Understanding Implicit Memory

A Cognitive Neuroscience Approach

Daniel L. Schacter *Harvard University*

Dissociations between implicit and explicit memory have attracted considerable attention in recent memory research. A central issue concerns whether such dissociations require the postulation of separate memory systems or are best understood in terms of different processes operating within a single system. This article presents a cognitive neuroscience approach *to implicit memory in general and the systems-processes debate in particular, which draws on evidence from research with brain-damaged patients, neuroimaging techniques, and nonhuman primates. The article illustrates how a cognitive neuroscience orientation can help to supply a basis for postulating memory systems, can provide useful constraints for processing views, and can encourage the use of research strategies that the author refers to as* cross-domain hypothesis testing *and* cross-domain hypothesis generation, *respectively. The cognitive neuroscience orientation suggests a complementary role for multiple systems and processing approaches.*

In the introduction to an excellent review of memory and amnesia research, Rozin (1976) wistfully remarked, "I find myself wishing that I were writing this paper a little less than a hundred years ago, in 1890, at the close of a decade that I would consider the golden age of memory" (p. 3). Considering the lasting achievements of that decade—Ebbinghaus's pioneering experiments, Ribot's observations on disorders of memory, Korsakoff's description of the amnesic syndrome that now bears his name, and William James's (1890/1983) superb chapters on memory in the epic *The Principles of Psychology*—Rozin's characterization is highly appropriate.

It is too early to say whether future writers will someday look back on the decade of the 1980s as another golden age of memory. Nevertheless, it already seems clear that the 1980s will be viewed as a golden age, or at least the beginning of a golden age, for one issue in memory research: the investigation of *implicit memory* (Graf & Schacter, 1985; Schacter, 1987). Implicit memory is an unintentional, nonconscious form of retention that can be contrasted with *explicit memory,* which involves conscious recollection of previous experiences. Explicit memory is typically assessed with recall and recognition tasks that require intentional retrieval of information from a specific prior study episode, whereas implicit memory is assessed with tasks that do not require conscious recollection of specific episodes.

Although the explicit–implicit distinction was introduced during the 1980s, the sort of contrast that it captures is not new; related distinctions between conscious and unconscious memories, to take just one example, have been around for more than a century (for historical considerations, see Roediger, 1990b; Schacter, 1987). The critical development during the past decade has been the systematic demonstration, exploration, and attempted explanation of dissociations between explicit and implicit memory. Some of these dissociations have been provided by experiments demonstrating that brain-damaged amnesic patients with severe impairments of explicit memory can exhibit intact implicit memory; others come from studies showing that specific experimental variables produce different and even opposite effects on explicit and implicit memory tasks (for reviews, see Richardson-Klavehn & Bjork, 1988; Roediger, 1990b; Schacter, 1987; Shimamura, 1986). Fueled by these striking and frequently counter-intuitive dissociations, the study of implicit memory emerged from the decade of the 1980s at the forefront of memory research.

In this article I outline a general research strategy for attempting to understand implicit memory that I refer to as a *cognitive neuroscience approach.* This approach is motivated by the general idea that it is useful to combine cognitive research and theory, on the one hand, with neuropsychological and neurobiological observations about brain systems, on the other, making use of data from brain-damaged patients, neuroimaging techniques, and even lesion and single-cell recording studies of nonhuman animals. The cognitive neuroscience orientation has itself undergone rapid development during the past decade and

Editor's note. Articles based on APA award addresses that appear in the *American Psychologist* are scholarly articles by distinguished contributors to the field. As such, they are given special consideratioin in the *American Psychologist's* editorial selection process.

This article was originally presented as a Distinguished Scientific Award for an Early Career Contribution to Psychology address at the 99th Annual Convention of the American Psychological Association in San Francisco in August 1991.

Author's note. The work described in this article has been supported by Air Force Office of Scientific Research Grant 90-0187, National Institute on Aging Grant 1 RO1 AG08441-01, and a grant from the McDonnell-Pew Cognitive Neuroscience Program.

I am grateful to Barbara Church, Lynn Cooper, and Steve Rapcsak for their collaborative efforts on several of the experiments summarized in the article. I thank Douglas Nelson and Henry L. Roediger for comments on an earlier draft of the paper and Dana Osowiecki for help with preparation of the manuscript.

Correspondence concerning this article should be addressed to Daniel L. Schacter, Department of Psychology, Harvard University, 33 Kirkland St., Cambridge, MA 02138.

 0003-066X/92/$2.00
Vol. 47, No. 4, 559–569

is now a major force in the study of perception, attention, language, and emotion (cf. Gazzaniga, 1984; Kosslyn, Flynn, Amsterdam, & Wang, 1990; LeDoux & Hirst, 1986; Weingartner & Lister, 1991). A growing number of investigators have adopted a cognitive neuroscience approach to the study of human memory (for a representative sampling, see Olton, Gamzu, & Corkin, 1985; Squire & Butters, 1984; Squire, Weinberger, Lynch, & McGaugh, 1992; for a historical review, see Polster, Nadel, & Schacter, 1991).[1]

I will discuss the cognitive neuroscience orientation in relation to a major issue that has arisen in implicit memory research: the debate between memory systems and processing accounts of implicit–explicit dissociations. The former account holds that implicit memory effects depend on brain systems that are distinct from the memory system that supports explicit remembering (cf. Cohen, 1984; Hayman & Tulving, 1989; Keane, Gabrieli, Fennema, Growden, & Corkin, 1991; Schacter, 1990; Squire, 1987; Tulving & Schacter, 1990; Weiskrantz, 1989); the latter account holds that postulation of multiple memory systems is neither necessary nor justified and that relevant dissociations can be understood in terms of relations between processing operations carried out during study and test (cf. Blaxton, 1989; Jacoby, 1983; Masson, 1989; Roediger, Weldon, & Challis, 1989).

I suggest that a cognitive neuroscience orientation may help to resolve, or at least guide the investigation of, several key issues in the systems versus processes debate. More specifically, I will discuss four important features of a cognitive neuroscience approach in relation to this debate: (a) It provides an empirical basis for postulating memory systems that is independent of dissociations observed in implicit–explicit memory experiments; (b) it aids development of well-specified systems views that can suggest helpful constraints for processing approaches; (c) it encourages the use of *cross-domain hypothesis testing;* and (d) it also encourages the use of *cross-domain hypothesis generation.* I will illustrate each of these features with relevant examples from my own and others' laboratories.

Basis for Postulating Memory Systems

As noted earlier, interest in implicit memory has been fueled by the observation of dissociations between tasks that tap implicit and explicit memory, respectively. Consider, for example, the stem completion task, in which subjects are given three-letter word beginnings (e.g., TAB) and are asked to complete them with the first word that comes to mind; no reference is made to a prior study episode. Implicit memory is indicated when subjects complete a stem more frequently with a word that was recently presented on a study list (e.g., TABLE) than with a word that was not presented on the list (e.g., TABLET); this facilitation of task performance is known as direct or repetition priming (e.g., Tulving & Schacter, 1990). It is well-established that priming effects on the stem completion task can be dissociated from explicit memory. For instance, as indicated initially by the classic studies of Warrington and Weiskrantz (1974), patients with organic amnesia can show normal priming effects on stem completion performance, despite severely impaired explicit memory (cf. Graf, Squire, & Mandler, 1984; Warrington & Weiskrantz). Dissociations between stem completion priming and explicit memory have also been observed with normal, nonamnesic subjects. One of the more compelling phenomena involves the well-known depth-of-processing effect, which was initially established during the 1970s in studies of explicit memory (e.g., Craik & Tulving, 1975): Semantic study processing (i.e., thinking about the meaning of a word) generally produces much higher levels of subsequent recall and recognition performance than does nonsemantic study processing (i.e., thinking about the physical features of a word). By contrast, the magnitude of priming effects on the stem completion task are little affected—and sometimes entirely unaffected—by differences in depth of processing that are produced by different study tasks (cf. Bowers & Schacter, 1990; Graf & Mandler, 1984). Study–test modality shifts can also yield striking implicit–explicit dissociations: When a word is presented in one modality during the study task (i.e., auditory) and presented in another during test (i.e., visual), stem completion priming effects are reduced significantly, whereas explicit memory performance is little affected (Graf, Shimamura, & Squire, 1985; Schacter & Graf, 1989).

These kinds of dissociations are now familiar to memory researchers, and a comparable list could be readily constructed for various other implicit and explicit tasks. The critical question for the present purposes concerns their relation to the multiple memory systems debate: Do dissociations between implicit and explicit memory tasks constitute either a necessary or sufficient condition for postulating that different memory systems support performance on the two types of task? Although dissociations clearly constitute a necessary condition for making such claims—it would be difficult to argue convincingly for multiple memory systems in the absence of any evidence that they operate differently—it seems equally clear that they do not constitute a sufficient condition. There are several reasons why one cannot make simple leaps from empirical dissociations to postulation of memory systems (e.g., Dunn & Kirsner, 1988; Jacoby, 1983), but perhaps the most compelling argument is related to the apparent ubiquity of dissociations in memory research. It has been known for many years that dissociations can be produced between explicit memory tasks—recall and recognition are prime examples—and it has been established more recently that dissociations can be produced between implicit memory tasks (cf.

[1] Much of what is discussed in this article could just as easily be described with the phrase *cognitive neuropsychology* as with the phrase *cognitive neuroscience.* However, the term *cognitive neuropsychology* often connotes a purely functional approach to patients with cognitive deficits that does not make use of, or encourage interest in, evidence and ideas about brain systems and processes. Because I believe that neural constraints can be important for cognitive theorizing, I use the term cognitive neuroscience instead of cognitive neuropsychology.

Blaxton, 1989; Witherspoon & Moscovitch, 1989). Thus, if we were to accept the idea that an empirical dissociation between, say, Explicit Task X and Implicit Task Y is alone sufficient to claim that different memory systems support performance on the two tasks, theoretical chaos would likely ensue: A long list of explicit memory systems, to say nothing of implicit memory systems, would be quickly composed (Roediger, 1990a). On the other hand, we have already acknowledged that empirical dissociations constitute a necessary condition for postulating multiple memory systems. How, then, can we extricate ourselves from the apparent impasse?

I suggest that it is crucial to have a basis for postulating different memory systems that is independent of dissociations observed in implicit–explicit memory experiments and that a cognitive neuroscience orientation can help to provide it. If claims about memory systems are supported by independent evidence—and are not made simply in response to the latest experimental dissociation between implicit and explicit memory tasks—then the aforementioned theoretical chaos can be greatly reduced by applying the logic of converging operations (Garner, Hake, & Eriksen, 1956).

To illustrate the point concretely, consider a criticism of the multiple memory systems approach offered by Roediger (1990a, 1990b) and Blaxton (1989). These investigators noted that one account of dissociations between word completion and word identification tasks, on the one hand, and recall and recognition tasks, on the other, is that priming effects are mediated by a semantic memory system, whereas explicit remembering depends on an episodic memory system (e.g., Tulving, 1983). In contrast, Roediger and Blaxton argued that both explicit and implicit memory are mediated by different types of processing in a single (episodic) memory system. Specifically, they invoked the principle of transfer-appropriate processing (Morris, Bransford, & Franks, 1977), which holds that memory performance depends on the extent to which processing operations performed during a study task match or overlap with processing operations performed during a memory test. They suggested further, in conformity with previous suggestions by Jacoby (1983), that implicit tasks such as stem completion and word identification depend largely on data-driven processing (i.e., bottom-up processing that is driven primarily by perceptual properties of study and test materials), whereas explicit tasks such as recall and recognition depend largely on conceptually driven processing (i.e., top-down processing that is driven primarily by subject-initiated activities such as elaborating and organizing). This general position allowed Roediger and Blaxton to account for the previously mentioned finding that semantic–elaborative study processing increases explicit but not implicit memory, whereas changes in modality and other physical features of target stimuli can affect implicit more than explicit memory.

In an attempt to compare directly the processing and systems accounts, Roediger (1990b) and Blaxton (1989) noted that claims for different memory systems had been based on comparisons between data-driven implicit tests (e.g., word completion) and conceptually driven explicit tests (e.g., recall and recognition). In line with their argument that type of processing is the crucial determinant of dissociations, they contended that it should be possible to produce dissociations between data-driven implicit tasks, such as word completion, and conceptually driven implicit tasks, such as answering general knowledge questions (see Blaxton for further discussion and details). Blaxton has indeed reported several experiments in which such dissociations were found, even though both types of tasks could be construed, according to her logic, as "semantic memory" tasks.

How does the multiple systems theorist respond to such results? As Blaxton (1989) and Roediger (1990b) noted, it is possible to postulate separate memory systems for data-driven and conceptually driven implicit tasks in response to the observed dissociation, but such an account is unparsimonious and lacks explanatory power. I concur entirely: An unprincipled, post hoc postulation of additional systems in response to a new experimental dissociation is the quickest route to the sort of theoretical chaos that we all wish to avoid. However, consider the issue in light of the aforementioned point that independent evidence is required to support claims for multiple memory systems. We are then led to ask whether data exist independently of Blaxton's results that support the hypothesis that priming on data-driven and conceptually driven tests is mediated by different systems.

Research from various sectors of cognitive neuroscience suggests a positive answer to this question. The critical evidence is provided by studies of patients who show relatively intact access to perceptual–structural knowledge of words or objects, despite severely impaired access to semantic knowledge of the same items (e.g., Riddoch & Humphreys, 1987; Schwartz, Saffran, & Marin, 1980; Warrington, 1982). These studies suggest that representation–retrieval of the visual form of words and objects depends on a system other than semantic memory. Similarly, studies of lexical processing using positron emission tomography (PET) indicate that visual word form information and semantic information are handled by separate brain regions (e.g., Petersen, Fox, Posner, Mintun, & Raichle, 1988). These kinds of observations suggest the existence of a perceptual representation system (PRS; cf. Schacter, 1990; Tulving & Schacter, 1990) that can function independently of (although it typically interacts extensively with) semantic memory.

We have argued that PRS plays a significant role in priming effects observed on data-driven implicit tests, an idea that fits well with previously mentioned findings that priming on such tasks is relatively unaffected by semantic versus nonsemantic study processing and greatly affected by study–test changes in modality and other kinds of perceptual information (see Schacter, 1990; Schacter, Cooper, & Delaney, 1990; Schacter, Cooper, Tharan, & Rubens, 1991; Schacter, Rapcsak, Rubens, Tharan, & Laguna, 1990; Tulving & Schacter, 1990). By contrast, semantic memory is held to be critically involved in priming on conceptually driven implicit tests (Schacter, 1990; Tulving & Schacter, 1990; see also Keane et al., 1991). The critical point here is that the idea that perceptual and conceptual priming depend on different systems was motivated by evidence from brain-damaged patients and PET imaging that is independent of the dissociation between data-driven and conceptually driven tasks reported by Blaxton (1989). Thus, a cognitive neuroscience orientation allows the formulation of a multiple systems framework that can accommodate—even though it was not formulated in response to—the Blaxton data. Indeed, recent studies have provided more direct evidence that different systems are involved in perceptual and conceptual priming (Keane et al., 1991; Tulving, Hayman, & Macdonald, 1991).

This example illustrates how a cognitive neuroscience orientation can help multiple systems approaches to avoid the pitfalls associated with unprincipled, post hoc postulation of memory systems. There are other ways to minimize these problems, such as by paying careful attention to the functional properties and computational capacities of putative memory systems (cf. Kosslyn et al., 1990; Sherry & Schacter, 1987; Tulving, 1983). Combining such considerations with a cognitive neuroscience orientation is clearly desirable.

Constraints for Processing Views

A difficulty with processing views is that they do not always allow one to specify, independently of experimental outcomes, the pattern of results that would indicate the presence of transfer-appropriate processing effects (cf. Graf & Ryan, 1990; Roediger et al., 1989). For example, imagine a word completion experiment in which a physical feature of a word (e.g., upper or lower case, type font) is either changed or held constant between study and test. If there is less priming when the feature is changed than when it is held constant, this can be taken as evidence for transfer-appropriate processing: The processing operations performed at study and test do not match as well in the former as in the latter condition. However, if priming is the same in the two conditions, it can always be argued that the manipulated feature was not relevant to study or test processing. In fact, both outcomes have been observed (e.g., Graf & Ryan, 1990).

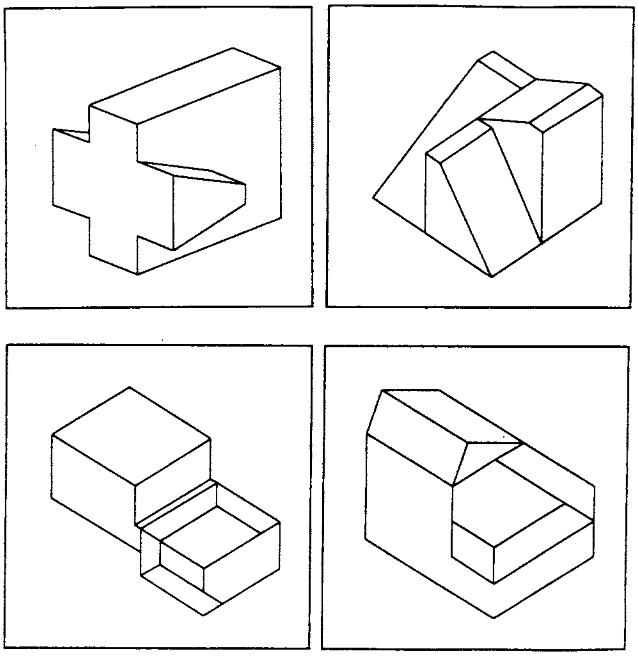
A cognitive neuroscience orientation can help to clarify this interpretive ambiguity. Specifically, I suggest that it can facilitate the development of systems views that provide useful *constraints* for processing approaches, which in turn allow for firmer a priori predictions about experimental outcomes. Two examples help to illustrate the point. The first comes from a recent study by Marsolek, Kosslyn, and Squire (1992), in which subjects saw a list of familiar words and were then asked to complete three-letter stems with the first word that came to mind. On the completion test, the stems were presented either to the left hemisphere or to the right hemisphere through brief visual exposures in either the right or left hemifield. In the most directly relevant experiments, the case of target items (i.e., upper or lower case) was either the same or different at study and test. Marsolek et al. found that priming was reduced by case changes when stems were presented to the right hemisphere, but was unaffected by this manipulation when stems were presented to the left hemisphere.

It is not clear how a transfer-appropriate processing view would account for this pattern of results because the same materials and processing requirements were present in both the left and right hemifield conditions. However, Marsolek et al. (1992) drew on independent evidence from cognitive neuroscience concerning the characteristics of the hemispheres to argue that a left-hemisphere subsystem computes abstract word form representations that do not preserve specific features of particular inputs, whereas a right-hemisphere subsystem computes perceptually specific word form representations (in the present terminology, both could be viewed as PRS subsystems). From this perspective, it follows that priming in the right but not the left hemisphere is influenced by changes in the visual form of studied words. More important, the cognitive neuroscience analysis developed by Marsolek et al. provides just the sort of constraints that a processing view requires to make sense of the results: Given some knowledge of the characteristics of the two subsystems, processing theorists might well predict the occurrence of specific priming when the right hemisphere is queried and abstract priming when the left hemisphere is queried. But for processing theorists to make such predictions, they must incorporate the constraints provided by the cognitive neuroscience-based systems analysis.

A second example that illustrates a similar point is provided by a series of studies that Lynn Cooper and I have conducted on implicit memory for novel visual objects (Cooper, Schacter, Ballesteros, & Moore, 1992; Schacter, Cooper, & Delaney, 1990; Schacter, Cooper, Delaney, Peterson, & Tharan, 1991; Schacter, Cooper, Tharan, & Rubens, 1991). In our paradigm, subjects study line drawings of novel objects (Figure 1) and are then given either an explicit memory task (yes or no recognition) or an implicit memory task. To assess implicit memory, we developed an object decision task that exploits an important property of the target objects: One half of them are structurally possible (they could actually exist in three-dimensional form), whereas the other half are structurally impossible (they contain structural ambiguities and impossibilities that would prevent them from being realized in three dimensions). On this task, subjects are given brief (e.g., 50 ms) exposures to studied and nonstudied objects and decide whether each object is possible or impossible; no reference is made to the study episode. Priming or implicit memory on this task is indicated by more accurate object decisions about studied than nonstudied items.

A series of experiments has documented the existence of object decision priming and delineated several of its properties. For the present purposes, a few key findings are worth noting explicitly. First, robust priming on the object decision task is observed for structurally possible objects, but not for structurally impossible objects (Schacter, Cooper, & Delaney, 1990); indeed, we failed to

Figure 1
Examples of Stimuli Used in Experiments on Implicit and Explicit Memory for Novel Objects



Note. The objects in the upper row are structurally possible, whereas the objects in the lower row are structurally impossible. Subjects study both types of objects in various encoding conditions. Implicit memory is tested with an object decision task, in which studied and nonstudied objects are flashed briefly and subjects decide whether each one is possible or impossible; explicit memory is assessed with a yes or no recognition task, in which subjects indicate whether they recollect having seen each object during the study task. From "Implicit memory for unfamiliar objects depends on access to structural descriptions" by D. L. Schacter, L. A. Cooper, and S. M. Delaney, 1990, *Journal of Experimental Psychology: General, 119*, p. 7. Copyright 1990 by the American Psychological Association. Adapted by permission.

observe priming of impossible objects even following multiple study–list exposures that produced high levels of explicit memory (Schacter, Cooper, Delaney, et al., 1991). Second, priming of possible objects is observed following study tasks that require encoding of information about the global three-dimensional structure of an object (e.g., judging whether an object faces primarily to the left or to the right) but is not observed following study tasks that require encoding of information about local two-dimensional features (e.g., judging whether an object has more horizontal or vertical lines; Schacter, Cooper, & Delaney, 1990). Third, the priming effect for possible objects is not increased, and is sometimes reduced, by encoding tasks that require subjects to link target objects with preexisting semantic knowledge, even though such encoding manipulations greatly enhance explicit memory for the same objects (Schacter, Cooper, & Delaney, 1990; Schacter & Cooper, 1991). Fourth, priming on the object decision task appears to be preserved in patients with memory disorders (Schacter, Cooper, Tharan, & Rubens, 1991) and in elderly adults (Schacter, Cooper, & Valdiserri, in press).

These findings, taken together with the previously mentioned dissociations between structural and semantic knowledge in patients with object processing deficits (cf. Riddoch & Humphreys 1987; Warrington, 1982), have led us to argue that object decision priming is mediated to a large extent by a PRS subsystem that computes structural descriptions (Sutherland, 1968) of objects—that is, representations of the global relations among parts of an object. By this view, priming of impossible objects is not observed because it is difficult to represent internally their global structure (there is no globally consistent structural description of an impossible object), and semantic–functional encoding tasks do not enhance priming because the structural description system operates at a presemantic level. Note that several independent lines of evidence from studies of brain-lesioned monkeys and single-cell recordings indicate that regions of inferior temporal cortex (IT) play a major role in computing the global form and structure of visual objects (for a review, see Plaut & Farah, 1990). It is thus possible that IT or the analogous system in humans plays a significant role in object decision priming.

Many studies have shown that the response of IT cells is typically little affected or entirely unaffected by changes in the retinal size of an object (see Plaut & Farah, 1990). Thus, if object decision priming depends significantly on a system like IT, then the magnitude of the effect should not be influenced by a simple study–test change in an object's retinal size. Cooper et al. (1992) have recently performed such an experiment, and the data indicate clearly that object decision priming is unaffected by changing the size of an object between study and test, even though explicit recognition memory is lower in the different size than in the same size condition. We also found that changing the left–right reflection of target objects (i.e., mirror image reversal) between study and test had little effect on priming, again consistent with known properties of IT (see Plaut & Farah; for similar priming results with familiar objects, see Biederman & Cooper, 1991).

Now consider these results from the perspective of transfer-appropriate processing, using the data on size-invariant priming to illustrate the point (the same argument could be made with respect to the mirror-image results). Applying the logic that has been used to account for the effects of changing surface features of target items on other perceptually based implicit tests, it would be expected that in the different size condition, processing operations performed at study and test do not match as well as in the same size condition. Accordingly, size change should produce a decrement in priming. Because the data show otherwise, an advocate of transfer-appropriate processing might argue that priming was unaffected by size change because neither the study nor test tasks required specific processing of object size. The problem with this argument is that size change *did* affect recognition performance, even though subjects were not specifically required to process size information on this task; they simply indicated whether they had seen the object earlier, whether or not it was the same size as on the study list.

These interpretive ambiguities can be clarified by making use of the constraints provided by a cognitive neuroscience analysis: If a system similar to IT plays an important role in object decision priming and if retinal size is not a relevant property for this system, then the absence of size change effects is no embarrassment to a transfer-appropriate processing view. As in the earlier example, hypotheses about the properties of a system that is involved in a particular type of priming can help to guide and refine predictions about the kinds of transfer-appropriate processing effects that should be observed. Stated slightly differently, the nature of transfer-appropriate processing may be different in different systems, depending on the computational constraints that characterize a specific system.

Cross-Domain Hypothesis Testing

The typical research strategy in studies of implicit memory is to test theoretical hypotheses in the same domain in which they were generated—for cognitive psychologists, by examining the performance of college students, and for neuropsychologists, by examining the performance of patients with memory disorders. Although there has been considerable interaction in recent years between students of normal and abnormal memory, a cognitive neuroscience orientation can help to broaden our research horizons even further by encouraging the use of what I will refer to as *cross-domain hypothesis testing:* evaluating ideas and theories about the nature of implicit memory in domains other than the ones in which the hypotheses were originally formulated.

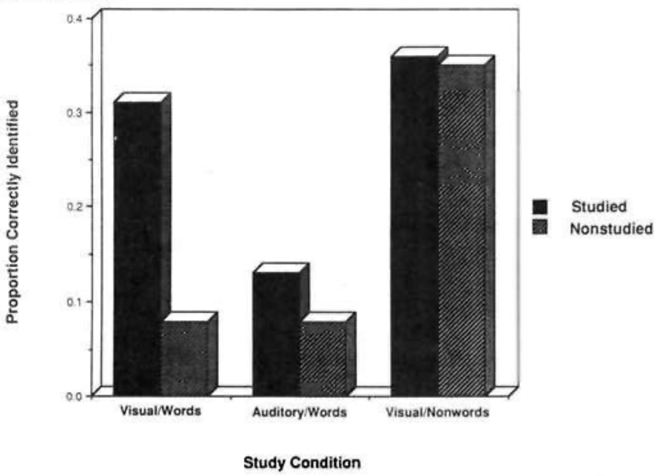
The easiest way to illustrate the strategy is with an example. To do so, I consider a recent study in which we (Schacter, Rapcsak, et al., 1990) examined priming in a patient with a reading deficit known as *alexia without agraphia* or *letter-by-letter reading.* Such patients are unable to read words unless they resort to a laborious letter-by-letter strategy. The deficit affects all types of words, is indicated by the presence of a strong influence of word length on reading time, and is typically associated with lesions to the left occipital cortex (e.g., Reuter-Lorenz & Brunn, 1990).

Research and theorizing about letter-by-letter readers has typically proceeded separately from and independently of the implicit memory literature. There is, however, a potential link between the two domains, provided by the visual word form system. On the one hand, we have suggested that the visual word form system can be viewed as a PRS subsystem that is critically involved in word priming effects on data-driven implicit tasks (Schacter, 1990). On the other hand, issues concerning the status of the word form system have been central to debates about the nature of the deficit in letter-by-letter reading. Warrington and Shallice (1980) argued that the reading problems of these patients are produced by deficits in the word form system, which normally supports whole word reading. With the word form system dysfunctional, patients read letter-by-letter by somehow making use of their preserved spelling systems. In contrast, Patterson and Kay (1982) argued that the word form system is preserved in these patients and that their deficit is attributable to a problem with parallel, but not serial, transmission of information from letter representations to the word form system. Although the locus of the deficit may vary from patient to patient, recent evidence suggests that the word form system is largely preserved in at least some letter-by-letter readers (e.g., Reuter-Lorenz & Brunn, 1990).

We had the opportunity to study a patient, P.T., whose performance on various cognitive and neuropsychological tests yielded evidence of a preserved word form system (see Schacter, Rapcsak, et al., 1990, for details). On the basis of our ideas about the role of this subsystem in implicit memory, we hypothesized that P.T. should show robust priming despite her reading impairment. To examine the issue, we performed an experiment in which P.T. studied a list of common words that appeared one at a time on a computer screen; she was given ample time to read each word in a letter-by-letter manner. To assess priming, we used a perceptual identification test, in which words are exposed for brief durations and the subject attempts to identify them; priming is indicated by more accurate identification of studied than of nonstudied words (e.g., Jacoby & Dallas, 1981). Although exposure rates of under 50 ms are typically used in studies with normal subjects, P.T. reported that she was unable to see even a single letter at such brief durations. Accordingly, we used a 500-ms test exposure (normal control subjects perform perfectly under such conditions, so we did not use control subjects in this study). As indicated by Figure 2, P.T. showed large priming effects under these conditions, even though she had great difficulty identifying nonstudied words. Figure 2 also presents representative data from experiments showing that priming in P.T. was modality specific and that it was not observed for illegal nonwords (e.g., BTLEA). The latter finding indicates that priming cannot be attributed to activation of individual letter representations, and thus strengthens the case that the word form system was critically involved.

However investigators ultimately conceive the role of the word form system in priming, this case study illustrates how the strategy of cross-domain hypothesis testing can link two previously separate sets of ideas: Hypotheses about preservation of the word form system in letter-by-letter readers were formulated independently of implicit memory research, and hypotheses about the role of the word form system in implicit memory were formulated independently of research on letter-by-letter readers. Cross-domain hypothesis testing of this kind can serve at least two interrelated functions. First, it can help to ensure that implicit memory research does not develop in an overly narrow or insular manner, without regard to cognate fields of interest. Second, if hypotheses that are generated in one domain receive support when tested in a separate domain, they acquire a degree of external validity that is not readily conferred by repeated testing within a single domain. Although a cognitive neuroscience orientation is certainly not the only way to build bridges

Figure 2
Summary of Results From Experiments by Schacter, Rapcsak, Rubens. Tharan, and Laguna (1990), in Which Patient P.T., a Letter-by-Letter Reader, Studied a List of Five to Six Letter Words or Nonwords and Was Then Given a Visual Identification Task in Which Studied and Nonstudied Items Were Presented for 500 Msec



Note. Proportion correct on the identification task is displayed in three different conditions. The leftmost bars show that visual exposure to a list of familiar words produced substantial priming, as indicated by significantly more accurate identification of studied than of nonstudied words. The center bars show lack of priming following auditory study of familiar words, as indicated by a nonsignificant difference between identification of studied and nonstudied words. The rightmost bars show lack of priming following visual study of illegal nonwords, as indicated by no differences between the proportion of letters identified correctly in studied and nonstudied items.

among separate research areas that are relevant to implicit memory (cf. Jacoby, 1991), it seems clear that it can provide a rich source of research opportunities that might otherwise be overlooked.

Cross-Domain Hypothesis Generation

The final feature of a cognitive neuroscience orientation that I will consider, *cross-domain hypothesis generation,* can be thought of as a complement to the hypothesis testing strategy outlined in the previous section. The idea here is to draw on ideas and findings from various sectors of cognitive neuroscience to generate hypotheses about implicit memory that are then tested in implicit–explicit memory studies. This kind of strategy has already been illustrated in examples considered earlier, such as using observations of structural–semantic dissociations in patients with reading and object processing deficits to generate hypotheses about the role of PRS in priming (Schacter, 1990; Schacter, Cooper, & Delaney, 1990) and drawing on findings of size invariance in IT to generate hypotheses about the characteristics of object decision priming (Cooper et al., 1992). To conclude, I will consider some recent research in which we (Schacter & Church, in press) have used cross-domain hypothesis generation to guide a series of experiments on auditory implicit memory. We have used observations from cognitive neuroscience at two points in this research: first, to motivate the experiments theoretically, and second, to suggest and test a possible account of findings from our initial experiments.

Our approach to auditory implicit memory was guided by neuropsychological studies of patients who exhibit dissociations between access to form and semantic information in the auditory domain that are similar to those discussed earlier in the visual domain (e.g., Riddoch & Humphreys, 1987; Schwartz et al., 1980; Warrington, 1982). More specifically, patients with so-called word meaning deafness are unable to understand spoken words (e.g., Ellis & Young, 1988). However, they can repeat spoken words quite well and show some ability to write words to dictation, thus suggesting that they can gain access to stored auditory word form representations. It is interesting that such patients show normal access to semantic information in the visual modality, indicating that the impairment in these cases may be attributable to disconnection between a relatively intact system that handles acoustic–phonological properties of spoken words and a relatively intact semantic system (Ellis & Young). Unfortunately, these patients are extremely rare, so inferences based on their performance must be treated cautiously. Rather more frequently encountered are patients with transcortical sensory aphasia (e.g., Kertesz, Sheppard, & MacKenzie, 1982), who exhibit spared abilities to repeat spoken words and write them to dictation, together with impaired comprehension. In these patients, however, the comprehension deficit is also observed in other modalities, thus indicating damage to the semantic system itself.

These dissociations point toward the existence of a PRS subsystem that handles information about auditory word forms separately from semantic information (cf. Ellis & Young, 1988). If this reasoning is correct and if PRS subserves implicit memory in the auditory domain, then it should be possible to show that implicit memory on an appropriate auditory test is relatively unaffected by manipulations of semantic versus nonsemantic study processing. To examine the possibility, we (Schacter & Church, in press) used an implicit task that requires identification of auditorily presented words that are masked in white noise. Priming on this task is indicated by more accurate identification of previously studied words than of nonstudied words (e.g., Jackson & Morton, 1984). Explicit memory was assessed with an auditory yes or no recognition task. For the study task, all of the subjects heard a series of words spoken by various male and female voices. To manipulate semantic versus nonsemantic processing, one half of the subjects made a category judgment about each word (i.e., they indicated to which of four categories the word belongs), whereas the other half made a pitch judgment about each word (i.e., they judged the pitch of the voice on a four-point scale).

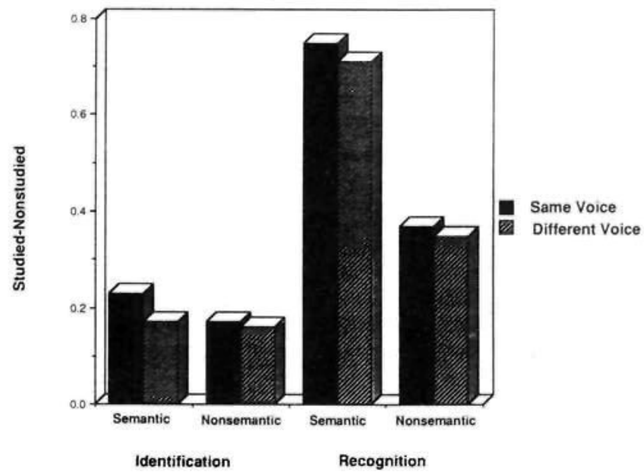
We also examined the specificity of auditory priming by testing one half of the words with the *same* voice that was used during the study task and the other half in a *different* voice; when a different voice was used at study and test, the voice change always entailed a change of gender (i.e., male–female or female–male). Jackson and Morton (1984) included a similar manipulation and found no effects of voice change on priming of auditory word identification. Note, however, that all of the subjects in their experiment performed a semantic study task (judging whether a word represents an animate or inanimate object). A recent experiment by Graf and Ryan (1990) suggested that specificity effects in visual word identification are observed only when subjects focus on visual characteristics of words during the study task. Analogously, it is possible that voice specificity effects in auditory word identification require specific encoding of voice characteristics during the study task. If so, then we should observe greater voice specificity effects in the pitch encoding condition than in the category encoding condition.

Two experiments using this basic design yielded a consistent pattern of results (see Schacter & Church, in press, for details of individual experiments). Explicit memory was much higher following the category than the pitch encoding task, whereas priming of auditory word identification was either less affected or entirely unaffected by the study task manipulation (Figure 3). These data are largely consistent with the idea generated from studies of transcortical sensory aphasics and word meaning deafness patients that a presemantic PRS subsystem contributes significantly to auditory priming. However, there were no significant effects of voice change on priming (or explicit memory), even in the pitch encoding condition (Figure 3).

Why did we (Schacter & Church, in press) fail to observe any effects of the voice change manipulation on priming? The result does not appear to be attributable to a simple inability of subjects to discriminate between male and female voices when they are masked in white noise; follow-up work indicated that subjects can do so quite readily on our task. Although any number of other explanations could be advanced (e.g., Jackson & Morton, 1984), we drew on the cognitive neuroscience literature to generate a hypothesis that draws on research concerning auditory processing in the left and right hemispheres. The hypothesis consists of three key components: (a) Both left- and right-hemisphere subsystems play a role in auditory priming, (b) voice specificity effects may depend on a right-hemisphere subsystem, and (c) the auditory identification test that we used minimized the possible contribution of the right-hemisphere subsystem. Let me elaborate briefly on these ideas.

Various investigators have argued that auditory processing differs in the two hemispheres: The left hemisphere relies on categorical or abstract auditory information and operates primarily on phonemes, whereas the right hemisphere relies more on "acoustic gestalts" and operates primarily on prosodic features of speech, including voice information (cf. Liberman, 1982; Zaidel, 1985). Several lines of evidence link the right hemisphere with access to voice information. Right hemisphere lesions are associated with voice recognition deficits (e.g., Van Lancker, Cummings, Kreiman, & Dobkin, 1988) and are also associated with impairments in processing various features of prosody (e.g., Ross, 1981). In addition, studies of normal subjects using dichotic listening techniques have shown a left-ear (i.e., right-hemisphere) advantage for certain types of voice information, in contrast to the usual right-ear advantage for speech (e.g., Blumstein & Cooper, 1974; Shipley-Brown, Dingwall, Berlin, Yeni-Komshian, & Gordon-Salant, 1988).

Figure 3
Summary Data From Two Experiments by Schacter and Church (in press) on Priming of Auditory Word Identification



Note. Subjects initially heard a list of familiar words spoken by a series of male and female voices, engaging in either a semantic or a nonsemantic encoding task. Priming was then assessed with an auditory word identification test in which studied and nonstudied words were masked in white noise, and explicit memory was assessed with a yes or no recognition test. The figure presents priming scores that were computed by subtracting the proportion of nonstudied words that were identified correctly from the proportion of studied words that were identified correctly and corrected recognition scores that were computed by subtracting the proportion of "yes" responses to nonstudied items (i.e., false alarms) from the proportion of "yes" responses to studied items (i.e., hits). Recognition memory, but not priming on the identification test, was higher following the semantic than the nonsemantic encoding task. Performance on both recognition and identification tasks was not significantly affected by whether the speaker's voice was the same or different at study and test.

Assuming that some sort of link exists between the right hemisphere and access to voice information, how does this relate to the absence of voice specificity effects in priming of auditory word identification? Zaidel (1978) reported evidence from the study of split-brain patients indicating that the right hemisphere has great difficulty processing spoken words that are embedded in background noise. Because the words on our (Schachter & Church, in press) auditory identification task were masked with white noise, it is conceivable that we inadvertently minimized or even excluded the effective participation of the right hemisphere in the task. In view of the link between the right hemisphere and voice information—as well as the previously discussed link between the right hemisphere and specificity effects in visual priming (Marsolek et al., 1992)—it is tempting to conjecture that the voice-independent priming that we observed may be partly attributable to the functional exclusion of the right hemisphere from implicit task performance.

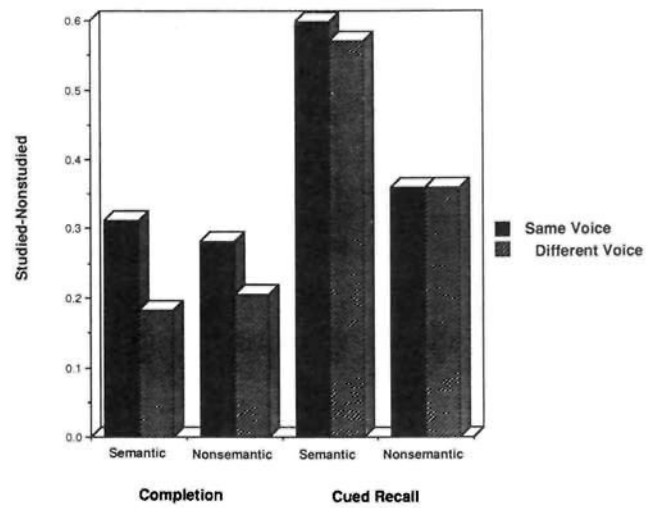
Although speculative, this hypothesis does have a testable consequence: When an auditory implicit task is used that does *not* involve background noise, thus allowing the right hemisphere to contribute significantly to performance, priming should be reduced by voice change between study and test. Data bearing on this issue are provided by experiments that we have performed using an auditory stem completion task (cf. Bassili, Smith, & MacLeod, 1989), in which the subject hears either a male or a female voice pronounce the first syllable of a word (the speaker actually enunciates the entire word, and the utterance is edited on the Macintosh). The subject's task is to report the first word that comes to mind upon hearing the auditory stem, and priming is indicated by higher completion rates for stems that represent studied words than for stems that represent nonstudied words. To test explicit memory, subjects are given the identical stem together with cued recall instructions to think back to the study list and try to remember the correct word.

We (Schacter & Church, in press) have completed two experiments using these tests. In each experiment, subjects initially heard a list of words that were spoken by the same male and female voices used in previous studies. One group of subjects performed a nonsemantic study task that required attention to voice characteristics, and another group performed a semantic study task that did not require specific encoding of voice characteristics; one half of the studied words were tested with the same voice, and the other half were tested with a different voice. The critical outcome of both experiments was that priming effects (but not explicit memory) were reduced significantly by the voice change manipulation. Figure 4 summarizes the data from one of the experiments, in which the semantic study task required rating the number of alternative meanings for each word and the nonsemantic study task required rating how clearly each voice enunciated a target word. It is interesting that there was no evidence that voice change effects were greater following the nonsemantic study task than following the semantic study task. As in previous experiments, however, there was a strong interaction between type of study task and type of test: Explicit memory was much higher following semantic than nonsemantic encoding, whereas priming was essentially identical following the two study tasks.

These data are consistent with the hypothesis that voice specificity effects in auditory priming are attributable, at least in part, to the involvement of a right-hemisphere PRS subsystem. Clearly, however, the evidence supporting this idea is rather indirect; until and unless there is direct evidence for a link between voice specificity in priming and the right hemisphere, this hypothesis must be viewed as merely suggestive (see Schacter & Church, in press, for further discussion and alternative hypotheses). More important for the present purposes, these studies illustrate how a cognitive neuroscience perspective can facilitate the use of cross-domain hypothesis generation and thereby suggest novel experiments and ideas that might have otherwise been overlooked.

Figure 4

Results From an Experiment by Schacter and Church (in press) on Priming of Auditory Stem Completion



Note. Subjects initially heard a list of familiar words spoken by a series of male and female voices, engaging in either a semantic or nonsemantic encoding task. Priming was then assessed with an auditory stem completion task, in which subjects heard the first syllable of studied and nonstudied words and responded with the first word that came to mind. Explicit memory was assessed with a cued recall test. The figure presents priming and corrected recall scores that were computed by subtracting the proportion of nonstudied stems that were completed correctly from the proportion of studied stems that were completed correctly. Cued recall performance, but not priming on the completion task, was significantly higher following semantic than nonsemantic encoding. By contrast, priming, but not cued recall, was significantly higher when speaker's voice was the same at study and test than when it was different.

Concluding Comments

The systematic study of implicit memory is a relatively recent development. Although numerous reliable experimental procedures have been developed and robust experimental phenomena have been established, theoretical understanding of the nature of implicit memory is still rather rudimentary. It may well turn out, for example, that multiple systems and processing accounts are ultimately viewed as complementary, and not mutually exclusive, theoretical approaches (cf. Hayman & Tulving, 1989; Nelson, Schreiber, & McEvoy, 1992; Roediger, 1990b; Schacter, 1990; Tulving & Schacter, 1990). Whatever the outcome of this particular debate, it seems clear that at this early stage of research, the existence of a variety of theoretical viewpoints and investigative strategies is desirable.

Although I have emphasized the virtues of adopting a cognitive neuroscience orientation, the approach is not without its own limitations and pitfalls. Consider, for example, the point made earlier that neurophysiological data on size- and reflection-invariant object representation in inferior temporal cortex helped us to predict, and to some extent understand, findings of size- and reflection-invariant priming on the object decision task (Cooper et al., 1992). Note, however, that we were able to make use of these neural constraints only because the neurophysiological data on size- and reflection-invariance of IT representations are relatively clear-cut (Plaut & Farah, 1990). By contrast, when we initiated new experiments examining the effects of study-to-test changes in picture-plane orientation and color on object decision priming (Cooper, Schacter, & Moore, 1991), the cognitive neuroscience literature proved less helpful, primarily because data concerning the neural basis of these aspects of object representation are less clear-cut than are the data on size and reflection (e.g., Plaut & Farah, 1990). Thus, when neurophysiological and neuropsychological evidence is weak or unclear, a cognitive neuroscience orientation will not provide the sort of useful constraints discussed earlier.

A related limitation is that the cognitive neuroscience literature may often be mute concerning a particular finding or hypothesis. Returning again to the studies by Cooper et al. (1992), we found that study-to-test transformations of object size and reflection significantly impaired explicit memory. The neurophysiological studies on single-cell recordings and lesion effects that helped to illuminate the priming data simply do not speak directly to these findings on explicit memory, so our attempts to understand them relied entirely on cognitive concepts (Cooper et al., 1992). More generally, investigators studying implicit and explicit memory in human subjects who wish to make use of cognitive neuroscience evidence would do well to avoid an overly simplistic reductionist approach, in which explanatory efforts go no further than attempting to identify the brain locus of a particular phenomenon; theoretical accounts must also be couched at, and do justice to, the cognitive level of analysis (cf. Polster et al., 1991; Schacter, 1986).

As implied by the foregoing, the cognitive neuroscience orientation discussed here represents just one avenue of approach to implicit memory, and it should be pursued in addition to, rather than instead of, other strategies. Perhaps the main virtue of the cognitive neuroscience orientation is that it encourages us to draw on data and ideas from diverse areas of investigation. In so doing, it also encourages reliance on the logic of converging operations (cf. Roediger, 1990b) and can thus help to ensure that research on implicit memory remains broadly focused on fundamental issues concerning the nature of mind and brain.

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