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irmly entrenched in the memory literature. We vill use this distinction to continue our examination of memory processing.

Storing and Retrieving Information from Short-Term Memory

Information processing models of memory suggest that sensory information is perceived and held briefly in a sensory register, before being passed to STM. What is the capacity and duration of the sensory registers? Do they differ by sensory modality? New experimental techniques were designed to address such questions.

Storing Sensory Information

Sperling (1960) tested the amount of information available in very brief visual displays by using a variant of the probe technique, with presentation of a letter matrix consisting of three rows of four letters each (e.g., SQHM). The matrix was presented for a few hundred msec and then removed, followed by a high-, medium- or low-pitched tone, indicating which row of letters was to be recalled. Note that the tone serves as a *poststimulus cue* because the subject does not know what is to be tested until after all items have been presented. The results, using this partial report procedure, indicate that subjects have more information available immediately after presentation than they are able to produce before losing part of it. Sperling found average recall of slightly more than 3 letters out of a line of 4 letters, suggesting that 9 to 10 items are available in memory from the three by four matrix immediately after presentation. This number contrasts with the whole report procedure of approximately 5 items recalled when subjects are asked for all 12 letters and shows the rapid loss of information while subjects are attempting to produce their responses (sometimes referred to as output interference). However, the information retained in visual sensory memory, or **iconic memory,** is held for only a very brief period. Within approximately 500 msec, one-half of a second, the partial report method falls to about 1.5 items, equivalent to the 5 items observed with the whole report procedure. Apparently, during the short period of time that an item or set of items is held in the iconic store, the information must be transformed into a representation that can be maintained in STM.

Does a similar process occur with auditory sensory information? Darwin, Turvey, and Crowder (1972) answered this question by constructing an auditory analogy to Sperling's experiment. They presented sets of four rapidly spoken single-digit numbers over each of three speakers located to the left, directly in front of, and to the right of the subjects. The spatial locations of the speaker correspond to the three rows in the visual matrix. After the auditory presentation of the numbers, partial report of one set was cued by a flashing light over the speaker location from which the numbers were to be recalled. As with visual presentation, recall accuracy for the whole report of the entire set of 12 numbers was about 5. Compared to iconic memory, the advantage of immediate partial report of only a subset of the items was small, equivalent to only about one-half of an item. However, the duration of auditory sensory memory, or **echoic memory,** was much longer than iconic memory, extending for 2 to 4 seconds after presentation. Consequently, echoic memory appears to have a smaller capacity, but longer duration, than iconic memory. This result is consistent with what might be called the "huh" experience, familiar to everyone: a friend says something to you when you are not listening and you respond with an intelligent "huh?" but before your friend can repeat the comment, you "hear" the original remark (like an echo).

Transfer to STM

As we have noted before, in some theories, STM is also referred to as "working memory." Information processed through the sensory registers must be actively maintained and manipulated as it is being used to handle other cognitive demands or being transformed for long-term storage. How does this temporary storage system work? Both auditory and visual rehearsal mechanisms have been proposed.

Many models of memory have incorporated an auditory or speech mechanism as part of working memory, with the most common label being the **phonological loop** (Baddeley, 1990), in which input sensory information is coded in terms of speech that can be repeated or rehearsed. The evidence for phonological coding and rehearsal comes from many sources, including the modality effects described before. In early experiments on STM, it was noted that the shorter the verbal description of the TBR material, the better the recall (Glanzer & Clark, 1963). In memory span experiments, letters that have similar-sounding names (*B*, *C*, *E*) are more often confused in recall even when they are presented visually (Conrad & Hull, 1964).

Baddeley (1990) has proposed a visual working memory system that he calls the "visuo-spatial sketch pad," which maintains visual imagery and spatial information. Supporting evidence comes from the ability to rotate three-dimensional figures mentally and choose between normal and mirror-image alternatives (Shepard & Metzler, 1971).

Retrieval from STM

Once information is stored in STM, how is that information used to answer questions? A variant of the "yes-no" recognition procedure known as **memory scanning** has been developed to study retrieval from STM (Sternberg, 1966, 1969). The memory scanning procedure also illustrates the use of response or **reaction time** (RT) to measure variation in memory performance even when recall is perfect. In Sternberg's procedure, subjects are given a brief list of items called a "memory set" (e.g., the digits 8, 5, 2, 7). Because the number of items in the set is chosen to be well within the memory span of approximately seven items, the subject can easily hold them in memory. Instead of asking the subject to recall all the items from the memory set, the experimenter shows a single item and the subject must push a button to respond "yes," indicating that the number was one of the items in the set or another button to respond "no," it wasn't.

Because most subjects can perform this task without making any mistakes, accuracy data are not very informative. So, the subject's reaction time—the time between presentation of the test stimulus and the response (usually pushing one of two buttons marked "yes" and "no")—is the primary dependent variable. RT is a common response measure in other areas of psychology like perception and psychophysics, problem solving, and decision making. (See box 7.4.)

Sternberg was interested in how variations in RT correspond to variations in the number of items in the set as a way of telling him about the processing that goes on in retrieval from STM. He suggested three processing strategies that might be used by subjects to decide if a presented number was a member of the memory set (see figure 7.7). According to a **parallel processing** hypothesis, the subject can examine everything in STM at one time with no more effort than it takes to look at part of it. This hypothesis leads to the prediction that variations in the number of items in the set will not affect RT as long as the memory span is not reached (panel a of figure 7.7). According to the **serial processing** hypothesis, the subject can examine only one item in the memory set at a time. This hypothesis predicts an increase in RT as the number of items in the set increases. On trials where the test item is not part of the original set, the subject must compare the items in the set one at a time with the test item before responding "no." However, on positive trials where the test item is one of the items in the set, the subject must compare individual items in STM with the test item before coming up with a "match" and responding "yes." Sternberg's (1966) data support the serial hypothesis and reject the parallel processing interpretation by showing that RT does increase as the size of the memory set increases, but there is still an additional question about the nature of the serial scanning process.

Clearly, a subject must check every item before responding "no." But if the memory set does contain a match to the test item, does the subject stop the scanning process and respond as soon as the match is encountered (a "self-terminating" search) or complete the scanning process and check all items before responding (an "exhaustive" search)? The two possibilities produce two clearly different predictions about the relation between RTs for positive and negative responses as shown in panels

BOX 7.4

Use of Reaction Time (RT) Measures

When the ultimate response to a stimulus varies little across experimental conditions, reaction time (RT) measures often provide the best means of understanding the processes governing the response. In recognition memory tasks the RT may include the time required to perform such processes as perceiving a test stimulus and comparing it to items in the memory set. RT should reflect the time to perform these processes.

The use of RT measures can be traced back to the early work of Donders (1862), who devised a "subtractive procedure" for using RT to investigate psychological processes. Suppose there are two tasks, X and Y, in which task Y includes all of task X plus some other component Q (i.e., Y = X + Q). If we measure RT for the completion of tasks X and Y, and then subtract the two, we can derive the time it took for component Q even though Q was not directly observable. In order for this logic to be correct, the time to complete each component must not overlap, a requirement that is often difficult to prove. (See Sternberg, 1969, for a sophisticated, modern treatment of the Donders method.)

In the Sternberg (1969) memory-scanning example in the text, the assumption of separate time for each step is easier to accept because the same task (matching target and memory set numbers) must be repeated for each number held in memory. Therefore, the difference in RTs for different set sizes can be subtracted to estimate the time for each comparison. The linear increase in RT as the number of items held in STM increases gives us more confidence that the function describes how items in STM are scanned.

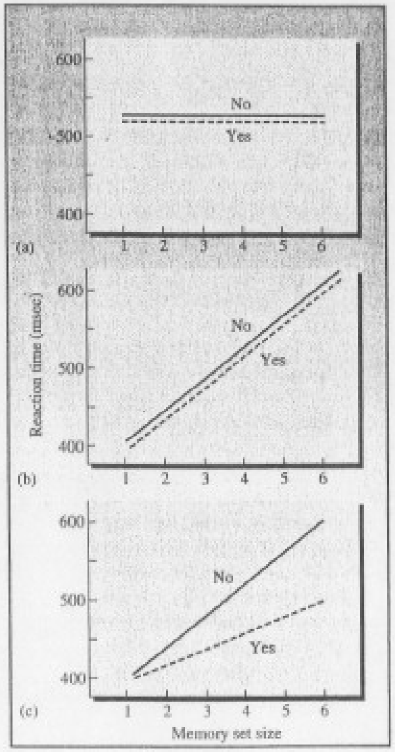
b and c of figure 7.7. For the exhaustive search, "yes" and "no" responses should show the same increase in RT as the set size increases because the same number of items must be checked in both cases. However, for a self-terminating search, only about half of the items must be checked before a "yes" response, so positive responses should be faster than negative responses with the difference between "yes" and "no" responses increasing as the set size increases. For example, if the set size is four, all four must be checked before a "no" response is made. If the memory set contains the test item, one-fourth of the time it will be in each of the four possible positions. Hence, one-fourth of the time only one item must be checked, producing a very fast "yes," and one-fourth of the time, all four items must be checked, producing a "yes" as slow as a "no" response. On average, 2.5 items must be checked before a positive response can be made. (Thought question: If the set size is N, what is the average number of items that must be checked to find a positive match?)

Although it may seem more efficient to use a self-terminating search, Sternberg's and hundreds of later experiments clearly indicate that we scan STM with a serial, exhaustive search as demonstrated by the parallel RT functions for positive and negative responses as a function of set size (as shown in panel b of figure 7.7). Note that the slope of the function can be interpreted as the rate of scanning STM, in the range of 40–50 msec/item, and the intercept represents all other information processing components including perceiving and encoding the stimulus and executing the response.

Storing and Retrieving Information from Long-Term Memory

At the beginning of this chapter, we examined one kind of long-term memory and how it was affected by interference from similar materials. Because early memory theorists from Ebbinghaus on were primarily interested in the origins of memory and the most basic phenomena of retention, they tended to ignore complex factors that shape human cognitive abilities. In particular, by concentrating on verbal, rote retention, they minimized the influence of organization and meaning in increasing our ability to retain large amounts of factual information. After introducing the fundamental distinction between episodic and semantic memory, and continuing with a discussion of organizational factors, we will briefly consider methods for studying state-dependent memory, imagery, and implicit memory.

FIGURE 7.7 Three possible outcomes of the Sternberg memory-scanning experiment: (a) parallel processing of all items in STM, (b) serial exhaustive processing, and (c) serial, self-terminating search of STM.



Episodic and Semantic Memory

In the last section, figure 7.6 showed a model of memory in which the long-term store included both "episodic" and "semantic" information. According to Tulving (1972) who made this distinction, **episodic memory** refers to the records of an individual's personal experiences, whereas **semantic memory** refers to the accumulated information and rules necessary for the use of language. Tulving further described semantic memory as "a mental thesaurus, organized knowledge a person possesses about words and other verbal symbols, their meaning and referents. . . ." Thus semantic memory is involved in the understanding of the meaning of the language contained in episodic memory. Semantic memory is less prone to forgetting: you may forget the distinction between retroactive and proactive inhibition but you are able to reread boxes 7.1 and 7.2 and understand the meanings of the definitions contained there. In contrast, episodic memory requires a personal record of experience. Knowing the meaning of "horse" is a reflection of semantic memory; knowing the last time you saw a horse or encountered the word "horse" is an example of episodic memory. Therefore, most of the early research with interference theory was concerned with episodic memory.

A critical component of semantic memory is that it depends on understanding and meaning. Because information we understand well appears to be resistant to loss, semantic information is easier to acquire and more slowly forgotten than episodic material. Semantic knowledge also appears to be relatively independent of contextual situation; we know the meaning of the word *horse* regardless of where we are or what we are doing. Box 7.5 describes an interesting real-world phenomenon of long-term memory when semantic memory momentarily fails us, the "tip-of-the-tongue" phenomenon, and how it can be studied in the laboratory.