Think About It

Do we really remember everything that's ever happened to us?

Do memory aids like "ROY G. BIV" (for the colors of the rainbow) really help us to remember?

What are infants' earliest memories?

Do witnesses to a crime always remember what they observed accurately?

Can people recover repressed memories of traumatic experiences?

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Consider the following memorable tales of memory, both true.

True Story 1. A woman in her forties, known only by the initials A. J., has such an astounding memory that she's left even seasoned psychological researchers shaking their heads in bewilderment. Although emotionally quite normal, A. J. is markedly abnormal in one way: She remembers just about everything she's ever experienced. When given a date, like March 17, 1989, she can report precisely what she was doing on that day—taking a test, eating dinner with a good friend, or traveling to a new city. The claims here are extraordinary, but they've now been confirmed by research. Scientists have confirmed that she's almost always right. Moreover, she remembers on what day of the week that date fell. In 2003, a team of investigators asked A. J. to remember all of the dates of Easter over the past 24 years. She got all but two correct and reported accurately what she'd done each day (Parker, Cahill, & McCaugh, 2006).

A. J., like about a dozen other people identified thus far, "suffers" from an exceedingly rare condition called hyperthymestic syndrome: memory of life events that's too good. Or does she really suffer? It's not entirely clear, because she regards her remarkable memory as both a curse and a blessing (Price & Davis, 2008). A. J. says that she sometimes remembers painful events that she'd prefer to forget, but also that she'd never want to give up her special memory "gift." As to the causes of hyperthymestic syndrome, scientists are baffled (Foer, 2007). Nevertheless, recent research suggests subtle differences in brain structure between people with and without this condition, especially involving brain regions involved in autobiographical memory (LePort et al., 2012).

True Story 2. In 1997, Nadean Cool, a 44-year-old nurse's aide in Wisconsin, won a $2.4 million malpractice settlement against her psychotherapist. Nadean entered treatment with relatively mild emotional problems, such as depressed mood and binge eating. Yet after five years of treatment, Nadean supposedly "recovered" childhood memories of having been a member of a murderous satanic cult, of being raped, and of witnessing the murder of her 8-year-old childhood friend. Her therapist also persuaded her that she harbored more than 130 personalities, including demons, angels, children, and a duck. (Her therapist apparently even listed her treatment as group therapy on the grounds that he needed to treat numerous different personalities.)

All of these memories surfaced after Nadean participated in repeated sessions involving *guided imagery*—in which therapists ask clients to imagine past events—and *hypnotic age regression*—in which therapists use hypnosis to "return" clients to the psychological state of childhood (see Chapter 5). The therapist also subjected Nadean to an exorcism and 15-hour marathon therapy sessions. As therapy progressed, she became overwhelmed by images of terrifying memories she was convinced were genuine. Eventually, however, Nadean came to doubt the reality of these memories, and she terminated treatment.

In a very real sense, we *are* our memories. Our memories define not only our past, but also our sense of identity. For A. J., life is like "a movie in her mind that never stops," as she puts it. Her recollections of her life and interactions with friends are remarkably vivid and emotionally intense. A. J.'s memory has shaped her personality in profound ways.

Moreover, when our memories change, as did Nadean Cool's, so do our identities. Following psychotherapy, Nadean came to believe she was a victim of brutal and repeated child abuse. She even came to believe she suffered from a severe condition, namely, *dissociative identity disorder*, or DID (known formerly as multiple personality disorder; see Chapter 15), which is supposedly characterized by the existence of "alter" personalities, or *alters*.

How Memory Operates: The Memory Assembly Line

7.1 Identify the ways that memories do and don't accurately reflect experiences.

7.2 Explain the function, span, and duration of each of the three memory systems.

7.3 Differentiate the subtypes of long-term memory.

We can define **memory** as the retention of information over time. We have memories for many different kinds of information, ranging from our sixteenth birthday party, to how to ride a bike, to the shape of a pyramid. Our memories work pretty well most of

memory
retention of information over time

the time. Odds are high that tomorrow you'll find your way into school or work just fine and that, with a little luck, you'll even remember some of what you read in this chapter. Yet in other cases, our memories fail us, often when we least expect it. How many times have you misplaced your keys or cell phone or forgotten the names of people you've met over and over again? We call this seeming contradiction the *paradox of memory:* Our memories are surprisingly good in some situations and surprisingly poor in others.

Salvador Dali's classic painting *The Persistence of Memory* is a powerful reminder that our memories are much more like melting wax than hardened metal. They often change over time, far more than we realize.

The Paradox of Memory

To a large extent, this chapter is the story of this paradox. As we'll see, the answer to the paradox of memory hinges on a crucial fact: *The same memory mechanisms that serve us well in most circumstances can sometimes cause us problems in others.*

WHEN OUR MEMORIES SERVE US WELL. Research shows that our memories are often astonishingly accurate. Most of us can recognize our schoolmates decades later and recite the lyrics to dozens, even hundreds, of songs. Consider a study in which college students viewed 2,560 photographs of objects or scenes for a few seconds each. Three days later, the researchers showed these students each original photograph paired with a new one. Remarkably, the students correctly picked out the original photographs 93 percent of the time (Standing, Conezio, & Haber, 1970). In another case, a researcher contacted participants 17 years(!) after they'd viewed over 100 line drawings for one to three seconds in a laboratory study. They identified these drawings at better-than-chance rates compared with participants who'd never seen the drawings (Mitchell, 2006).

The memories of a small subset of individuals with a condition known as *infantile autism* are even more astonishing. Contrary to popular misconception (Stone & Rosenbaum, 1988), most individuals with autism lack specialized memory abilities, but there are impressive exceptions. Take the case of Kim Peek, who was the inspiration for the 1998 Academy Award–winning film *Rain Man* (Peek died in 2009). Peek's IQ was 87, noticeably below the average of approximately 100. Yet Peek memorized about 12,000 books word for word, the ZIP Codes of every town in the United States, and the number of every highway connecting every city in the United States (Foer, 2007; Treffert & Christensen, 2005). Kim Peek was also a *calendar calculator:* If you gave him any past or future date, like October 17, 2094, he'd give you the correct day of the week in a matter of seconds. Not surprisingly, Kim earned the nickname of "Kim-puter" among researchers who studied his astonishing memory feats.

Kim Peek, the "real Rain Man" (who passed away in 2009), exhibited phenomenal memory despite low overall intelligence.

Yet as we learned with A. J., it's not only people with autism who possess remarkable memory capacities. Consider the case of Rajan Mahadevan (better known simply as Rajan), now a lecturer in the psychology department of the University of Tennessee. Rajan's memory feats are so spectacular that they were spoofed on an episode of the cartoon show *The Simpsons.* Rajan had somehow managed to memorize the number *pi*—the ratio of a circle's diameter to its radius—to a remarkable 38,811 digits (see **FIGURE 7.1**). When he recited them, it took him three hours at a rate of more than three digits per second (by the way, if you're curious, the world record for remembering pi is now up to over 80,000 digits; Foer, 2007). Yet Rajan also provides a wonderful illustration of the paradox of memory. Despite finding pi to be a piece of cake, he kept forgetting the location of the men's restroom at the University of Minnesota psychology department although it was just down the hall from where he'd been tested repeatedly (Biederman et al., 1992).

Pi=3.

1415926535	8979323846	2643383279	5028841971	6939937510	(50)
5820974944	5923078164	0628620899	8628034825	3421170679	(100)
8214808651	3282306647	0938446095	5058223172	5359408128	(150)
4811174502	8410270193	8521105559	6446229489	5493038196	(200)
4428810975	6659334461	2847564823	3786783165	2712019091	(250)
4564856692	3460348610	4543266482	1339360726	0249141273	(300)
7245870066	0631558817	4881520920	9628292540	9171536436	(350)
7892590360	0113305305	4882046652	1384146951	9415116094	(400)
3305727036	5759591953	0921861173	8193261179	3105118548	(450)
0744623799	6274956735	1885752724	8912279381	8301194912	(500)
9833673362	4406566430	8602139494	6395224737	1907021798	(550)
6094370277	0539217176	2931767523	8467481846	7669405132	(600)
0005681271	4526356082	7785771342	7577896091	7363717872	(650)
1468440901	2249534301	5654958537	1050792279	6892589235	(700)
4201995611	2129021960	8640344181	5981362977	4771309960	(750)
5187072113	4999999837	2978049951	0597317328	1609631859	(800)
5024459455	3469083026	4252230825	3344685035	2619311881	(850)
7101000313	7838752886	5875332083	8142061717	7669147303	(900)
5982534904	2875546873	1159562863	8823537875	9375195778	(950)
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	(1000)

FIGURE 7.1 Rajan's Demonstration Sheet of Digits of Pi. Rajan's feats demonstrate the uppermost end of the capacity of human memory.

How did Rajan pull off his amazing feat? We'll find out later in the chapter.

WHEN OUR MEMORIES FAIL US. In some exceedingly rare cases, as with A. J., memory is virtually perfect. Many others of us have extremely good memories in one or two narrow domains, like art history, baseball batting averages, or Civil War trivia. Yet as the case of Nadean Cool illustrates, memory can be surprisingly malleable and prone to error.

Most and perhaps all of us are vulnerable to false memories under the right conditions. Here's a simple demonstration that requires only a pen or pencil and a sheet of paper (for maximum effect, you may want to try this demonstration along with a group of friends). Read the list of words below, taking about a second per word. Read the left column first, then the middle column, then the right. Ready? Okay, begin.

Bed	Cot	Sheets
Pillow	Dream	Rest
Tired	Snore	Yawn
Darkness	Blanket	Couch

Now, put down your textbook, and take a minute or so to jot down as many of these words as you can recall.

Did you remember *couch*? If so, give yourself a point. How about *snore*? If so, good—give yourself another point.

Okay, how about *sleep*? If you're like about a third of typical people, you "remembered" seeing the word *sleep*. But now take a close look at the list. The word *sleep* isn't there.

If you or your friends remembered seeing this word on the list, you experienced a **memory illusion**: a false but subjectively compelling memory (Brainerd, Reyna, & Zember, 2011; Deese, 1959; Roediger & McDermott, 1995, 1999). Like visual illusions (see Chapter 4), most memory illusions are by-products of our brain's generally adaptive tendency to go beyond the information available to it. By doing so, our brain helps us make sense of the world, but it sometimes leads us astray (Gilovich, 1991; Kida, 2006). In this case, you may have remembered seeing the word *sleep* because it was linked closely in meaning to the other words on the list—namely, bed, dream, and rest. As a consequence, you may have been fooled into remembering that the word *sleep* was there. By relying on the *representativeness heuristic* (see Chapter 8)—like goes with like—we simplify things to make them easier to remember. In this case, though, our use of this handy heuristic comes with a modest price: a memory illusion.

The Reconstructive Nature of Memory

This demonstration drives home a crucial point: Our memories frequently fool us and fail us. Indeed, a central theme of this chapter is that our memories are far more reconstructive than reproductive. When we try to recall an event, we *actively reconstruct* our memories using the cues and information available to us. We don't *passively reproduce* our memories, as we would if we were downloading information from a web page. Remembering is largely a matter of patching together our often fuzzy recollection with our best hunches about what really happened. When we recall our past experiences, we rarely, if ever, reproduce precise replicas of them (Neisser & Hyman, 1999; Mori, 2008). We should therefore be skeptical of claims that certain vivid memories or even dreams are exact "photocopies" of past events (van der Kolk et al., 1984).

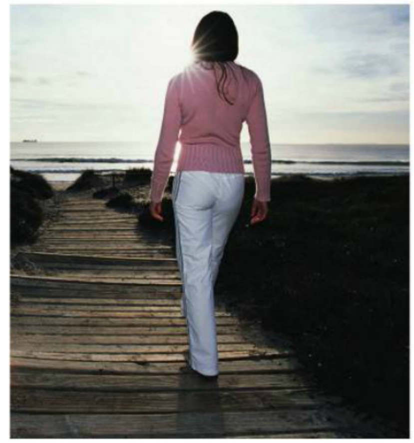
In fact, it's easy to show that our memories are often reconstructive. After reading this sentence, close your eyes for a few moments and picture your most recent walk along a beach, lake, or pond. Then, after opening your eyes, ask yourself what you "saw."

Did you see yourself as if from a distance, seeing yourself as an outside observer would? Many people report this visual perspective. As Sigmund Freud noted well over a century ago, such memories provide an existence proof (see Chapter 2) that at least some of our memories are reconstructive (Schacter, 1996). You couldn't possibly have *seen* yourself from a distance, because you don't see yourself when you look at

memory illusion
false but subjectively compelling memory

your surroundings: You must have constructed that memory rather than recalled it in its original form (Nigro & Neisser, 1983). Interestingly, Asians are more likely than European Americans to see themselves at a distance in such memories (Cohen & Gunz, 2002; Martin & Jones, 2012). This result fits with findings that members of many Asian cultures are more likely than members of Western cultures to adopt others' perspectives (see Chapters 1 and 10). So our memories are probably shaped by not only our hunches and expectations, but also by our cultural backgrounds.

The science of memory offers yet another striking example of how research contradicts popular opinion (Alvarez & Brown, 2001). A survey of the general public revealed that 64 percent of Americans believe that "human memory works like a video camera, accurately recording the events we see and hear" (Simons & Chabris, 2011, p. 3). In that survey, 38 percent of respondents said that once a memory is formed, it never changes. Even most psychotherapists believe that everything we learn is permanently stored in the mind (Loftus & Loftus, 1980; Yapko, 1994). Yet as we'll soon discover, research paints a very different picture of human memory. How can our memories be so good in some cases and so bad in others? How can we explain both the astonishing memories of people like A. J. and Rajan and the faulty memories of people like Nadean Cool? To grasp the paradox of memory, we need to figure out how some of our experiences make it into our memories, whereas so many others never do. To do so, let's embark on a guided tour of the factory assembly line inside our heads.



When you picture yourself taking a recent walk on the beach, do you see yourself as an outside observer would? If so, such a recollection provides compelling evidence that memory can be reconstructive.

The Three Systems of Memory

Up to this point, we've been talking about memory as though it were a single thing. It isn't. Most psychologists distinguish among three major *systems* of memory: sensory memory, short-term memory, and long-term memory, as depicted in **FIGURE 7.2** (Atkinson & Shiffrin, 1968; Waugh & Norman, 1965). These systems serve different purposes and vary along at least two important dimensions: *span*—how much information each system can hold—and *duration*—over how long a period of time that system can hold information.

In reality, the distinctions among these three memory systems aren't always clear-cut. Moreover, many modern researchers suspect that there are more than three memory systems (Baddeley, 1993; Healy & McNamara, 1996). For the sake of simplicity, we'll begin by discussing the three-systems model, although we'll point out some ambiguities along the way.

We can think of these three systems much like different factory workers along an assembly line. The first system, *sensory memory*, is tied closely to the raw materials of our experiences, our perceptions of the world; it holds these perceptions for just a few seconds or less before passing *some* of them on to the second system. This second system, *short-term memory*, works actively with the information handed to it, transforming it into more meaningful material before passing *some* of it on to the third system. Short-term memory holds on to information longer than sensory memory does, but not much longer. The third and final system, *long-term memory*, permits us to retain important information for minutes, days, weeks, months, or even years. In some cases, the information in long-term memory lasts for a lifetime. The odds are high, for example, that you'll remember your first kiss and your high school graduation for many decades, perhaps until the last day of your life. As you can tell from our use of the word *some* in the previous sentences, we lose a great deal of information at each relay station in the memory assembly line.

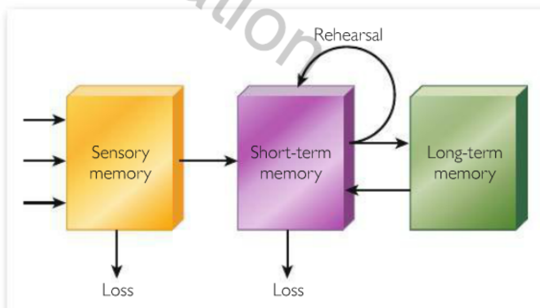


FIGURE 7.2 The Three-Memory Model. This model subdivides memory into sensory, short-term, and long-term memory. Information flows from left to right, but also from right to left in the case of information retrieved from long-term memory and moved into short-term memory (Atkinson & Shiffrin, 1968).

Explore in **MyPsychLab** the **Concept:** Key Processes in Stages of Memory

SENSORY MEMORY. If you're anywhere near a television set, turn it on for 10 seconds or so. What did you see?

Regardless of what program you were watching, you almost certainly experienced a steady and uninterrupted stream of visual information. In reality, that continuous stream of images was an illusion, because television programs and movies consist of a series of disconnected frames, each separated by an extremely brief interlude of darkness you can't perceive. Yet your brain sees these frames as blending together into a seamless whole, in part because it continues to detect each frame for an extremely brief period of time after it disappears.

That is, our brains retain each frame in our **sensory memory**, the first factory worker in the assembly line of memory. Sensory memory briefly maintains our perceptions in a "buffer" area before passing them on to the next memory system, which is short-term memory. Sensory memory is a helpful system, because it buys our brains a bit of extra time to process incoming sensations. It also allows us to "fill in the blanks" in our perceptions and see the world as an unbroken stream of events.

Iconic memory: After a lightning strike, we retain a visual image of it for about one second. (*Source:* © Ralph Wetmore.)

Psychologists believe that each sense, including vision, hearing, touch, taste, and smell, has its own form of sensory memory. In the case of television or movie clips, we experience an **iconic memory**, the type of sensory memory that applies to vision (Persuh, Genzer, & Melara, 2012). Iconic memories last for only about a second, and then they're gone forever.

Psychologist George Sperling (1960) conducted a pioneering study that demonstrated the existence of iconic memory. He quickly flashed participants a display of 12 letters, with four letters arranged in three rows, as shown in **FIGURE 7.3**. The display lasted only about one-twentieth of a second, and participants had to recall as many letters within the display as they could. Sperling found that most participants could recall only four or five letters. Surprisingly, different participants remembered different letters. This finding suggested to Sperling that all 12 letters had an equal chance of being recalled but that no one person could recall them all. This finding was puzzling. After all, if participants had remembered the whole visual display, why could they recall only a handful of letters and no more?

S	D	F	G
P	W	H	J
X	C	V	N

FIGURE 7.3 Display of 12 Letters as Used in Sperling's 1960 Study. Sperling's partial report method demonstrated that all displayed letters were held in sensory memory, but decayed rapidly before all of them could be transferred to short-term memory (Sperling, 1960).

To find out, Sperling had a "flash" of insight, pun intended. Immediately after he flashed the 12 letters, he presented a tone (high, medium, or low) to signal participants which of the three rows (top, middle, or bottom) to report. Then he randomly instructed participants to report only one of the three rows. When he used this technique, he found that virtually all participants now got almost all letters in that row correct. This finding confirmed Sperling's hunch: Participants had access to all 12 letters in their memories. Sperling concluded that our iconic memories fade so quickly that we can't access all the information before it disappears. So Sperling's participants were able to take in all of the information, but retained it in memory only long enough to read off a few letters.

Iconic memory may help to explain the remarkable, and exceedingly rare, phenomenon of *eidetic imagery,* popularly called "photographic memory." People with eidetic memory, most of them children, can supposedly hold a visual image in their minds with such clarity that they can describe it perfectly or almost perfectly (see **FIGURE 7.4**). Some psychologists believe that eidetic memory reflects an unusually long persistence of the iconic image in some fortunate people. Nevertheless, it's not clear that any memories are truly photographic, because even these memories often contain minor errors, such as information that wasn't in the original visual stimulus (Minsky, 1986; Rothen, Meier, & Ward, 2012).

Sensory memory applies to hearing, too. Now read that last sentence aloud: "Sensory memory applies to hearing, too." If you pause for a few moments after saying it, you'll be able to replay the words precisely as you heard them for a few seconds, much like a soft echo reverberating from a mountaintop. That's why psychologists call this form of sensory memory **echoic memory** (Neisser, 1967). In contrast to iconic memories, echoic memories can last as long as 5 to 10 seconds (Cowan, Lichty, & Grove, 1990), conveniently permitting you to take notes on your psychology professor's most recent sentence even after he or she has finished saying it. Interestingly, there's also some evidence of eidetic memories for hearing, in which a few fortunate individuals report that their echoic memories persist for unusually long periods of time. Now, wouldn't that make taking lecture notes a breeze?

sensory memory
brief storage of perceptual information before it is passed to short-term memory

iconic memory
visual sensory memory

echoic memory
auditory sensory memory

SHORT-TERM MEMORY. Once information makes it past our sensory buffers, it passes into our **short-term memory**, a second system for retaining information in our memories for brief periods of time. Short-term memory is the second factory worker in our memory assembly line. Short-term memory is closely related to what psychologists call *working memory*, which refers to our ability to hold on to information we're currently thinking about, attending to, or processing actively (Baddeley, 1993; Baddeley & Hitch, 1974; Unsworth & Engle, 2007). If sensory memory is what feeds raw materials into the assembly line, short-term memory is the workspace where construction happens. After construction takes place, we either move the product into the warehouse for long-term storage or, in some cases, scrap it altogether.

If short-term memory is a short stop on the assembly line, just how brief is it? In the late 1950s, a husband-and-wife team decided to find out.

FIGURE 7.4 Alice with Cheshire Cat. Memory psychologists have used variations of this drawing from Lewis Carroll's *Alice's Adventures in Wonderland* to test for eidetic imagery. To find out if you have eidetic memory, look at the drawing for no longer than 30 seconds and then cover it with a sheet of paper. Do that now before reading on. Now, can you remember how many stripes were on the cat's tail? Few adults can remember such details (Gray & Gummerman, 1975), although eidetic memory is much more prevalent among elementary school children (Haber, 1979).

Watch in **MyPsychLab** the **Video:** Randall Engle: What Is Working Memory?

The Duration of Short-Term Memory. Lloyd and Margaret Peterson (1959) presented participants with lists of three letters each, such as MKP or ASN, and then asked them to recall these three-letter strings. In some cases, they made participants wait only three seconds before recalling the letters; in other cases, they made them wait up to 18 seconds. Each time, they told participants to count backward by threes while they were waiting.

Many psychologists were surprised by the Petersons' results, and you may be, too. They found that after about 10 or 15 seconds, most participants *did no better than chance*. So the duration of short-term memory is quite brief; it's probably no longer than about 20 seconds. Some researchers believe it's even shorter than that, perhaps even less than five seconds, because some participants in the Peterson and Peterson study may have been able to silently rehearse the letters even when counting backward (Sebrects, Marsh, & Seamon, 1989). Incidentally, many people misuse the term *short-term memory* in everyday language. For example, they may say that their "short-term memory isn't working" because they forgot what they had for dinner yesterday. As we've seen, the duration of short-term memory is far briefer than that.

Memory Loss from Short-Term Memory: Decay versus Interference. Why did the Petersons' participants lose their short-term memories so quickly, just as we quickly lose our memories of phone numbers we've just heard? The most obvious explanation is that short-term memories **decay**, that is, fade away over time. The longer we wait, the less is left. Yet there's a competing explanation for the loss of information from short-term memory: **interference**. According to this view, our memories get in the way of each other. That is, our memories are very much like radio signals. They don't change over time, but they're harder to detect if they're jammed by other signals.

RULING OUT RIVAL HYPOTHESES
Have important alternative explanations for the findings been excluded?

As it turns out, there's evidence for both decay and interference. Recent physiological evidence for decay comes from research suggesting that the birth of new neurons in the hippocampus (see Chapter 3) leads to the decay of memories in that brain region (Kitamura et al., 2009). As we create new memories, our old ones gradually fade away. Nevertheless, there's even stronger evidence for the role of interference in memory loss. For example, two investigators (Waugh & Norman, 1965) presented participants with many different lists of 16 digits, such as 6 2 7 1 8 5 3 4 2 6 9 7 4 5 8 3. Right after participants saw each list, the researchers gave them one "target" digit to focus on and then asked participants which digit came after this target digit. In all cases, this target digit appeared twice in the list, and participants had to remember the digit that came after its *first* presentation in the list. In the digit list above, the target item might be "8," so we'd search for the first 8 in the list—and the correct response would be 5.

short-term memory
memory system that retains information for limited durations

decay
fading of information from memory over time

interference
loss of information from memory because of competition from additional incoming information

RULING OUT RIVAL HYPOTHESES ▶
Have important alternative explanations for the findings been excluded?

? This player is actively engaged in a racquetball match. If she was an experienced tennis player before attempting racquetball, the odds are high that her tennis swings would initially get in the way of her learning how to swing a racquetball racquet properly. That is, it will take her a while to "unlearn" her tennis swings. **What kind of interference is she experiencing?** (See answer upside down.)

As an ingenious means of ruling out alternative hypotheses, the experimenters manipulated two variables to figure out which of them influenced forgetting. Specifically, they manipulated (1) where in the list the target digit appeared (early or late) and (2) how rapidly they presented digits to participants—either quickly (one digit every second) or slowly (one digit every four seconds). They told participants to listen carefully to each digit, but not to rehearse it mentally. Now, if decay were the principal culprit in forgetting, participants' performance should become worse when researchers read the list slowly because more time had passed between digits. In contrast, if interference were the principal culprit, participants' performance should become worse when the target digit appeared later rather than earlier in the list, regardless of speed, because memory for later digits is hampered by memory for earlier digits.

The results showed that interference is the major factor in forgetting. Participants' forgetting is due almost entirely to where in the list the target digit appears, rather than to the speed of presentation (Keppel & Underwood, 1962). Still, most researchers believe that both decay and interference play some role in short-term memory loss (Altmann & Schunn, 2002).

We're not quite done with our examination of interference yet, because it turns out that there are two different kinds of interference (Ebert & Anderson, 2009; Underwood, 1957). One kind, **retroactive interference**, occurs when learning something new hampers earlier learning: The new interferes with the old (think of the prefix *retro-*, because retroactive interference works in a reverse direction). If you've learned one language, say Spanish, and then later learned a somewhat similar language, perhaps Italian, you probably found that you started making mistakes in Spanish you'd never made before. Specifically, you may have found yourself using Italian words, like *buono*, for Spanish words, like *bueno* (both *buono* and *bueno* mean "good").

In contrast, **proactive interference** occurs when earlier learning gets in the way of new learning: The old interferes with the new. For example, knowing how to play tennis might interfere with our attempt to learn to play racquetball, which requires a much smaller racquet. Not surprisingly, both retroactive and proactive interference are more likely to occur when the old and new stimuli that we've learned are similar. Learning a new language doesn't much affect our ability to master a new spaghetti recipe.

The Capacity of Short-Term Memory: The Magic Number. We've already seen that short-term memory doesn't last very long. Twenty seconds, or even less, and—poof—the memory is gone, unless we've made an extra-special effort to retain it. But how large is the *span* of short-term memory?

Try reading each of the following rows of numbers, one row at a time, at a rate of one number per second. Once you're done with each row, close your eyes and try writing down what you remember. Ready? Okay, begin.

9 – 5 – 2
2 – 9 – 7 – 3
5 – 7 – 4 – 9 – 2
6 – 2 – 7 – 3 – 8 – 4
2 – 4 – 1 – 8 – 6 – 4 – 7
3 – 9 – 5 – 7 – 4 – 1 – 8 – 9
8 – 4 – 6 – 3 – 1 – 7 – 4 – 2 – 5
5 – 2 – 9 – 3 – 4 – 6 – 1 – 8 – 5 – 7

You've just taken a test of "digit span." How'd you make out? Odds are that you breezed through three digits, started to find four digits a bit tricky, and maxed out at somewhere between five and nine digits. It's unlikely you got the ten-digit list completely right; if you did, you've earned the right to call yourself a memory superstar.

That's because the digit span of most adults is between five and nine digits, with an average of seven digits. Indeed, this finding is so consistent among people that psychologist George Miller (1956) referred to seven plus or minus two pieces of information as the **Magic Number**.

retroactive interference
interference with retention of old information due to acquisition of new information

proactive interference
interference with acquisition of new information due to previous learning of information

Magic Number
the span of short-term memory, according to George Miller: seven plus or minus two pieces of information

Simulate in **MyPsychLab** the **Experiment:** Digit Span

Answer: Proactive interference (the old interfering with the new).

According to Miller, the Magic Number is the universal limit of short-term memory, and it applies to just about all information we encounter: numbers, letters, people, vegetables, and cities. Because it's hard to retain much more than seven plus or minus two pieces of information in our short-term memory, it's almost surely not a coincidence that telephone numbers in North America are exactly seven digits long, not counting the area code (some European phone numbers are slightly longer, but few exceed nine, the upper limit for the Magic Number). Some psychologists have since argued that Miller's Magic Number may overestimate the capacity of short-term memory, and that the true Magic Number may be as low as four (Cowan, 2001; Mathy & Feldman, 2011). Regardless of who's right, it's clear that the capacity of short-term memory is extremely limited.

Chunking. If our short-term memory capacity is no more than nine digits, and perhaps much less, how do we manage to remember larger amounts of information than this for brief periods of time? Read the following sentence; then wait a few seconds and recite it back to yourself: **Harry Potter's white owl Hedwig flew off into the dark and stormy night.** Were you able to remember most or even all of it? The odds are high that you were. Yet this sentence contained 13 words, which exceeds the Magic Number. How did you accomplish this feat?

We can expand our ability to remember things in the short term by using a technique called **chunking**: organizing material into meaningful groupings. For example, look at the following string of 15 letters for a few seconds, and then try to recall them:

K A C F J N A B I S B C F U I

How'd you do? Odds are you didn't do too well, probably right around the Magic Number, that is, only a subset of the letters listed. Okay, now try this 15-letter string.

C I A U S A F B I N B C J F K

Did you do any better this time? It's the same 15 letters, but you probably noticed something different about this group than the first group: They consisted of meaningful abbreviations. So you probably "chunked" these 15 letters into five meaningful groups of three letters each: CIA, USA, FBI, NBC, JFK. In this way, you reduced the number of items you needed to remember from 15 to only 5. In fact, you might have gotten this number down to less than five by combining CIA and FBI (both the initials of U.S. government intelligence agencies) into one chunk.

Chunking explains how Rajan performed his remarkable pi memorization feats. He memorized enormous numbers of area codes, dates of famous historical events, and other meaningful numbers embedded within the list of pi digits to effectively reduce more than 30,000 digits to a much smaller number.

Experts rely on chunking to help them recall complicated information. For example, chess masters recall *realistic* chess positions far better than do novices, yet do no better than novices at recalling random chess positions, suggesting that experts organize meaningful chess positions into broader patterns (Chase & Simon, 1973; Gobet & Simon, 1998).

Rehearsal. Whereas chunking increases the span of short-term memory, a strategy called rehearsal extends the duration of information in short-term memory. **Rehearsal** is repeating the information mentally, or even aloud. In that way, we keep the information "alive" in our short-term memories, just as a juggler keeps a bunch of bowling pins "alive" by continuing to catch them and toss them back into the air. Of course, if he pauses for a second to scratch his nose, the bowling pins come crashing to the ground. Similarly, if we stop rehearsing and shift our attention elsewhere, we'll quickly lose material from our short-term memory.

There are two major types of rehearsal. The first, **maintenance rehearsal**, simply involves repeating the stimuli in their original form; we don't attempt to change the original stimuli in any way. We engage in maintenance rehearsal whenever we hear a phone number and keep on repeating it—either aloud or in our minds—until we're ready to dial the number. In this way, we keep the information "alive" in our short-term memory. Of course, if someone interrupts us while we're rehearsing, we'll forget the number.

Factoid

After two years of training, one man named S. F. was able to get his digit span memory up to 79 digits using chunking (Chase & Ericcson, 1981; Foer, 2011). Among other tricks, S. F., who was a runner, memorized enormous numbers of world record times for track events and used them to chunk numbers into bigger units. Yet S. F. hadn't really increased his short-term memory capacity at all, only his chunking ability. His memory span for letters was only a measly six, well within the range of the Magic Number achieved by the rest of us memory slackers.

Master chess players recall realistic chess positions, like the one above, better than do beginners. But they do no better than beginners at recalling unrealistic chess positions. So the experts' edge stems not from raw memory power, but from chunking.

chunking
organizing information into meaningful groupings, allowing us to extend the span of short-term memory

rehearsal
repeating information to extend the duration of retention in short-term memory

maintenance rehearsal
repeating stimuli in their original form to retain them in short-term memory

FIGURE 7.5 Word Pairs. Using elaborative rehearsal helps us recall the word pair *dog–shoe* (Paivio, 1969).

The second type of rehearsal, **elaborative rehearsal**, usually takes more effort. In this type of rehearsal, we "elaborate" on the stimuli we need to remember by linking them in some meaningful way, perhaps by visualizing them or trying to understand their interrelationship (Craik & Lockhart, 1972).

To grasp the difference between maintenance and elaborative rehearsal, let's imagine that a researcher gave us a *paired-associate task*. In this task, the investigator first presents us with various pairs of words, such as *dog–shoe*, *tree–pipe*, *key–monkey*, and *kite–president*. Then, she presents us with the first word in each pair—*dog*, *tree*, and so on—and asks us to remember the second word in the pair. If we used maintenance rehearsal, we'd simply repeat the words in each pair over and over again as soon as we heard it—*dog–shoe*, *dog–shoe*, *dog–shoe*, and so on. In contrast, if we used elaborative rehearsal, we'd try to link the words in each pair in a meaningful way. One effective way of accomplishing this goal is to come up with a meaningful, perhaps even absurd, visual image that combines both stimuli (Ghetti et al., 2008; Paivio, 1969) (see **FIGURE 7.5**). Research shows that we're especially likely to remember the two stimuli if we picture them interacting in some fashion (Blumenfeld et al., 2010; Wollen, Weber, & Lowry, 1972). That's probably because doing so allows us to chunk them into a single integrated stimulus. So to remember the word pair *dog–rocket*, for example, we could picture a dog piloting a rocket ship or a rocket ship barking like a dog.

Elaborative rehearsal usually works better than maintenance rehearsal (Harris & Qualls, 2000). This finding demolishes a widely held misconception about memory: that rote memorization is typically the best means of retaining information. There's a take-home lesson here when it comes to our study habits. To remember complex information, it's almost always better to connect that information with things we already know than to merely keep repeating it.

Depth of Processing. This finding is consistent with a **levels-of-processing** model of memory. According to this model, the more deeply we process information, the better we tend to remember it. This model identifies three levels of processing of verbal information (Craik & Lockhart, 1972): visual, phonological (sound-related), and semantic (meaning-related). Visual processing is the most shallow; phonological, somewhat less shallow; and semantic, the deepest. To understand the differences among these three levels, try to remember the following sentence:

ALL PEOPLE CREATE THEIR OWN MEANING OF LIFE.

If you relied on *visual* processing, you'd hone in on how the sentence looks. For example, you might try to focus on the fact that the sentence consists entirely of capital letters. If you relied on *phonological* processing, you'd focus on how the words in the sentence sound. Most likely, you'd repeat the sentence again and again until it began to sound boringly familiar. Finally, if you relied on *semantic* processing, you'd emphasize the sentence's meaning. You might elaborate on how you've tried to create your own meaning of life and how doing so has been helpful to you. Research shows that deeper levels of processing, especially semantic processing, tend to produce more enduring long-term memories (Craik & Tulving, 1975).

Simulate in **MyPsychLab** the **Experiment:** Depth of Processing

FALSIFIABILITY
Can the claim be disproved?

Still, some psychologists have criticized the levels-of-processing model as largely unfalsifiable (Baddeley, 1993). According to them, it's virtually impossible to determine how deeply we've processed a memory in the first place, so we could never independently test the claim that more deeply processed memories are better remembered. Moreover, critics claim that proponents of the levels-of-processing model are merely equating "depth" with how well participants later remember. There may well be some truth to this criticism. Still, it's safe to say that the more meaning we can supply to a stimulus, the more likely we are to recall it in the long term.

LONG-TERM MEMORY. Now that the second factory assembly line worker—short-term memory—has finished her construction job, what does she pass on to the third and final worker? And how does what the third worker receives differ from what the second worker

elaborative rehearsal
linking stimuli to each other in a meaningful way to improve retention of information in short-term memory

levels of processing
depth of transforming information, which influences how easily we remember it

started out with? **Long-term memory**, the third worker, is our relatively enduring store of information. It includes the facts, experiences, and skills we've acquired over our lifetimes.

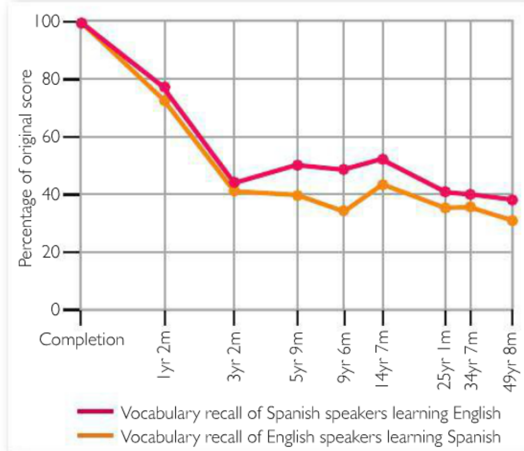


FIGURE 7.6 Long-Term Memory Retention. The classic work of Harry Bahrick (1984) shows that retention of a foreign language remains remarkably constant for spans of almost 50 years after an initial drop. (*Source:* Adapted from Bahrick, 1984, Figure 3)

Differences between Long-Term and Short-Term Memory. Long-term memory differs from short-term memory in several important ways. First, in contrast to short-term memory, which can typically hold at most seven to nine stimuli in hand at a single time, the capacity of long-term memory is huge. Just how huge? No one knows for sure. Some scientists estimate that a typical person's memory holds about as much information as 500 huge online encyclopedias, each about 1,500 pages long (Cordón, 2005). So if someone praises you on your "encyclopedic memory," accept the compliment. They're probably right.

Second, although information in short-term memory vanishes after only about 20 seconds at most, information in long-term memory often endures for years, even decades—and sometimes permanently. Consider the work of psychologist Harry Bahrick, who has studied individuals' memory for languages they learned in school over many decades. In **FIGURE 7.6**, we can see that people's memory declines markedly about two to three years after taking a Spanish course. Yet after about two years, the decline becomes quite gradual. Indeed, it begins to level out after a while, with almost no additional loss for up to 50 years after they took the course (Bahrick & Phelps, 1987). Bahrick referred to this kind of long-term memory, which remains "frozen" over time, as **permastore**, as an analogy to the permafrost found in the Arctic or Antarctic that never melts.

Third, the types of mistakes we commit in long-term memory differ from those we make in short-term memory. Long-term memory errors tend to be *semantic*, that is, based on the meaning of the information we've received. So we might misremember a "poodle" as a "terrier." In contrast, short-term memory errors tend to be *acoustic*, that is, based on the sound of the information we've received (Conrad, 1964; Wickelgren, 1965). So we might misremember hearing "noodle" rather than "poodle."

Primacy and Recency Effects. When we try to remember a large number of items, such as a grocery list or a schedule of events, we often forget some of them. To some extent, psychologists can predict which items we're more likely to forget and which we're more likely to remember.

To demonstrate this point, read the list of 20 words below, either to yourself or aloud. Read the left column first, then the middle column, then the right one. Then, turn away from your book and take a few minutes to try to recall as many of these words as you can in any order you'd like. Ready? Begin.

Ball	Sky	Store
Shoe	Desk	Pencil
Tree	Car	Grass
Dog	Rope	Man
Paper	Dress	Cloud
Bird	Xylophone	Hat
House	Knife	Vase

If you're like most people, you probably did a bit better with the early words, like *ball*, *shoe*, and *tree*, than with the words in the middle of the list. That's the **primacy effect**: the tendency to remember stimuli, like words, early in a list. Also, you may have done a bit better with the later words, like *cloud*, *hat*, and *vase*. That's the **recency effect**: the tendency to remember stimuli later in a list. As an aside, there's a decent chance you remembered the word *xylophone*, which seems to be something of an oddball in the list. That's because

long-term memory
relatively enduring (from minutes to years) retention of information stored regarding our facts, experiences, and skills

permastore
type of long-term memory that appears to be permanent

primacy effect
tendency to remember words at the beginning of a list especially well

recency effect
tendency to remember words at the end of a list especially well