

Priming and Multiple Memory Systems: Perceptual Mechanisms of Implicit Memory

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Abstract

■ Research examining the relation between explicit and implicit forms of memory has generated a great deal of evidence concerning the issue of multiple memory systems. This article focuses on an extensively studied implicit memory phenomenon, known as direct or repetition priming, and examines the hypothesis that priming effects on various tasks reflect the operation of a perceptual representation system (PRS)—a class

of cortically based subsystems that operate at a presemantic level and support nonconscious expressions of memory. Three PRS subsystems are examined: visual word form, structural description, and auditory word form. Pertinent cognitive, neuropsychological, and neurobiological evidence is reviewed, alternative classificatory schemes are discussed, and important conceptual and terminological issues are considered. ■

INTRODUCTION

During the past 25 years, questions concerning the nature and number of memory systems have been at the forefront of cognitive, neuropsychological, and neurobiological research (for historical overview, see Polster, Nadel, & Schacter, 1991). In the study of human memory, a key line of evidence for multiple memory systems has been provided by investigations concerned with the descriptive distinction between *explicit* and *implicit* forms of memory (Graf & Schacter, 1985; Schacter, 1987). Explicit memory refers to intentional or conscious recollection of prior experiences, as assessed in the laboratory by traditional tests of recall or recognition; implicit memory, by contrast, refers to changes in performance or behavior that are produced by prior experiences on tests that do not require any intentional or conscious recollection of those experiences. The distinction between explicit and implicit memory is similar to distinctions between *memory with awareness* vs. *memory without awareness* (Jacoby & Witherspoon, 1982), *declarative memory* vs. *nondeclarative memory* (Squire, 1992), and *direct memory* vs. *indirect memory* (Johnson & Hasher, 1987). However, these distinctions are used less frequently in the literature than is the explicit/implicit distinction, and there are various reasons to prefer the explicit/implicit contrast over alternative terms (Roediger, 1990).

The explicit/implicit distinction is a *descriptive* one that contrasts two different ways in which memory for previous experience can be expressed; it does not refer to, or necessarily imply the existence of, distinct underlying

memory systems. However, interest in the relation between explicit and implicit forms of memory has been sparked by demonstrations of striking dissociations between the two that do indeed suggest that different underlying systems are involved in explicit and implicit memory, respectively. Thus, for example, it has been known for many years that amnesic patients exhibit robust and sometimes normal learning of various perceptual, motor, and cognitive skills despite impaired or absent explicit memory for having acquired them (e.g., Cohen & Squire, 1980; Milner, Corkin, & Teuber, 1968). Amnesic patients can also exhibit classical conditioning effects despite poor explicit memory (Daum, Channon, & Canavar, 1989; Weiskrantz & Warrington, 1979), and acquire knowledge needed to perform complex computer-related tasks despite the absence of any recollection for having previously performed the tasks (Glisky, Schacter, & Tulving, 1986; Glisky & Schacter, 1987, 1988, 1989).

Perhaps the most intensively studied form of implicit memory has come to be known as repetition or direct *priming*: the facilitated identification of perceptual objects from reduced cues as a consequence of a specific prior exposure to an object (e.g., Tulving & Schacter, 1990). Priming can be thought of as a form of implicit memory in the sense that it can occur independently of any conscious or explicit recollection of a previous encounter with a stimulus. Thus, amnesic patients can show entirely normal priming as a consequence of a recent encounter with a word or object, despite impaired or even absent explicit memory for the word or object; and studies of nonamnesic, normal subjects have shown that

various experimental manipulations affect priming and explicit memory in different and even opposite ways (for reviews, see Richardson-Klavehn & Bjork, 1988; Roediger, 1990; Schacter, 1987; Schacter, Chiu, & Ochsner, 1993; Shimamura, 1986). These and other observations indicate that the kind of information about a recently encountered word or object that supports priming is quite different from the kind of information that supports explicit recollection for an encounter with the word or object. Moreover, priming has also been dissociated from skill learning: studies of dementia indicate that patients with Alzheimer's disease show impaired priming and intact motor skill learning, whereas patients with Huntington's disease show the opposite pattern (e.g., Butters, Heindel, & Salmon, 1990). A number of investigators have argued further that priming is the expression of a neurocognitive system that differs functionally and neuroanatomically from the neurocognitive system that supports explicit remembering and skill learning, respectively (cf., Cohen, 1984; Schacter, 1985, 1990; Butters et al., 1990; Squire, 1987, 1992; Tulving, 1985; Tulving & Schacter, 1990).

This article examines in some detail one such proposal, namely, that priming reflects, to a very large extent, the operations of a perceptual representation system (PRS) that can function independently of the episodic or declarative memory system that supports explicit memory (Schacter, 1990, 1992; Tulving & Schacter, 1990). PRS refers to a class of domain-specific subsystems, based in cortical regions, that process and represent information about the form and structure, but not the meaning and other associative properties, of words and objects. This article will focus on delineating and evaluating characteristics of, and evidence for, three PRS subsystems: visual word form, structural description, and auditory word form. Although they probably do not constitute an exhaustive list of PRS subsystems, various kinds of evidence about them is available, including data from priming studies. Each of the subsystems differs from the others in several ways, but all share common features: they operate at a *presemantic* level, that is, at a level of processing that does not involve access to the meanings of words or objects, and they are involved in *nonconscious* expressions of memory for previous experiences. After discussing pertinent issues and results at some length, I will conclude by considering briefly alternative conceptualizations of PRS subsystems and the relation between perceptual and conceptual forms of priming.

PRS SUBSYSTEMS AND PRIMING

Visual Word Form System

The term "visual word form system" was first used by Warrington and Shallice (1980) in the context of their research on patients suffering from a type of reading impairment known as letter-by-letter reading. Warrington and Shallice (1980) proposed that the deficit in at least

some of these patients could be attributed to the breakdown of a system that represents information about the visual and orthographic form of words. Evidence that such a system operates at a presemantic level is provided by studies that have focused on brain-damaged patients who maintain relatively intact abilities to read words yet exhibit little or no understanding of them (cf. Sartori, Masterson, & Job, 1987; Schwartz, Saffran, & Marin, 1980). Importantly, such patients can read words with irregular spellings, thereby indicating that they can gain access to the representations in the word form system (see Schacter, 1990, for further elaboration). Data from neuroimaging studies using positron emission tomography (PET) suggest that the visual form system is based in regions of extrastriate occipital cortex and is neuroanatomically distinct from brain regions subserving semantic processing (e.g., Petersen et al., 1989).

Several lines of evidence have led to the proposal that the visual word form system subserves priming effects on so-called data driven or perceptually based implicit memory tasks, such as *stem* or *fragment completion*, where subjects provide the first word that comes to mind in response to three-letter stems or graphemic fragments, and *perceptual* or *word identification*, where subjects attempt to identify briefly presented words. One such line of evidence is that amnesic patients show normal priming of familiar words and word pairs on completion, identification, and similar tasks (cf. Cermak et al., 1985; Graf, Squire, & Mandler, 1984; Moscovitch, 1982; Schacter, 1985; Shimamura & Squire, 1984; Tulving, Hayman, & Macdonald, 1991; Warrington & Weiskrantz, 1974). These results are consistent with the proposal that visual word priming is mediated by a perceptual system based in posterior cortical regions, because the critical sites of brain damage in amnesic patients typically involve the limbic system and medial temporal lobe structures; posterior cortex is spared in the amnesic syndrome (e.g., Rozin, 1976; Scoville & Milner, 1957; Squire, 1992; Weiskrantz, 1985).

Further evidence from the study of amnesia that bears on this idea has been provided by studies that have examined whether amnesic patients show intact priming of novel word forms—that is, nonwords (e.g., numdy) that do not have preexisting memory representations. Such effects, which have been shown in normal subjects (e.g., Feustel, Shffrin, & Salasoo, 1983; Rueckl, 1990), provide evidence against the idea that priming is mediated simply by the activation of preexisting representations, and instead suggest the creation of a novel perceptual representation by the word form system (Schacter, 1990). Accordingly, if priming of verbal items in amnesic patients is indeed mediated by an intact word form system, such patients should show priming for nonwords as well as familiar words. Although several studies have reported impaired or absent priming of nonwords in some amnesic patients (i.e., Korsakoff patients and demented subjects; cf. Cermak et al., 1985; Diamond &

Rozin, 1984; Smith & Oscar-Berman, 1990), recent research has provided clear evidence that non-Korsakoff amnesics, and even some Korsakoff patients, can show normal or near-normal priming of nonwords under appropriate experimental conditions (cf. Cermak, Verfaellie, Milberg, Letourneau, & Blackford, 1991; Gabrieli & Keane, 1988; Gordon, 1988; Haist, Musen, & Squire, 1991; Musen & Squire, 1991; for detailed review, see Bowers & Schacter, 1992). Thus, the weight of evidence is consistent with the proposition that a spared visual word form system supports priming in amnesic patients.

A second line of evidence that bears on the word form system hypothesis has been provided by experiments examining the effects of semantic vs. nonsemantic study tasks on priming and explicit memory. It has been known since the initiation of research in the levels of processing framework during the 1970s that explicit recall and recognition of a list of target words is much higher following semantic study tasks (e.g., judging the meaning of a word) than nonsemantic study tasks (e.g., counting the number of vowels and consonants in a word; see Craik & Tulving, 1975). Many studies that have been done since have shown that the same manipulations have little or no effect on priming in such data-driven implicit tests as stem completion (Bowers & Schacter, 1990; Graf & Mandler, 1984), fragment completion (Roediger, Weldon, Stadler, & Riegler, 1992), and perceptual identification (Jacoby & Dallas, 1981).

The foregoing findings are important because they provide support for the idea that priming is a presemantic phenomenon: if visual word priming depends on a form-based system that does not represent a word's meaning, then it makes sense that semantic study tasks that improve explicit memory do not confer the same benefit on priming. It is therefore worth noting that conditions do exist in which the magnitude of visual word priming is increased significantly by semantic study processing relative to nonsemantic study processing (e.g., Bowers & Schacter, 1990). However, the results from Bowers and Schacter's experiments suggest strongly that when such effects are observed, they can be attributed to the use of explicit memory strategies by subjects who have "caught on" concerning the relation between the implicit task and the study list. Through the use of a postexperimental questionnaire, Bowers and Schacter determined that subjects who exhibited awareness of the relation between the completion test and the study list showed higher completion rates following semantic than nonsemantic study tasks, whereas subjects who remained unaware of the study-test relation showed equivalent priming following the two study tasks.

A third line of evidence bearing on the nature of the system that subserves visual word priming comes from experiments in which perceptual attributes of target items are changed between study and test. The argument here is that if a visually based system plays a major role in priming, then the magnitude of the effect should be

reduced when relevant perceptual attributes are changed between study and test. Various manipulations have been used to evaluate this proposal, and a range of experimental outcomes has been observed, including findings that study-to-test changes in perceptual attributes of target items either reduce or eliminate priming (for review and discussion, see Kirsner, Dunn, & Standen, 1989; Roediger, Weldon, & Challis, 1989; Schacter, 1990; Schacter, Chiu, & Ochsner, 1993). For the present purposes, we focus on the theoretical implications of results from two types of stimulus transformations: (1) modality shifts and (2) changes in the format of target words.

Experiments that have examined effects of modality shifts (i.e., target words are presented auditorily and tested visually) have yielded a relatively consistent pattern of results: priming on completion, identification, and similar tasks is always reduced, and sometimes eliminated, by study-test modality shifts (cf. Graf, Shimamura, & Squire, 1985; Jacoby & Dallas, 1981; Clarke & Morton, 1983; Kirsner & Smith, 1974; Morton, 1979; Roediger & Blaxton, 1987). The observed reduction in priming as a consequence of modality shift supports the visual word form system hypothesis. However, the fact that significant cross-modal priming is typically observed, particularly with stem- and fragment-completion tests, suggests that word priming is not based entirely on visual/perceptual processes, a point that will be elaborated on later.

The question of whether visual word priming is affected by study-test changes in the specific format of target items (e.g., typefont, upper/lower case) is of great interest theoretically: If priming is reduced or eliminated by alterations in perceptual format, we have evidence that the system underlying visual word priming computes highly specific perceptual representations of the particular word tokens encountered on a study list; if priming is unaffected by such changes, we have evidence that the system operates at a more abstract level. Moreover, comparative analysis of which perceptual features do and do not impair priming when changed between study and test could provide rather precise information concerning the representational properties of the system underlying priming. A great deal of experimental effort has been devoted to this issue, and has yielded a rather mixed pattern of results. On the one hand, a number of studies have provided evidence that transformations of typefont, case, and orthographic structure can have a significant impact on priming (e.g., Gardiner, 1988; Jacoby & Hayman, 1987; Hayman & Tulving, 1989; Roediger & Blaxton, 1987; Scarborough, Cortese, & Scarborough, 1977; Whittlesea, 1990). On the other hand, however, other studies have failed to obtain effects of similar manipulations (e.g., Carr, Brown, & Charambolous, 1989; Clarke & Morton, 1983; Tardif & Craik, 1989).

Although some of the conflicting results may be attributable to subtle aspects of experimental procedures (cf. Carr et al., 1989; Whittlesea, 1990), recent studies have helped to clarify matters by elucidating, within the same

experimental situation, conditions under which study-to-test transformation of perceptual features do and do not impair priming. Thus, Graf and Ryan (1990) found that study-to-test changes in typefont reduced priming on a word identification test when the study task required subjects to focus on perceptual features of words, but not when the study task focused on word meaning (cf. Jacoby, Levy, & Steinbach, 1992). Marsolek, Kosslyn, and Squire (1992) found that changing case of target words between study and test reduced stem completion priming when test stems were presented to the right hemisphere (via the left visual field) but not when test stems were presented to the left hemisphere (via the right visual field).

These findings indicate that a visual encounter with a word does not necessarily or inevitably create a highly specific and novel representation of it in the word form system, but also indicate that specific perceptual representations are created under appropriate conditions. The Graf and Ryan (1990) data suggest that the system creates novel perceptual representations only when initial processing focuses on visual characteristics of a word, and perhaps only when unusual typefonts are encountered. The Marsolek et al. (1992) data suggest that this effect may depend on right hemisphere involvement—that is, the right hemisphere may constitute the substrate of the novel perceptual representations that produce format-specific priming effects. Marsolek et al. have suggested further that it is necessary to fractionate the word form system into two further subsystems: a left hemisphere subsystem that computes abstract word form representations (i.e., it produces one output for many inputs) and a right hemisphere subsystem that computes perceptually specific word form representations (i.e., it produces a single output for a particular input). They reasoned that these two computations are functionally incompatible (Sherry & Schacter, 1987)—a system designed to perform one would have difficulty carrying out the other—and hence must be performed by different subsystems. We will return to this point later in the paper.

Structural Description System

The term *structural description* refers to a representation of relations among parts of an object that specifies the global form and structure of the object (cf. Sutherland, 1968; Winston, 1975). Several investigators have argued that structural descriptions are computed by a specific brain system—termed the *structural description system* by Riddoch and Humphreys (1987)—that does not handle semantic-level information about the associative and functional properties of objects (cf. Kosslyn, Flynn, Amsterdam, & Wang, 1990; Riddoch & Humphreys, 1987; Warrington, 1975, 1982). We (e.g., Schacter, 1990, 1992; Schacter, Cooper, & Delaney, 1990; Tulving & Schacter, 1990) have suggested that the structural description sys-

tem can be viewed as a PRS subsystem that is involved in various priming effects that have been observed in the domain of visual object processing. As with the visual word form system, evidence that the structural description system operates at a presemantic level has been provided in the first instance by neuropsychological studies of brain-damaged patients. Specifically, a number of investigators have described patients who have severe deficits in gaining access to semantic information about visual objects, but exhibit relatively intact access to perceptual/structural knowledge of the same objects (e.g., Riddoch & Humphreys, 1987; Sartori & Job, 1988; Warrington & Taylor, 1978). Such patients perform quite poorly when required to name pictured objects, when tested for functional knowledge of what a visual object is used for, or when queried regarding associative knowledge of where an object is typically encountered. But they perform relatively well when given tests that tap knowledge of object structure, such as matching different views of common objects or distinguishing between real and nonsense objects.

There has been a good deal less work on visual object priming than on visual word priming, but as with the visual word form system, three main kinds of evidence implicate the structural description system as a major substrate of priming: spared implicit memory in amnesic patients, invariance of priming across semantic vs. nonsemantic study task manipulations, and effects of study-to-test transformation of various stimulus properties. I will first consider each type of evidence in the context of an experimental paradigm that my colleagues and I developed to test the structural description system hypothesis, and then briefly note pertinent data from other, related implicit memory tasks.

The paradigm that we have developed for examining priming of structural descriptions makes use of two-dimensional line drawings that depict unfamiliar three-dimensional visual objects (see Fig. 1). Although all of the objects are novel, half of them are structurally possible—they could exist in three-dimensional form—whereas the other half are structurally impossible—they contain surface and edge violations that would prohibit them from existing in three-dimensions (see Schacter, Cooper, & Delaney, 1990, for more details on objects). In a typical experiment, subjects initially study a list of possible and impossible objects by making various kinds of judgments about them, and are then given an *object decision test* to assess priming, or a yes/no recognition test to assess explicit memory. For the object decision test, previously studied and nonstudied objects are presented quite briefly (e.g., 50–100 msec), one at a time, and subjects decide whether they are possible or impossible. The reasoning is that (1) making the possible/impossible object decision requires access to information about three-dimensional structure of an object, and (2) to the extent that subjects have acquired information about object structure during the study trial, object de-

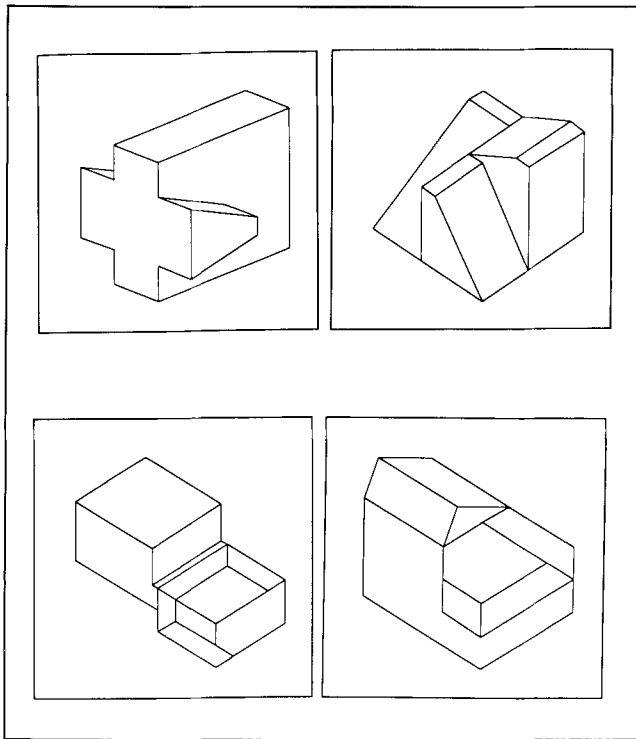


Figure 1. Sample of drawings used in experiments on implicit and explicit memory for novel objects. The drawings in the upper row depict *possible* objects that could exist in three-dimensional form. The drawings in the lower row depict *impossible* objects that contain structural violations that would prohibit them from actually existing in three-dimensional form. See text for further explanation.

decisions should be more accurate for previously studied objects than for nonstudied objects. An initial experiment revealed that significant priming is observed on the object decision task following a study task that requires analysis of global object structure but not following a study task that focuses attention on local object features (Schacter, Cooper, & Delaney, 1990). Moreover, the priming effect was observed for structurally possible objects but not for structurally impossible objects. The failure to observe priming of impossible objects has been replicated many times, and may indicate that it is difficult to form an internal representation of the global structure of an impossible object (see Schacter, Cooper, & Delaney, 1990; Schacter, Cooper, Delaney, Tharan, & Peterson, 1991).

The foregoing findings are consistent with the idea that priming on the object decision task is supported by newly formed structural descriptions of previously studied objects. Evidence that the priming effect reflects the operation of a presemantic structural description system—distinct from episodic memory—is provided by experiments in which we have compared encoding tasks that require processing of object structure (e.g., deciding whether an object faces primarily to the left or to the right) with encoding tasks that require processing of semantic and functional properties of objects. Figure 2

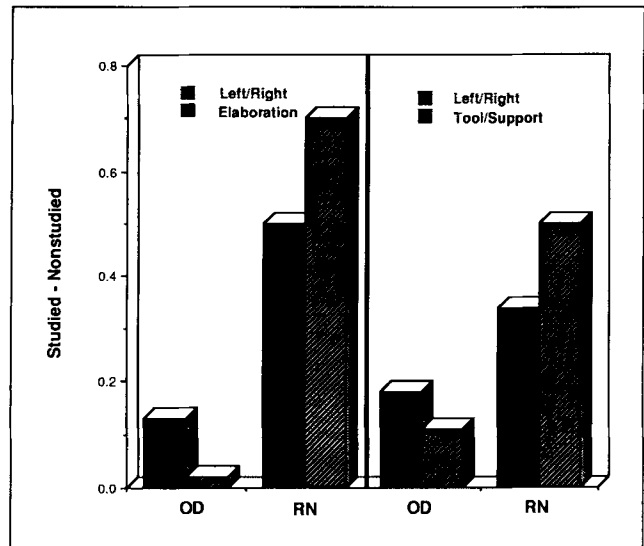


Figure 2. Summary of two experiments examining object decision priming (OD) and recognition memory (RN) using the possible and impossible figures presented in Figure 1. Only data for possible objects are shown, because no priming of impossible objects was observed in either experiment. The left panel presents results from an experiment by Schacter, Cooper, and Delaney (1990) in which subjects initially either judged whether the object faces primarily to the left or to the right, or generated the name of a real-world object that the target reminded them of most. The figure presents priming scores from the object decision task that were computed by subtracting the proportion of nonstudied possible objects classified correctly from the proportion of studied possible objects classified correctly, and corrected recognition scores that were computed by subtracting “yes” responses to nonstudied objects (i.e., false alarms), from “yes” responses to studied objects (hits). The right panel presents priming and corrected recognition scores from an experiment in which subjects performed either the left/right study task or a functional encoding task in which they judged whether an object would be best used as a tool or for support (Schacter & Cooper, 1991).

displays the results of two such experiments. The left-most panel depicts priming and recognition scores following a structural encoding task (left/right judgment) and an elaborative encoding task that taps subjects’ semantic knowledge of real world objects (they are required to generate a verbal label of a common object that each drawing reminds them of most). A striking crossover interaction was observed (Schacter, Cooper, & Delaney, 1990): Explicit recognition was much higher following elaborative than structural encoding, whereas the opposite pattern was found for object decision. Indeed, the elaborative task failed to produce significant priming on the object decision task, a finding that is probably attributable to the fact that subjects often based their elaborations on local, two-dimensional features of target objects. The right-most panel shows a similar crossover interaction from an experiment in which the left/right encoding task was compared to a functional encoding task in which subjects decided whether target objects could be best used as a tool or for support (Schacter, Cooper, Delaney, Peterson, & Tharan, 1991).

The functional encoding task did, however, produce some priming, probably because making the decision about function requires some analysis of structure.

These results are entirely consistent with the idea that object decision priming depends on a presemantic system that is dedicated to the analysis and representation of object structure, and does not handle information about the semantic and functional properties of objects. We have also found that object decision priming was spared in a group of amnesic patients who showed poor explicit memory for the objects on a recognition test (Schacter, Cooper, Tharan, & Rubens, 1991). This finding suggests that the priming effect, and the structural description system that supports it, are not critically dependent on the limbic structures that are typically damaged in amnesic patients.

Further information regarding the functional properties and possible neuroanatomical basis of the structural description system is provided by experiments in which we have examined the effects on priming of changing size, reflection, and picture plane orientation of target objects between study and test. The results of these experiments are relatively clear cut: study-to-test changes in size and left/right reflection of objects have no effect on priming despite producing an impairment of recognition memory (Cooper, Schacter, Ballesteros, & Moore, 1992), whereas changing the picture plane orientation of target objects by 120, 180, or 240 degrees from a standard orientation eliminates priming and also reduces recognition memory substantially (Cooper, Schacter, & Moore, 1991). This pattern of results suggests that the structural description system computes object representations that do *not* include information about size or left-right reflection, but *do* include information that specifies the relation between the parts of an object on the one hand and its principal axis and reference frame on the other (Cooper et al., 1991, 1992).

Data from other studies on priming of nonverbal information provide converging evidence on the foregoing points. Evidence for the presemantic nature of priming has been obtained on implicit tests that involve completing fragments of familiar pictures with the first object that comes to mind (Schacter, Delaney, & Merikle, 1990) or identifying novel dot patterns (Musen, 1991). Spared priming of novel dot patterns has also been documented in amnesic patients (Gabrieli, Milberg, Keane, & Corkin, 1990). And invariance of priming across study-to-test changes in size and reflection has been documented in paradigm that involves naming and renaming pictures of familiar objects (Biederman & Cooper, 1992).

Although relatively little information is available concerning the exact neural locus of the structural description system, the findings on size and reflection invariant priming have led to the proposal that regions of inferior temporal cortex may be involved (Biederman & Cooper, 1992; Cooper et al., 1992; Schacter, Cooper, Tharan, & Rubens, 1991). This idea is based to a large extent on

findings from single cell recordings and brain lesions in nonhuman primates indicating that inferior temporal regions are involved in the computation of size and reflection invariant object representations (for review, see Plaut & Farah, 1990). It is possible, of course, that the precise neuroanatomical locus of this system differs in monkey and man, but the human data on this point are not conclusive. Studies using PET imaging should help to clarify the matter, and we are in the process of completing such a study with the possible/impossible object decision task.

Auditory Word Form System

The great majority of research on priming and implicit memory has focused on visual paradigms and processes; there has been relatively little investigation of, and theorizing about, implicit memory in the auditory domain (see Schacter & Church, 1992, for review). Nevertheless, neuropsychological evidence on auditory processing deficits has revealed a form/semantic dissociation that is similar in kind to those discussed in previous sections, and that implicates the existence of a presemantic auditory subsystem of PRS. Specifically, patients have been identified who exhibit severe deficits in understanding spoken language together with relatively intact abilities to repeat and write-to-dictation auditorily presented words and sentences. In cases of *word meaning deafness*, the semantic deficit is modality specific; patients show relatively spared comprehension of visual inputs (e.g., Kohn & Friedman, 1986). In cases of *transcortical sensory aphasia*, comprehension is impaired in both the auditory and visual modalities (e.g., Coslett, Roeltgen, Rothi, & Heilman, 1987). By contrast, patients characterized by *pure word deafness* exhibit selective deficits in repetition of spoken words (e.g., Metz-Lutz & Dahl, 1984). Taken together, these observations point toward the existence of a presemantic auditory word form system that is dedicated to the processing and representation of acoustic/phonological information, but not semantic information, about spoken words (Ellis & Young, 1988). PET studies suggest that regions of posterior temporoparietal cortex may be involved in encoding of phonological word forms (Peterson et al., 1989).

Relatively little work has been done to link the auditory word form system with priming effects that have been observed on auditory implicit tests, but some data are available concerning two of the key issues discussed in previous sections: invariance of priming as a function of semantic vs. nonsemantic encoding processes, and effects of study-to-test changes in perceptual attributes of targets on the magnitude of priming.

Several recent experiments from our laboratory have provided evidence supporting the idea that auditory priming depends on a presemantic system. In studies with college students, we have examined auditory priming on two tests that are quite similar to the perceptual

or data-driven implicit memory tasks used previously in the visual domain: auditory word identification and auditory stem completion (Schacter & Church, 1992). In the former task, subjects hear previously studied and nonstudied words that are masked by white noise, and attempt to identify them; in the latter task, subjects hear the initial syllable of studied and nonstudied words, and respond with the first word that pops to mind (the syllable stimulus is created by editing a whole word utterance on a Macintosh system). To investigate whether priming on these tasks depends on semantic-level processes, during the study phase of the experiment subjects heard a series of spoken words and either performed a semantic encoding task (e.g., rating the number of meanings associated with the word) or a nonsemantic encoding task (e.g., rating the clarity with which the speaker enunciated the word). Implicit and explicit memory were tested after brief delays of several minutes. A series of five experiments yielded a consistent pattern of results: explicit memory was considerably higher following semantic than nonsemantic encoding tasks, whereas the magnitude of priming on identification and completion tasks was either less affected or entirely unaffected by the study task manipulation.

Further evidence bearing on the hypothesis that auditory priming reflects the operation of a presemantic system is provided by a recent study in which we assessed priming in a case of word meaning deafness (Schacter, McGlynn, Milberg, & Church, 1992). The patient, J. P., suffered a large stroke-induced lesion within the distribution of the left middle cerebral artery that affected primarily the anterior portions of Wernicke's area, largely sparing posterior temporoparietal cortex. He has great difficulty understanding spoken words. For example, J. P. exhibits a severe impairment on the auditory comprehension subtests of the Boston Diagnostic Aphasia Examination, whereas he shows only mild deficits on subtests that assess repetition of spoken words, writing to dictation, or comprehension of visual input. If, as we have suggested, priming on a task such as auditory word identification is mediated by a presemantic system, then J. P. should show robust priming despite his semantic impairment. Using the identification-in-noise task from Schacter and Church (1992), we indeed observed intact priming in J. P. relative to four matched control subjects (Fig. 3).

While the foregoing results support the idea that auditory priming need not involve access to semantic representations, they do not indicate what kinds of processes and representations are involved in the phenomenon. Evidence that priming is based largely on an auditory *perceptual* system is provided by experiments on study/test modality shifts: When target words are studied visually, priming on auditory word identification (Ellis, 1982; Jackson & Morton, 1984) and stem completion (Bassilli, Smith, & MacLeod, 1989) tasks is reduced significantly relative to auditory study conditions. Given that

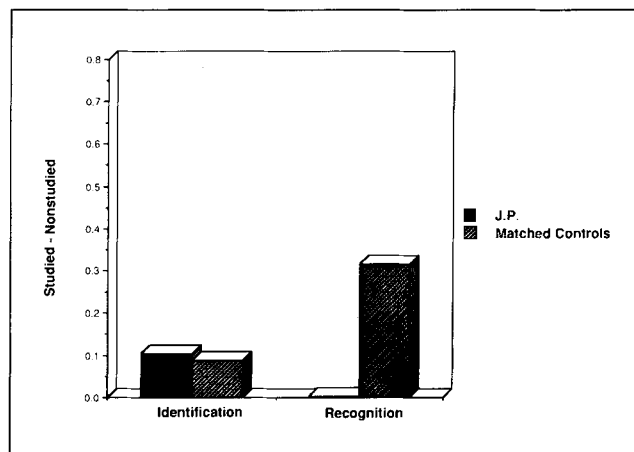


Figure 3. Results of an experiment that examined priming of auditory word identification and explicit recognition memory in a patient with word meaning deafness (J. P.) and four matched controls (Schacter, McGlynn, Milberg, & Church, 1992). The figure presents priming scores from the auditory identification task that were computed by subtracting the proportion of nonstudied words identified correctly from the proportion of studied words identified correctly, and corrected recognition scores that were computed by subtracting "yes" responses to nonstudied words from "yes" responses to studied words. J. P.'s corrected recognition score was zero.

a modality-specific auditory system plays a key role in priming, an important question concerns the nature of this system: Is auditory priming based on acoustic features of spoken input that are specific to a particular speaker, or is priming based on more abstract phonological representations that do not include speaker-specific perceptual information?

The issue was addressed initially in experiments by Jackson and Morton (1984), who examined priming on the auditory identification test when target words were spoken by the same voice at study and test, and when they were spoken by different voices (male vs. female) at study and test. They observed priming effects of comparable magnitude in the same- and different-voice conditions, and argued on this basis that priming depends entirely on abstract (but modality specific) representations of invariant phonological features of spoken words. In experiments discussed earlier, Schacter and Church (1992) also found nonsignificant effects of study-to-test changes in speaker's voice on priming of auditory identification performance. In fact, Schacter and Church observed voice-invariant priming even following nonsemantic study tasks that focused subjects' attention on characteristics of speaker's voice (cf. Graf & Ryan, 1990).

While the foregoing results are consistent with the idea that auditory priming depends on a system that represents abstract phonological word forms, it is also possible that the absence of voice-change effects in the Jackson and Morton (1984) and Schacter and Church (1992) experiments reflects idiosyncratic features of the auditory identification test that was used in these experiments.

Specifically, Schacter and Church suggested that the use of white noise on the identification test may have interfered with processing those components of the acoustic waveform that provide access to voice information. Consistent with this suggestion, when we examined the effect of changing speaker's voice on priming of the auditory stem completion task—which does not involve the use of white noise—significant voice change effects were observed in each of two experiments. Data from one of those experiments are presented in Figure 4, which shows that priming was lower in the different-voice than in the same-voice condition following both semantic and nonsemantic encoding tasks. The voice change manipulation had no effect on explicit memory, whereas the semantic vs. nonsemantic study task manipulation affected explicit memory but not priming. To ascertain that the presence/absence of white noise is the critical factor determining whether voice changes effects on priming are or are not observed, we performed an additional experiment with auditory stem completion that was identical in all respects to the previous one except for one change: stems were masked by white noise. Under these conditions, we observed significant priming but no effect of voice change (Schacter and Church, 1992).

This general pattern of results is similar to that observed in studies of visual word priming: priming is influenced by changes in perceptual features of target words in some experimental conditions but not in others. The critical issue for the present purposes concerns the theoretical implications of such observations for understanding the kind of subsystem that subserves auditory priming. Schacter and Church (1992) offered one speculative possibility that implicates left and right hemi-

sphere subsystems in abstract and perceptually specific components of auditory priming, respectively. The reasoning is relatively straightforward, and turns on three kinds of observations. First, a number of investigators have argued that the left hemisphere represents abstract or categorical phonological information, whereas the right hemisphere represents perceptually specific "acoustic gestalts," including information about speaker's voice (cf. Gazzaniga, 1975; Lieberman, 1982; Mann & Lieberman, 1983; Sidtis & Gazzaniga, 1981; Zaidel, 1985). Second, several types of empirical evidence link the right hemisphere with access to voice information: patients with right hemisphere lesions are characterized by voice recognition impairments (e.g., Van Lancker & Kreiman, 1987) and by difficulties in processing voice prosody (e.g., Ross, 1981); and studies of normal subjects using dichotic listening techniques have shown a left-ear (i.e., right hemisphere) advantage for processing intonational contours (e.g., Blumstein & Cooper, 1974). Third, evidence from split-brain patients indicates that the right hemisphere is greatly impaired—more than the left—when required to process spoken words that are presented in background noise (Zaidel, 1978).

Given that voice-change effects in auditory priming appear to be dependent on white noise, and that the right hemisphere represents voice information and is especially sensitive to background noise, it is possible that voice change effects are not observed when target items are masked by noise because a right hemisphere subsystem has been effectively excluded from contributing to task performance. Stated slightly differently, auditory priming may depend both on a left hemisphere subsystem that represents abstract phonological information and a right hemisphere subsystem that represents voice-specific acoustic information. When both subsystems can contribute to implicit task performance (i.e., if no white noise is used), voice change effects will be observed; but when only the left hemisphere subsystem can contribute (i.e., if white noise eliminates right hemisphere contributions), voice change effects will not be observed. The general idea that two lateralized subsystems are involved in auditory priming is quite similar to that offered by Marsolek et al. (1992) to account for the finding that perceptual specificity effects in visual word priming were observed when test stems were presented to the right hemisphere, whereas abstract priming was observed when stems were presented to the left hemisphere.

It must be emphasized, of course, that Schacter and Church's argument for right hemisphere involvement in voice specific priming is based entirely on indirect evidence and hence must be treated cautiously. To test this hypothesis more directly, we have recently initiated experiments that use dichotic listening techniques to examine voice change effects on priming. A large body of literature indicates that with dichotic presentation, verbal stimuli presented to the right ear (i.e., left hemisphere)

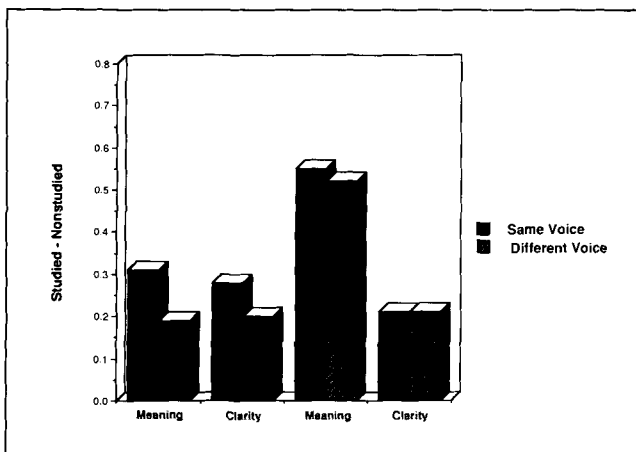


Figure 4. Results of an experiment that examined priming of auditory stem completion and explicit cued recall following word meaning and voice clarity encoding tasks (Schacter & Church, 1992). Target words were spoken in the same voice or a different voice at study and test. The figure presents priming scores and corrected recall scores that were computed by subtracting the proportion of nonstudied target words that subjects provided from the proportion of studied target words that they provided.

are more accurately reported than are verbal stimuli presented to the left ear (e.g., Bryden, 1988; Wexler, 1988) and, as noted earlier, there is some evidence that voice information is processed more efficiently by the left ear (i.e., right hemisphere; Blumstein & Cooper, 1974). Accordingly, we hypothesized that priming effects would be reduced by study-to-test changes in speaker's voice when test stimuli were presented to the left ear, but not when they were presented to the right ear. In the one experiment that we have completed (Schacter, Aminoff, & Church, 1992), subjects initially made clarity-of-enunciation judgments concerning a series of words that were spoken by male or female voices. They were then given a dichotic version of the auditory stem completion task: Stems representing studied or nonstudied target words were presented to either the left or right ear, a nontarget distractor stem was presented to the opposite ear (to inhibit the hemisphere ipsilateral to the target stimulus), and subjects were instructed to respond with the first word that came to mind in response to the stem presented to either the left ear or the right ear (left ear and right ear presentations were ordered randomly for individual subjects, and they were cued to the appropriate ear on each test trial). Results indicated that for right-ear presentations, virtually identical amounts of priming were observed in same- and different-voice conditions, whereas for left-ear presentations, more priming was observed in the same-voice than in the different-voice condition. Indeed, left-ear presentations did not yield a significant priming effect in the different-voice condition. In view of the fact that data from dichotic listening experiments are sometimes variable across procedures and subject populations (e.g., Harshman, 1988), these data must be treated cautiously pending replication. Nevertheless, they support the idea that two lateralized subsystems are involved in voice-specific and voice-nonspecific components of auditory priming.

Taken together, experiments examining semantic vs. nonsemantic study processing and study-to-test changes in speaker's voice support the idea that presemantic PRS subsystems support auditory priming. Note, however, that no published studies of amnesic patients are available that bear directly on these hypotheses. In a recently completed experiment, we examined auditory priming in a mixed group of Korsakoff and non-Korsakoff amnesic patients (Schacter, Church, & Treadwell, 1992). Using the auditory identification test and the semantic/nonsemantic study tasks developed by Schacter and Church (1992, Experiment 2), we observed entirely normal priming in the amnesic group. These results provide converging evidence for the PRS account.

CONCLUDING COMMENTS: SYSTEMS AND SUBSYSTEMS

This article has focused on the contributions of presemantic perceptual subsystems to priming effects on

data-driven implicit memory tests in visual and auditory domains. However, it can be questioned whether the entire priming effect on such tasks can be attributed to perceptual processes. As noted earlier, experiments examining the effects of study-to-test modality shifts have reported reduced priming in cross-modality conditions relative to within-modality conditions, but have generally documented significant cross-modal effects; priming is rarely eliminated by modality shifts (for review, see Kirsner et al., 1989; Roediger & Blaxton, 1987). Some authors have assumed that the existence of cross-modal priming necessarily implies the involvement of semantic or conceptual processes in priming (e.g., Hirshman, Snodgrass, Mindes, & Feenan, 1990; Keane, Gabrieli, Fenema, Growdon, & Corkin, 1991). For example, Keane et al. (1991) have argued that the existence of significant cross-modal priming on the stem completion task indicates that a lexical/semantic system plays a role in stem completion priming. If their reasoning is correct, it will be necessary to qualify the statement that priming on stem completion (and other tasks that include a significant cross-modal component) is mediated entirely by subsystems that operate at a presemantic level (see also Masson and Macleod, 1992).

There are, however, some grounds for questioning the conclusion that cross-modal priming necessarily implicates the involvement of semantic-level processes. Kirsner et al. (1989), for instance, have suggested two alternative sources of cross-modal priming on visual implicit tests: phonological representations or amodal "production records" (i.e., motor programs involved in response production) that are activated by an auditory study presentation. Their own review of the literature led Kirsner et al. to favor the production record hypothesis. Similarly, McClelland and Pring (1991) provided evidence supporting the hypothesis that cross-modal effects on priming of auditory stem completion are attributable to phonological processes. Whether or not these ideas about the basis of cross-modal priming are ultimately correct, they underscore the point that the presence of cross-modal priming need not signal the involvement of conceptual or semantic processes. Nevertheless, it is clear that priming can be observed on tasks that involve semantic processing, such as answering general knowledge questions or producing category instances in response to a category label. The magnitude of priming on such tasks is increased by semantic relative to nonsemantic study processing (Hamann, 1990) and can be dissociated from perceptually based priming (Blaxton, 1989). These kinds of observations indicate that conceptual priming is based on different processes than perceptual priming (Blaxton, 1989; Roediger, 1990; Tulving & Schacter, 1990)—processes that occur outside of PRS—although the precise locus of the effects has not been well specified.

This article has focused on three PRS subsystems: visual word form, structural description, and auditory word

form. In each case, the existence of a putative subsystem was postulated on the basis of neuropsychological observations concerning patients who exhibit form/semantic dissociations within a particular domain; the role of that subsystem in priming was inferred from patterns of effects of various experimental and subject variables. The fact that the PRS account is supported by converging evidence from independent research domains is an important strength of this general approach (see Schacter, 1992). However, results were also considered that support a further fractionation of the visual and auditory word form systems into lateralized subsystems: a left-hemisphere component that operates on abstract (but modality-specific) word form information, and a right-hemisphere component that operates on highly specific visual or auditory perceptual information. Experimental evidence supporting the idea that such lateralized subsystems contribute differentially to priming in visual and auditory domains is still rather scanty, and will require further replication and examination. Nonetheless, it is worth emphasizing that there is converging evidence for lateralized subsystems of the kind that have been postulated on the basis of the priming results: in the visual domain, recent PET data are consistent with the idea that left posterior regions are involved in processing abstract orthographic information whereas right posterior regions are involved in processing specific perceptual features of words and nonwords (Petersen, Fox, Snyder, & Raichle, 1990); and in the auditory domain, several kinds of evidence discussed earlier (see also Schacter & Church, 1992) suggest the existence of abstract and specific auditory subsystems.

If we accept for the moment the idea that lateralized perceptual subsystems contribute to priming, questions arise concerning the nature of their relation to the three subsystems that have been the focus of this article: Is it necessary to fractionate the visual word form, structural description, and auditory word form systems into left-hemisphere and right-hemisphere subsystems, yielding a total of six distinct PRS subsystems? Or is it more useful to think in terms of a visual form system and an auditory form system that can each be fractionated into left- and right-hemisphere components, yielding four basic PRS subsystems? Although we cannot provide conclusive answers to these questions at this early stage of research and theorizing, they raise fundamental problems that will require careful analysis. It is likely that progress in thinking about such questions with respect to implicit memory will be facilitated by considering them in relation to debates in cognitive neuropsychology concerning the nature and number of visual and auditory recognition systems (e.g., Farah, 1991; Humphreys & Riddoch, 1987; Ellis & Young, 1988).

Questions concerning relations among PRS subsystems raise a more general issue concerning the use of the terms "system" and "subsystem" in discussion of PRS and multiple memory systems more generally. Throughout

this article and elsewhere, I have referred to a perceptual representation *system* and to visual word form, structural description, and auditory word form *subsystems*. The latter term is used to reflect the idea that each of the subsystems performs distinct input-output computations within a particular domain. For example, the kinds of modality-specific computations performed by the visual and auditory word form subsystems, and the memory representations that they create, must differ from one another because of fundamental differences in the nature of visual and acoustic inputs to these subsystems. Similarly, as noted earlier, the computational case for postulating lateralized subsystems rests on the notion that the computations performed by abstract (left hemisphere) and specific (right hemisphere) perceptual subsystems are functionally incompatible with one another (Marsolek et al., 1992; Sherry & Schacter, 1987). In view of these considerations, one could argue that it is more accurate to refer simply to perceptual representation *systems* than to invoke a monolithic perceptual representation *system*. I have indeed used the terms "perceptual representation systems" and "perceptual representation system" interchangeably (Schacter, 1990), and the spirit of theorizing presented in this article and elsewhere is entirely consistent with such usage. The main reason for invoking the term perceptual representation system is to emphasize the notion that all of the various subsystems are tied together by common features: they are cortically based, operate at a presemantic level on domain-specific perceptual information, and support nonconscious expressions of memory. Thus, the term *subsystem* is used to refer to a neurally instantiated input-output unit that performs certain kinds of memory functions, whereas the term *system* is used at a more abstract level of description to refer to common features of a class of subsystems. Further consideration of the ways in which these and other terms are used will be necessary not only with respect to the particular issues addressed in this article, but also in more general discussions and debates concerning the nature and number of memory systems.

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