the use of imagery, but as we will see in Chapter 8, memory is enhanced when we create relationships among the items to be remembered. One further hint: The more bizarre the image you create, the better the recall.

APPLE  DOOR  BOWL
KNIFE  BELT  RAISINS
PLATE  BROOM  CEREAL
GLASS  TOWEL  CUP
MILK  SOAP  CRACKER

Another way around the serial position effect is simply to accept that people will forget the ideas in the middle of a message and remember only the information at the beginning and end of messages. Commercials for prescription medicines typically place the description of the drug’s possible side effects in the middle of the commercial. This helps to make the negative information less memorable. The product’s name is spoken at the beginning and end of the advertisement in order to make it more memorable.

**SECTION SUMMARY**

**The Serial Position Effect**
The items in the middle of a list are not as likely to be recalled as those at the beginning or end of a list and it doesn’t matter whether the list is made up of TV advertisements, introductions to people at a party, or the main points in a textbook paragraph. This phenomenon, called the serial position effect, is represented visually as a U-shaped curve and reflects the dual operation of short-term memory and long-term memory. It is more distinctive for auditory presentations of information than for visually based presentations; this is called the modality effect. Each portion of the curve can be separately affected by the conditions in which the information is presented. If information is presented rapidly, it is difficult for a person to attend to each item so the primacy portion (first part of the curve) will show poor performance. If a delay occurs between the time the list is presented and the time it is recalled, the recency portion of the curve (last part of the curve) will show poor performance. Methods exist to help individuals avoid the serial position effect. These methods involve making each item in a list meaningful and mentally connecting list items to one another to form a memorable image.

**Working Memory: The Structure Beneath Short-Term Memory**
We have seen that STM behaves differently depending on whether the things to be remembered are presented visually or auditorily, rapidly or slowly, or whether the items activate information stored in long-term memory and where in a sequence of
facts a critical item falls. Cognitive psychologists have developed a theory of the underlying mechanisms of STM not only to explain the properties of STM, but also to explain how STM helps us interact with the world and accomplish our goals. This emphasis on the active and structural aspects of STM began with the work of Miller, Galanter, and Pribram (1960). They called STM working memory to emphasize that it serves as our support system for doing cognitive work, such as reasoning, listening, or making decisions.

Great progress in this effort to replace the static model of STM with a more process-oriented model of working memory was made by Baddeley and Hitch (1974, 1976, 1977). They defined working memory as a limited capacity system that allows us to store and manipulate information temporarily so that we can perform everyday tasks. Their model of working memory is composed of the four subsystems shown in Figure 5.8: a phonological loop, a visuospatial sketchpad, an episodic buffer, and a central executive. The goal of the remainder of this section is to describe the cognitive functions performed by each of these WM components and to show how the properties of short-term memory can be explained by the mechanisms of working memory.

The Phonological Loop

Sound is a primary means of conveying information. Even when we read silently, we often generate internal (subvocal) speech: a sound-based (phonological) representation of the visually presented words (e.g., Bookheimer, Zeffiro, Blaxton, Gaillard, & Theodore, 1995). Like the serial position effect, sound is one of the basic codes of STM. Not surprisingly, one of the subsystems in working memory is dedicated to the temporary storage of phonological information. This system is called the phonological loop and it contains two components: the phonological store, a reservoir in which an acoustic or phonological representation of the stimulus is stored; and the articulatory control process (like maintenance rehearsal), which automatically refreshes and maintains the elements in the phonological store. This control process refreshes the items in the phonological loop as if they were being rehearsed, though of course the process is subvocal, no sound is actually made.

Without the articulatory control process, the phonological store would be roughly equivalent to the original description of STM, because without the constant activation of the articulatory control process, items to be remembered would be lost over time. According to the WM model, the articulatory control process “refreshes” or automatically gives energy to each element in roughly a 2-second cycle. Any sounds (names, numbers, etc.) that can be repeated in 2 seconds can be maintained in WM.
Short-Term Memory and Working Memory

(Schweikert & Boruff, 1986). If a set of items requires more than 2 seconds to be repeated, some loss of information from memory will result because there is a trade-off in WM between the rate of loss and the rehearsal rate. When the items in the phonological loop are numerous or difficult to pronounce, the articulatory control process cannot keep up with refreshing all of the information in the phonological loop: The more information you have to process, the more information you will lose from working memory. This aspect of WM accounts for the fact that STM capacity has a limit because of the work required by the articulatory control process.

**Neuropsychology of the Phonological Loop** Specific areas of the brain are associated with the functions of the phonological loop and other subsystems of working memory. These are illustrated in [Figure 5.9](#). The basic storage function of the phonological loop is associated with activity in the left parietal region (Nyberg & Cabeza, 2000; Shallice & Vallar, 1990; Warrington, 1971). It may also connect just below the left parietal region to the superior temporal lobe (Buchsbaum & D’Esposito, 2008), a central area for language processing, which will be discussed in Chapters 10 and 11. The refreshing of items within the phonological loop is associated with activity in the prefrontal cortex (Awh, Jonides, Smith, Schaumacher, Koepp, & Katz, 1996; Paulescu, Frith, & Frackowiak, 1993). This part of the brain helps people understand human speech (see Chapter 9) and is connected to an area of the cortex, called the motor area, which gives commands to the muscles that allow us to speak. The fact that the areas of the brain related to WM are also important to speech supports the hypothesis that the articulatory control process is speech based. Moreover, the fact that the brain areas associated with storage of words are separate from the area that refreshes those words is evidence that the phonological loop is separate from the functioning of the articulatory control process.

**The Visuospatial Sketchpad** Sometimes we are called upon to remember a picture, a dance sequence, or imagine a route through a new neighborhood. The cognitive processes that are mobilized to perform these actions rely on another component of working memory: the **visuospatial sketchpad** (see Figure 5.8). This WM component is responsible for storing visually presented information such as drawings or remembering kinesthetic (motor) movements such as dance steps. For example, when you read the word “cat” you see the letters and store them; however, if time permits you might also retrieve a visual image of your favorite cat and store that in the sketchpad along with the written letters. It works the other way as well: If you see a picture of a cat, you may implicitly verbalize something like the word “cat” (Glanzer & Clark, 1964; Smith & Larson, 1970). However, this requires the participation of the central executive, described later. The importance of the visuospatial sketchpad is evident when reading a textbook like this one that has words, figures, and
illustrations that are related to one another. In this case, both the sketchpad and the phonological loop are working together to combine the information that is presented on the page as both words and pictures. The sketchpad maintains the visual representation of stimuli as well as their spatial position on the page (Hegarty & Just, 1989; Schacter, Wagner, & Buckner, 2000).

The visuospatial sketchpad contains two structures: the visual cache and the inner scribe (Logie, 1995, 2003; illustrated in Figure 5.8). The visual cache temporarily stores visual information that comes from perceptual experience and contains information about the form and color of what we perceive (Smyth & Pendleton, 1989). And, as if it were storing a picture, it also contains some spatial information about what is perceived. In contrast, the inner scribe performs at least two functions. First, it refreshes all of the stored information contained in the visuospatial sketchpad. Second, it briefly stores spatial relationships associated with bodily movement. The two together are involved in our common experience of visual imagery. The visual cache holds the images and the inner scribe can manipulate them. Both require the involvement of part of the central executive called the visual buffer to create our images (Logie, 1995; see also Bruyer & Scailquin, 1998; Pearson, 2001). Visual imagery will be an important topic in Chapter 8.

In an experiment to determine whether the visuospatial sketchpad and the phonological loop are independent systems, university students were asked to memorize a miniature checkerboard with black and white squares: a perceptual task associated with the visuospatial sketchpad (Cocchini, Logie, Della Sala, MacPherson, & Baddeley, 2002). At the same time, the students either engaged in a motor task (also associated with the visuospatial sketchpad) or a verbal task (associated with the phonological loop). The motor task consisted of using a computer stylus to track a “ladybug” moving on a computer screen. The verbal task required the students to repeat back an ever-changing sequence of numbers (a typical digit-span procedure). Consistent with the concept of a visuospatial sketchpad, tracking the ladybug interfered with remembering the checkerboard (a spatial task). The digit-span task associated with the phonological loop, however, did not interfere with remembering the checkerboard. Thus, a spatial motor task interferes with perceptual information stored in the visuospatial sketchpad, but a phonological task does not. These findings support the theory that the visuospatial sketchpad and the phonological loop are separate, independent systems.

**Neuropsychology of the Visuospatial Sketchpad** The visuospatial sketchpad is represented in the brain in a manner similar to the phonological loop (see Figure 5.9) except that it is represented primarily on the right side of the brain (Courtney, Ungerleider, Keil, & Haxby, 1997; Smith et al, 1995). Cognitive neuroscience provides evidence in support of the theoretical distinction between the visual cache and the inner scribe. The functioning of these
systems is associated with separate neurological areas (Levy & Goldman-Rakic, 2000; Sala, Rama, & Courtney, 2003).

Clinical cases also provide evidence for two subsystems. In one case, an individual with a lesion in the right prefrontal cortex had difficulty remembering spatial relationships among objects (information associated with the inner scribe), yet had no difficulty perceiving those same objects (information associated with the visual cache; Carlesimo, Perri, Turriziani, Tomaiuolo, & Caltagirone, 2001). The same effect can be seen in laboratory experiments. In one study researchers were able to “knock out” the ongoing electrical activity of the part of the brain associated with the functioning of the inner scribe using a procedure called repetitive transcranial magnetic stimulation (rTMS). By doing so, they were able to interfere with a volunteer’s ability to remember the arrangements of dots (illustrated in FIGURE 5.10), but not a volunteer’s memory for pictures. When the researchers

![Diagram](image)

**FIGURE 5.10 The Scribe and the Cache Are Separate Systems** In this study, researchers were able to show that the inner scribe and the visual cache are separate systems. Volunteers performed two tasks: spatial memory for the pattern of dots (using the inner scribe) or memory for faces (using the visual cache). When performing these tasks, volunteers had targeted areas of their brain briefly knocked out by a pulse of repetitive transcranial magnetic stimulation (rTMS). When the rTMS pulse is sent to the area where the inner scribe functions (the dorsolateral medial prefrontal cortex) the dot pattern task is interrupted, but not the face recognition task. In contrast, when the rTMS pulse is sent to the visual cache area (ventrolateral prefrontal cortex), the face memory task is interrupted, but not the dot pattern memory task.

Source: Mottaghy, Gangitano, Sparing, Krause, and Pascual-Leone, 2002
subsequently used rTMS to knock out the brain area associated with the visual cache, they were able to interfere with memory for pictures, but not memory for the spatial arrangements of dots (Mottaghy, Gangitano, Sparing, Krause, & Pascual-Leone, 2002). This testing procedure demonstrates the independence of the two components of the visuospatial sketchpad.

The Episodic Buffer

When people are engaged in a conversation, they have to keep track of what has been said, the responses to what has been said, and their assumptions about what individual speakers intended by their remarks. It is as if every conversation is a ministory or “episode” with a beginning, middle, and end. To keep track of such episodes, researchers argue that WM contains an episodic buffer, which acts as an integrative system that places events occurring in the visuospatial sketchpad and the phonological loop into a coherent sequence along with memory for the goals that initiated those events (Baddeley, 2000, 2004). Because the episodic buffer keeps track of the sequence of sentences that are spoken to us, it is natural to suppose that some part of the phonological loop would be connected to episodic memory. This is just what neuroscientists have found: The lower portion of the parietal lobe (near where the phonological loop seems to function) acts as an interface between episodic memory and the executive systems. Of course we should not think that the episodic buffer is localized only to this area of the brain. Rather we must always suppose that this part of the brain operates in coordination with other regions of the brain to perform the basic WM functioning (e.g., Vilberg & Rugg, 2008).

To appreciate the usefulness of the episodic buffer, remember that STM research has found that the typical person can remember a list of about 5 to 9 unrelated words. Yet, when those words are organized as a normal sentence, memory span increases to 15 or 16 words (Baddeley, Vallar, & Wilson, 1987). This phenomenon is most evident in people whose attention is working well (Baddeley & Wilson, 2002). The episodic buffer strings the sounds and words together to form a connected, time-based sequence to hold the words together as a sentence (as when we are able to chunk a sequence of words). It is the episodic buffer that also accounts for how people remember lists of unrelated items (not in a sentence), which was described earlier as the serial position effect.

The concept of the episodic buffer helps us to understand an oddity in the clinical literature. There are individuals who suffer from a kind of amnesia that affects their short-term memory. Their memory span might be one or two unrelated words presented either aurally or visually. They can’t repeat back more words than that and they have a great deal of difficulty understanding what is going on around them. However, if they are presented with words that form a sentence, the number of words they are able to repeat is often doubled (Baddeley & Wilson, 2002). This suggests that there is a sequencing process that is able to hold items together with a kind of time-based glue. This sequence works through the episodic buffer. The episodic buffer does not seem to have a
unique area of the brain that performs its functions. It is probably redundantly represented in a number of places (Baddeley, 2002). This is sensible because the buffer is called upon to organize so many systems.

The Central Executive

According to Baddeley’s model, working memory contains a fourth component, the **central executive**, which coordinates the activities of the visuospatial sketchpad, phonological loop, and episodic buffer, and also communicates with long-term memory via the episodic buffer (Baddeley, 1998, 2002). The central executive is not a memory store: It is a control system that guides attention and allocates resources to maximize performance. The attention system was discussed in Chapter 3 along with the basic spotlight metaphor. Sometimes the spotlight is moved by automatic processes and other times by more controlled processes. The central executive is the main system for controlling attention.

Researchers have designed a task to test the central executive’s effectiveness in different people (Daneman & Carpenter, 1980, 1983; Daneman & Merikle, 1996). In this task, participants are supposed to read a series of short sentences and remember the last word of each sentence. Then they are tested on how many of the last words they are able to recall. The number of such words that a participant is able to recall reflects the ability of the central executive to control two tasks at once: reading sentences and remembering unrelated words. WM span, which basically determines WM efficiency (Turner & Engle, 1989), varies among people and correlates with standard measures of fluid intelligence (the ability to reason and make decisions on the fly; Kyllonen & Christal, 1990). As we will see in the chapters on language, WM span also predicts reading comprehension (Conway, Kane, & Engle, 2003; Swanson & Jerman, 2007).

The central executive coordinates, manipulates, and updates the content of the WM divisions (Baddeley & Logie, 1999). In general, executive functions, such as planning and paying attention, are centered in this area of the prefrontal cortex where the central executive is identified (see Figure 5.9). People who have damage to this region suffer an inability to plan an action (Owen, Evans, & Petrides, 1996), difficulty attending to relevant aspects of their environment, or difficulty handling multiple tasks at once (D’Esposito, Detre, Alsop, & Shin, 1995).

A test that measures central executive functioning is the Paced Auditory Serial Addition Task (PASAT; see **FIGURE 5.11**). The PASAT requires participants to add aurally presented consecutive numbers at a rate of about 2.4 seconds per number and announce the sum. This is more difficult than you might assume because the participant must not confuse the addition that he or she has just stated aloud with the next number presented. For example, if the first number is 4 and the second number is 6, the answer is 10. If the third number is 3, the answer is 9 (6 + 3). The participant must resist the temptation to say 13 (10 + 3; Gronwall, 1977).
A person’s score on this test is the number of correct additions. This test makes only minor demands on arithmetic knowledge, but puts a premium on the individual’s ability to do three things at once: add two numbers, keep track of the previously presented digit in working memory, and inhibit the sum of the previous two digits. The PASAT score relates to central executive functioning in the real world and is positively correlated with a person’s level of vigilance: his or her ability to detect the presence of unlikely events (Weber, 1988). It also relates somewhat to a person’s IQ (Spreen & Strauss, 1991; Wiens, Fuller, & Crossen, 1997). The PASAT has a diagnostic use: People who have recently suffered a concussion have greatly diminished PASAT performances (Erlanger, Kutner, Barth, & Barnes, 1999; Gronwall & Sampson, 1974).

It has already been mentioned that the PASAT is a measure of central executive functioning. Most studies indicate that both age and intelligence affect performance on the PASAT. In general, older people (50-year-olds) perform worse than younger people (20-year-olds), and those with higher IQ scores have stronger PASAT performance than those with lower IQ scores (Wiens et al., 1997). These effects suggest a biological basis for the efficiency of the central executive in working memory. Added to this is the effect of brain trauma on central executive functioning. Not only is the PASAT sensitive to the changes in cognitive functioning that result from concussions, it is also sensitive to more permanent cognitive damage following traumatic brain injury (Sohlberg & Mateer, 1989).

A word of caution is useful here. Although it is easy to point to the functioning of the frontal lobes as the location of the central executive, we must remember that the frontal lobes are connected to so many other areas of the brain that we can be confident neuropsychological research will show that additional areas outside the frontal lobes are likely to contribute to executive control.

**SECTION SUMMARY**

**Working Memory: The Structure Beneath Short-Term Memory**

Most cognitive researchers view short-term memory as reflecting a set of structures and processes called working memory. The working memory model consists of four divisions interacting with each other: the phonological loop, visuospatial sketchpad, episodic buffer, and central executive. The first three of these are limited-capacity memory structures that hold different representations of what we experience: sounds, visual and kinesthetic images, and sequential patterns that coordinate these representations. The central executive is responsible for attending...