CHAPTER THREE

The Modal Model

There seems to be a presence-chamber in my mind where full consciousness holds court, and where two or three ideas are at the same time in audience, and an ante-chamber full of more or less allied ideas, which is situated just beyond the full ken of consciousness. Out of this ante-chamber the ideas most readily allied to those in the presence-chamber appear to be summoned in a mechanically logical way and to have their turn of audience.

—Sir Francis Galton (1883)

Primary Memory

The publication of Broadbent's *Perception and Communication* in 1958 and of the papers by Miller (1956), Brown (1958), and Peterson and Peterson (1959) mark the beginning of the modern history of dividing memory into multiple stores with one store specialized for briefly holding information. This system has variously been called *primary memory*, *working memory*, *short-term memory*, and *short-term store*.

Memory had often been divided into multiple memory systems; for example, Burnham (1888, p. 575) documents forerunners of both iconic and echoic memory (see Chapter 2). Short-term store (STS) was based on what Exner called primary memory and Richet called elementary memory (Burnham, 1888). Although William James is usually given credit for coining the term *primary memory*, it was in fact Sigmund Exner (1846–1926), a physiological psychologist at Vienna, to whom James gives credit (James, 1890, p. 600).

Exner's contribution was published in 1879 in Leipzig in Ludimar Hermann's *Handbuch der Physiologie*.

James (1890) distinguished primary memory from secondary memory or memory proper, tracing the concept back to Wilhelm Wundt's work on *Umfang*. This German term is difficult to translate precisely as there is no real English equivalent, but it implies a kind of immediate consciousness of that which is still present. James (1890) elaborates:

> The objects we feel in this directly intuited past differ from properly recollected objects. An object which is recollected, in the proper sense of the term, is one which has been absent from consciousness altogether, and now revives anew. . . . But an object of primary memory is not thus brought back; it never was lost; its date was never cut off in consciousness from that of the immediately present moment. In fact, it comes to us as belonging to the rearward portion of the present space of time, and not to the genuine past. (pp. 608–609)

The short-term memory (STM) of the late 1950s and early 1960s was a combination of the idea of primary memory with the computer metaphor of memory; it was of limited capacity, very short duration, primarily verbal in nature, and intended mainly as a buffer where information could be temporarily stored. And just as a computer memory "forgets" when the power is turned off, so too does STM "forget" when attention is withdrawn and the maintenance process—rehearsal—is prevented. This view became so prevalent so quickly that by 1963, Melton devoted a paper to discussing "whether single-repetition, short-term memory and multiple-repetition, long-term memory are a dichotomy or points on a continuum" (p. 3). Melton's cogent arguments against multiple stores notwithstanding, the ensuing two-store conception of memory reached its most explicit form in papers by Waugh and Norman (1965), Atkinson and Shiffrin (1968), and Glanzer (1972) and a volume edited by Norman (1970). The resultant *modal model*, so termed by Murdock (1974), became the dominating, albeit not unanimous, view of memory. In this chapter, we will examine the various forms this model took.

Broadbent's Model

The most influential of the early approaches to primary memory was that of Donald Broadbent (1958). He characterized the human processor as a series of systems through which information flows, much as it does in electronic and communication systems. Information from the environment is received through the senses and is held temporarily in a preattentive sensory store (the S-system), the forerunner of iconic and echoic memory. From the S-system, information is filtered and arrives in a limited capacity store, the P-system, the site of conscious awareness. For Broadbent, the combination of the S- and P-systems constituted immediate or primary memory. Note how these systems were foreshadowed by Galton (1883), as indicated by the opening quotation for this chapter. For information to remain in primary memory, it had to be rehearsed; without rehearsal, information was assumed to fade. Secondary or long-term memory was believed to be a third, more permanent memory system, and it was thought that information passes through primary memory on its way to more or less permanent storage.

Three assumptions of Broadbent's view were retained by almost all subsequent models: (1) Primary and secondary memory involve separate memory systems. (2) Primary memory has a limited capacity. (3) Because information fades quickly in primary memory, information is retained only when it is actively rehearsed.

Recall that Sperling (1960) suggested that information in iconic memory needs to be recoded if it is to be maintained. Rather than store information in a form identical to its actual physical features, as sensory memory systems do, primary memory stores information in a speechlike code. Two early experiments by Conrad (1964) and Wickelgren (1965) quickly established that the main code or form of representation in primary memory was acoustic or sound-based. Conrad (1964) presented subjects with lists of letters, some that looked similar but sounded quite different (such as *V* and *X*) and others that looked quite different but sounded almost identical (such as *V* and *C*). Some subjects read the letters silently, and others heard the letters pronounced aloud. Surprisingly, Conrad found that regardless of whether the subjects had seen or heard the letters, any errors that were made tended to be based on acoustic similarity rather than on visual similarity. Both he and Wickelgren (1965) argued that the main code in primary memory is acoustic, suggesting that subjects are remembering the sound of the to-be-remembered items using some form of inner speech.

Baddeley (1966) found comparable results. He presented subjects with four types of lists. In the phonologically similar list, the words sounded very similar, such as *man*, *mad*, *cap*, *can*, and *map*. The control list had words of similar frequency but different sounds: *pen*, *rig*, *day*, *bar*, and *sup*. In the semantically similar list, the words all meant the same thing: *big*, *huge*, *broad*, *long*, and *tall*. Here the control list was *old*, *late*, *thin*, *wet*, and *hot*. The results of the study are shown in Figure 3.1. Similarity of meaning had very little effect, but similarity of sound resulted in very poor performance. These results are entirely consistent with other studies that show that in primary memory the dominant code appears to be acoustic, a form of inner speech.

One way of testing the idea that information in primary memory uses inner speech is to prevent subjects from rehearsing the items subvocally. If this is done successfully, the errors should no longer be based on acoustic similarity. Murray (1967) was the first to use a procedure known as *articulatory suppression* to prevent subvocal rehearsal. Throughout

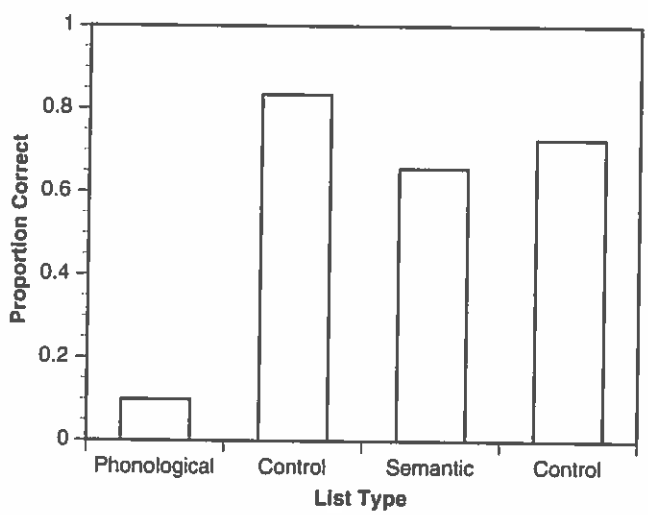

Figure 3.1 Proportion of words recalled correctly as a function of list type. SOURCE: Baddeley (1966).

the presentation of the list items, subjects were required to say the word *the* over and over, out loud. In the articulatory suppression condition, subjects were able to recall correctly about two-thirds of the items that they had seen, but the errors they made were now different. Without articulatory suppression, subjects were more likely than would be expected by chance alone to incorrectly recall an item that sounded like the target item. With articulatory suppression, this was no longer the case; acoustically similar items were no longer the most likely errors. However, visually similar items were not more likely to be errors either. Although the mode of representing the information under conditions of articulatory suppression was not known, the mode was not visual.

Despite the observation that most people use a speech code to represent information in primary memory, this is neither a universal nor an obligatory code. R. Conrad (1972; see also Cowan, Cartwright, Winterowd, & Sherk, 1987; Locke & Fehr, 1970) demonstrated that young children do not show the same patterns of acoustic errors until they are about 5 or 6 years old. Even then, it takes several more years before their performance shows the same error pattern as that of adults.

The capacity of primary memory was a key question that many researchers attempted to address. The title of George Miller's (1956) paper was the now famous phrase "The Magical Number Seven, Plus or Minus Two," reflecting the most common estimate of the limitations of information processing. Miller arrived at this estimate after examining data from a variety of different paradigms, and he began the article with a parody of Senator Joseph McCarthy:

> My problem is that I have been persecuted by an integer. For seven years this number has followed me around, has intruded in my most private data, and has assaulted me from the pages of our most public journals. This number assumes a variety of disguises, being sometimes a little larger and sometimes a little smaller than usual, but never changing so much as to be unrecognizable. The persistence with which this number plagues me is far more than a random accident. There is, to quote a famous senator, a design behind it, some pattern governing its appearances. Either there really is something unusual about the number or else I am suffering from delusions of persecution. (p. 81)

Miller described the results from a number of different paradigms, all of which seemed to converge on the idea of a central limitation on people's ability to process information. His first topic concerns a finding that rarely fails to provoke disbelief: People are unable to learn to identify a set of items that vary along only one dimension if there are more than a few items. For example, in an *absolute identification* experiment, a subject might hear a set of nine tones that vary only in frequency. On each trial, one of these tones is played for the subject, who then tries to identify it. The subject is informed whether the response is correct and, if not, what the correct response should have been. The results of such an experiment are shown in Figure 3.2. The highest and lowest frequency tones are identified quite well (around 65% correct), but the closer to the middle of the set, the worse the performance. Generally speaking, once the number of items reaches about eight or nine, subjects become unable to perform the task without errors; interestingly, errors persist regardless of the range and practice (Pollack, 1952, 1953; Shiffrin & Nosofsky, 1993).

CogLab Experiment
http://coglab.wadsworth.com/experiments/AbsoluteIdentification/

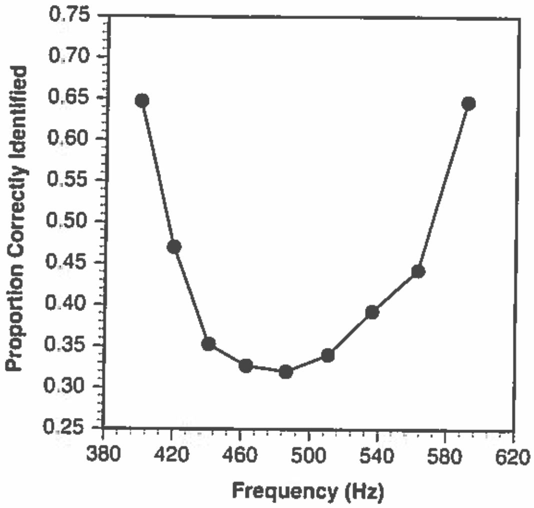

Figure 3.2 Proportion of times a particular tone was correctly identified using the method of absolute identification.
SOURCE: Neath & Knoedler (1997).

When stimuli vary along more than one dimension, identification is much better. For example, most people can easily identify the 26 letters of the alphabet, even when they are handwritten. Because the letters vary along multiple dimensions, they are easier to discriminate from one another. When there is only one dimension involved—regardless of whether that dimension is frequency, length, height, or intensity—subjects will not be able to perform accurately once the number of items exceeds about seven.

A second topic that Miller discussed was the limitations of memory span. In 1887, Joseph Jacobs published a paper discussing his interest in measuring his students' mental capacity. His measure, known as the *memory span*, was defined as the number of items (usually digits) that can be repeated immediately in order 50% of the time. When this measure is used, the span is typically the same number that haunted Miller: seven, plus or minus two. More specifically, 90% of the adult population is able to recall at least five items in order but not more than eight (Matarazzo, 1972).

A third topic of Miller's (1956) paper concerned the question of what defines an item. For example, the list 1492200118651066 has 16 digits in it. According to the limits of memory span, you should not be able to remember that many items. However, if you recode the list into the dates 1492, 2001, 1865, and 1066, you need remember only four items or "chunks" of information.

H. A. Simon (1974) expanded on Miller's ideas of a chunk, demonstrating that the number of chunks that can be recalled is variable. As shown in Table 3.1, when the stimuli comprised 1-syllable items, the number of syllables recalled was 7, the number of words recalled was also 7, and the number of chunks was also 7. However, when the stimuli comprised 3-syllable items, the number of syllables recalled increased to 18, the number of words recalled dipped slightly, and the number of chunks recalled also dropped slightly. The best performance, in terms of maximum number of syllables and words recalled, came with eight-word phrases; the worst performance, in terms of the number of chunks, was also with eight-word phrases. Cowan (2001) provides a detailed review of this issue.

Table 3.1 Memory span expressed in chunks for different kinds of material: one-, two-, or three-syllable words or two- or eight-word phrases

	Span			
Stimuli	*Syllables*	*Words*	*Imputed Chunks*	*Syllables per Chunk*
1-syllable	7	7	7	1.0
2-syllable	14	7	7	2.0
3-syllable	18	6	6	3.0
2-word	22	9	4	5.5
8-word	26	22	3	8.7

Source: Simon (1974).

Thus, with an increase in the amount of information in the chunk, there was a decrease in the number of chunks that could be remembered. Although the capacity of short-term store was an important issue at that time, the answer to the question depended on both the measure and the type of stimuli used. The limit on how much information could be retained in short-term store, then, was *not* constant.

The Brown-Peterson Paradigm

Peterson and Peterson (1959) reported an experiment that used a procedure similar to one used by Brown (1958). Their purpose was to investigate the rate at which information is lost or decays in STM. The general procedure, now known as the *Brown-Peterson paradigm*, is for the experimenter to read a consonant trigram (three consonants in a row, such as DBX) to a subject and then read a three-digit number out loud. The number of items is substantially less than almost everybody's memory span. The subject's task is then to count backward by threes (or fours) from the three-digit number for a certain amount of time. At the end of this period, the subject is asked to recall the three consonants in order. The purpose of the counting backward is to prevent rehearsal while minimizing overt interference: The digits are sufficiently different from the letters that they should not interfere. Peterson and Peterson varied how long the subjects counted backward, including conditions of 3, 6, 9, 12, 15, and 18 seconds (s). The results are shown in Figure 3.3. What is most noteworthy is that after as little as 18 s of counting backward, subjects could recall only about 10% of the items.

These results, along with those reported by Murdock (1961), Hellyer (1962), and Fuchs and Melton (1974), were generally interpreted as demonstrating the very rapid decay of information in short-term memory when rehearsal is prevented. In Chapter 6, we shall see that much of the data from the Brown-Peterson paradigm is inconsistent with a decay interpretation (Capaldi & Neath, 1995); rather, the reduced performance is due to interference. Briefly, Keppel and Underwood (1962) demonstrated that if you examine performance on the very first trial of the Brown-Peterson task, there is no difference in performance in the various delay conditions: Whether subjects count backward for 3 s or 18 s, performance is equal in the two conditions. At that time, however, less was known about the task, and so most researchers explained it in terms of decay from short-term store.

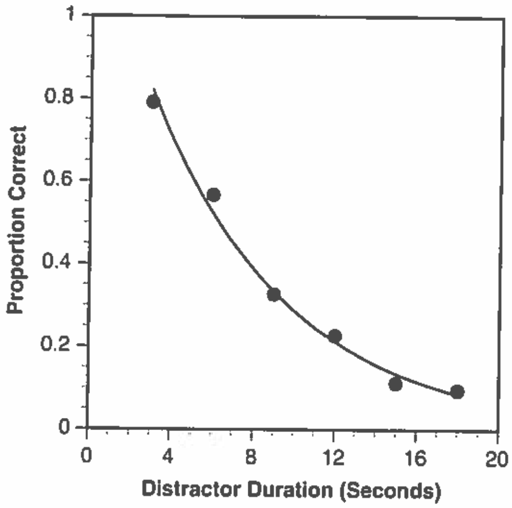

Figure 3.3 Proportion of consonant trigrams recalled correctly as a function of the distractor task duration.
SOURCE: Peterson & Peterson (1959).

CogLab Experiment
http://coglab.wadsworth.com/experiments/BrownPeterson/

Waugh and Norman's Model

To account for these and many other observations, many researchers divided memory into two structures. Of the many different versions, two models stand out as particularly influential. The first was developed by Waugh and Norman (1965), who specifically divided memory into *primary* and *secondary* memory, resurrecting the terms from James (1890). According to their model, perceived information first enters primary memory, a limited capacity structure. From primary memory, some information is lost by displacement, as newly arriving items "bump out" already existing items. Other information might be rehearsed and thus remain in primary memory longer. Rehearsal also causes the information to be transferred to secondary memory, which has no capacity limitation. Recall can be based on information in primary memory, secondary memory, or both.

According to the model, it should be possible to measure the capacity of primary memory. If items are continuously presented to a subject, there should be a point at which primary memory is full and the new input has to displace the old input. At this point, recall for those items that have been displaced will depend solely on secondary memory. If rehearsal is prevented, then there should be no memory left for the items formerly in primary memory. Preventing rehearsal will ensure that the items are not refreshed in primary memory and are not transferred to secondary memory.

In one of their experiments, Waugh and Norman (1965) instructed subjects not to rehearse. To the extent that subjects followed these instructions, the items from primary

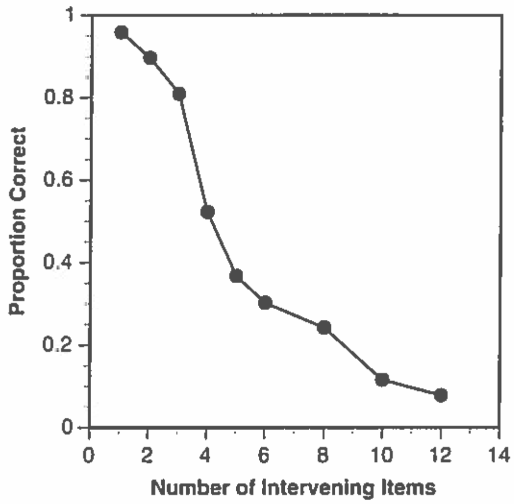

Figure 3.4 Proportion of items recalled correctly as a function of the number of intervening items. The data plotted are averaged from the two presentation rates. SOURCE: Waugh & Norman (1965).

memory should not be transferred to secondary memory. The researchers presented lists of 16 digits at a rate of either 1 digit per second or 4 digits per second. After all 16 items had been presented, a single item (a probe) was presented. The subject's task was to recall the digit that had followed the probe item in the original series. The results are replotted in Figure 3.4.

Presentation rate had only a small and inconsistent effect; memory performance depended primarily on how many items had intervened between presentation and test. The farther back in the list the probe item was, the lower the probability of correctly recalling the next item. Waugh and Norman emphasized two key aspects of their data. First, there was a very sharp drop in performance after about three or four items. Second, the asymptote of the function approached 0. This means that after a large number of items intervened, the subjects could not recall the target item. This finding reinforced the idea that the instructions not to rehearse had been obeyed and that the digits had not been transferred to secondary memory. Waugh and Norman (1965) interpreted Peterson and Peterson's (1959) results as consistent with their view. The distracting activity would have displaced the information from primary memory, but what little rehearsal there was would have transferred some of the information to secondary memory. The approximately 10% recall after 18 seconds of distracting activity would reflect the secondary memory component in the Brown-Peterson task.

Atkinson and Shiffrin's Dual-Store Model

The second model was developed in a series of papers by Richard Atkinson and Richard Shiffrin. Atkinson and Shiffrin (1968) distinguished between *structural* and *processing* components of memory. The structure is thought to be those parts of the memory system that do not change, whereas the control processes are thought to be flexible and under a person's control. Although often used as an example of a dual-store model, this model ac-

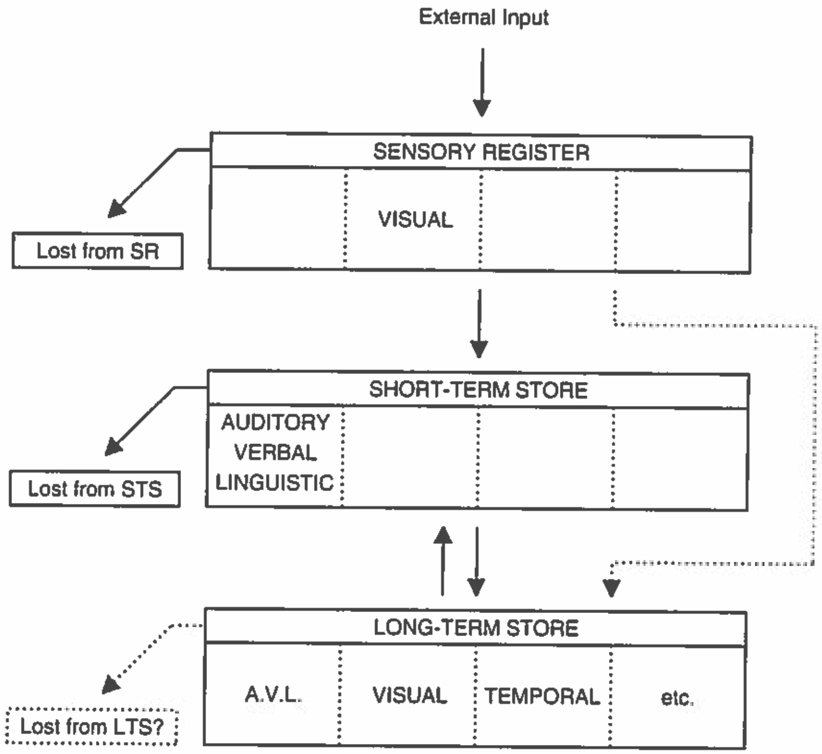

Figure 3.5 The structure of Atkinson and Shiffrin's (1968) model.
SOURCE: Adapted from Atkinson & Shiffrin (1968).

tually posits three structural components of memory (see Figure 3.5). The first structures are the *sensory registers*, one for each modality. Visual information enters a visual sensory register, auditory information enters an auditory sensory register, and haptic (touch) information enters a haptic sensory register. Atkinson and Shiffrin based their description of the visual sensory register on the work of Sperling, described in Chapter 2. Relatively little was known then about the auditory sensory register, but as the model was developed, it took on the properties of echoic memory.

Short-term store (STS) closely resembles Broadbent's P-system. It is of limited capacity, very short duration, and intended mainly as a buffer where information can be stored temporarily. Long-term store (LTS), in contrast, is a permanent, unlimited capacity store. This is where all enduring memories are stored, including knowledge, personal history, and anything else that one remembers. All information is eventually lost completely from the sensory registers and the short-term store, whereas information in the long-term store is relatively permanent (although it may be modified or rendered temporarily irretrievable as the result of other incoming information).

All information entering LTS has to go through STS (with a possible exception, discussed next, denoted by the dotted line from the sensory register), and whenever an item is retrieved from LTS it again has to enter STS. It is important to note that information is not really transferred, for that implies that the original copy is lost. Rather, information is copied from one store to the other, leaving the original item in place. (The analogy of faxing is quite useful: Usually a copy arrives at the destination, and most of the time it is legible. Some faxes do not "go through," however, and some of the information that arrives may not be readable.)

The emphasis of the Atkinson and Shiffrin (1968) model is on the control processes that manipulate the flow of information, and this flow is to a large extent under the subject's control. Control processes are "selected, constructed, and used at the option of the subject" and can be "readily modified or reprogrammed at the will of the subject" (Atkinson & Shiffrin, 1968, p. 90). Of the various control processes, the most important are rehearsal, coding, and retrieval. *Rehearsal* is necessary to preserve information in STS and copy it to LTS. The type of *coding*—what aspects of the information are registered—can determine what kinds of information will be remembered and what other information will be associated with it. *Retrieval* is most important for getting information from LTS, but the problem is more complicated than it might first appear. How does the retrieval process know what to look for, and how does it determine when to stop searching? Humans are particularly adept at knowing that they do not know something, and it is obvious that they are not performing an exhaustive search. (We will examine the retrieval process in Chapter 10.)

To make these issues a little clearer, let us follow a word through various stages of processing. A subject simultaneously hears the word *cow* spoken and sees it presented visually on a computer screen. The physical properties of each stimulus will be represented in the respective sensory stores: the shape of the letters in iconic memory, and the sound of the word in echoic memory. Control processes in each sensory store determine which portions of the information get transferred to STS. It could be the fact that an uppercase C was presented, or the whole word *cow*, or the sound of the word, or the gender of the voice that presented it, or the color of the word, or the background noise that accompanied the word, or any other similar information. Let's assume that it was the sound of the word that was transferred, so that now STS contains acoustic information that defines the word *cow*.

Rehearsal could be simple rote—merely repeating the sound—or it could be elaborative, focusing on the meaning of the word, on the image of a cow, of things associated with cows, of a distant memory of cow tipping, and so on. Such associates (for example, the word *milk*, the sound "moo," the image of a dairy cow) are copied from LTS to STS. STS, then, can store information in a variety of codes—visual, acoustic, verbal, and so on. Rehearsal is under the control of the subject, and, to a certain extent, so are the coding options. There is normally a preference for one kind of coding for a particular type of stimulus, but there is also great flexibility.

Atkinson and Shiffrin (1968) justified the division of memory into separate stores by citing several lines of converging evidence. First, they cited the papers by Miller, Broadbent, and Peterson and Peterson. They were aware of the Keppel and Underwood (1962) paper ascribing performance in the Brown-Peterson task to interference (discussed in Chapter 6), but Atkinson and Shiffrin suggested an alternative explanation. They noted that subjects in a Brown-Peterson experiment can devote attention to the to-be-remembered item for only a brief period of time before they have to begin counting backward. During this brief period, some of the information will get transferred to LTS. This explanation is supported by the observation that even after 18 s of counting backward, performance was not at 0; rather, subjects were recalling about 10% of the information. Interference occurs not in STS, according to this account, but in the search of LTS. Because of the interference in LTS, performance is determined almost entirely by STS.

Atkinson and Shiffrin (1968) assumed that the memory trace was composed of a multicomponent array consisting of a number of pieces of information, possibly redundant, correlated, or even in error. The traces do decay, but the decay rate can be affected by control processes. This explains why sometimes presentation rate does not affect estimates of decay (Waugh & Norman, 1965) and sometimes it does (Conrad & Hille, 1958).

For simplicity, Atkinson and Shiffrin focused most on the auditory-verbal-linguistic, or a-v-l, aspect of both STS and LTS. They acknowledged that other forms of information can be represented in both STS and LTS, but most work at that time had explored memory for verbal stimuli. The reason for the three terms was that it became impossible to determine whether the format was acoustic, articulatory, or some other similar form (for example, Conrad, 1964; Hintzman, 1967).

Information can be transferred from STS to LTS via rehearsal. Again, the term *transfer* is a little misleading because it implies that the original information is actually moved. Rather, Atkinson, and Shiffrin meant that a copy was made in LTS. Although transfer was seen as an unvarying feature of the system, the amount and form of transfer could be affected by the particular control processes used. Most important, they assumed that transfer began and continued during the entire time an item was in STS.

The reason for assuming that transfer occurs throughout the time that an item resides in STS was the finding that learning takes place even when the subject is not trying to remember the material. For example, Hebb (1961) presented a series of nine-item lists to 40 subjects. The lists were made up of the digits 1–9, presented in random order, and the task was to recall the items in order. Most of the lists contained novel orderings, but one list was repeated every third trial. For example, a particular subject would see the exact same list on trials 3, 6, 9, 12, and so on until trial 24. The results, shown in Figure 3.6, have been replicated by Melton (1963) and more recently by McKelvie (1987). Even when those subjects who noticed the repetition were dropped from the analysis, the effect of repetition was still present. The key finding is that simple repetition of an item, even if the subjects are unaware of the repetition, leads to better performance.

Mechanic (1964) found similar results, but in a different paradigm. According to Atkinson and Shiffrin, performance on the repeated series improved because each time the items in the series were encountered, some of the information was transferred to LTS. The amount of transfer can vary with the task, and—at least in this paradigm—several repetitions were required before there was a meaningful difference between the repeated and novel series.

We will discuss LTS in more detail later (see Chapter 10); for now, we will just sketch out the basic features. There is no universal, unchanging process of transfer. Most likely, the transfer process results in multiple copies of the original item, each of which can be either partial or complete. This assumption is based on results like those of Brown and McNeill (1966) concerning the "tip of the tongue" phenomenon. This is the situation that occurs when you cannot recall a specific piece of information, but you can provide some correct information (such as the first letter or the number of syllables) and you can accurately predict whether or not you would recognize the correct answer. According to Atkinson and Shiffrin, the reason for this situation is that you have accessed a partial trace rather than a complete trace. Some of the information is correct, but there is not enough to allow successful recall. When presented with the correct answer, another retrieval attempt is made, this time with more information, and so a complete trace is likely to be found.

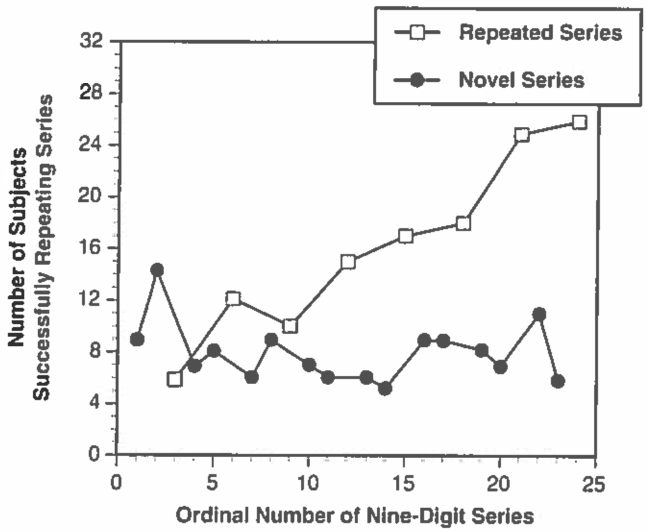

Figure 3.6 The number of subjects, out of 40, who successfully recalled a nine-digit series as a function of the position of the nine-digit series within a set of 24 trials. The repeated series was the same nine-item list repeated every third trial. SOURCE: From "Distinctive Features of Learning in the Higher Animal," by D. O. Hebb. In J. F. Delafresnaye (Ed.), *Brain Mechanisms and Learning: A Symposium*. Copyright © 1961 Blackwell Scientific Publications Ltd. Reprinted with permission.

CogLab Experiment
http://coglab.wadsworth.com/experiments/Sternberg/

STS has two main control processes, retrieval and rehearsal. Although many theorists do not say much about retrieval from STS, Atkinson and Shiffrin emphasized the highly specialized nature of these processes. Because of decay, any retrieval process must be very fast and highly efficient. The most likely candidate comes from the work of Saul Sternberg (1966). He presented subjects with a short list of items, such as 2, 5, 3, 8, followed by a test item, or probe. A positive probe is an item that occurred in the list (such as 5 in the current example); a negative probe is an item that did not occur. Sternberg measured response time (RT), how long it took subjects to say that the probe item did or did not occur; the results are shown in Figure 3.7.

Two features of the data are noteworthy. First, the addition of an extra item in the search set results in a consistent increase in reaction time of about 40 ms. Second, the data from the positive and negative probes are almost identical. The equation of the best-fitting straight line was RT = 397 + 38 n, where n is the number of items in the search set. This can be interpreted as saying that the basic task took approximately 400 ms to perform, with an additional 40 ms to compare each item. Similar results were found for nonverbal stimuli.

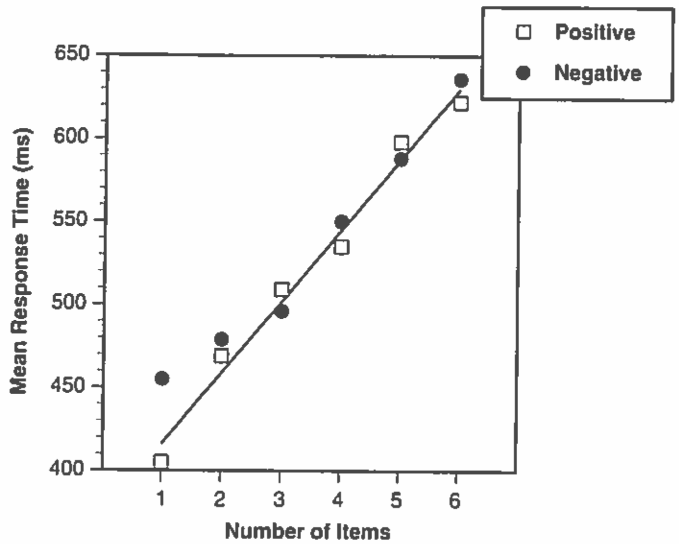

Figure 3.7 The mean time to determine whether a probe item was in the original list of items (positive probe) or was not in the original list (negative probe) as a function of the number of items in the list.
SOURCE: Reprinted with permission from "High Speed Scanning in Human Memory," by S. Sternberg, 1966, *Science*, *153*, 652–654. Copyright © 1966 American Association for the Advancement of Science.

Sternberg interpreted these data as supporting an *exhaustive serial scanning model*. For a negative probe, this makes sense. The probe is compared with each item in the search set, one at a time (hence *serial*). Because the probe did not occur, the search must involve comparisons with every list item (hence *exhaustive*). But the same is true when the probe is positive. An exhaustive search on a positive trial means that subjects will continue the search *after* they have found the item they were searching for. Although this may not sound very plausible, remember that we are dealing with STS, and any operation must be fast and efficient. Sternberg suggested that in order to keep the search fast, an *automatic process* is used. Once started, an automatic process must continue until completion; however, other processes can operate at the same time. Sternberg's idea is that the matching process is automatic, and, once a match is found, some note of this is made. At the end of the search, the subject examines the marker, and if it is positive, the subject presses the "yes" button; if negative, the subject presses the "no" button. Although consistent with the Atkinson and Shiffrin (1968) model, subsequent research has found the situation to be far more complex, and the simple serial exhaustive search interpretation is no longer tenable (see Van Zandt & Townsend, 1993).

The other major control process in STS is rehearsal. For the a-v-l part of STS, rehearsal was assumed to be like saying the items over and over. In certain situations, rehearsal can set up a buffer in which this rehearsal process is optimized. The buffer can be thought of as a bin that has a certain number of slots; each new item enters the rehearsal buffer and, if the buffer is already full, knocks out an item that is already there. Whether an item enters the rehearsal buffer is up to the subject, who directs the rehearsal process.

There are two possibilities for determining which items get bumped. One is a method based on the duration of the item in STS, with the oldest item getting bumped first. The second is a random method, where an item in STS is randomly selected to be bumped. The rehearsal process will be discussed in more detail in later chapters.

Many theorists proposed models similar to those of Waugh and Norman (1965) and Atkinson and Shiffrin (1968), some offering only slight modifications and others adding extra systems; however, almost all shared the same basic structures and processes. This general view became the dominant framework and was termed the *modal model* after the statistical measure *mode* (Murdock, 1974). The mode is a measure of central tendency; in a distribution of values, it is the value that occurs most frequently. Many examples of similar models can be seen in the volume edited by Norman (1970), and a paper by Glanzer (1972) critically reviews much of the evidence that supports this general conception.

Even though the models have been presented as verbal theories, one version of the Atkinson and Shiffrin (1968) model was a formal, mathematical model that made specific predictions for many different paradigms. For example, assume that it takes 1.1 s for an item in STS to decay such that it can no longer be identified. Let's further assume that it takes 0.25 s to rehearse or refresh an item and that only one item can be rehearsed at a time. (These numbers, although somewhat arbitrary, are nonetheless plausible.) The result is that no more than five items could be consistently maintained in STS without information loss. Another set of assumptions concerned the probability that an item in STS will get successfully copied into LTS. This probability is determined by the duration and the quality of the rehearsal. The final assumptions concerned the probability that an item could be recalled. Among the parameters were ones for guessing, for the buffer size (how many items could be maintained in STS), the probability of entering the buffer, the transfer rate from STS to LTS, and the decay rate of information in STS. The result was an equation that, when the parameters were estimated, could be used to make precise predictions about how much information could be recalled in a variety of situations (see Atkinson & Shiffrin 1968, p. 129).

Although the Atkinson and Shiffrin (1968) version of the modal model was very precise, many other versions were much vaguer and usually contained just the briefest description of how STS and LTS interacted. Indeed, many ignored some of the issues that Atkinson and Shiffrin had considered and discussed at great length.

The Serial Position Curve and the Modal Model

Many experiments that tested predictions of the modal model concerned the serial position function observable with *free recall*. Kirkpatrick (1894) introduced the method of free recall, noting that few students "gave the words in order, and it was quite noticeable that the first and last words were less frequently omitted than any others" (p. 606). Because free recall is really unconstrained recall, it is quite likely that different subjects are using different strategies; after all, the instructions just say, "Recall the items."

CogLab Experiment
http://coglab.wadsworth.com/experiments/SerialPosition/

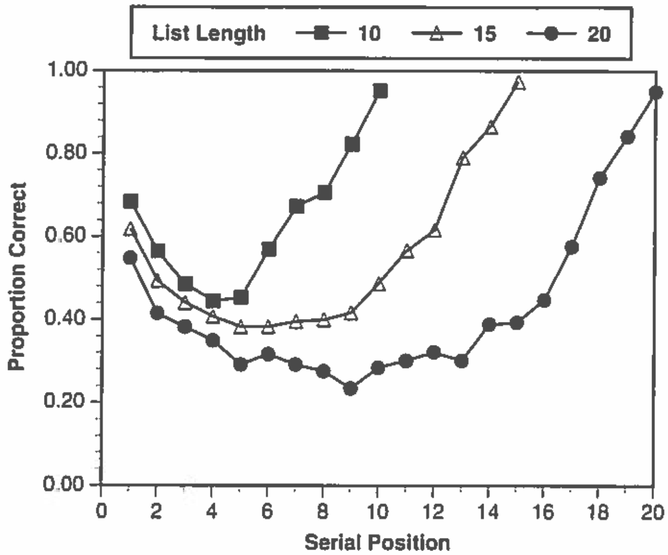

Figure 3.8 Serial positions curves showing the proportion of items recalled correctly in a free recall test as a function of input position for three different list lengths. SOURCE: Data from Murdock (1962).

Murdock (1962) reported a free recall experiment in which he presented lists of items that varied in length. Figure 3.8 shows the free recall data for lists of 10, 15, and 20 items. For all three list lengths, a typical serial position curve can be seen. For each list, there was a pronounced *recency effect*, with excellent recall of the last few items. The middle part of each list was not well recalled, but there was a *primacy effect*—better recall of the first few items. Murdock (1962, p. 485) concluded that the recency effect "appears to be essentially independent of list length" (see also Postman & Phillips, 1965).

When we examined the modality effect in Chapter 2, we saw that serial recall produced serial position curves. Free recall leads to similar-looking curves, but there are two important differences. First, in free recall, the recency effect is generally more pronounced relative to the primacy effect. Second, the recency effect in free recall can be seen with both auditory and visual presentation.

According to the modal model (e.g., Atkinson & Shiffrin, 1968; Glanzer, 1972; Waugh & Norman, 1965), primacy is due to the extra rehearsal the first few items get, which copies them into LTS, and recency is due to the dumping of items from STS. For example, when the first item in a list is presented, subjects can devote 100% of their rehearsal to this item; when the second item is presented, subjects can devote only 50% of their rehearsal to this item. Because the first item is rehearsed more, it has a greater probability of being transferred to LTS. A strong prediction of the model, then, is that if the number of rehearsals per item can be measured, they will decline as more and more items are presented.

Rundus and Atkinson (1970) examined this relationship by adopting a procedure that allowed them to measure the number of times an item was rehearsed. Subjects were told that they could rehearse whichever items they wanted to, but they must do it out

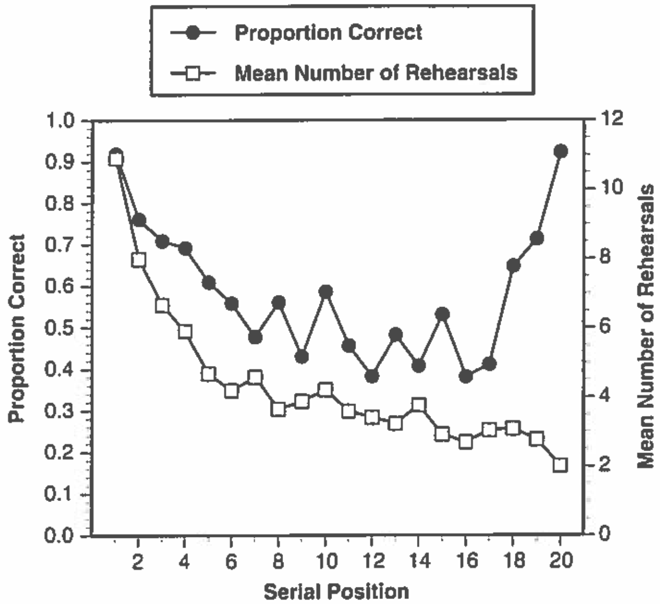

Figure 3.9 The proportion of items recalled correctly as a function of serial position and the mean number of rehearsals devoted to each item at each serial position. SOURCE: From "Rehearsal Processes in Free Recall: A Procedure for Direct Observation," by D. Rundus and R. C. Atkinson, 1970, *Journal of Verbal Learning and Verbal Behavior*, 9, 99–105. Copyright © 1970 Academic Press, Inc. Reprinted with permission.

loud. The subjects saw lists of 20 common nouns, and each word was presented for 5 seconds. The results, shown in Figure 3.9, show the predicted relationship between the number of rehearsals (shown on the right y-axis) and the proportion correctly recalled (shown on the left y-axis). Early items received the most rehearsals and were recalled very well—the primacy effect. Items at the end of the list were also recalled well—the recency effect—but they had relatively few rehearsals. This finding is consistent with the modal model's claim that primacy is due to rehearsal and recency is due to dumping from short-term store. The middle items are not recalled well, but they also do not receive many rehearsals.

One might be concerned that the overt rehearsal procedure could introduce a confound: Overt rehearsal might place extra demands on the cognitive system, altering the number of items that can be remembered. Although an appropriate concern, it does not seem warranted; Murdock and Metcalfe (1978) directly compared memory when rehearsal was covert or overt and found few differences.

According to the modal model, the primacy effect results from extra rehearsals, which increase the probability of transferring information to long-term store, and the recency effect results from dumping from short-term store. Analysis of output order confirms that the last few items are indeed recalled first (e.g., Welch & Burnett, 1924). A strong prediction of the model, then, is that if recall is delayed, the primacy effect should remain unaltered but the recency effect should disappear. Primacy will remain because

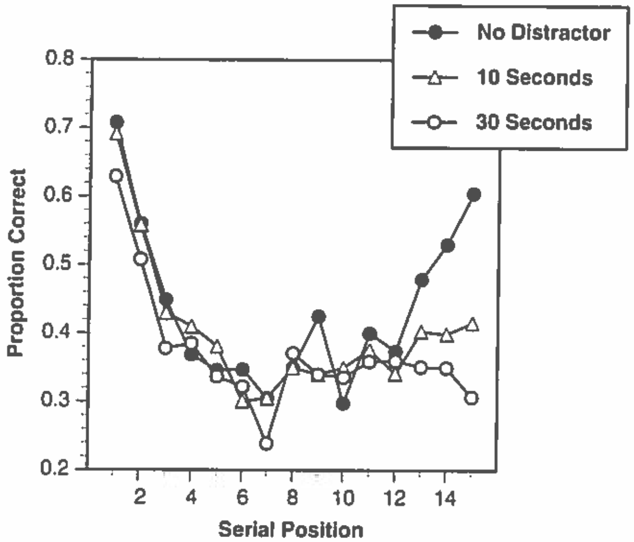

Figure 3.10 The proportion of items recalled correctly as a function of serial position in a free recall test when there is no distractor task, or when subjects are required to count backward for 10 or 30 seconds before recalling the items. SOURCE: From "Two Storage Mechanisms in Free Recall," by M. Glanzer and A. R. Cunitz, 1966, *Journal of Verbal Learning and Verbal Behavior, 5*, 351–360. Copyright © 1966 Academic Press, Inc. Reprinted with permission.

once an item is in long-term store, it can be recalled after long delays. Recency will be eliminated because the items are not in long-term store, and items in short-term store cannot be retained for long without rehearsal.

To test this prediction, Glanzer and Cunitz (1966; see also Postman & Phillips, 1965) presented 15-item lists to subjects. In the control condition, subjects immediately recalled as many of the words as they could. In the other two conditions, subjects engaged in a distractor activity (counting backward) for either 10 or 30 seconds before recalling the items. The results are shown in Figure 3.10.

The control group showed the typical serial position function. Subjects in the two distractor groups recalled the same number of items as the control subjects, with one important exception: The longer they had to wait until recall, the fewer items from the end of the list were recalled. According to the modal model, because counting backward fills up short-term store with numbers, the words are not available for output at the time of recall. The more numbers that are processed in short-term store, the less chance there is that a to-be-remembered item survives. Recall for earlier parts of the list was not affected, because those items were recalled from long-term store.

The modal model, then, accounts for the following results: (1) The serial position curve is seen regardless of list length. (2) The first items recalled will be the last few list items, followed by the first few list items. (3) Items will be rehearsed less and less as the serial position increases. (4) The recency effect, but not the primacy effect, is abolished if recall is delayed.

Problems with the Modal Model

Although the modal model correctly predicted and accounted for numerous results from free recall experiments, a series of studies soon demonstrated that the simple ascription of the recency effect to short-term store and the primacy effect to long-term store was no longer plausible.

The first series of studies examined the so-called long-term recency effect. In the typical free recall experiment, subjects receive 12 or so list items and then recall those items immediately; a recency effect is typically observed. When Glanzer and Cunitz (1966) added 30 seconds of distractor activity at the end of the list, the recency effect was eliminated (see Figure 3.10). However, when Bjork and Whitten (1974) added distractor activity after *every* item in the list, including the final item, the recency effect re-emerged. In their procedure, a word is shown, and the subject then performs a task that involves processing sufficient information to fill STS and that is sufficiently difficult that all of the subject's resources are diverted from rehearsal and to solving the task. Then the second word is shown, followed by another period of distracting activity. This is known as the *continual distractor task* because the subjects are continually distracted from rehearsing the to-be-remembered items. This finding has been replicated numerous times (e.g., Baddeley & Hitch, 1974, 1977; Glenberg, Bradley, Kraus, & Renzaglia, 1983; Tzeng, 1973).

An experiment reported by Watkins, Neath, and Sechler (1989) illustrates the essentials of the continual distractor task. They presented a 12-item list of words to subjects for free recall. After every word, the subjects heard the digits 1 through 9 presented one at a time in random order, and they had to recall the order of presentation of the digits. Thus, the subjects heard a word, then heard and recalled nine digits in order, then heard the second item, then heard and recalled nine digits in order, and so on throughout the list. The results are shown in Figure 3.11. The most important finding is that when distracting activity occurs after every item, including the final item, there is a substantial recency effect. Recall of the digits also shows a recency effect.

Recall that when Glanzer and Cunitz (1966) added distractor activity at the end of the list, the recency effect was eliminated. The explanation was that the distractor task removed the recency items from short-term store. When distractor activity occurs after every item, including the final item, the recency effect is again observed, even though the to-be-remembered list items should have been removed from short-term memory by the distractor task. These types of results led Bjork and Whitten (1974) to conclude that "the customary two-process theoretical account of immediate free recall is certainly incomplete, if not wrong" (p. 189).

Bjork and Whitten (1974) suggested that a relatively simple rule might be operating. This rule, now known as the *ratio rule* (Glenberg et al., 1983), relates the size of the recency effect to the amount of time an item has to be remembered until recall and the amount of time that separates the items in the list. The measure of recency used is the slope of the best-fitting straight line over the last three positions. The two time measurements are the time between the presentation of list items (known as the *interitem presentation interval* or *IPI*) and the time between the presentation of the final item and the recall test (known as the *retention interval* or *RI*). Nairne and his colleagues (Nairne, Neath, Serra, & Byun, 1997) measured the size of the recency effect when the ratio of the IPI to RI varied from as large as 12:1 to as small as 1:12. The results are shown in Figure 3.12.

Experiment *Recency Effects in Free Recall*

Purpose: To demonstrate the effect of distracting activity on the recency effect in free recall

Subjects: Thirty-six subjects are recommended; 12 should be assigned to the immediate condition, 12 to the delay condition, and 12 to the continual distractor condition. Subject 1 should be in the immediate condition, Subject 2 in the delay condition, Subject 3 in the continual distractor condition, Subject 4 in the immediate condition, and so on.

Materials: Table C in the Appendix contains a list of 96 two-syllable words randomly drawn from the Toronto word pool. For each subject, construct 8 lists, each of which contains 12 words. Table B in the Appendix contains lists of the digits 1 through 9 in random order that will be used for the distractor task. Also prepare answer sheets with 8 rows of boxes or blanks in which the subject will write down the words. Subjects in the delay condition will need an answer sheet on which to write down the digits in order 8 times, and subjects in the continual distractor condition will need an answer sheet on which to write down the digits in order 96 times.

Procedure: For the immediate group, read the list of 12 words to the subject at a rate of approximately one word every 2 s. At the end of the list, have the subject recall as many of the words as possible by writing them down, in any order, on the prepared answer sheet. The only change for the delay group is to have the subjects engage in distractor activity after the final word and before recalling the words. Read a series of digits out loud at a rate of one digit per second and have the subjects recall the digits in order; then have the subjects recall the words. The only change for the continual distractor group is to have the subjects engage in distractor activity after every list item; thus, these subjects will hear and recall 12 lists of digits before recalling the words from that list.

Instructions for the Immediate Group: "This experiment tests your ability to recall a list of words. I will read a list of 12 unrelated words, and as soon as the list is over, I would like you to write down as many words as you can remember. You can write down the words in any order, and it is better to guess than to leave a space blank. Any questions?"

Instructions for the Delayed Group: "This experiment tests your ability to recall two different lists. I will read a list of 12 unrelated words, and then I'll read a list of the digits 1 through 9 in random order. I would like you to write down the digits in order on the first line on your answer sheet and then, when I indicate, write down the words. You can write down the words in any order, but you need to write down the digits in the original presentation order. It is better to guess than to leave a space blank. Any questions?"

Instructions for the Continual Distractor Group: "This experiment tests your ability to recall two different lists. I will read a list of 12 unrelated words. After I read each word, I'll read a list of the digits 1 through 9 in random order. I would like you to write down the digits in order on the first line on your answer sheet. When you have finished, I will then read the second word on the list and then another list of digits. I will alternate reading a word and a list of digits until all 12 words have been read. At the end, I would like you to write down as many of the words as you can remember. You can write down the words in any order, but you need to write down the digits in the original presentation order. It is better to guess than to leave a space blank. Any questions?"

Scoring and Analysis: For each list, count the number of times the first word was written down; it does not matter where the word was written down as long as it appeared on the list. This number will range from 0 to 8. Do the same for each of the other serial positions. Construct three serial position functions, one for each condition. To do this, add up the individual subject data, and divide by the number of subjects.

Optional Enhancements: Score performance on the distractor task, and plot recall as individual serial positions.

SOURCE: Based on experiments by Glanzer & Cunitz (1966), Bjork & Whitten (1974), and Watkins, Neath, & Sechler (1989).

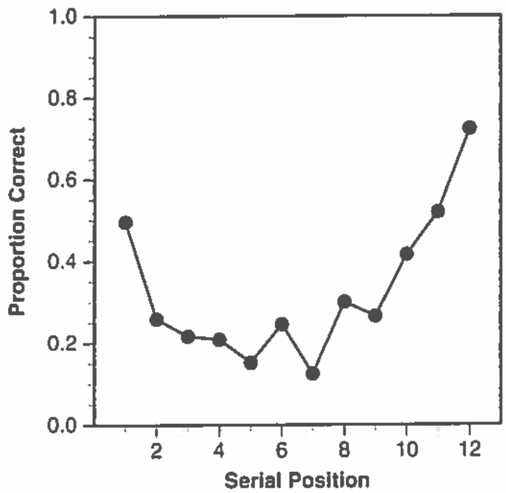

Figure 3.11 The proportion of words freely recalled as a function of serial position in the continual distractor paradigm. Each word, including the final word, was followed by a distractor task in which the subject heard nine digits presented in random order and then recalled these items. SOURCE: From "Recency Effect in Recall of a Word List When an Immediate Memory Task Is Performed," by M. J. Watkins, I. Neath, and E. S. Sechler, 1989, *American Journal of Psychology, 102*, 265–270. Copyright © 1989 University of Illinois Press. Reprinted with permission.

The ratio rule suggests that the absolute amount of time that an item has to be remembered is not important. Instead, the recency effect should be similar when the ratios are similar: A ratio of 1 s to 1 s gives the same prediction as a ratio of 1 min to 1 min or 1 hr to 1 hr. Indeed, some recency effects have been observed when the IPI and RI are measured in weeks or years (Baddeley & Hitch, 1977; Pinto & Baddeley, 1991; Roediger & Crowder, 1976).

Some researchers have tried to save the modal model by arguing either that the long-term recency effect is somehow different from the short-term recency effect, or that different processes are used. The experimental data do not support this distinction. For example, Greene (1986) found that variables that affected recency when recall immediately followed list presentation affected recency when recall was delayed in the same way. Given both the existence of the ratio rule and empirical findings that variables affect both the short- and long-term recency effects similarly, it becomes difficult to argue that the two types of recency effects are different.

Koppenaal and Glanzer (1990) noted that in a typical continual distractor experiment, the subjects receive the same distractor task after every list item. Because of the extensive practice on the task, Koppenaal and Glanzer argued, subjects might be able to learn to time-share, alternating their processing between rehearsing the list items to keep the last few in short-term memory and performing the distractor task. If this view is correct, when the task changes, the time-sharing mechanism should be disrupted and subjects should not be able to keep the final words in short-term memory while performing the new task. Thus, if the type of distractor task is changed, the recency effect should no longer be observed.

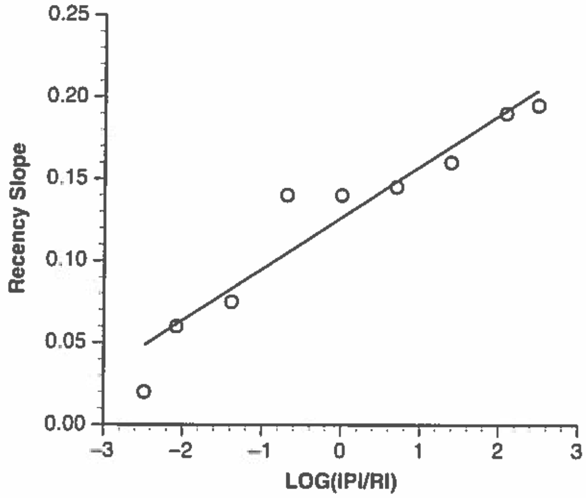

Figure 3.12 The ratio rule in free recall. IPI is the interitem presentation interval, or the time between items; RI is the retention interval, or the time between when the list ends and recall begins.
SOURCE: Data from Nairne, Neath, Serra, & Byun (1997).

They ran an experiment that had more than one kind of distractor task. The arithmetic distractor task required that subjects read a three-digit number out loud, add 1 to the number, and report the sum. The word distractor task required that subjects read six pairs of unrelated words out loud. In one condition, subjects received only the arithmetic task after every list item or only the word task after every list item. In the other condition, the distractor task that followed the final list item was different from the distractor task that followed all the other list items. Free recall in the unchanging distractor condition again yielded a recency effect, but recall in the changing distractor condition showed no recency effect.

This view makes at least three predictions. First, no changing distractor effect should be observable under incidental learning conditions. If subjects are unaware that there will be a recall test at the end of the list, there is no reason for them to rehearse and keep the final items in short-term memory; nor is there a need to develop the elaborate multitasking strategy. Without active rehearsal, the final list items should not be in short-term memory at the time of a surprise free recall test. Second, no changing distractor effect should be observable when the change in distractor activity occurs after the first list item. Koppenaal and Glanzer's (1990) account of the changing distractor effect hinges on the idea of rehearsal disruption: Encountering a novel distractor task within a list disrupts a multitasking rehearsal strategy that permits the subject to both rehearse and perform the distractor task. When the first item is presented, the subject has no way of knowing whether the list is going to be in the changing or the unchanging condition; it is only when the second item and its distractor activity are presented that the subject knows whether the first item was followed by the different distractor task. However, even at this stage, it is not until the third item and its distractor task are presented that the subject knows which distractor task—the one after the first item or the one after the second item—is the unusual one. Performance should be identical in both the unchanging and

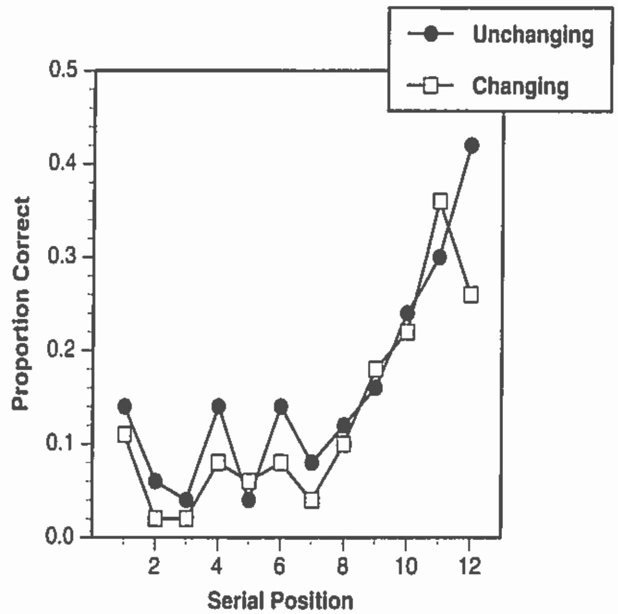

Figure 3.13 Mean number of words recalled in a surprise free recall test following incidental learning when the distractor task stays the same after every item (unchanging) and when there is a novel task after the final item (changing). SOURCE: Neath (1993a).

changing conditions at position 1. Finally, if the distractor task changes after every list item, there should be no recency effect because there will have been no opportunity to develop the multitasking strategy.

Neath (1993a) tested these predictions. In Experiment 1, subjects were told that the experimenter was interested in what made people hesitate while reading aloud from a computer screen. Subjects were told that they would see three different kinds of stimuli that they should read as quickly and as clearly as they could. The stimuli were actually the same as those used by Koppenaal and Glanzer (1990), but subjects were unaware that a surprise recall test would occur. A surprise test was used so that it would be highly unlikely that the subjects would rehearse the list items. Each subject received only one list, and at the end of presentation subjects were asked to recall the words. Not only was there a recency effect in the unchanging distractor condition, there was a reliable changing distractor effect in the changing condition (see Figure 3.13). This result is problematic for Koppenaal and Glanzer's (1990) account because there should have been no information left in STS and thus no recency. And even if there were recency, there should be no effect of changing the distractor, because there was no rehearsal to disrupt.

A second experiment showed that recall is impaired for the first item if the first item is followed by the novel task. The effect is observable at any serial position.

In a final experiment, Neath (1993a) again used an unchanging and a changing condition, but also added a third condition in which a different distractor task occurred after every item—the continually changing condition. In this condition, each of the five list items was followed by a different distractor task. The rehearsal disruption account predicts

Table 3.2 Summary of experiments that examine the recency effect in free recall and the effect of placing various kinds of distractor tasks after various items

Manipulation	*Result*	*Example Reference*
No distractor task	Recency effect	Murdock (1962)
Distractor task after final item only	Recency disappears	Glanzer & Cunitz (1965)
Distractor after every item, including the final (continual distractor paradigm)	Recency reappears	Bjork & Whitten (1974)
Distractor task A after every item except distractor task B after final item	Recency disappeares (changing distractor effect)	Koppenaal & Glanzer (1992)
Different distractor tasks after every item	Recency reappears	Neath (1993a)

a changing distractor effect at every serial position, and thus predicts no recency. Neath did find a recency effect in the unchanging condition and no recency effect in the changing condition, but contrary to the prediction of the rehearsal disruption account, there was also a recency effect in the continually changing condition. Thus, there is a recency effect for free recall of items when there is no distractor activity; the recency effect is eliminated when distractor activity follows just the final item; the recency effect returns when there is distractor activity after every item; the recency effect is again eliminated when the distractor task changes after the final item; and the recency effect again emerges when the distractor task changes after every item. These results are clearly problematic for any view that attributes recency to the dumping of items from short-term memory (see also Thapar & Greene, 1993).

Table 3.2 summarizes much of the research on the effects of various distractor tasks on the recency portion of the serial position curve. However, both this summary and the ratio rule focus mainly on recency effects; they do not relate both primacy and recency effects together. Whereas the modal model suggests that primacy and recency effects emerge from different processes, a study by Tan and Ward (2000) suggests that primacy and recency effects might not only be related, but might be due to the same process.

Tan and Ward (2000) used a procedure in which subjects were asked to rehearse out loud. They were shown a list of 20 items and were asked to read each item out loud. The subjects were informed that they could use the interval between words to rehearse any previous items, but they should do so out loud. The data from one condition from their Experiment 1 are shown in Figure 3.14. First, the standard serial position curve is seen when the proportion of items recalled correctly is plotted as a function of the nominal serial position—the order in which the items were presented. However, Figure 3.14 also shows the same data plotted as a function of each item's *functional serial position*—a rank ordering of when each item was last rehearsed. Using this latter measure, Serial Position 20 means that item was the very last item rehearsed out loud; Serial Position 1 means that item was the very first item rehearsed out loud. What is striking about the figure is that it appears that the major determinant of the serial position function is when an item was last rehearsed.

Tan and Ward (2000) demonstrated that an extension of the ratio rule easily accommodates their findings: Rehearsal, in their scheme, reorders the items both in terms of serial position and, more important, in terms of time. They explain previous examples in which variables had different effects on primacy and recency. For example, Glanzer and

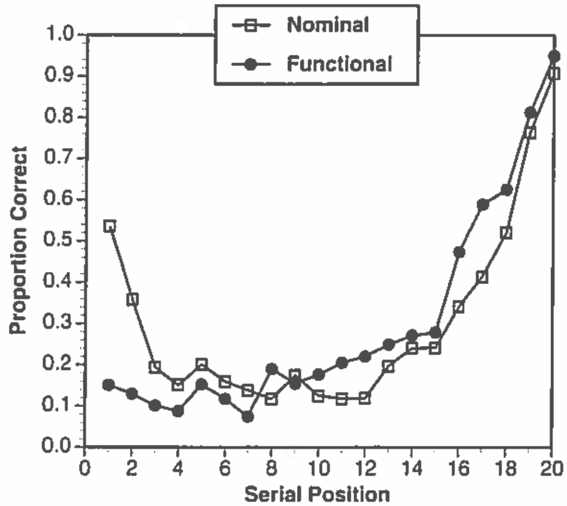

Figure 3.14 Proportion of items recalled correctly as a function of nominal (or input) serial position (white squares), and the same data replotted showing the proportion of items correctly recalled as a function of functional serial position (black circles). The functional serial position shows the ranking of when the items were last rehearsed. SOURCE: Tan & Ward (2000).

Cuntiz (1966) found that faster presentation rates reduced recall of early list items but not of recency items. This was interpreted at the time as support for the modal model. Tan and Ward suggest that the effect of increasing the presentation rate is to prevent the early items from being rehearsed as often as with a slower rate and also to prevent them from being rehearsed near the end of the list. This will change the functional serial position of each item and will look like selective impairment of primacy items. Ward (in press) shows how this account explains the list-length effect shown in Figure 3.8. A similar way of explaining serial position effects in free recall has been offered by Brown, Neath, and Chater (2002).

Summary of the Modal Model

The modal model turns out not to explain the serial position effect in free recall very well. Instead, the ratio rule, perhaps operating in the way described by Tan and Ward (2000), offers a more parsimonious account. There are several other problems—some empirical and some logical—with most versions of the modal model.

First, as Crowder (1976) pointed out, items in sensory memory must be postcategorical because they already have their names. Because these names and other, similar kinds of information presumably reside in secondary memory, there must be some overlap. Although Atkinson and Shiffrin (1968) assume some contact of this sort (see the dotted line in Figure 3.3), most versions do not. Unless information from sensory memory makes contact with long-term store prior to entry into short-term store, there will be no way of identifying or categorizing the information. If information has gone from sensory register to long-term store, does it then go back to sensory register or to short-term store? Why not just stay in long-term store?

A second logical problem also concerns the flow of information between the systems. As Nairne (1996) points out, given the architecture of almost all versions of the modal model, there will always be contamination of one presumed store with the other. Information recalled from long-term memory has to pass through short-term memory on the way in and on the way out. Information in primary memory has to be linked to information in secondary memory so that it can be identified and categorized in the first place. Any response from any task should reflect both stores, and because of this inherent contamination, it would seem impossible to separate the types of codes.

This observation calls into question the general proposal that primary memory codes information on the basis of phonological or acoustic information and secondary memory codes items according to semantic information (Kintsch & Buschke, 1969). Indeed, there is evidence of both acoustic interference in long-term memory (Dale & McGlaughlin, 1971) and semantic confusion errors in primary memory (Shulman, 1970, 1972; Walker & Hulme, 1999).

We have described the development of the modal model, a structural account of short-term memory, in some detail. The two reasons for this in-depth explanation are that (1) the modal model has exerted more influence on memory research for a longer time than any other view, and (2) the modal model is far more sophisticated than many descriptions suggest, with several formal mathematical versions. Nonetheless, the modal model cannot account for (1) the results from the continual distractor paradigm, (2) the related ratio rule, and (3) the changing distractor effect. Furthermore, it suffers two major logical problems, already noted.

Chapter Summary

William James proposed a distinction between primary memory and secondary memory (memory proper). Memory proper occurs when an item is absent for some time from consciousness and has to be revived; in contrast, primary memory concerns items that remain in conscious awareness continuously from their presentation. It was not until the 1950s, however, that most memory researchers proposed distinct systems for storing information over the short and long term. The typical model assumed that (1) short- and long-term memory involve separate memory systems, (2) STM has a limited capacity, and (3) information in STM decays quickly unless actively rehearsed. Much of the evidence supporting the distinction came from studying the serial position function observed with free recall, although data from the Brown-Peterson paradigm were also important. Researchers have long noted empirical and logical problems with this distinction (e.g., Melton, 1963; Crowder, 1982a), most notably the inability to explain recency effects in general. The majority of memory researchers abandoned this approach for ones that emphasized memory processes more than memory structures, as detailed in the next chapter.