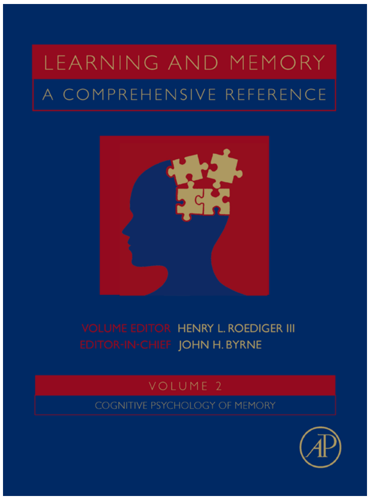

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2.03 Sensory Memory

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2.03.1 Introduction

Sensory memory refers to the short-lived memory for sensory details of events. This can include how things looked, sounded, felt, smelled, and tasted. To some extent, this type of information must persist in long-term memory. It allows us to recognize a familiar voice over the telephone or to recognize the taste of a favorite food. However, the human information processing system seems to be designed in such a way that the richness of sensory memories is quickly lost, leaving behind more categorized memories. For example, when one hears or reads a sentence, the gist is strongly saved but the exact manner in which the material was presented is more quickly lost; verbatim wording is readily accessible only for the most recent phrase, and it is incomplete even for that phrase (Sachs, 1967; Jarvella, 1970). Physical features of stimuli do leave long-term memory traces that influence later behavior (Kolers, 1974; Cowan, 1984; Weldon et al., 1995), but these may lack the fine-grained subtlety of short-lived sensory memories. Sensory memory is typically distinguished from mental imagery, which can include sensory-like qualities but is typically less detailed. For example, one may form an image of a U.S. penny (one-cent coin), but it is distinguished from a sensory memory in its vagueness, such as not really knowing which way Lincoln's head faces.

It has long been recognized that at least some sorts of sensory memory operate in a manner that is different from other forms of memory. In classic research on attention, subjects were asked to repeat a message presented to one ear and ignore a conflicting message presented to the other ear concurrently. Although they could recall little of the message presented to the ear to be ignored, when the task ended the last few words of that message often could be recalled (Broadbent, 1958). This suggested that the information in the unattended message was held temporarily in a form that soon would be lost if it were not attended. A natural way to understand that phenomenon is that the temporary storage consists of sensory information and a longer-lasting record can be saved only if that sensory information is attended before it fades away, which allows the formation of memory for the words that were spoken.

Sperling (1960) carried out a classic study that dramatically illustrated the difference between sensory and abstract forms of memory for a recent event. Subjects saw a briefly presented array with three rows of characters and then received a tone indicating whether the top, middle, or bottom row should be recalled (a partial-report cue). If the tone was presented soon enough, almost all characters in the designated row could be recalled, provided that there were four or fewer characters in the row. As the delay between the array and the tone cue was increased, performance diminished, quickly at first and then more slowly, curving down to a steady level (asymptote) within 1 s. By that point, the cue came too late to be of use, and subjects could remember only as many characters as one would expect if the limit were about four characters retained from the entire display. This pattern of results could be accounted for on the basis of two types of memory: a sensory memory that held the entire display like a snapshot for a very short time, even though the number of characters was far too large to be attended at once, and a more abstract memory that could hold only about four items. The partial-report cue could influence which part of the sensory memory was transferred to an abstract form and then reported, but the cue had to be presented before the sensory memory faded.

One can see from this finding that an understanding of sensory memory is critical for an understanding of performance on memory tests. Even if one is trying to assess the availability of abstract forms of memory, the contribution of sensory memory must be either eliminated or taken into account. Beyond that, sensory memory is an important aspect of our conscious experience of the outside world, as we will see.

One thing that makes sensory memory controversial is that the boundaries between it and other types of memory are debatable. By some accounts, there is a distinction between sensory storage that comes before perception and postperceptual storage (Massaro and Loftus, 1996). It does appear that there are two phases of temporary memory for stimulus qualities: a brief phase that seems like a continuation of the stimulus for about a quarter second, and a second phase that seems like a vivid recollection for some seconds (Massaro, 1975a; Cowan, 1984, 1988, 1995). However, one could argue that the process of perception begins quite rapidly in the brain, and that the first phase of memory for sensation is already part of perception. When this brief memory begins to fade away, it is not the same thing as a picture becoming hazy or indistinct, as if viewed through a fog. Instead, it is as if different features of each object can be lost separately. In Sperling's (1960) type of procedure, for example, the errors that crop up as the partial-report cue is delayed (or omitted) appear to be primarily location errors, in which a character is reported at the wrong location rather than forgotten completely (Townsend, 1973; Mewhort et al., 1981; Irwin and Yeomans, 1986). Consistent with this, a great deal of neurological research suggests that different features of an object, such as its identity versus its location, are perceived using different neural subsystems (in vision: Haxby et al., 1991; in hearing: Alain et al., 2001; in touch: Pons et al., 1992), and that perception of an object therefore requires a subsequent integration of these features. Sensory memory could include a constellation of features that have not necessarily been integrated. The full integration of these features into objects could require attention (Treisman and Gelade, 1980), which could result in a nonsensory type of memory.

It also may be that the brief sort of sensory memory is not truly a memory as such but, rather, a side effect of perceptual processing. The difference is that the neural effect of a stimulus giving rise to sensation begins before the stimulus ends and, for very brief stimuli, may not even reach a peak until some time after the stimulus has ended. The duration of this sensory memory appears longer for less intense stimuli. Such findings suggest that the sensory persistence of the stimulus may reflect conscious access to neural processes involved in perception (cf. Weichselgartner and Sperling, 1985; Dixon and Di Lollo, 1994; Massaro and Loftus, 1996; Loftus and Irwin, 1998).

Given such debates, it is important to back up and examine the distinctions regarding sensory memory that often are taken as its defining characteristics.

2.03.2 Defining Characteristics of Sensory Memory

2.03.2.1 Memory for Stimuli As Opposed to Ideas

Consider how the perception of a newborn infant must differ from that of an adult: it differs in many ways, but one important difference is as follows. The infant has a range of sensory experiences, but there is not yet any way to attach significance or meaning to most of those experiences. An adult does have meanings, or ideas, to attach to experiences. For example, if an American adult sees a red octagon, it may remind him or her of a traffic stop sign. Yet it seems reasonable to believe that there is perception and memory of the shape and color that can be separated from its meaning. That may not be exactly true, inasmuch as it is difficult for people to remember or perhaps even to perceive objects without some influence of their knowledge that apples are red, grass is green, and so on (Bartleson, 1960; Ratner and McCarthy, 1990). After identification of a stimulus and its meaning has taken place, there may be neural feedback to the parts of the brain that perceive sensations. Nevertheless, to a first approximation, we can think of sensory memory as the memory for the knowledge-free, sensation-based characteristics of stimuli that resemble what a newborn would perceive. If it turns out to be impossible to think of sensory memory in this way, the postulation of a distinction between sensory and nonsensory forms of memory may have to be weakened.

2.03.2.2 Memory for Information More Fine-Grained Than a Familiar Category

A critical step in perception is categorization: gaining the knowledge that a particular stimulus is an example of items in a certain category, whether or not one knows a verbal label for that category. For example, one can perceive two successive piano notes as coming from different tone categories even if one does not know or remember the names of those categories. Sensory memory is typically viewed as coming before that step of categorization. As a result, it can include fine details that distinguish items within a category, such as differences in tone frequency too small to change the identity of the note, except to make it slightly out of tune (Keller et al., 1995), differences between two slightly different pronunciations of the same vowel (Pisoni, 1973), or differences between two slightly different shades of the same color (Massaro, 1975a). In each case, if slightly different stimuli are presented in close succession (ideally within about 250 ms of each other), the sensory memory of the first stimulus can be compared to the second stimulus with good acuity. This characteristic could be important, as when one is trying to learn exactly how to imitate a word spoken in an unfamiliar language or, in infants, learning language in the first place.

2.03.2.3 Memory Even for Unattended Stimuli

As mentioned in the introduction, the concept of sensory memory arose to explain how people can briefly retain more information than they can process. The concept of a short-lived sensory memory for unattended information was present in the selective listening procedure (Broadbent, 1958) and the partial-report procedure using visual arrays (Sperling, 1960). Darwin et al. (1972) brought these two lines of research together by constructing an auditory analogue of Sperling's procedure. In this analogue, an array of three simultaneous spoken characters presented to left, center, and right spatial locations was followed by a second such array and then a test for the information presented at one location. Similar findings were obtained using arrays of tones (Treisman and Rostron, 1972; Rostron, 1974).

In the auditory studies, it was not possible to present 12 or more simultaneous stimuli as Sperling (1960) did in the visual modality. Consequently, it is possible that subjects were able to carry out a perceptual analysis of the sounds. Nevertheless, other evidence suggests that the perceptual analysis is incomplete and that the items need not have received full attention to have been remembered in the procedure of Darwin et al. (1972). Cowan et al. (1990) carried out a procedure in which nine syllables (*bee, bih, beh, dee, dih, deh, gee, gih, geh*) were presented at random intervals through headphones while the subject ignored them and silently read a novel. When a light signal occasionally appeared, the subject was to stop reading and identify the last spoken syllable, which occurred 1, 5, or 10 s ago. Generally, performance was good at a 1-s retention interval and decreased dramatically across the longer intervals. However, in an experiment in which subjects had to monitor the speech stream while reading (pushing a button if *dih* was presented), there was no forgetting across retention intervals, even though the monitoring task was performed correctly on only 60% of the trials. In another experiment, the reading was whispered by the subject and recorded so that diversions in attention away from the reading could be observed (as 1-s pauses in reading). It was found that consonant perception was much better on trials in which there were diversions of attention while the target syllable was presented. The sensory form of memory may only be adequate for vowel perception, and memory for consonants may be nonsensory in nature and may require attention to be formed. Vowels are more or less steady-state sounds, whereas stop consonants involve rapid acoustic changes that may be too complex to be maintained in a long form of sensory memory.

In sum, it seems apt to say that sensory memory is a special type of memory that may not require attention to be formed. It cannot hold all aspects of the environment; perhaps it comprises a snapshot of information or slice of time and is unable to hold much information that changes over time. Nevertheless, it is sufficient to save information about far more than one can attentively process at once and thereby serves as a sort of multichannel bulletin board helping the perceiver to shift attention from one sensory channel to another as the incoming information warrants.

2.03.3 Why Study Sensory Memory?

Cognitive psychologists and other students of human behavior have not been consistently enthralled by the concept of sensory memory. The majority of them are interested in learning how meaningful information is processed, and for that enterprise, the fate of sensory information seems to be of secondary interest. Taking this paucity of interest further, Haber (1983) asserted that sensory memory is a byproduct of processing that is not really of any use in ecologically relevant circumstances, with rare exceptions such as when one wants to read on a dark, rainy night by the light produced by flashes of lightning. However, there are several key reasons why sensory memory is of interest. Some important phenomena in the modern world make use of visual sensory memory; without its smearing of the effects of sensation, we would not perceive motion pictures as moving but, rather, as a rapid succession of still frames. It seems likely, as well, that there are analogous phenomena in the natural world. As one spots a deer running across the forest, the continual disappearance of parts of the animal behind trees and reappearance of those parts is reconstructed by one's perceptual system to form a continuous event, the deer running. Sensory memory may be critical in allowing this smooth percept to be formed. In audition, the case is straightforward, inasmuch as sounds inherently change over time. Some mental device must capture segments of the sounds in order to interpret them. For example, as we already have noted, language learning may depend on sensory memory for how words are pronounced. Some less obvious reasons to be interested in sensory memory are as follows.

2.03.3.1 Understanding Qualia and Consciousness

Philosophers speak of qualia, the essential mental states corresponding to experiences. These may be considered the building blocks of conscious experience. The equivalent notion within psychology is the study of subjective experience that can be traced back to the introspectionist method of Wilhelm Wundt, who founded the first laboratory of experimental psychology in 1879. Experimental methods related to introspection make use of similarities in the verbal descriptions of an event across individuals. Descriptions of fleeting events get at the smallest temporal unit of consciousness, or psychological moment, during which all events appear simultaneous even if they are not (e.g., Stroud, 1955; Lichtenstein, 1961; Allport, 1968; Eriksen and Collins, 1968; Creel et al., 1970; Robinson and Pollack, 1971). In the typical experiment to examine this concept, multiple visual displays (such as two sets of dots) are presented rapidly, and when they are presented in close enough temporal proximity, they are perceived as a single image that includes all of the presented items (e.g., all of the dots together). The presentation time within which there is perceived simultaneity depends on stimulus factors but is typically in the range of 100 to 200 ms. One account of the psychological moment states that the sensory memory of the first presentation still must be sufficiently active when the second presentation arrives, so that it becomes impossible to tell the difference between sensory memory and sensation, allowing them to be fused into an apparently simultaneous percept. On that basis one can explain, for example, why a loud noise and a closely following quieter noise can be perceptually fused into a single noise if the gap between them is no more than 100 ms or so (Plomp, 1964). The second noise must be mistaken for part of the decaying sensory trace of the first noise, and the chances of that happening increase as the gap between them gets shorter and the second noise gets quieter.

There were two competing hypotheses of the psychological moment, and only one of them is consistent with a sensory memory account. According to a continuous-moment hypothesis, the psychological moment is a sliding window of time. This is compatible with the notion that the sensory memory of each stimulus can be combined with immediately successive stimuli. In contrast, according to a discrete-moment hypothesis, there are successive windows defined by internal neural events (e.g., oscillation in the firing of neurons so as to collect incoming sensory signals). Two brief events occurring, say, 80 ms apart would fall in either the same psychological moment or in different moments, depending on when they happened to occur relative to the boundary between successive moments.

Allport (1968) carried out an experiment to decide between these hypotheses that seems especially elegant and decisive. On every trial, 12 horizontal lines were presented in rapid succession, over and over, progressing from a line high on the oscilloscope screen to lines lower and lower on the screen. Only one line was presented at a given time, but because of perceived simultaneity, multiple lines were visible at once. The rate of succession was adjusted for each subject until exactly 11 of the 12 lines were visible at once. At this rate, one could observe what was termed shadow movement as the remaining line that could not be seen changed over time. Now, according to a continuous-moment hypothesis, the shadow should move from top to bottom. While the 12th, lowest line is presented, the sensory afterimage of the 1st, highest line is the oldest and fades. While this line 1 is again presented, the sensory afterimage of line 2 becomes the oldest and fades; while line 2 is again presented, the sensory afterimage of line 3 becomes the oldest and fades; and so on. In contrast, according to a discrete moment hypothesis, the shadow should move from bottom to top. If lines 1–11 fit within one discrete perceptual moment, line 12 is not visible. Then line 12, along with the next presentation of lines 1–10, will all fit into the next moment, and line 11 will not be visible; then lines 11–12 along with the next presentation of lines 1–9 will all fit into the next moment, and line 10 will not be visible; and so on. The results consistently showed downward shadow movement, supporting a continuous psychological moment and a sensory memory explanation.

2.03.3.2 Understanding Group Differences in Information Processing

If the psychological moment is determined by sensory memory, then group differences in sensory memory have important implications for how the groups perceive the world. It determines which events will be grouped together within the duration of sensory memory and which will be separated, beyond that duration (e.g., Dixon and DiLollo, 1994; Loftus and Irwin, 1998).

A study by Cowan et al. (1982) suggested that 8- to 9-week-old infants have a longer first phase of sensory memory than adults do. The procedure that was used was one of auditory backward recognition masking (Massaro, 1975b). In that type of procedure in adults, two brief sounds are presented in rapid succession, and the subject is to identify the first sound in a multiple-choice test. Performance improves as the time between the onsets of the first and second sounds (the stimulus onset asynchrony or SOA) increases to about 250 ms. Even if the choices are so close that performance is substantially below 100%, performance levels off to an asymptotic level at about that SOA. The explanation (in concert with other, convergent procedures that we discuss later) is that information must be extracted over time from sensory memory into a more abstract form of memory until the second sound masks or overwrites the sensory memory of the first sound, interrupting the process of extracting information. By an SOA of 250 ms, the auditory sensory memory fades, so delays of the second, masking stimulus beyond that point would not help. For infant study, an *ah-ah* vowel pair was presented repeatedly, but with different SOAs among the pairs. Sometimes, an *eh-ah* pair was presented instead, but the access to this different pair was restricted to pairs with a particular SOA. The dependent measure of sound discrimination was how long and how vigorously infants were willing to suck on a pacifier that yielded not food but access to pairs that changed from *ah-ah* to *eh-ah,* rather than being stuck with a monotonous repetition of *ah-ah*. (For other infants, the assignment of the two vowels was reversed.) Higher sucking rates for this condition than for a condition in which there was no acoustic benefit of sucking yielded evidence of sound discrimination when the changes occurred within pairs with a 400-ms SOA, but not when the changes occurred within pairs with the 250-ms SOA that is sufficient for optimal performance in adult studies.

Various methods also have been used to show that the duration of sensory memory may differ from the norm in children with mental retardation (Campbell, and Meyer, 1981) or reading disability (Sipe and Engle, 1986) and in patients who have had unilateral temporal lobectomy (Efron et al., 1985). It is not known whether sensory memory abnormality contributes to cognitive disabilities in these groups.

2.03.3.3 Eliminating Contamination from Nonsensory Aspects of Cognition

Even if one is interested in abstract forms of memory, it is necessary to examine sensory memory in order to control its contribution in various test procedures. A good example is the procedure of Luck and Vogel (1997) to examine working memory. An array of simple, schematic objects is presented and then followed by a second array identical to the first or differing in the identity of one of the objects. In such procedures, people can remember about four items (cf. Sperling, 1960). If the interest is on that working memory limit, then one needs to be sure that sensory memory has faded away before the test. One could use a partial-report cue to determine when it has faded, as Sperling did. Another method is to mask the array with another, interfering array after various intervals and to determine how much information already has been transferred from sensory memory to working memory. Woodman and Vogel (2005) did that and suggested that sensory memory for items in an array was transferred to working memory at a rate of about 50 ms per item in the array.

A similar point could be made with respect to understanding attention. Imagine an experiment in which different word lists are presented simultaneously to the left and right ears. Suppose one has evidence suggesting that an individual can attend to both channels of speech at once. Such evidence may be misleading. If the speech is presented too slowly, there is the possibility of instead (1) attending to the word presented to one ear, and then (2) switching attention to the other ear in time to perceive the sensory memory of the word presented to that ear. If this is the case, speeding up the presentation may eliminate evidence that both channels are being perceived. For an example of this see Wood et al. (1997). In attention research, as in working memory research, the effect of sensory memory must be taken into account.

2.03.4 Techniques to Examine Sensory Memory

Of necessity, we already have discussed a number of techniques used to examine sensory memory. Now it should be helpful to take a brief inventory of these methods. In taking this inventory it is important to keep in mind that different methods disagree. Still, it may be proposed that different outcomes theoretically might result from a common sensory memory. For example, a subjective impression of the duration of a stimulus might result from the duration for which the sensory neural response exceeds a certain intensity, whereas a measure of information about the stimulus might result from an integration of the neural response intensity over time (cf. Cowan, 1987; Loftus and Irwin, 1998).

2.03.4.1 Sensory Persistence Procedures

In the most straightforward types of investigation, stimuli extended over time are perceived as being simultaneous, as in the investigations of the psychological moment described above. Johann Andreas Segner, a German physicist and mathematician living in the 1700s, attached a glowing coal to a cartwheel, rotating the wheel at various speeds. He found that a complete circle was perceived if the wheel was rotated at a rate of at least 100 ms per rotation. This implies that the sensory memory of the glowing coal fell below some minimal level of brightness by about 100 ms.

Efron (1970a,b,c) carried out quite a nice set of experiments to refine the sensory persistence procedure. An indicator (e.g., a click) stimulus was presented along with a target stimulus (e.g., a light flash), and the study estimated when the indicator sounded as if it occurred at the same time as the offset of the target (or, in a control condition, the onset of the target). The result was that the onset of the target was only very slightly overestimated, whereas the offset was overestimated by up to about 200 ms. The nature of the overestimation depended heavily on the duration of the target, such that the target appeared to have a minimal perceived duration of about 200 ms. Very similar results were obtained when the target was visual and when it was auditory. The duration of a perception appears to be the duration of the perceptual response, and if the target stimulus is brief, it reflects the duration of the target plus its perceptual afterimage or sensory memory.

2.03.4.2 Partial-Report Procedures

We already have described the procedures like that of Sperling (1960) and Darwin et al. (1972), in which an array of items is followed by a partial-report cue that allows part of the sensory memory representation to be transferred to a more abstract, categorized, reportable state, working memory. One enigma worthy of consideration is that, whereas persistence procedures have produced similar results for vision and audition, partial-report procedures seem to produce much shorter periods of cue utility for vision (under 1 s) than for audition (about 4 s). We return to this enigma when discussing theories of forgetting from sensory memory.

2.03.4.3 Selective-Attention Procedures

We have touched upon procedures in which an auditory stimulus is ignored at the time of its presentation and only subsequently receives the benefit of attention applied to the sensory memory (Broadbent, 1958; Cowan et al., 1990; there are various other examples such as Treisman, 1964; Norman, 1969; Glucksberg and Cowen, 1970).

It is possible also to examine memory for unattended material in the visual modality. Various techniques can be used to get the subject to contract or expand the focus of visual attention (Eriksen and St. James, 1986; LaBerge and Brown, 1989), and one can then examine memory for information inside or outside of the attentional focus. One difficulty is that there is poorer perceptual analysis of information in the periphery of the visual field, regardless of whether that part of the field is the focus of attention. Usually, the center of the visual field of gaze is also the focus of attention, so attention and visual acuity are confounded. (That is not the case in audition, for which there is no change in the effectors accompanying attention.) Luckily, it is possible to direct a subject's attention to an area outside of the center of gaze (e.g., Brefczynski and DeYoe, 1999). For this reason, it is theoretically possible to determine the effects of attention on visual perception and examine memory for centrally presented but unattended stimuli. It does seem clear that visual attention affects perception, but more research is needed to reveal the details of unattended sensory images in the center of gaze.

2.03.4.4 Backward-Masking Procedures

We already have touched upon the technique of backward masking, in which a brief target stimulus is followed by a mask and impedes recognition of the target. Notably, little masking occurs if the mask precedes the target (Massaro, 1973). This confirms that the critical aspect of backward masking is overwriting of the target's sensory memory by the mask, not the mere proximity of target and mask. It is also noteworthy that the period of backward masking obtained in the auditory modality is quite similar to the visual modality (Turvey, 1973). That appears to be true also in persistence procedures, but not in partial-report or selective-attention procedures, a point to which we return shortly.

One benefit of the masking procedure is that it can be used to show that the neural locus of sensory memory is not entirely peripheral. Turvey (1973) showed that substantial backward masking occurs even when the target was presented to one ear and the mask was presented to the other ear. (For convergent evidence of a central locus of the visual afterimage using a persistence technique, see Haber and Standing, 1969, 1970.) Kallman and Morris (1984) showed something similar in audition, though the opposite conclusion is often cited (Hawkins and Presson, 1977). Cowan (1995, Section 2.5) cited physiological studies supporting the notion that auditory sensory memory has a central locus.

2.03.5 Theories of Forgetting From Sensory Memory

2.03.5.1 Modality-Specific Rates of Decay

It is interesting to see how a scientific field responds to inconsistency. Although the methods described above have been present for quite some time, most theoretical mentions of sensory memory in textbooks seem to go along with the conclusion that auditory memory outlasts visual memory. That could account for the findings of partial-report and selective-attention procedures, but not the findings of persistence and backward-masking procedures. An alternative view is described in the sections that follow.

2.03.5.2 Two Phases of Sensory Memory with Different Rates of Decay

The study of Sperling (1960) was truly seminal in the field. When Darwin et al. (1972) found that sensory memory appeared to be useful for a much longer period in audition (about 4 s) than Sperling found in vision (less than 1 s), it led to the belief that auditory memory lasts longer than visual memory. However, Massaro (1976) offered a different interpretation. Whereas Sperling's experiments used a large number of simultaneous characters (e.g., 12), the smaller number of simultaneous characters used by Darwin et al. (1972) allowed perceptual analysis. According to this view, the sensory memory observed by Sperling was preperceptual, whereas that was not true of the memory observed in the auditory studies. Consistent with Massaro's view, Cowan (1984, 1988, 1995) summarized evidence from various procedures that there are two phases of sensory memory in both the visual and auditory modalities (as well as in other modalities): a short, literal phase lasting about 250 ms and a longer, second phase lasting several seconds. The second phase was said to comprise temporarily activated sensory features in long-term memory and was said to be both functionally similar to temporarily activated semantic features in long-term memory and much more processed than the first phase.

A couple of studies, one in vision and one in audition, provide striking evidence that there are two types of sensory memory. Phillips (1974) presented two spatial patterns of black and white squares that differed in at most the fill of one square. At short interpattern delays, performance was excellent but was harmed if there was a displacement of the screen location from the first pattern to the second. It was as if the subject actually could see the superimposition of the patterns. In contrast, at longer delays, performance was poorer, and displacement of the screen location did not matter. This suggests that the longer representation was more abstract than the shorter representation.

Kallman and Massaro (1979) carried out a backward-masking procedure in which a standard tone had to be compared to a subsequent comparison tone. Either the standard or the comparison tone was followed by a masking tone. At issue in this experiment was the effect of the similarity between the mask and the tone it masked. When the mask followed the standard tone, it could result in either interference with extraction of information from the sensory trace, which could be termed Masking Type 1, or overwriting of information about the tone even after it has been extracted from the sensory trace, which could be termed Masking Type 2. As the interval between the standard tone and the mask increased, Masking Type 1 presumably disappeared, whereas Masking Type 2 remained. On other trials, it was the comparison tone that was masked, and therefore, only Masking Type 1 was possible; a judgment could be made as soon as information was extracted from that comparison tone. Given that similarity effects were obtained only for Masking Type 2, it was possible to distinguish two phases of auditory memory with different properties. These were termed preperceptual auditory storage and synthesized auditory memory, respectively. These terms correspond to the short and long auditory stores of Cowan (1984).

2.03.5.3 No-Decay Theories

Last, it must be mentioned that some investigators have proposed that there are no decaying memories, including no decaying sensory memory. These investigators view the decline in performance with increasing retention intervals as a matter of a loss of temporal distinctiveness of the items at the end of the list (Neath and Crowder, 1990; Crowder, 1993; Nairne, 2002). That type of theory, combined with the notion that there is better temporal distinctiveness in the auditory modality (e.g., Glenberg and Swanson, 1986), could help to explain why there is an advantage for items at the end of a verbal list presented in the auditory as opposed to the visual modality (cf. Penney, 1989; Marks and Crowder, 1997; Beaman and Morton, 2000; Cowan et al., 2004). However, it is not an easy matter to distinguish between decay and distinctiveness accounts.

Cowan et al. (1997) considered that there might be a distinctiveness explanation for performance in two-tone comparison procedures, in which performance decreases as a function of the time between the standard and comparison tones. As that time increases, it may become larger than the time between trials, so that the tones are not neatly grouped in episodic memory into the trials to which they belong. To overcome this problem Cowan et al. manipulated the time between trials as well as the time between the standard and comparison tones within a trial. Examining trials with the ratio between these two times held constant, and performance decreased only slightly as the time between the standard and comparison tone increased, until it exceeded 6 s. Between 6 and 12 s, the drop was a bit more severe. However, Cowan et al. (2001) reexamined the evidence, taking into account distinctiveness caused by intervals before the penultimate trial, and found no strong evidence of decay (although the data were preliminary in this regard).

A remaining possibility is that, in these procedures, sensory memory information that is attended can be rehearsed (Keller et al., 1995). A study that argues against the effects of time on nonsensory short-term memory (Lewandowsky et al., 2004) takes into account verbal rehearsal, but not the possibility of an attention-based, possibly nonverbal type of rehearsal (cf. Barrouillet et al., 2004). It remains to be seen whether sensory information that is unattended at the time that it is presented, and thus cannot be rehearsed, is lost over time in a way that can be explained by temporal distinctiveness or in a way that cannot be so explained.

2.03.6 Comments on the Future of Research on Sensory Memory

Sensory memory is one of the oldest topics in experimental psychology. Currently, there is only a small to moderate amount of ongoing research on the topic, but that does not imply that the great problems in the field have been solved, or that the field has become trivial or uninteresting. Sensory memory is an intrinsically fascinating set of neural mechanisms that must be strongly associated with basic conscious experience. As brain researchers investigate how humans know what is real and what is only imaginary, their research no doubt will lead them back to the persistent mysteries within the topic of sensory memory.

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