phase of the experiment, these subjects were presented with the three words they had generated (self-generated retrieval cues) for half the nouns, or with three words that someone else had generated (other-person-generated retrieval cues) for the other half of the nouns. Their task was to remember the noun they had seen during the study phase.

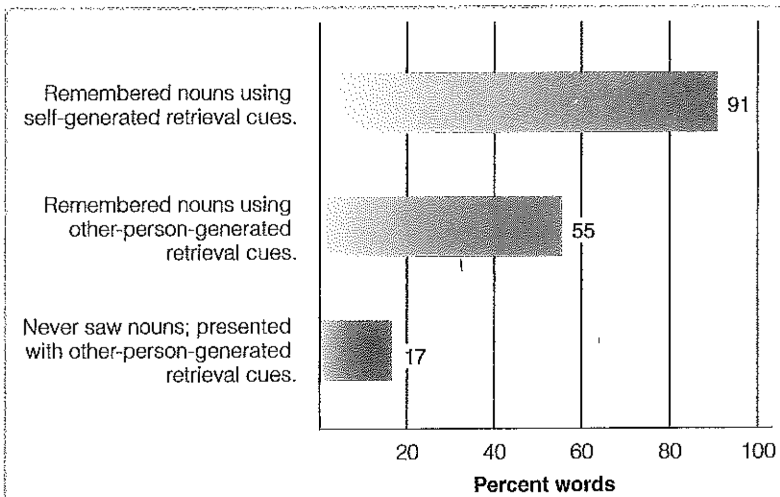

Figure 7.9 Results of Mantyla's (1986) experiment. Memory was best when retrieval cues were created by the person (top bar), and not as good when retrieval cues were created by someone else (middle bar). Control subjects who tried to guess the words based on retrieval cues generated by someone else did poorly (bottom bar).

The results indicated that when the self-generated retrieval cues were presented, subjects remembered 91 percent of the words (top bar in Figure 7.9), but when the other-person-generated retrieval cues were presented, subjects remembered only 55 percent of the words (second bar in Figure 7.9).

You might think it would be possible to guess *banana* from three properties like *yellow*, *bunches*, and *edible*, even if you had never been presented with the word *banana*. But when Mantyla ran another control group in which he presented the cue words generated by someone else to subjects who had never seen the 504 nouns, these subjects were able to determine only 17 percent of the nouns. The results of this experiment demonstrate that retrieval cues (the three words) provide extremely effective information for retrieving memories, but that *retrieval cues are significantly more effective when they are created by the person whose memory is being tested*. (Also see Wagenaar, 1986, which describes a study in which Wagenaar was able to remember almost all of 2,400 diary entries he kept over a 6-year period by using retrieval cues.)

MATCHING CONDITIONS OF ENCODING AND RETRIEVAL

The retrieval cues in the two experiments we just described were verbal "hints"—category names like "furniture" in the Tulving and Pearlstone experiment and three-word descriptions created by the subjects in the Mantyla experiment. But we have also seen another kind of "hint" that can help with retrieval: returning to a specific location, such as Angela's grandparents' house or my office.

Let's consider what happened in the office example, in which I needed to return to my office to retrieve my thought about taking a DVD to class. The key to remembering the DVD was that I retrieved the thought "Bring the DVD" by returning to the place where I had originally encoded that thought. This example illustrates the following basic principle: *Retrieval can be increased by matching the conditions at retrieval to the conditions that existed at encoding.*

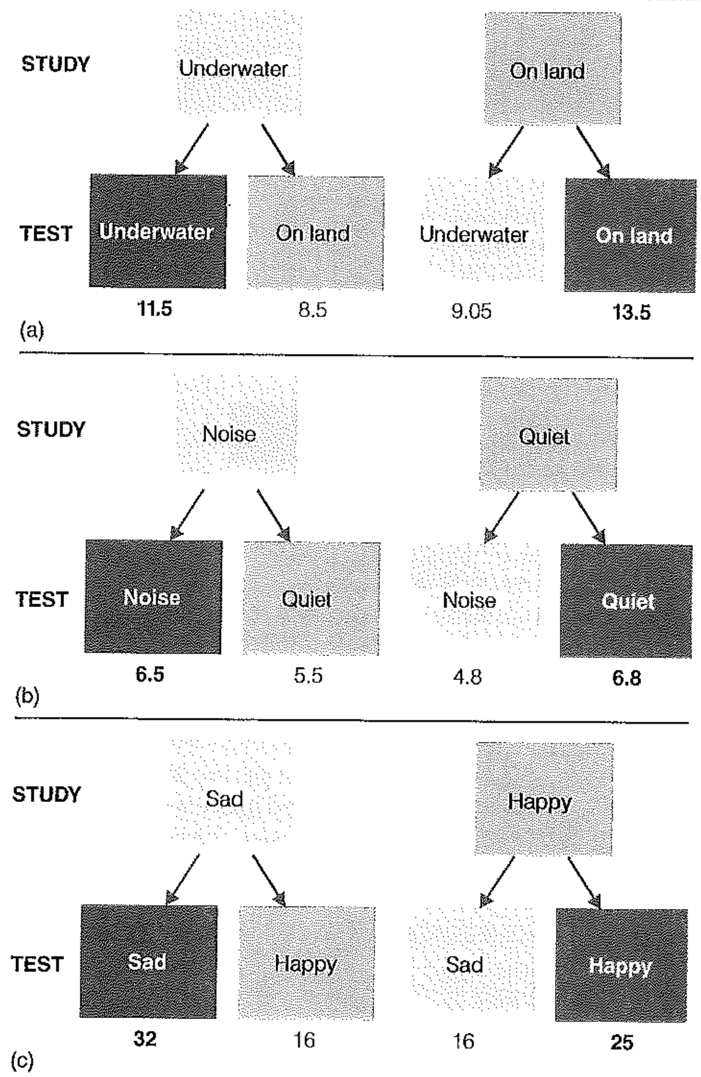

Figure 7.10 Design and results for (a) Godden and Baddeley's (1975) "diving" experiment; (b) Grant et al.'s (1998) "studying" experiment; (c) Eich and Metcalfe's (1989) "mood" experiment. Results for each test condition are indicated by the number directly under that condition. The matching colors (light green to dark green, and light orange to dark orange) indicate situations in which study and test conditions matched.

We will now describe three specific situations in which retrieval is increased by matching conditions at retrieval to conditions at encoding. These different ways to achieve matching are (1) encoding specificity—matching the *context* in which encoding and retrieval occur; (2) state-dependent learning—matching the *internal mood* present during encoding and retrieval; and (3) transfer-appropriate processing—matching the *task* involved in encoding and retrieval.

ENCODING SPECIFICITY The principle of **encoding specificity** states that we encode information along with its context. For example, Angela encoded many experiences within the context of her grandparents' house. When she reinstated this context by returning to the house many years later, she remembered many of these experiences.

A classic experiment that demonstrates encoding specificity is D. R. Godden and Alan Baddeley's (1975) "diving experiment." In this experiment, one group of subjects put on diving equipment and studied a list of words underwater, and another group studied the words on land (Figure 7.10a). These groups were then divided so that half the subjects in the land and water groups were tested for recall on land and half were tested underwater. The results, indicated by the numbers, show that the best recall occurred when encoding and retrieval occurred in the same location.

The results of the diving study, and many others, suggest that a good strategy for test taking would be to study in an environment similar to the environment in which you will be tested. Although this doesn't mean you necessarily have to do all of your studying in the classroom where you will be taking the exam, you might want to duplicate in your study situation some of the conditions that will exist during the exam.

This conclusion about studying is supported by an experiment by Harry Grant and coworkers (1998), using the design in Figure 7.10b. Subjects read an article on psychoimmunology while wearing headphones. The subjects in the "quiet" condition heard nothing in the headphones. Subjects in the "noise" condition heard a tape of background noise recorded during lunchtime in a university cafeteria (which they were told to ignore). Half the subjects in each group were then given a short-answer test on the article under the quiet condition, and the other half were tested under the noise condition.

The results indicate that subjects did better when the testing condition matched the study condition. Because your next cognitive psychology exam will take place under quiet conditions, it might make sense to study under quiet conditions. (Interestingly, a number of my students report that having outside stimulation such as music or television present helps them study. This idea clearly violates the principle of encoding specificity. Can you think of some reasons that students might nonetheless say this?)

STATE-DEPENDENT LEARNING Another example of how matching the conditions at encoding and retrieval can influence memory is **state-dependent learning**—learning that is associated with a particular *internal state,* such as mood or state of awareness. According to the principle of state-dependent learning, memory will be better when a person's internal state (mood or awareness) during retrieval matches his or her internal state during encoding. For example, Eric Eich and Janet Metcalfe (1989) demonstrated that memory is better when a person's mood during retrieval matches his or her mood during encoding. They did this by asking subjects to think positive thoughts while listening to "merry" or happy music, or depressing thoughts while listening to "melancholic" or sad music (**Figure 7.10c**). Subjects rated their mood while listening to the music, and the encoding part of the experiment began when their rating reached "very pleasant" or "very unpleasant." Once this occurred, usually within 15 to 20 minutes, subjects studied lists of words while in their positive or negative mood.

After the study session ended, the subjects were told to return in 2 days (although those in the sad group stayed in the lab a little longer, snacking on cookies and chatting with the experimenter while happy music played in the background, so they wouldn't leave the laboratory in a bad mood). Two days later, the subjects returned, and the same procedure was used to put them in a positive or negative mood. When they reached the mood, they were given a memory test for the words they had studied 2 days earlier. The results indicate that they did better when their mood at retrieval matched their mood during encoding (also see Eich, 1995).

The two ways of matching encoding and retrieval that we have described so far have involved matching the physical situation (encoding specificity) or an internal feeling (state-dependent learning). Our next example involves matching the type of *cognitive task* at encoding and retrieval.

MATCHING THE COGNITIVE TASK: TRANSFER-APPROPRIATE PROCESSING Donald Morris and coworkers (1977) did an experiment that showed that retrieval is better if the same cognitive tasks are involved during both encoding and retrieval. The procedure for their experiment was as follows:

Part I. Encoding

Subjects heard a sentence with one word replaced by "blank" and 2 seconds later they heard a target word. There were two encoding conditions. In the *meaning condition*, the task was to answer "yes" or "no" based on the *meaning* of the word when it filled in the blank. In the *rhyming condition*, subjects answered "yes" or "no" based on the *sound* of the word. Here are some examples:

Meaning Condition

1. Sentence: The *blank* had a silver engine.
   Target word: *train* Correct answer: "yes"
2. Sentence: The *blank* walked down the street.
   Target word: *building* Correct answer: "no"

Rhyming Condition

1. Sentence: *Blank* rhymes with pain.
   Target word: *Train* Correct answer: "yes"
2. Sentence: *Blank* rhymes with car.
   Target word: *Building* Correct answer: "no"

The important thing about these two groups of subjects is that they were asked to *process* the words differently. In one case, they had to focus on the word's meaning to answer the question, and in the other case they focused on the word's sound.

Part II. Retrieval

The question Morris was interested in was how the subjects' ability to retrieve the target words would be affected by the way they processed the words during the retrieval part of the experiment. There were a number of different conditions in this part of the experiment, but we are going to focus on what happened when subjects were required to process words in terms of their sounds.

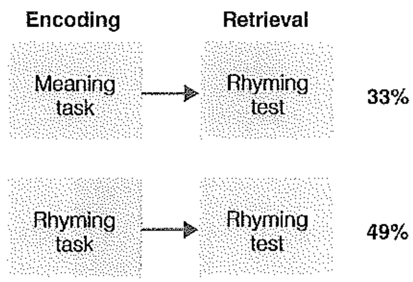

Figure 7.11 Design and results for the Morris et al. (1977) experiment. Subjects who did a rhyming-based encoding task did better on the rhyming test than subjects who did a meaning-based encoding task. This result would not be predicted by levels of processing theory but is predicted by the principle that better retrieval occurs if the encoding and retrieval tasks are matched. © Cengage Learning

Subjects in both the meaning group and the rhyming group were presented with a series of test words, one by one. Some of the test words rhymed with target words presented during encoding; some did not. Their task was to answer "yes" if the test word rhymed with one of the target words and "no" if it didn't. In the examples below, notice that the test words were always different from the target word.

Test word: *rain*	Answer:	"yes" (because it rhymes with the previously presented target word *train*)
Test word: *building*	Answer:	"no" (because it doesn't rhyme with any of the target words that were presented during encoding)

The key result of this experiment was that the subjects' retrieval performance depended on whether the retrieval task matched the encoding task. As shown in **Figure 7.11**, subjects who had focused on rhyming during encoding remembered more words than subjects who had focused on meaning. Thus, subjects who had focused on the word's *sound* during the first part of the experiment did better when the test involved focusing on sound. This result—better performance when the *type of processing* matches in encoding and retrieval—is called **transfer-appropriate processing.**

Transfer-appropriate processing is like encoding specificity and state-dependent learning because it demonstrates that matching conditions during encoding and retrieval improves performance. But, in addition, the result of this experiment has important implications for the levels of processing theory discussed earlier. Remember that the main idea behind levels of processing theory is that deeper processing leads to better encoding and, therefore, better retrieval. Levels of processing theory would predict that subjects who were in the meaning group during encoding would experience "deeper" processing, so they should perform better. Instead, the rhyming group performed better. Thus, in addition to showing that matching the tasks at encoding and retrieval is important, Morris's experiment shows that deeper processing at encoding does not always result in better retrieval, as proposed by levels of processing theory.

Our approach to encoding and retrieval has so far focused on behavioral experiments that consider how conditions of encoding and retrieval affect memory. But there is another approach to studying encoding and retrieval that focuses on physiology. In the rest of this chapter, we will look "under the hood" of memory to consider how physiological changes that occur during encoding influence our ability to retrieve memory for an experience later.

TEST YOURSELF 7.2

1. Retrieval cues are a powerful way to improve the chances that we will remember something. Why can we say that memory performance is better when you use a word in a sentence, create an image, or relate it to yourself, all techniques involving retrieval cues?
2. What is cued recall? Compare it to free recall.
3. Describe the Tulving and Pearlstone cued recall experiment and Mantyla's experiment in which he presented 600 words to his subjects. What was the procedure and what was the result for each experiment, and what does each tell us about retrieval?
4. What is encoding specificity? Describe Baddeley and Godden's "diving" experiment and Grant's studying experiment. What does each one illustrate about encoding specificity? About cued recall?
5. What is state-dependent learning? Describe Eich's experiment.
6. Describe Morris's experiment. What aspect of encoding and retrieval was Morris studying? What implications do the results of this experiment have for matching encoding and retrieval? For levels of processing theory?

Consolidation: The Life History of Memories

Memories have a history. Right after an event or learning has occurred, we remember many details of what happened or what we have learned. But with the passage of time and the accumulation of additional experiences, some of these memories are lost, some change their character, and some might end up being changed from what actually happened.

Another observation about memory is that while every experience creates the potential for a new memory, new memories are fragile and can therefore be disrupted. This was first demonstrated experimentally by German psychologists Georg Müller and Alfons Pilzecker (1900; also see Dewar et al., 2007), who did an experiment in which two groups of subjects learned lists of nonsense syllables. The "immediate" group learned one list and then immediately learned a second list. The "delay" group learned the first list and then waited for 6 minutes before learning the second list (Figure 7.12). When recall for the first list was measured, subjects in the delay group remembered 48 percent of the syllables, but subjects in the immediate (no delay) group remembered only 28 percent. Apparently, immediately presenting the second list to the "no delay" group interrupted the forming of a stable memory for the first list. Based on this result, Müller and Pilzecker proposed the term **consolidation**, which is defined as *the process that transforms new memories from a fragile state, in which they can be disrupted, to a more permanent state, in which they are resistant to disruption.*

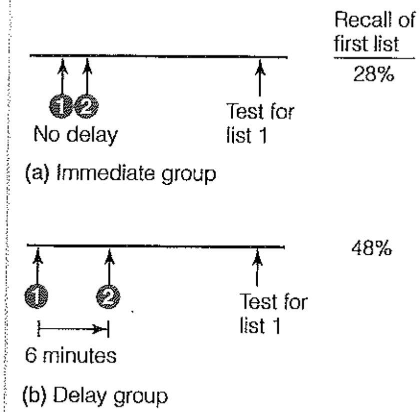

Figure 7.12 Procedure for Müller and Pilzecker's experiment. (a) In the immediate (no delay) condition, subjects used the first list (1) and then immediately learned the second list (2). (b) In the delay condition, the second list was learned after a 6-minute delay. Numbers on the right indicate the percentage of items from the first list recalled when memory for that list was tested later.

In the more than 100 years since Müller and Pilzecker's pioneering experiment, researchers have discovered a great deal about the mechanisms responsible for consolidation and have distinguished two types, based on mechanisms that involve both synapses and neural circuits. Remember from Chapter 2 that synapses are the small spaces between the end of one neuron and the cell body or dendrite of another neuron (see Figure 2.5, page 30), and that when signals reach the end of a neuron, they cause neurotransmitters to be released onto the next neuron. Neural circuits are interconnected groups of neurons. **Synaptic consolidation**, which takes place over minutes or hours, involves structural changes at synapses. **Systems consolidation**, which takes place over months or even years, involves the gradual reorganization of neural circuits within the brain (Nader & Einarsson, 2010).

The fact that synaptic consolidation is relatively fast and systems consolidation is slower doesn't mean that we should think of them as two stages of a process that occur one after the other, like short-term memory and long-term memory in the modal model of memory (Figure 5.2). It is more accurate to think of them as occurring together, as shown in Figure 7.13, but at different speeds and at different levels of the nervous system. When something happens, a process is triggered that causes changes at the synapse. Meanwhile, a longer-term process begins that involves reorganization of neural circuits. Thus, synaptic and systems consolidation are processes that occur simultaneously—one that works rapidly, at the level of the synapse, and another that works more slowly, at the level of neural circuits.

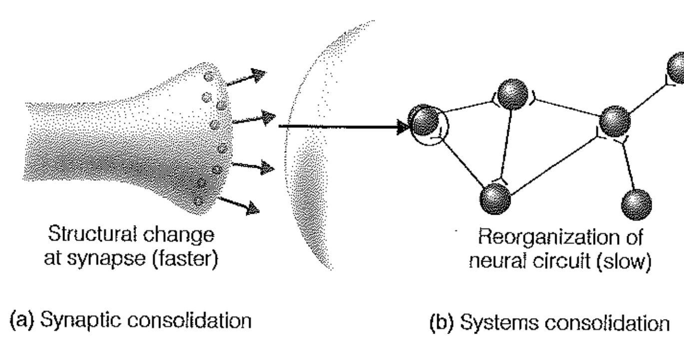

Figure 7.13 Synaptic and systems consolidation. (a) Synaptic consolidation involves changes at the synapses. (a) Systems consolidation involves reorganization of neural connections and takes place over a longer time span.

SYNAPTIC CONSOLIDATION: EXPERIENCE CAUSES CHANGES AT THE SYNAPSE

According to an idea first proposed by the Canadian psychologist Donald Hebb (1948), learning and memory are represented in the brain by physiological changes that take place at the synapse. Let's assume that a particular experience causes nerve impulses to travel down the axon of neuron A in Figure 7.14a, and when these impulses reach the synapse, neurotransmitter is released onto neuron B. Hebb's idea was that

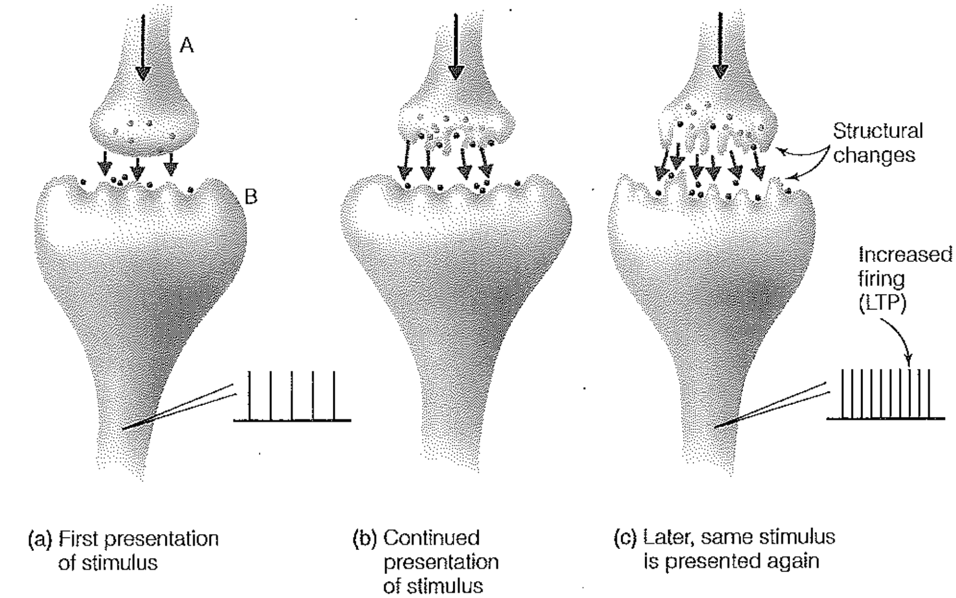

Figure 7.14 What happens at a synapse as (a) a stimulus is first presented. The record next to the electrode indicates the rate of firing recorded from the axon of neuron B. (b) As the stimulus is repeated, structural changes are beginning to occur. (c) After many repetitions, more complex connections have developed between the two neurons, which causes an increase in the firing rate, even though the stimulus is the same one that was presented in (a).

repeated activity can strengthen the synapse by causing structural changes, greater transmitter release, and increased firing (Figures 7.14b and 7.14c). Hebb also proposed that changes that occur in the hundreds or thousands of synapses that are activated around the same time by a particular experience provide a neural record of the experience. For example, your experience of last New Year's Eve, according to this idea, is represented by the pattern of structural changes that occur at many synapses.

Hebb's proposal that synaptic changes provide a record of experiences became the starting point for modern research on the physiology of memory. Researchers who followed Hebb's lead determined that activity at the synapse causes a sequence of chemical reactions, which result in the synthesis of new proteins that cause structural changes at the synapse like those shown in Figure 7.14c (Chklovskii et al., 2004; Kida et al., 2002).

One of the outcomes of structural changes at the synapse is a strengthening of synaptic transmission. This strengthening results in a phenomenon called **long-term potentiation (LTP)**—enhanced firing of neurons after repeated stimulation (Bliss & Lomo, 1973; Bliss et al., 2003; Kandel, 2001). Long-term potentiation is illustrated by the firing records in Figure 7.14. The first time neuron A is stimulated, neuron B fires slowly (Figure 7.14a). However, after repeated stimulation (Figure 7.14b), neuron B fires much more rapidly to the same stimulus (Figure 7.14c).

Results such as these indicate how experiences can cause changes at the synapse. Memories for an experience cause changes in many thousands of synapses, and a specific experience is probably represented by the pattern of firing across this group of neurons. This idea of memories being represented by a pattern of firing is similar to the idea of population coding we introduced in Chapter 2 (see page 36).

Early research, inspired by Hebb's pioneering work on the role of the synapse in memory, focused on synaptic consolidation. More recent research has focused on systems consolidation, investigating the role of the hippocampus and cortical areas in the formation of memories.

SYSTEMS CONSOLIDATION: THE HIPPOCAMPUS AND THE CORTEX

The case of H.M., who lost his ability to form new memories after his hippocampus was removed (Chapter 6, page 160), indicates the importance of the hippocampus in forming new memories. Once it became clear that the hippocampus is essential for forming new memories, researchers began determining exactly how the hippocampus responds to stimuli and how it participates in the process of systems consolidation. One outcome of this research was the proposal of the sequence of steps shown in **Figure 7.15**. This picture of the process of consolidation, called the **standard model of consolidation**, proposes that incoming information activates a number of areas in the cortex (**Figure 7.15a**). Activation is distributed across the cortex because memories typically involve many sensory and cognitive areas. For example, your memory for last New Year's Eve could include sights, sounds, and possibly smells, as well as emotions you were feeling and thoughts you were thinking at the stroke of midnight. To deal with the fact that the activity resulting from this experience is distributed across many cortical areas, the cortex communicates with the hippocampus, as indicated by the colored lines in **Figure 7.15a**. The hippocampus coordinates the activity of the different cortical areas, which, at this point, are not yet connected in the cortex.

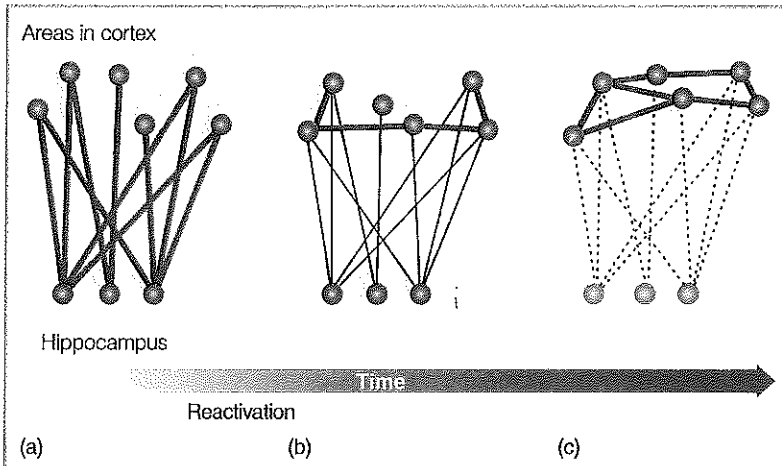

Figure 7.15 Sequence of events that occur during consolidation, according to the standard model of consolidation. (a) Connections between the cortex and the hippocampus are initially strong. (b) As time passes, activity occurs between the hippocampus and the cortex, a process called reactivation. (c) Over time, connections are formed between cortical areas, and the connections between hippocampus and cortex are weakened and eventually vanish.
(Source: Adapted from P. W. Frankland & B. Bontempi, The organization of recent and remote memories, Neuroscience, 6, *119–130, 2005.)*

The major mechanism of consolidation is **reactivation**, a process in which the hippocampus replays the neural activity associated with a memory. During reactivation, activity occurs in the network connecting the hippocampus and the cortex (**Figure 7.15b**), and this activity helps form direct connections between the various cortical areas (**Figure 7.15c**). This way of thinking about the interaction between the hippocampus and the cortex pictures the hippocampus as acting like a "glue" that binds together the representations of memory from different cortical areas.

This standard model was based partially on observations of memory loss caused by trauma or injury. It is well known that head trauma, as might be experienced by a football player taking a hard hit as he runs downfield, can cause a loss of memory. Thus, as the player is sitting on the bench after the impact, he might not be aware of what happened during the seconds or minutes before getting hit. This loss of memory for events that occurred before the injury, called **retrograde amnesia**, can extend back minutes, hours, or even years, depending on the nature of the injury.

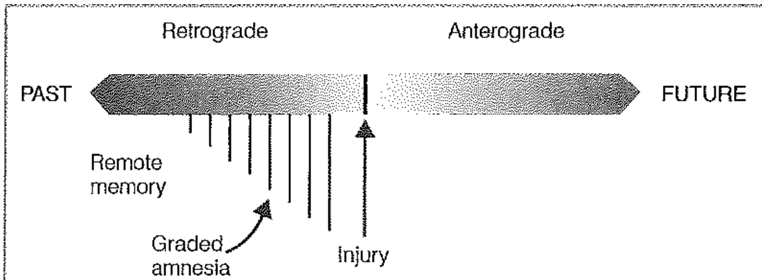

Figure 7.16 Anterograde amnesia is amnesia for events that occur after an injury (the inability to form new memories). Retrograde amnesia is amnesia for events that happened before the injury (the inability to remember information from the past). The vertical lines, which symbolize the amount of retrograde amnesia, indicate that amnesia is more severe for events or learning that was closer in time leading up to the injury. This is the graded nature of retrograde amnesia.

Figure 7.16 illustrates a characteristic of retrograde amnesia called **graded amnesia**—the amnesia tends to be most severe for events that happened just before the injury and to become less severe for earlier events. This gradual decrease in amnesia corresponds, according to the standard model, to the changes in connections between the hippocampus and cortical areas shown in **Figures 7.15b** and **7.15c**; as time passes after an event, connections between the cortical areas are formed and strengthened, and the connections between the hippocampus and cortex weaken and eventually vanish. Thus, according to the standard model of consolidation, the hippocampus is strongly active when memories are first formed and initially recalled but becomes less involved as memories are consolidated, until eventually the connections between cortical areas themselves are sufficient to retrieve *remote memories*—memories for events that occurred long ago.

Most researchers accept that both the hippocampus and the cortex are involved in consolidation. There is, however, some disagreement regarding whether the hippocampus is important only at the beginning of consolidation, as depicted in **Figure 7.15**, or whether the hippocampus continues to be important, even for remote memories.

According to the **multiple trace model of consolidation**, the hippocampus is involved in retrieval of episodic memories, even if they originated long ago (Nadel & Moscovitch, 1997). Evidence for this idea comes from experiments like one by Asaf Gilboa and coworkers (2004), who elicited recent and remote episodic memories by showing subjects photographs of themselves engaging in various activities that were taken at times ranging from very recently to the distant past, when they were 5 years old. The results of this experiment showed that the hippocampus was activated during retrieval of both recent and remote episodic memories.

But this doesn't mean that the hippocampus is involved in all aspects of memory retrieval. Indre Viskontas and coworkers (2009) demonstrated that the response of the hippocampus can change over time. These researchers had subjects view pairs of stimuli, such as the alligator and the candle in **Figure 7.17a**, while undergoing fMRI in a scanner. Subjects were told to imagine the items in each pair interacting with each other. Then 10 minutes later and 1 week later, subjects saw the original pairs plus some others they had not seen and were told to respond to each pair in one of three ways: (1) *remember* (R), meaning "I remember seeing the pair when it was originally presented"; (2) *know* (K), meaning "The pair definitely looks familiar, but I don't remember when I was originally seeing it"; or (3) *don't*, meaning "I don't remember or know the stimuli." As we saw in Chapter 6, when we described the remember/know procedure (see Method, page 165), *remember* responses indicate episodic memory and *know* responses indicate semantic memory.

The behavioral results, shown in **Figure 7.17b**, show that there were more *remember* (episodic) responses than *know* (semantic) responses after 10 minutes, but that only half of the *remember* responses remained after 1 week. This is exactly what we would expect from other research showing that memories lose their episodic character over time, which we described in Chapter 6 (page 166) as the semanticization of remote memories.

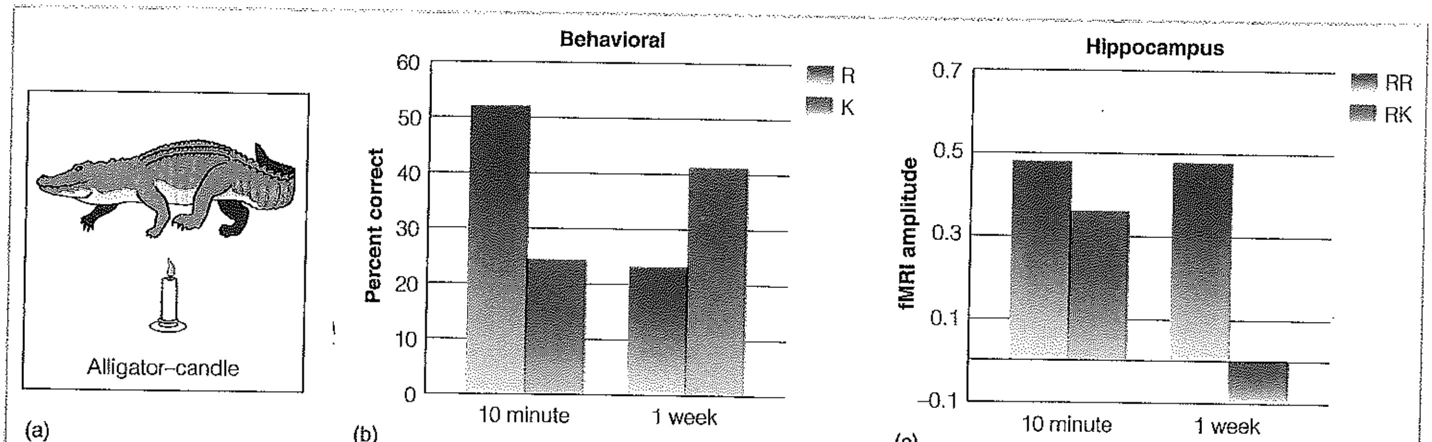

Figure 7.17 Stimulus and results for the Viskontas et al. (2009) experiment. (a) Subjects saw picture pairs like this one while being scanned. (b) When asked to remember the pairs, the *remember* response, which corresponds to episodic memory, was high at 10 minutes, but decreased after 1 week. (c) Activity of the hippocampus remained the same for pictures that were remembered at both 10 minutes and 1 week (RR), but decreased for pictures for which the *remember* response was absent at 1 week (RK). *(Source: Adapted from I. V. Viskontas, V. A. Carr, S. A. Engel, & B. J. Kowlton, The neural correlates of recollection: Hippocampal activation declines as episodic memory fades,* Hippocampus, *19, 265–272, Figures 1, 3, & 6, 2009.)*

But what's happening in the brain as the episodic memories are being lost? Viskontas determined the hippocampus's response for pairs to which subjects responded *remember* both at 10 minutes and at 1 week (RR pairs) and for pairs to which subjects responded *remember* at 10 minutes but *know* at 1 week (RK pairs). The results, in **Figure 7.17c**, are striking: The hippocampus response remained high for RR pairs (the ones that remained episodic at 1 week), but dropped to near zero for RK pairs (the ones that had lost their episodic character at 1 week). What this means is that the hippocampus response does change over time, but only for stimuli that have lost their episodic character.

Thus, the response of the hippocampus decreases over time, as proposed by the standard model of consolidation. However, in contrast to the standard model's claim that the hippocampus is not necessary for the retrieval of remote memories, the decrease in response occurs only for memories that have lost their episodic character and are now more semantic in nature. The fact that the hippocampus remains involved in the retrieval of episodic memories is consistent with the multiple trace model of consolidation (Bonnici et al., 2012; Soderlund et al., 2012; Svoboda & Levine, 2009). Research is continuing regarding the physiological basis of consolidation, with some researchers favoring the standard model and others the multiple trace or other models (Hardt et al., 2013; Smith & Squire, 2009; Squire & Bayley, 2007). In addition to research on different models of consolidation, another active area of research is concerned with the relationship between consolidation and sleep.

CONSOLIDATION AND SLEEP: ENHANCING MEMORY

Hamlet says, in his "To be or not to be" soliloquy, "To sleep, perchance to dream." But memory researchers might modify that statement to read "To sleep, perchance to consolidate memory." Not as poetic as Hamlet's statement perhaps, but recent research supports the idea that while the reactivation process associated with consolidation may begin as soon as a memory is formed, it is particularly strong during sleep.

Steffan Gais and coworkers (2006) tested the idea that sleep enhances consolidation by having high school students learn a list of 24 pairs of English–German vocabulary words. The "sleep" group studied the words and then went to sleep within 3 hours. The "awake" group studied the words and remained awake for 10 hours before getting a night's sleep. Both groups were tested within 24 to 36 hours after studying the vocabulary lists. (The actual experiment involved a number of different "sleep" and "awake" groups in order to control for time of day and other factors we aren't going to consider here.) The results of the experiment, shown in **Figure 7.18**, indicate that students in the sleep group forgot much less material than students in the awake group. Why does going to sleep shortly after learning enhance memory? One reason is that going to sleep eliminates environmental stimuli that might interfere with consolidation. Another reason is that consolidation appears to be enhanced during sleep.

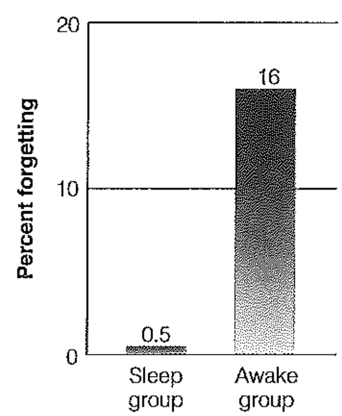

Figure 7.18 Results of the Gais et al. (2007) experiment in which memory for word pairs was tested for two groups. The sleep group went to sleep shortly after learning a list of word pairs. The awake group stayed awake for quite a while after learning the word pairs. Both groups did get to sleep before testing, so they were equally rested before being tested, but the performance of the sleep group was better.

Interestingly, not only is there evidence that consolidation is enhanced during sleep, but there is also evidence that some memories are more likely to be consolidated than others. This was demonstrated in an experiment by Ines Wilhelm and coworkers (2011) in which subjects learned a task and were then told either that they would be tested on the task later or that they would be tested on a different task later. After a night's sleep, subjects in both groups were tested on the task to determine if what they *expected* had any effect on consolidation. (In some experiments, some subjects were tested after staying awake. The memory of these groups was worse than the memory of the sleep groups, as was expected from the results of experiments like the one by Gais, described above. We will focus here on what happened for the subjects who went to sleep.)

One of the tasks in Wilhelm's experiment was a card memory task similar to the game Concentration. Subjects would see an array of gray "cards" on the computer screen, with two turned over to reveal one pair of pictures (**Figure 7.19a**). Subjects saw each card pair twice and then learned the locations by practicing. One card would be "turned over" on the screen, and they indicated where they thought the matching card was located. After receiving the correct answer, they continued practicing until they were able to answer correctly

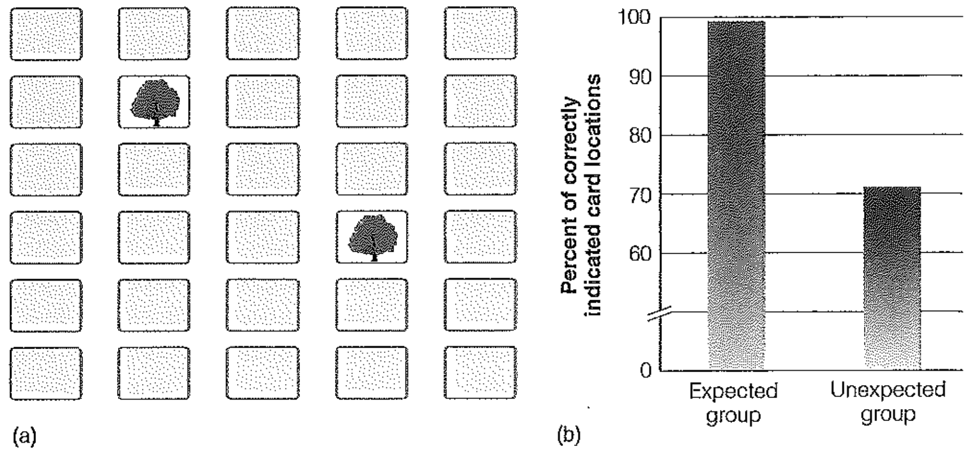

Figure 7.19 Stimuli and results for the Wilhelm et al. (2011) experiment. (a) The subjects' task was to remember where each pair of pictures was located. One pair is shown turned over here. (b) After sleeping, the performance of the group that had expected to be tested on the task was better than the performance of the group that did not expect to be tested. This illustrates preferential consolidation for the material that subjects expected would be tested. *(Source: Part b from I. Wilhelm, S. Diekelmann, I. Molzow, A. Ayoub, M. Molle, & J. Born, Sleep selectively enhances memory expected to be of future relevance,* Journal of Neuroscience, 31, *1563–1569, Figure 3a, 2011.)*

60 percent of the time. After their training, they were told either that they would be tested on this task 9 hours later (the *expected group*) or that they would be tested on another task (the *unexpected group*).

Memory performance after a night's sleep, shown in **Figure 7.19b**, indicates that the expected group performed significantly better than the unexpected group. Thus, even though both groups had the same training and received the same amount of sleep, memory for the task was stronger if subjects expected they would be tested. Results such as this suggest that when we sleep after learning, memories that are more important are more likely to be strengthened by consolidation (see also Fischer & Born, 2009; Payne et al., 2008, 2012; Rauchs et al., 2011; Saletin et al., 2011; van Dongen et al., 2012). Thus, we sleep, perchance to selectively consolidate memories for things that might be most useful to remember later!

We have come a long way from Müller and Pilzecker's demonstration of consolidation. But there is one more twist to this story, which involves returning to our original definition of consolidation. Consolidation, according to our definition, is *the process that transforms new memories from a fragile state, in which they can be disrupted, to a more permanent state, in which they are resistant to disruption* (page 193). This definition implies that once memories are consolidated, they become more permanent. As it turns out, this idea of truly permanent memories has been questioned by research that shows that retrieving a memory can cause that memory to become fragile, just as it was when it was first formed.

CONSOLIDATION AND RETRIEVAL: RECONSOLIDATION

Consider the following situation: You are visiting your childhood home. Driving along the roads that lead to your parents' house seems almost automatic, because the route is strongly stamped into your memory. But as you turn onto a street that was part of your old route, you are surprised to find that it is now a dead end. Construction that happened while you were gone has blocked your old route. Eventually, you discover a new route to reach your destination, and—this is the important part—you *update your memory* to form a new map of the route to your parents' home (Bailey & Balsam, 2013).

This example of updating your memory is not unique. It happens all the time. We are constantly learning new things and modifying information stored in memory in order to deal with new circumstances. Thus, although it is useful to be able to remember the past, it is also useful to be able to not let these memories hinder our ability to adapt to new situations.

Recent research, first on rats and then on humans, has suggested a possible mechanism for updating memories. These experiments support the idea that when a memory is retrieved, it becomes fragile, as it was when it was originally formed, and that when it is in this fragile state, it needs to be consolidated again—a process called **reconsolidation**.

The reason this is important is that when the memory has become fragile again, and before it has been reconsolidated, it can be changed or eliminated. According to this idea, retrieving a memory not only puts us in touch with something that happened in the past, but it also opens the door for either modifying or forgetting the memory.

The possibility that retrieved memories can become fragile was demonstrated in an experiment by Karim Nader and coworkers (2000a, 2000b) involving a rat. Nader used classical conditioning (see Chapter 6, page 172) to create a fear response in the rat of "freezing" (not moving) to presentation of a tone. This was achieved by pairing the tone with a shock. Although the tone initially caused no response in the rat, pairing it with the shock caused the tone to take on properties of the shock, so the rat froze in place when the tone was presented alone. Thus, in this experiment, memory for the tone–shock pairing is indicated when the rat freezes to the tone.

The design of the experiment is shown in **Figure 7.20**. In each of the three conditions, the rat receives a tone–shock pairing and is injected with *anisomycin*, an antibiotic that inhibits protein synthesis and so prevents changes at the synapse that are responsible for the formation of new memories. The key to this experiment is *when* the anisomycin is injected. If it is injected before consolidation has occurred, it eliminates memory, but if it is injected after consolidation occurs, it has no effect.

In Condition 1, the rat receives the pairing of the tone and the shock on Day 1, which causes it to freeze. But the anisomycin is injected right away, before consolidation has occurred (**Figure 7.20a**). The fact that the drug has prevented consolidation is indicated by the fact that when the tone is presented on Day 3, the rat doesn't freeze to the tone. That is, it behaves as if it never received the tone–shock pairing.

In Condition 2, the rat receives the pairing of the tone and shock on Day 1, as before, but doesn't receive anisomycin until Day 2, after consolidation has occurred. Thus, when the tone is presented on Day 3, the rat remembers the tone–shock pairing, as indicated by the fact that it freezes to the tone (**Figure 7.20b**).

Condition 3 is the crucial condition, because it creates a situation in which injecting the drug on Day 2 (which had no effect in Condition 2) can eliminate the memory of the tone–shock pairing. This situation is created by presenting the tone on Day 2 to reactivate the rat's memory for the tone–shock pairing. The rat freezes (indicating that memory has occurred) and then the anisomycin is injected. Because the memory was reactivated by presenting the tone, the anisomycin now has an effect. This is indicated by the fact that the rat doesn't freeze when the tone is presented on Day 3.

This result shows that when a memory is reactivated, it becomes fragile, just as it was immediately after it was first formed, and the drug can prevent reconsolidation. Thus, just as the original memory is fragile *until it is consolidated for the first time*, a reactivated memory becomes fragile *until it is reconsolidated*. Looked at in this way, memory becomes susceptible to being changed or disrupted every time it is retrieved. You might think that this is not a good thing. After all, putting your memory at risk of disruption every time you use it doesn't sound particularly useful.

From the driving example at the beginning of this section, however, we can appreciate that being able to update memory can be useful. In fact, updating can be crucial for

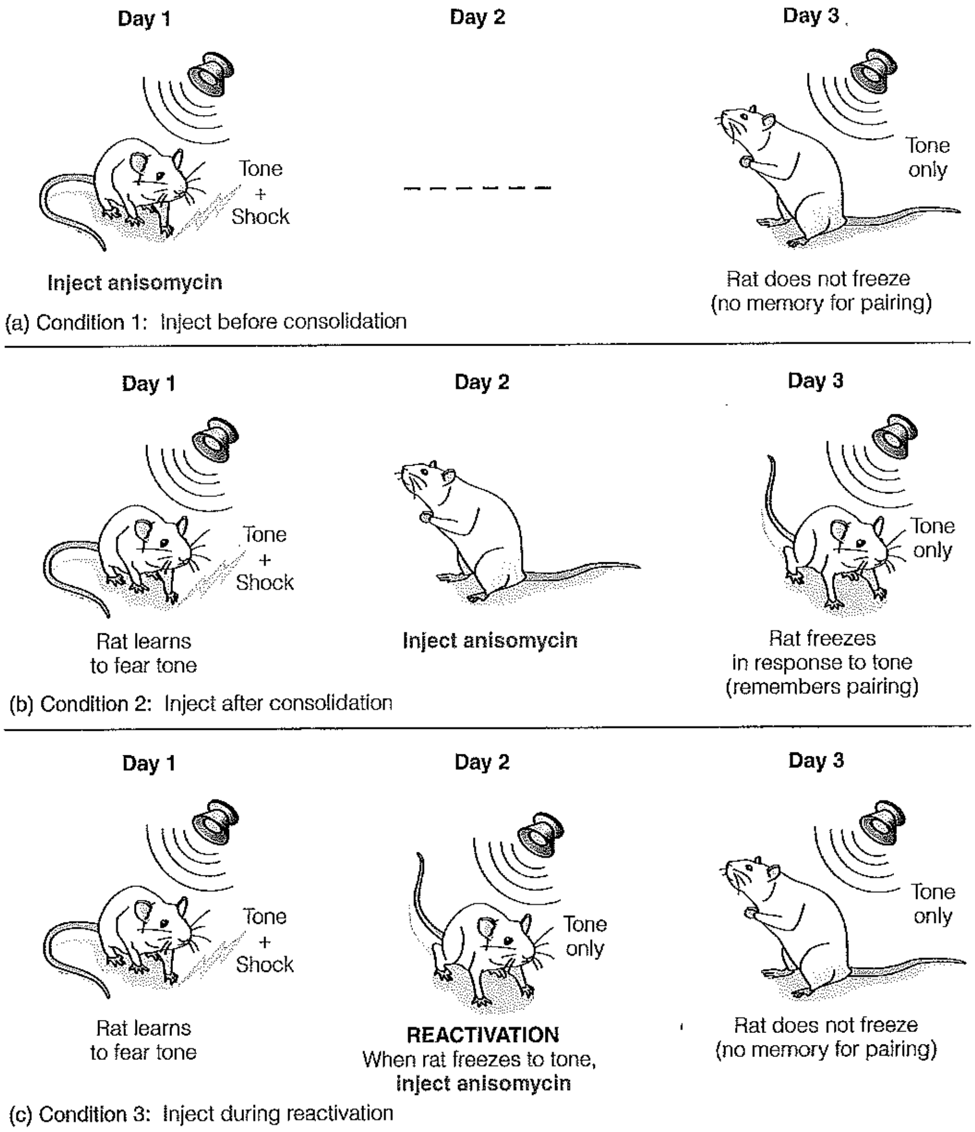

Figure 7.20 The Nader et al. (2000a) experiment on how injecting anisomycin affects fear conditioning. (a) Anisomycin is injected on Day 1, before consolidation, so memory for the tone–shock pairing is not formed. (b) Anisomycin is injected on Day 2, after consolidation, so memory for the tone–shock pairing remains. (c) Anisomycin is injected after reactivation on Day 2, so memory for the tone–shock pairing is eliminated.

survival. Consider, for example, an animal version of our driving example: A chipmunk returns to the location of a food source and finds that the food has been moved to a new location nearby. Returning to the original location reactivates the original memory, new information about the change in location updates the memory, and the updated memory is then reconsolidated.

Once Nader demonstrated that reactivated memories become fragile and subject to change, other researchers confirmed this finding, and some researchers looked for evidence of this phenomenon in humans. Almut Hupbach and coworkers (2007) provided evidence for the effect of reactivation in humans using the following procedure: On Day 1, subjects studied a list of words naming everyday objects such as *envelope, teabag,* and *shovel*

(List 1). On Day 2, one group (the reminder group) was reminded of their learning on Day 1 by being asked to remember their training sessions (but without actually recalling the objects). Immediately following this reminder, they learned a new list of objects (List 2). The other group (the no-reminder group) were not reminded of their previous training; they just learned the new list.

To see if having the reminder group think about their learning on Day 1 had any effect, both groups were asked, on Day 3, to remember List 1. The left pair of bars in Figure 7.21 indicates that the no-reminder group recalled 45 percent of the words from List 1 and mistakenly recalled only 5 percent of the words from List 2. (Remember that their task was to remember only the words from List 1.) The right pair of bars shows that something quite different happened for the reminder group. They recalled 36 percent of the words from List 1, but they also mistakenly recalled 24 percent of the words from List 2.

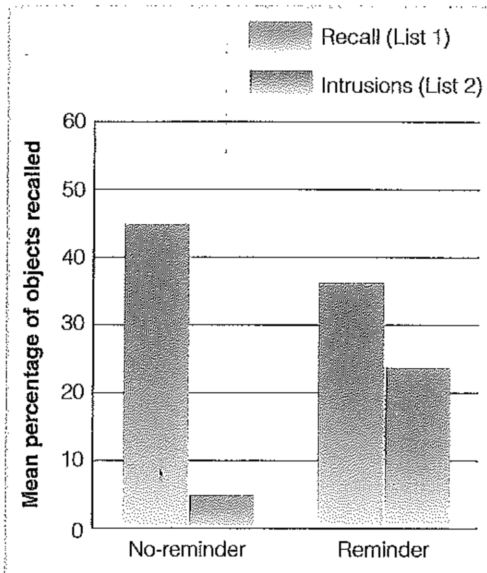

Figure 7.21 Results of Hupbach et al.'s (2007) experiment. The fact that the reminder group had more intrusions supports the idea that reactivation and reconsolidation can affect human memory. *(Source: Based on A. Hupbach, R. Gomez, O. Hardt, & L. Nadel, Reconsolidation of episodic memories: A subtle reminder triggers integration of new information,* Learning and Memory, 14, *47–53, 2007.)*

According to Hupbach, thinking back to the original training session reactivated the memory for List 1, making it vulnerable to being changed. Because subjects immediately learned List 2, some of these new words became integrated into the subjects' memory for List 1. Another way to express this idea is to say that the reminder reactivated memory for List 1 and "opened the door" for changes to occur in the subjects' memory for that list. Thus, in this example, the original memory was not eliminated, but it was changed.

One practical outcome of research on reconsolidation is a possible treatment for posttraumatic stress disorder (PTSD), a condition that occurs when, following a traumatic experience, a person experiences "flashbacks" of the experience, often accompanied by extreme anxiety and physical symptoms. Clinical psychologist Alain Brunet and coworkers (2008) tested the idea that reactivation of a memory followed by reconsolidation can help alleviate these symptoms. The basic method involved is to reactivate the person's memory for the traumatic event and then administer the drug *propranolol*. This drug blocks activation of stress hormone receptors in the amygdala, a part of the brain important for determining the emotional components of memory. This procedure might be equivalent to the administration of anisomycin on Day 2 in Condition 3 of Nader's experiment (Figure 7.20c).

Brunet ran two groups. One group of PTSD patients listened to a 30-second recording describing the circumstances of their traumatic experience and received propranolol. Another group listened to the recording describing their experience but received a placebo, which had no active ingredients.

One week later, both groups were told to imagine their traumatic experience while again listening to the 30-second recording. To determine their reaction to imagining their experience, Brunet measured their blood pressure and skin conductance. He found that the propranolol group experienced much smaller increases in heart rate and skin conductance than the placebo group. Apparently, presenting propranolol when the memory was reactivated a week earlier blocked the stress response in the amygdala, and this reduced the emotional reaction associated with remembering the trauma. Brunet has used this procedure to treat patients with PTSD, and many of the patients report significant reductions in their symptoms, even months after the treatment. (See Kindt et al., 2009, and Schiller et al., 2010, for other demonstrations of using reconsolidation to eliminate fear responses in humans.)

Research on reconsolidation and its potential applications is just in its infancy, but from what researchers have learned so far, it appears that our memory is not static or fixed. Rather, it is a "work in progress" that is constantly being constructed and remodeled in response to new learning and changing conditions. We will be describing this aspect of memory in detail in the next chapter, when we consider the creative, constructive properties of memory.

Something to Consider

EFFECTIVE STUDYING

How do you study? Students have developed numerous techniques, which vary depending on the type of material to be studied and what works for a particular student. When students are asked to describe their study techniques, the most popular are highlighting material in text or notes (Bell & Limber, 2010; Gurung et al., 2010) and rereading text or notes (Carrier, 2003; Karpicke et al., 2009; Wissman et al., 2012). Unfortunately, research has generally found that these popular techniques are not very effective (Dunlosky et al., 2013). Apparently, students use highlighting and rereading because they are easy to use, and because they are not aware of more effective methods. We will describe a number of ways of learning material that have been shown to be effective. Even if you think highlighting and rereading work for you, you might want to consider also using one or more of the techniques described below the next time you are studying.

ELABORATE

A process that helps transfer the material you are reading into long-term memory is elaboration—thinking about what you are reading and giving it meaning by relating it to other things that you know. This becomes easier as you learn more because what you have learned creates a structure on which to hang new information.

Techniques based on association, such as creating images that link two things, as in Figure 7.2, often prove useful for learning individual words or definitions. For example, when I was first learning the difference between proactive interference (old information interferes with learning new information; see page 128) and retroactive interference (new information interferes with remembering old information; see page 128), I thought of a "pro" football player smashing everything in his path as he runs forward in time, to remind me that proactive interference is the past influencing the present. I no longer need this image to remember what proactive interference is, but it was helpful when I was first learning this concept.

GENERATE AND TEST

The results of research on the generation effect (page 182) and the testing effect (page 186) indicate that devising situations in which you take an active role in creating material is a powerful way to achieve strong encoding and good long-term retrieval.

Testing is actually a form of generation, because it requires active involvement with the material. If you were going to test yourself, where would you get the test questions? One place could be questions that are sometimes provided, such as the Test Yourself questions in this book, or print or electronic study guides. Another way is to make up questions yourself. Because making up the questions involves active engagement with the material, it strengthens encoding of the material. Research has shown that students who read a text with the idea of *making up* questions did as well on an exam as students who read a text with the idea of *answering* questions later, and both groups did better than a group of students who did not create or answer questions (Frase, 1975).

Research has shown that many students believe that reviewing the material is more effective than testing themselves on it; when they do test themselves, it is to determine how they are doing, not as a tool to increase learning (Kornell & Son, 2009). As it turns out, self-testing accomplishes two things. It indicates what you know *and* increases your ability to remember what you know later.

ORGANIZE

The goal of organizing material is to create a framework that helps relate some information to other information to make the material more meaningful and therefore strengthen encoding. Organization can be achieved by making "trees," as in Figure 7.5, or outlines or lists that group similar facts or principles together.

Organization also helps reduce the load on your memory. We can illustrate this by looking at a perceptual example. If you see the black and white pattern in Figure 3.17 (page 65) as unrelated black and white areas, it is extremely difficult to describe what it is. However, once you've seen this pattern as a Dalmatian, it becomes meaningful and therefore much easier to describe and to remember (Wiseman & Neisser, 1974). Organization relates to the phenomenon of chunking that we discussed in Chapter 5. Grouping small elements into larger, more meaningful ones increases memory. Organizing material is one way to achieve this.

TAKE BREAKS

Saying "Take breaks" is another way of saying "Study in a number of shorter study sessions rather than trying to learn everything at once," or "Don't cram." There are good reasons to say these things. Research has shown that memory is better when studying is broken into a number of short sessions, with breaks in between, than when it is concentrated in one long session, even if the total study time is the same. This advantage for short study sessions is called the **spacing effect** (Reder & Anderson, 1982; Smith & Rothkopf, 1984).

Another angle on taking breaks is provided by research that shows that memory performance is enhanced if sleep follows learning (page 197). Although sleeping to avoid studying is probably not a good idea, sleeping soon after studying can improve consolidation, which can result in better memory.

AVOID "ILLUSIONS OF LEARNING"

One of the conclusions of both basic memory research and research on specific study techniques is that some study techniques favored by students may *appear* to be more effective than they actually are. For example, one reason for the popularity of rereading as a study technique is that it can create the illusion that learning is occurring. This happens because reading and rereading material results in greater *fluency*—that is, repetition causes the reading to become easier and easier. But although this enhanced ease of reading creates the illusion that the material is being learned, increased fluency doesn't necessarily translate into better memory for the material.

Another mechanism that creates the illusion of learning is the *familiarity effect*. Rereading causes material to become familiar, so when you encounter it a second or third time, there is a tendency to interpret this familiarity as indicating that you know the material. Unfortunately, recognizing material that is right in front of you doesn't necessarily mean that you will be able to remember it later.

Finally, beware of highlighting. A survey by Sarah Peterson (1992) found that 82 percent of students highlight, and most of them do so while they are reading the material for the first time. The problem with highlighting is that it seems like elaborative processing (you're taking an active role in your reading by highlighting important points), but it often becomes automatic behavior that involves moving the hand, but little deep thinking about the material.

When Peterson compared comprehension for a group of students who highlighted and a group who didn't, she found no difference between the performance of the two groups when they were tested on the material. Highlighting may be a good first step for some people, but it is usually important to go back over what you highlighted using techniques such as elaborative rehearsal or generating questions in order to get that information into your memory.

Looking at all of these techniques, we can see that many of them involve using more effective encoding strategies; elaborating, generating, testing, and organizing all encourage deeper processing of the material you are trying to learn. Making up questions about the material and answering these questions incorporates retrieval into studying. A recent survey of research on many different study techniques concluded that practice testing and distributed practice (taking breaks) are the two most effective study techniques (Dunlosky et al., 2013).

TEST YOURSELF 7.3

1. What is the idea behind the statement "Memories are stored at synapses"? What evidence supports this idea?
2. What is synaptic consolidation? Systems consolidation? How are they related to each other?
3. Describe how the standard model of consolidation explains systems consolidation. What is the multiple trace model of consolidation? Compare it to the standard model.
4. Describe the connection between sleep and consolidation. Be sure you understand the Gais and Wilhelm experiments.
5. What is reconsolidation? What are the implications of the results of experiments that demonstrate reconsolidation?
6. Describe the following five ways of improving the effectiveness of studying: (1) elaborate; (2) generate and test; (3) organize; (4) take breaks; (5) avoid "illusions of learning." How does each technique relate to findings about encoding and retrieval?

CHAPTER SUMMARY

1. Encoding is the process of acquiring information and transferring it into long-term memory (LTM). Retrieval is transferring information from LTM into working memory.
2. Some mechanisms of encoding are more effective than others in transferring information into LTM. Maintenance rehearsal helps maintain information in STM but is not an effective way of transferring information into LTM. Elaborative rehearsal is a better way to establish long-term memories.
3. Levels of processing theory states that memory depends on how information is encoded or programmed into the mind. According to this theory, shallow processing is not as effective as deep processing. An experiment by Craik and Tulving showed that memory was better following deep processing than following shallow processing.
4. The idea of levels of processing, while influential, suffers from the problem of circularity, because it is difficult to define depth of processing independently of memory.
5. Evidence that encoding influences retrieval includes research looking at the effect of (1) forming visual images, (2) linking words to yourself, (3) generating information (the generation effect), (4) organizing information, (5) relating words to survival value, and (6) practicing retrieval (the testing effect).
6. Retrieving long-term memories is aided by retrieval cues. This has been determined by cued recall experiments and experiments in which subjects created retrieval cues that later helped them retrieve memories.
7. Retrieval can be increased by matching conditions at retrieval to conditions that existed at encoding. This is illustrated by encoding specificity, state-dependent learning, and matching type of processing (transfer-appropriate processing).
8. The principle of encoding specificity states that we learn information along with its context. Godden and Baddeley's diving experiment and Grant's studying experiment illustrate the effectiveness of encoding and retrieving information under the same conditions.
9. According to the principle of state-dependent learning, a person's memory will be better when his or her internal state during retrieval matches the state during encoding. Eich's mood experiment supports this idea.
10. Matching types of processing refers to the finding that memory performance is enhanced when the type of coding that occurs during acquisition matches the type of retrieval that occurs during a memory test. The results of an experiment by Morris support this idea, which is called transfer-appropriate processing.
11. Consolidation is the process that transforms new memories from a fragile state into a more permanent state. Müller and Pilzecker carried out an early experiment that illustrated how memory is decreased when consolidation is disrupted.
12. Synaptic consolidation involves structural changes at synapses. Systems consolidation involves the gradual recognition of neural circuits.
13. Hebb introduced the idea that the formation of memories is associated with structural changes at the synapse. These structural changes are then translated into enhanced nerve firing, as indicated by long-term potentiation.
14. The standard model of consolidation proposes that memory retrieval depends on the hippocampus during consolidation but that after consolidation is complete, retrieval involves the cortex, and the hippocampus is no longer involved.

15. The multiple trace model states that the hippocampus is involved both when memories are being established and during the retrieval of remote episodic memories.

16. There is evidence supporting the standard model, but recent research indicates that retrieval of episodic memories can involve the hippocampus.

17. Consolidation is facilitated by sleep. There is also evidence that material people expect they will be asked to remember later is more likely to be consolidated during sleep.

18. Recent research indicates that memories can become susceptible to disruption when they are reactivated by retrieval. After reactivation, these memories must be reconsolidated. There is evidence for reconsolidation in humans and for the usefulness of reconsolidation therapy in treating conditions such as posttraumatic stress disorder.

19. Five memory principles that can be applied to studying are (1) elaborate, (2) generate and test, (3) organize, (4) take breaks, and (5) avoid "illusions of learning."

THINK ABOUT IT

1. Describe an experience in which retrieval cues led you to remember something. Such experiences might include returning to a place where your memory was initially formed, being somewhere that reminds you of an experience you had in the past, having someone else provide a "hint" to help you remember something, or reading about something that triggers a memory.

2. How do you study? Which study techniques that you use should be effective, according to the results of memory research? How could you improve your study techniques by taking into account the results of memory research? (Also see Preface to Students, pages xxvi–xxvii.)

KEY TERMS

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COGLAB EXPERIMENTS Number in parentheses refers to the experiment number in CogLab.

Encoding Specificity (28)
Levels of Processing (29)
Production Effect (30)
Von Restorff Effect (32)