Priming and Human Memory Systems
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We still know relatively little about priming at this early stage of research. Nevertheless it seems clear that it plays a more important role in human affairs than its late discovery would suggest. Although priming is typically observed only under carefully controlled experimental conditions, similar conditions frequently occur naturally, outside the laboratory. It is reasonable to assume, therefore, that priming represents a ubiquitous occurrence in everyday life.

One remarkable feature of priming is that, unlike other forms of cognitive memory, it is nonconscious (*8*). A person perceiving a familiar object is not aware that what is perceived is as much an expression of memory as it is of perception. The fact that people are not conscious of priming probably accounts for its late discovery. It is difficult to study phenomena whose existence one does not suspect.

The juxtaposition of its surmised ubiquity in human cognition and the lateness of its discovery, together with its nonconscious nature, have inspired an intense experimental and theoretical interest in priming. A central issue concerns its nature. What kind of memory is it?

In an early article on priming, we conjectured that the effects we had observed might "reflect the operation of some . . . as yet little understood memory system" other than semantic or episodic memory [p. 341 in (*9*)]. We now present a more seasoned version of this hypothesis. There is additional evidence to support the early idea, and we can say a bit more about the "little understood" system.

This evidence comes in two major categories. First, the many different kinds of dissociations between priming and explicit memory can best be explained by the idea of a pre-semantic perceptual system that can operate independently of episodic memory. Second, neuropsychological studies have revealed dissociations between the reading of words and perceptual identification of other kinds of objects on the one hand, and semantic knowledge of words and objects on the other. These dissociations, too, point to a pre-semantic perceptual system that can operate independently of semantic memory. We believe that priming and perceptual identification are expressions of a single perceptual representation system (PRS), which exists separately from but interacts closely with other memory systems (*10, 11*). We present the evidence and reasoning for this PRS hypothesis in what follows.

Phenomena of Priming

The evidence in the first category that supports the PRS hypothesis comprises five different kinds of dissociations, involving different tasks, different tests, different types of retrieval cues, different kinds of materials, and different subject populations (*12*), as follows:

1) Intact priming in densely amnesic patients. Amnesic patients cannot remember the study episode in the priming experiment even after a short interval, yet they show priming effects that are frequently as large as those in normal subjects (*13*).

2) Developmental dissociations between priming and explicit memory. Recognition memory in children increases with age, but priming effects can be as large in 3-year-olds as in college students. Similarly, elderly subjects have difficulty with recalling and recognizing items presented earlier, but their priming effects are indistinguishable from those of young adults (*14*).

3) Drug-induced dissociations. Drugs such as alcohol and scopolamine reduce performance in explicit recall and explicit recognition, but have little or no effect on priming (*15*).

4) Functional independence of priming and explicit memory in normal subjects. A large number of experiments showing such independence have been reported, involving different kinds of priming tasks and tests (*16*). Thus, for example, semantic elaboration of the study material enhances explicit memory, but has little effect on priming (*17*). On the other hand, the relation between the physical format of the studied material and that of the retrieval cues has relatively little effect on explicit memory, but may greatly affect the magnitude of priming (*18*). Similarly, loss of retention over time often seems to proceed differently in priming and in explicit memory, possibly because priming is little affected by the kinds of interference manipulations that reduce retention in explicit tasks (*19*).

5) Stochastic independence between successive tests on the same items. Priming effects are as large for the words that the subjects recognize as having been presented in the study phase as for the unrecognized words (*9, 20*).

The conclusions drawn from all of these empirical facts point in the same direction. At the psychological level of analysis it looks as if normal people faced with ambiguous stimuli are capable of adopting either a perceptual or a memory mode of cognitive operation. In the perceptual mode, the operations involve relating the present stimulus to the information stored in PRS. This operation reflects priming; perception is facilitated independently of any recollection of the learning episode. In the memory mode, the operations consist of matching the cue information to the information stored in episodic memory. If successful, the product of this match, or synergistic ecphory (*21*), is recollection of the event of the target item's occurrence in the study list. Our hypothesis is that cognitive operations in the perceptual mode involve PRS without any obligatory engagement of other memory systems, whereas operations in the memory mode depend on the resources of semantic and episodic memory.

At the physiological level of analysis, the evidence points to distinct brain mechanisms subserving priming. At least some of the computations involved in and necessary for retrieval of episodic information are disabled when the brain has been damaged, when it has not yet developed fully or has deteriorated in old age, or when the influence of certain drugs results in impairment of explicit memory. These same computations, however, are not necessary for priming. Such a state of affairs signals the distinction between brain systems concerned with explicit recollection of past events and primed identification of previously encountered objects—that is, between episodic memory and PRS.

We next elaborate on the evidence pertaining to two properties of PRS: (i) access to information in PRS is hyperspecific, probably because, unlike other cognitive memory systems, it contains no abstract focal traces, and (ii) its domain extends to nonverbal objects.

Hyperspecificity of Access

A number of experiments have shown that priming is stochastically independent of explicit memory (*11, 14, 22*). In these experiments, joint performance on two successive tests is analyzed item by item for each subject, and the outcome of the experiment is summarized in terms of relevant data pooled over all subject-items (*23*).

The original discovery of such independence (*9, 20*) was surprising, because the typical result of similar explicit memory experiments is one of dependence. For a while it was not known why priming measures yielded different results. We now have reason to believe that the finding reflects a basic property of PRS: the system seems to work without the kinds of stored focal traces that support the operations of semantic and episodic memory.

In experiments that support this proposal (*24*), subjects saw a long list of words, including words such as PYRAMID and

MOSQUITO, and then took two successive fragment completion tests directed at these words. The cues used on the tests were either the same (for example, "- Y - A - ID" on both tests) or they had minimal overlap (for example, "- O - Q - - TO" and "- - S - UI - O" on the first and second test, respectively). The task was to complete the fragments, regardless of whether the subject remembered the words' earlier presentation. The dependent variable was the degree of correlation between the two successive tests, measured by Yule's Q (a measure of correlation in the fourfold contingency table that varies from −1.0 to +1.0). The results showed that with identical cues on both tests, the correlation between the tests was reliable (Q values around 0.90). With different cues on the two tests, however, the correlation showed a drop to zero.

In further experiments (*25*), subjects were given successive fragment completion tests with nested cues. Again subjects saw a long list of words, such as AARDVARK and UMBRELLA, and then took two successive tests. In the first, they saw three-letter fragments (for example "- A - D - - R -" and "U - - R - L -"); in the second test they saw five-letter fragments that included the three letters previously seen ("- A R D - A R -" and "U - B R - L A"). The results showed that the two successive tests again were independent.

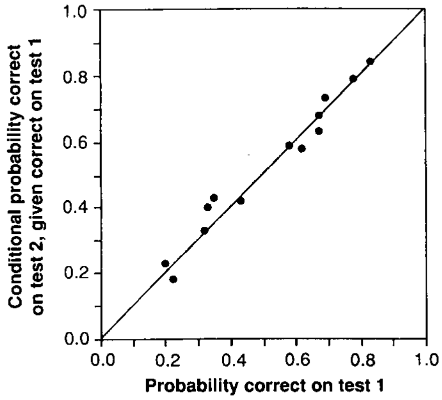

Fig. 1. Stochastic independence between the outcomes of successive memory tests in a number of experiments. One of the two tests was always a priming test, the other was either an explicit recognition test (*9, 11*) or the same priming test but with cues different from those used on the first test (*10, 24, 25*). In the graph, the conditional probability of successful production of a target item on the second test, given success on the first, is plotted as a function of the simple probability of successful recognition or production of the same target on the first test. Stochastic independence (absence of item-by-item correlation) between successive tests is indicated by the diagonal. The stochastic independence exhibited by these data differs from the outcomes of explicit memory tests under otherwise identical conditions [for example, figure 1 in (*27*)].

The data from successive tests of implicit memory (*10, 24, 25*) are summarized in Fig. 1, along with the data depicting the relation between implicit measures of memory and explicit recognition (*9, 11*). Each bivariate data point in Fig. 1 represents the outcome of an experiment or a condition in an experiment. The simple probability of success on one test is plotted against the conditional probability of success on the other, given success on the first. Stochastic independence between the tests, indicated by the main diagonal of the graph, holds equally for all the experiments.

These facts suggest that access to the information that supports priming is very inflexible, or hyperspecific. Success or failure of gaining access to a representation through one cue has no implications for success or failure of access to the same representation through a different cue, although the tests are otherwise highly reliable (*26*). Such a state of affairs suggests that priming of words is not supported by abstract focal traces representing these words, because PRS does not contain such traces. If it did, two sets of different cues directed at the same set of targets should exhibit at least moderate dependency, as they do in explicit memory (*27*). Thus it looks as if PRS, instead of containing focal traces of words, contains a multitude of distributed representations of particular words, each accessible through specific cues.

Priming of Nonverbal Information

Most experiments on priming have been conducted with verbal materials. But priming, dissociated from explicit memory, also occurs with nonverbal stimuli such as pictures, shapes, and faces (*28*).

In research on the priming of novel visual objects (*11*), subjects were shown two-dimensional line drawings depicting three-dimensional objects such as those in Fig. 2. All of the objects were novel in the sense that subjects had never seen them before. Half of the line drawings depicted structurally possible objects that can exist in three dimensions, and half depicted structurally impossible objects that contained surface and edge violations that ruled out their three-dimensional existence.

In the priming test the subjects made "object decisions." They had to decide whether a briefly flashed object was possible or impossible. Subjects were also tested for explicit recognition of the target stimuli after the object decision test.

The results of these experiments provided additional clues concerning the nature of the memory system that subserves priming. Priming did occur for structurally possible objects, but only if, at the time of study, the attention of the subject was directed to the global, three-dimensional structure of the stimuli. Under these conditions, priming was found to be dissociated from recognition both functionally and stochastically. Mere exposure to the structurally possible objects, whether at study or in a recognition test preceding the object decision test, did not produce priming. Nor was any priming of the structurally possible objects found as a result of semantically rich elaborative coding of the kind that greatly enhances explicit memory. Finally, no evidence for priming of structurally impossible objects was observed.

These findings suggest that priming of object perception critically depends on perception of objects as structured wholes, implying that PRS is dedicated to the processing of such structural descriptions (*29*). The fact that the elaborative encoding task, in which the subjects were required to think of real-world objects of which target drawings reminded them, did not produce priming in these experiments, whereas encoding tasks involving information about the global three-dimensional structural relations that define each object did, suggests that PRS operates at a pre-semantic level. The fact that priming did not occur for impossible objects in these experiments implies that PRS has evolved to perform only ecologically valid computations.

We now turn to the second general category of evidence for PRS: neuropsychological dissociations between perceptual identification

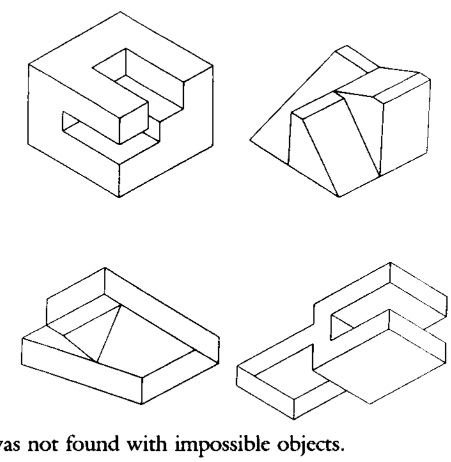

Fig. 2. Examples of possible and impossible objects used in experiments on object priming (*11*). The two upper drawings depict possible objects that could exist in three-dimensional form; the two lower drawings depict impossible objects that contain structural violations that would prohibit them from existing in three-dimensional form. Priming was found under certain encoding conditions with possible objects; it was not found with impossible objects.

and semantic memory. These dissociations, originally observed a hundred years ago (*30*), were seen as related to phenomena of priming and explicit memory only recently (*11*).

Neuropsychology of Perceptual Representation Systems

Neuropsychological studies have delineated different types of alexias or reading disorders that occur as a consequence of specific brain lesions (*31*). The critical data for our purposes are provided by studies of patients who exhibit the phenomenon of "reading without semantics" (*32*). Such patients are able to read aloud printed words, but they have little or no comprehension of these words when tested with various semantic or associative probes (*33*). Most important is that their ability to read irregular words, such as "cough" or "blood," is almost entirely preserved. Irregular words—unlike regular words—cannot be read on the basis of grapheme-to-phoneme conversion rules; their pronunciations cannot be "sounded out." Preserved reading of irregular words thus indicates that patients are able to gain access to stored representations of the words' visual forms. This dissociation between intact access to word form and impaired access to semantic information again supports the hypothesis that PRS operates at a pre-semantic level (*11, 34*). If the hypothesis is true, these patients, despite their semantic impairments, should show robust priming of words on appropriate tests.

Although evidence that bears directly on this prediction is not yet available, some relevant data are provided by experiments with an alexic patient (P.T.) who exhibits the phenomenon of letter-by-letter reading (*35*). Letter-by-letter readers are unable to recognize or read printed words unless they identify each letter sequentially (*36*). Neuropsychological assessment of P.T. suggested that her reading deficit stems from an impaired ability to transmit letter information in parallel to PRS, which is itself preserved. This analysis suggests that P.T., despite her alexia, should nevertheless show priming with words under conditions in which access to PRS occurs. And it was indeed found that, after letter-by-letter study of a list of words, P.T. showed priming in a word identification test. The priming was modality-specific, and it occurred despite P.T.'s great difficulty in identifying nonstudied words.

Studies of patients with pronounced impairments in recognizing everyday objects provide additional independent evidence for the existence of a pre-semantic system (*37*). The cognitive deficit of agnosic patients who are severely impaired in visual recognition of objects (*38*) seems to stem specifically from their inability to gain access to semantic or associative information about objects from visual input. For example, they have great difficulties with a task in which pictures of three objects are shown and the two that perform the same function must be selected (*39*). In addition, these agnosic patients are impaired when probed with questions concerning the functions or associative properties of visually displayed objects; yet the same patients show relatively intact performance on visual tests of the structural features of objects, such as tests of copying and judgments that objects seen from different perspectives are identical (*40*). It is this contrast between impaired access to semantic knowledge and relatively normal access to structural knowledge that has led to the proposal of a system that is separate from, but interacts with, the semantic system (or systems). Our analysis leads to the prediction that priming should be observed in such patients on tests that selectively engage PRS.

Relatively little is known about the neural substrates of priming (*41*). Observations of preserved priming in amnesic patients imply that priming is mediated by neural systems outside the medial temporal and diencephalic regions that are damaged in amnesia and that play an important role in explicit remembering. It has been suggested that priming depends on changes in cortical modules that are involved in processing specific attributes of stimulus information (*42*). Inherent in the concept of PRS are suggestions about which cortical modules may be involved. For example, studies performed with the neuroimaging technique of positron emission tomography have shown that passive reading of familiar words produces selective bilateral activation in the extrastriate cortex, thus suggesting that visual identification of words has an anterior occipital locus (*43*). This conclusion is consistent with the neuropsychological findings from patients with selective preservation of the word form system (*33*). Neuropsychological findings also indicate that object identification depends on the integrity of posterior cortical areas, especially in the right hemisphere (*39*).

Although this evidence bears directly on the neural bases of perceptual identification of words and objects, it can support only indirect inferences concerning the anatomical or physiological underpinnings of priming. If we assume that PRS subserves priming, then these results provide preliminary hints concerning the likely brain loci of priming phenomena. However, studies that examine the matter directly are currently lacking and badly needed.

Perceptual Versus Conceptual Priming

We have been concerned in this article with priming as expressed on perceptual tasks, in which processing is determined largely by physical properties of test cues. However, priming effects have also been observed on conceptual tests, in which semantic processing is required. For example, priming effects on both amnesic patients and normal subjects have been demonstrated for a task in which subjects are given the name of a category, for example "bird," and are asked to produce the first instance that comes to mind, for example, "eagle" (*44*). Similarly, priming effects involving the acquisition of new associations between unrelated words have been observed on cued word stem completion and free association tests in normal subjects (*45*), but only after semantic study. A theory that priming is an operation of PRS does not account for such effects.

We acknowledge that PRS plays little if any role in the semantic effects that have been observed on conceptual tests. Indeed, we believe that such effects have a different basis than the phenomena with which we have been concerned (*11*). In our view, what has been termed conceptually driven priming reflects a process of semantic learning: the modification of, or adding of new information to, semantic memory.

Three pieces of relevant evidence exist. First, conceptual priming is enhanced by semantic encoding (*45*). Second, dissociations between performance on perceptual and conceptual tests of priming have been observed in studies of college students (*46*), thereby suggesting that different processes support priming on the two types of tests. Third, amnesic patients can learn some new facts in the absence of episodic memory, although such learning is substantially impaired relative to the performance of normal subjects (*47*).

Additional evidence that semantic learning can be dissociated from both episodic memory and perceptual priming (*25*) was obtained in research conducted with K.C., an amnesic patient whose episodic memory is totally dysfunctional. He does not remember a single event from his life (*48*). Any new learning that he exhibits, therefore, must be based on a system or systems other than episodic memory. In a recent experiment, K.C. was presented with a long series of complex pictures and three-word phrases (for example, a picture of a group of fierce-looking native warriors was paired with the phrase STRONGMAN STARTED DYNASTY). The last word of the phrase was the target word to be learned by K.C. The materials had been constructed in such a manner that the target was not predictable either from the picture or from the first two words of the phrase. After multiple distributed exposures to 64 picture-phrase pairs, K.C. was given both perceptual tests that involved completing a graphemic fragment of a given target (for example, D-N-S--) and conceptual tests in which all or a part of the original picture-sentence context, but no fragment, was presented, and K.C. had to produce a word that fit the context. Substantial learning, retained for a number of weeks, was observed on both tasks. The critical result, however, was stochastic independence between the two tasks; the item-by-item correlation between the fragment tests and the conceptual tests was zero. This outcome is consistent with the view that perceptual priming is mediated by PRS, whereas conceptual priming involves the modification of semantic memory.

Conclusion

The evidence we have reviewed converges on the PRS hypothesis—that is, priming reflects the enhancement of the neural computations and correlated cognitive operations of the perceptual representation system, PRS. This evidence also delineates some properties of PRS: (i) it is concerned with identification of perceptual objects, including words; (ii) its neural computations are not critically dependent on the brain regions necessary for episodic and semantic memory operations; (iii) it develops early and is differentially preserved late in life; (iv) its operations are disconnected from consciousness, and its products do not provide a basis for awareness of previous experience; (v) it is relatively immune to the effects of drugs that affect other memory systems; (vi) information in it is distributed in multiple representations of particular words and objects; and (vii) access to representations is hyperspecific.

In our discussion of priming we have focused on differences between priming and other forms of memory. But similarities between them also exist; like other forms of memory, priming benefits from repetitions, exhibits forgetting over time, and varies with the relation between the conditions of encoding and retrieval. We think that these and other such "parallel effects" are theoretically uninteresting, since some similarities would be expected of all forms of memory—otherwise it would be difficult to justify their general label.

Nevertheless, some theorists, concentrating on similarities between priming and other forms of memory, and keen on upholding the parsimonious conceptualization of memory as a unitary cognitive system, have argued that priming and explicit forms of memory reflect task-dependent differences in utilization of various aspects of the information stored during a learning episode. These processing theories are usually based on a limited domain of data, such as cognitive psychology experiments with normal subjects. The processing theorists usually argue against the systems approach, claiming that they can explain the results of the experiments they consider without postulating different memory systems (*49*).

We agree that the understanding of processes and mechanisms is as vital an objective in the study of priming as it is in the study of other forms of memory. But we also wish to underscore the importance of the systems point of view, for two reasons. First, the systems view allows organization and integration of phenomena of priming in a manner that has not been realized within monolithic processing theories. Second, and more important, it is becoming increasingly clear that there are no universal principles of memory and that facts discovered about one form of memory need not hold for other forms. This is why systematic classification of memory systems, both psychological and physiological, is an essential prerequisite for the successful pursuit of the empirical and theoretical understanding of memory processes and mechanisms. The systems approach combined with appropriate processing theories seems to provide the most direct route to the future (*10, 11*).

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