GLOBAL EDITION

Human Learning

SEVENTH EDITION

Jeanne Ellis Ormrod

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HUMAN LEARNING

SEVENTH EDITION
GLOBAL EDITION

Jeanne Ellis Ormrod
University of Northern Colorado (Emerita)

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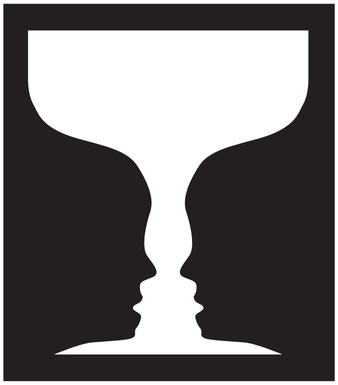
Figure 7.3
The Peter–Paul goblet.



sight—things that become the background (or *ground*) for the object. People may notice a few salient characteristics of background items (e.g., their color) but gain little other information about them.[7] From this perspective, the only way to gain detailed information about two or more items would be to shift the focus of attention from one item to another.

But now consider a situation in which you're driving your car while also carrying on a conversation with a friend. Certainly you're attending to two things—the road and the conversation—at the same time. To account for such a situation, many theorists describe attention as involving a **limited processing capacity**, with the number of stimuli being attended to depending on how much cognitive processing is required for each one (e.g., J. R. Anderson, 2005; Cowan, 2007; Pashler, 1992; Sergeant, 1996). If you're engaging in a difficult task, such as learning how to drive a car with a standard transmission, you might very well need to devote your full attention to that task and so not hear a thing your friend is telling you. However, if you're doing something more habitual or automatic, such as driving a standard transmission after years of driving experience, you can easily devote some attention to what your friend is saying. Many tasks, such as driving, become increasingly automatic over time, therefore requiring less and less of our attention. (I say more about this phenomenon, known as *automaticity,* in Chapter 8.) Even so, when people carry on a conversation while driving—say, on a cell phone—they have slower reaction times and are less likely to notice traffic signals (Strayer & Drews, 2007; Strayer & Johnston, 2001). Occasionally, people do become adept at splitting their attention among two complex tasks, but only when they have considerable practice in performing both tasks at the same time, ideally making the execution of one or both of them automatic. In most circumstances, human beings are *not* very good at multitasking (N. Carr, 2011; Foerde, Knowlton, & Poldrack, 2006; Kirschner & van Merriënboer, 2013; Lien, Ruthruff, & Johnston, 2006; Ophir, Nass, & Wagner, 2009).

Regardless of how we view attention, one thing is clear: People's ability to attend to the stimuli around them is limited, such that they usually can't attend to or otherwise learn from two complex situations at the same time. Thus, learners must be quite selective about the information they choose to process, and they must ignore—and so lose—much of the information they receive.

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[7]For recent analyses of the figure–ground phenomenon, see M. A. Peterson (1994); M. A. Peterson and Gibson (1994); Vecera, Vogel, and Woodman (2002).

Attention is closely connected with working memory, although theorists continue to debate *how* closely the two are linked (e.g., Cowan, 2007; Downing, 2000; Logie, 2011; Woodman, Vogel, & Luck, 2001). As you'll see now, working memory controls attention to some extent, and it, like attention, has a limited capacity.

Working Memory

Historically, cognitive psychologists typically used the term *short-term memory* (or *short-term store*) to refer to a storage mechanism that holds information for a brief time after it's attended to so that it can be mentally processed. But most theorists now believe that this component of memory is also where cognitive processing itself takes place, hence their more frequent use of the term **working memory.**

In essence, working memory is the component of memory in which active thinking occurs. You might think of it as the "awareness" or "consciousness" of the memory system (e.g., Paller, Voss, & Westerberg, 2009; Reznick, 2007; D. J. Siegel, 2012). It identifies information in the sensory register that warrants attention, saves the information for a longer period of time, and processes it further. It may also hold and process information that it retrieves from long-term memory—information that will help in interpreting newly received environmental input.

Working Memory's Central Executive Component

Many contemporary theorists have suggested that working memory has a subcomponent known as the **central executive** (see Figure 7.1). The central executive is, if you will, the "head of the head," in that it controls and monitors the flow and use of information throughout the memory system (e.g., Baddeley, 2007; Banich, 2009; J. H. Bernstein & Waber, 2007). As the brain continues to mature over the course of childhood and adolescence, this central executive function becomes increasingly sophisticated and effective (S. M. Carlson, Davis, & Leach, 2005; Luciana, Conklin, Hooper, & Yarger, 2005; E. Peterson & Welsh, 2014; Zelazo, Müller, Frye, & Marcovitch, 2003).

Yet even within a particular age-group, learners differ considerably in their central executive abilities—that is, they differ in how effectively they control what they attend to and in how extensively and effectively they process it (Hasher, Zacks, & May, 1999; Miyake & Friedman, 2012). Some of this variability is the result of individual differences in a brain-based characteristic known as **effortful control**, which I previously mentioned in Chapter 5. Not only do individual differences in effortful control affect learners' ability to inhibit impulsive behaviors (see Chapter 5) but they also affect learners' ability to resist distractions and keep their attention on what they're supposed to be doing. Thus, children with high levels of effortful control are higher achievers in the classroom (Blair & Razza, 2007; Liew, McTigue, Barrois, & Hughes, 2008; Masten et al., 2012; Rothbart, 2011; Valiente, Lemery-Calfant, Swanson, & Reiser, 2008).[8]

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[8]To a considerable degree, processes associated with working memory and the central executive appear to be located in the frontal lobes of the cortex and in certain structures in the middle of the brain known as *basal ganglia.* For instance, people with damage to their frontal lobes may have trouble controlling attention, planning a course of action, and inhibiting inappropriate responses (Aron, 2008; Baddeley, 2001; Kimberg, D'Esposito, & Farah, 1997; Miyake & Friedman, 2012).

Characteristics of Working Memory

Working memory is quite different from the sensory register in terms of capacity, forms of storage, and duration.

Capacity Unlike the sensory register, working memory appears to have a very limited capacity. After reviewing a number of early studies, George Miller (1956) characterized its capacity as the *magical number seven, plus or minus two:* According to Miller, people can hold from five to nine units of information in working memory at one time, with the average number of memorable units being about seven. Although the *number* of information units in working memory can't be increased beyond 7 ± 2, Miller suggested, the *amount* of information in each unit can be increased. For example, in discussions of working memory in undergraduate psychology classes, I have sometimes asked students to try to remember this string of digits:

5 1 8 9 3 4 2 7 6

Most of my students have been able to remember somewhere between six and eight digits. A few have remembered all nine by clumping them into groups of three like this:

5–1–8 9–3–4 2–7–6

This process of combining pieces of information in some way, called **chunking**, can slightly increase the amount of information that working memory's limited space can hold.

In recent decades, however, it has become clear that Miller's original estimate of 7 ± 2 is an overly simplistic view of working memory's capacity—for instance, notice the focus on meaningless sequences of numbers in the preceding paragraph—and may reflect a *maintenance rehearsal* process you'll learn about shortly. As an alternative, Cowan (2010) has suggested that young adults can typically keep only about three to five *meaningful* items (e.g., short sentences) in working memory. Playing off of a classic Beatles album title, Cowan calls this capacity the *magical mystery four.* Working memory's capacity for holding visual stimuli appears to be equally limited, and exactly *how many* visual stimuli it can hold—maybe four, or maybe only one or two—depends on how precisely each stimulus needs to be retained (Gallivan et al., 2011; A. M. Murray, Nobre, Clark, Cravo, & Stokes, 2013; W. Zhang & Luck, 2011).

Ultimately, it may be virtually impossible to pin down the true capacity of working memory, at least in terms of a specific number of discrete items that can be simultaneously held there. And in any case, learners appear to differ somewhat in terms of their working memory capacities (Alloway, Gathercole, Kirkwood, & Elliott, 2009; G. W. Evans & Schamberg, 2009).

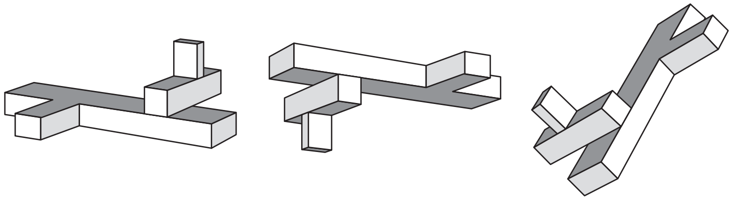
Furthermore, cognitive processing requirements may consume some of working memory's capacity, leaving less room for information storage. As an example, try to solve the following long-division problem in your head, without referring back to the page until after you've solved it:

$37\overline{)4281}$

Almost impossible, isn't it? You may have found that while you were dividing 37 into 42—getting a "1" with a remainder of "5"—you forgot the rest of the dividend. Simply remembering the problem's original six digits might be an easy task, but mentally *doing something* with them at the same time is too much for most people's working memories to handle.

Forms of storage A good deal of the information stored in working memory is encoded in an *auditory* form, especially when the information is language based (Logie, 2011; Cowan, Saults, & Morey, 2006; M. I. Posner & Rothbart, 2007). For example, in an early study by Conrad (1964),

Figure 7.4
Example of visual-spatial encoding in working memory.



adults were shown six-letter sequences, with letters being presented visually, one at a time, at three-fourths-of-a-second intervals. As soon as the last letter of a sequence had been presented, participants in the study wrote down all six of the letters they thought they had seen, guessing at any letters they couldn't easily recall. People's incorrect letters were typically similar in *sound*—not appearance—to the letters they actually saw. For example, the letter *F* was "remembered" as the auditorially similar letter *S* 131 times but as the visually similar letter *P* only 14 times. Similarly, the letter *V* was remembered as *B* 56 times but as *X* only 5 times.

Yet working memory almost certainly includes ways of encoding information in other forms as well, including visual, spatial, tactile, and psychomotor forms (Cowan et al., 2006; J. A. Harris, Miniussi, Harris, & Diamond, 2002; M. I. Posner & Rothbart, 2007; Serences, Ester, Vogel, & Awh, 2009; J. Wood, 2007). As an example of a task that requires both visual and spatial encoding—hence it's often called *visuospatial imagery*—look at Object A in Figure 7.4, and then look at Object B. Does B represent the same three-dimensional configuration as A? To answer this question, you must mentally "rotate" B in your head; if you rotate it 180 degrees, you'll mentally "see" that B is the same as A. Now compare Object C to Object A. If you "rotate" the right side of C down a bit and toward you, you should discover that C is *not* the same as A; instead, it's a mirror image of A. Shepard and Metzler (1971) asked adults to perform a task similar to the one I've presented here and measured people's reaction time to each pair of figures. Results were quite dramatic: Reaction times were almost entirely a function of how much a figure would have to be turned for it to be lined up with another figure. In other words, the participants were responding as if they were mentally rotating images, with more rotation resulting in a longer reaction time (also see L. A. Cooper & Shepard, 1973).

Many information processing theorists believe that working memory includes two or more distinct storage mechanisms that specialize in different sensory modalities (e.g., Baddeley, 2007; Logie, 2011; P. Shah & Miyake, 1996; E. E. Smith, 2000).[9] As an example, Alan Baddeley (e.g., 2001, 2007) suggests that a mechanism he calls a **phonological loop**[10] can keep a small amount of auditory information fresh through constant repetition (more about such repetition shortly).

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[9]Neurological evidence supports this idea: Tasks involving the processing of verbal, auditory information activate different parts of the brain than do tasks involving the processing of visual and spatial information. In fact, memory for spatial arrangements and locations may involve somewhat different areas of the brain than does memory for visual characteristics (Baddeley et al., 2009; Jonides, Lacey, & Nee, 2005; MacAndrew, Klatzky, Fiez, McClelland, & Becker, 2002; Serences et al., 2009).

[10]In his early writings, Baddeley called this an *articulatory loop*. However, he changed the term to reflect the fact that it involves the *sounds* (phonemes) of speech but doesn't necessarily involve actual speaking (articulation).

Meanwhile, a **visuospatial sketchpad** allows manipulation and short-term retention of visual material. Presumably, working memory also includes a "place" where information from multiple input modalities and also from long-term memory can interact and be integrated into an overall understanding of a particular situation or episode; Baddeley calls this component the **episodic buffer**.

Having modality-specific storage mechanisms seems to help us stretch our working memory capacity a little bit. We have an easier time performing two tasks at the same time when one task involves primarily auditory, verbal information and the other task is more visual and nonverbal in nature—for instance, when we're asked simultaneously to judge whether a series of sentences are true or false (an auditory, verbal task) and to perform tasks similar to the one in Figure 7.4. Even so, people in such situations may not be able to devote the amount of attention and mental energy to each task that they would use if they were doing only one of the tasks (Dunlosky, Rawson, Marsh, Nathan, & Willingham, 2013; Just et al., 2001; Schumacher et al., 2001).

Duration Working memory is just what its alternative name, *short-term memory,* implies: It's *short.* An experiment by Peterson and Peterson (1959) gives us some idea of how long information in working memory might last. In this experiment, adults were told three consonant letters (e.g., *D X P)* and then immediately asked to count backward by threes from a 3-digit number, which was different in each trial. At a signal that occurred anywhere from 3 to 18 seconds after the three consonants had been presented, the participants were asked to recall the consonants. When recall was delayed only 3 seconds, people were able to remember the letters with 80% accuracy; after an 18-second interval, however, their accuracy was only about 10%.

Considering research results such as those of Peterson and Peterson, the duration of working memory appears to be less than 30 seconds, and in many cases may be considerably shorter than this (e.g., W. Zhang & Luck, 2009). As is true for the sensory register, both decay and interference have been offered as explanations for working memory's short time span (Barrouillet & Camos, 2012; Cowan, 2007; Cowan, Wood, Nugent, & Treisman, 1997). Some information stored in working memory may fade away (i.e., decay) if it isn't processed further. Other information may be replaced by new input—as one of my professors used to say, it is "bumped out." For example, as a woman who for many years had a husband, three children, a dog, and two cats all living in the same house, I found myself frequently being interrupted in the middle of tasks. If I had a batch of cookies in the oven, and Jeff asked me to help him get a snack and Tina asked me to help her find something she'd misplaced, my cookies were very likely to be pushed from my working memory until I was confronted with new environmental input: the smell of something burning. My husband called me absentminded, but I knew better. My mind was definitely present, but the working component of it had a limited capacity, and new input interfered with the cookies-in-the-oven information I had previously stored in there.

Control Processes in Working Memory

Working memory, and especially its central executive component, appears to be the home of many processes important for learning, thinking, and behavior—for example, directing attention, drawing inferences, making decisions, solving problems, and inhibiting irrelevant thoughts and actions (Aron, 2008; Banich, 2009; Demetriou, Christou, Spanoudis, & Platsidou, 2002; Miyake & Friedman, 2012). For now we'll look at three control processes that affect the functioning of working memory itself: organization, retrieval, and maintenance rehearsal.

Organization Sometimes people increase what they can hold in working memory by organizing it in some way—that is, by pulling together two or more pieces of information into an integrated unit. We previously saw an example of such organization in Miller's (1956) concept of *chunking*—for instance, repeating the digit string

5 1 8 9 3 4 2 7 6

as three 3-digit chunks. Another common organizational strategy is to impose a rhythm or melody on the numbers (G. H. Bower & Springston, 1970). Still another way of organizing the digits is to attach some meaning to them—a process that involves retrieving information that's previously been stored in long-term memory. For instance, when I presented the 9-digit string to one of my undergraduate classes, a varsity football player named Dave remembered all nine digits and claimed he could have easily added a few more to the list. He explained his approach this way:

> Well, "51" is Jason, a guy who played center during my freshman year. "89" is Jeff, a wide receiver from my roommate's hometown. "34" is John, a current running back on my team—well, his number has changed, but I always think of him as "34." "2" is another Dave (not me), who's a wide receiver. And "76" is my good friend Dan. My number is 75, and so Dan's locker is next to mine.

By attaching meaning to the numbers, Dave also facilitated their storage in long-term memory. In Chapter 8, we'll look at such *meaningful learning* more closely.

Retrieval Retrieving information from working memory is often quite easy and automatic. Yet to some degree, how quickly and easily something is retrieved depends on how much information is stored there. For example, in one early study (S. Sternberg, 1966), college students were given a set of from one to six numbers, which the students presumably stored in working memory. Then an additional number was presented, and the students were asked whether that number had been among the original set. The time it took for students to answer the question depended almost entirely on the size of the number set already stored in working memory, with each successively larger set yielding a reaction time of about 40 milliseconds longer. From such results, it appears that retrieval of information from working memory may sometimes be a process of scanning all of working memory's contents, successively and exhaustively, until the desired information is found (also see J. G. Thomas, Milner, & Haberlandt, 2003).

Maintenance rehearsal Imagine that you need to call a neighbor, so you look up the neighbor's number in a telephone book. Because you've paid attention to the number, it's presumably in your working memory. But then you discover that you can't find your cell phone. You have no paper and pencil handy. What do you do to remember the number until you have access to a phone? If you're like most people, you probably repeat it to yourself over and over again.

Repeating information to keep it alive in working memory is a process known as **maintenance rehearsal**, which often takes the form of subvocal speech (Baddeley, 2007; Landauer, 1962; Sperling, 1967). Maintenance rehearsal provides a means for saving information from the forgetting processes of decay and interference; when such rehearsal isn't possible, information in working memory quickly disappears. As an example, recall Peterson and Peterson's (1959) experiment regarding working memory's duration that I described earlier. After participants in the study were given the three consonants they needed to remember, they were asked to count backward by threes until the signal for recall. Such backward counting kept them from rehearsing the three letters; otherwise, they might have kept them in working memory indefinitely simply by repeating them over and over as long as necessary.