

# Memory Systems Do Not Divide on Consciousness: Reinterpreting Memory in Terms of Activation and Binding

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There is a popular hypothesis that performance on implicit and explicit memory tasks reflects 2 distinct memory systems. Explicit memory is said to store those experiences that can be consciously recollected, and implicit memory is said to store experiences and affect subsequent behavior but to be unavailable to conscious awareness. Although this division based on awareness is a useful taxonomy for memory tasks, the authors review the evidence that the unconscious character of implicit memory does not necessitate that it be treated as a separate system of human memory. They also argue that some implicit and explicit memory tasks share the same memory representations and that the important distinction is whether the task (implicit or explicit) requires the formation of a new association. The authors review and critique dissociations from the behavioral, amnesia, and neuroimaging literatures that have been advanced in support of separate explicit and implicit memory systems by highlighting contradictory evidence and by illustrating how the data can be accounted for using a simple computational memory model that assumes the same memory representation for those disparate tasks.

*Keywords:* consciousness, implicit, explicit, dissociation, priming

The distinction between implicit and explicit memory has fueled a great deal of research regarding the nature of human memory. Defined in terms of their presupposed distinction, perhaps the most well-known definitions of implicit and explicit memory were proposed by Schacter (1987, p. 501) who said that “implicit memory is revealed when previous experiences facilitate performance on a task that does not require conscious or intentional recollection of those experiences,” whereas “explicit memory is revealed when performance on a task requires conscious recollection of previous experiences.” Whereas implicit memory is often measured in terms of a repetition priming effect (improved accuracy and/or reaction times for repeated stimuli) in fragment completion, lexical decision, naming, and word identification tasks, explicit memory tasks typically measure performance in recognition or recall tasks. Thus, the distinction between the phenomena labeled as implicit and explicit memory can be understood in terms

of whether a memory task requires a recollection of a prior experience.

The notion that implicit and explicit memory reflect the functioning of distinct memory systems is rooted in a collection of evidence for a *functional dissociation* wherein the same experimental variable produces qualitatively different results depending on the nature of the test (e.g., Church & Schacter, 1994; Graf & Mandler, 1984; Graf & Schacter, 1985; Jacoby & Dallas, 1981; Kelley & Lindsay, 1996; Light & Singh, 1987; Tulving, Schacter, & Stark, 1982). It has been argued that these functional dissociations imply that performance on the various tasks must therefore be mediated by distinct psychological systems (Schacter & Tulving, 1994).

There are three broad classes of arguments that have been put forward in support of the notion of separate implicit and explicit memory systems: (a) behavioral dissociations, such that a manipulation exists that affects some explicit memory tasks but not implicit memory tasks and, conversely, that a manipulation exists that affects implicit but not explicit memory tasks; (b) neuropsychological dissociations, such that amnesic patients perform differently than do healthy control participants on explicit memory tasks but perform comparably on implicit memory tasks; and (c) neuroimaging dissociations, such that patterns of brain activity of normal participants are different for the two types of tasks. The first two classes of arguments existed long before neuroimaging data were collected, but the evidence from functional magnetic resonance imaging (fMRI) has been considered strong as well. Together, these findings have led many researchers to accept the conventional wisdom that distinct implicit and explicit memory systems exist in the brain that have different representations and that are characterized by a division based on conscious awareness (e.g., Nadel & Moscovitch, 1997; Squire, 1992a, 1992b; Tulving & Schacter, 1990).

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Some of the ideas in this article were first presented by Lynne M. Reder in an invited address at the annual meeting of the Association for Psychological Science, 1999. This work was supported by National Institute of Mental Health Grant 2-R01-MH52808 to Lynne M. Reder. We thank John R. Anderson, Shaun Cook, Jared Danker, Rachel Diana, Paige (Angstadt) Faunce, Chris Paynter, Lindsay Victoria, and Cynthia Wible for helpful comments on a previous draft of this article and especially J. Oates for help preparing the manuscript.

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The notion that memory systems should divide on consciousness may derive from an earlier dichotomy between types of knowledge that distinguish *knowing how* (*skill*) versus *knowing that* (*fact*), also known as *procedural* versus *declarative memory* (Anderson, 1976; Cohen & Squire, 1980). Anderson (1976) noted that skill performance is not open to conscious inspection, and so it became tempting to assume that all memory performance that is not available to conscious inspection is part of a system distinct from what has been called declarative memory (e.g., Nadel & Moscovitch, 1997; Squire & Zola, 1998; Tulving & Schacter, 1990). *Repetition priming* refers to the phenomenon wherein previous exposure to a stimulus makes it more available (in terms of the probability of generating it, speed of recognizing it, etc.), and it often occurs without awareness of enhanced availability from an earlier exposure. The fact that priming tends to occur without awareness and that amnesic patients show essentially normal repetition priming and skill learning (e.g., Cohen, 1984; Cohen & Eichenbaum, 1993; Cohen & Squire, 1980) has contributed to the view that both phenomena derive from a system separate from the apparently damaged explicit memory “system.”

In our view, the mechanisms underlying repetition priming are quite separate from those involved in skill learning. Furthermore, amnesics’ performance on implicit memory tasks is not uniformly spared nor is their performance on explicit memory tasks uniformly impaired.

The critical feature that distinguishes tasks that are impaired from those that are spared under amnesia hinges on whether the task requires the formation of an association (or binding) between two concepts. This article presents the arguments in support of the hypothesis that the same memory representation underlies repetition priming and familiarity-based recognition judgments.

Despite the popularity of the view that conscious accessibility is the criterion that distinguishes the varieties of memory, not everyone agrees (or still agrees) that the proposed dichotomy best accounts for the accumulating data (e.g., Berry, Shanks, & Henson, 2008; Eichenbaum & Cohen, 2001; Roediger, 1990; Taatgen, 1999). This article reviews and evaluates the evidence that has been put forward in favor of the aforementioned consciousness-based distinction between implicit and explicit memory systems. Our position is that the popular distinction, which separates memory systems on the basis of consciousness, provides only a descriptive taxonomy that reflects the tasks used in the research rather than an accurate picture of the systems involved in the mind and brain. Moreover, the dichotomy between explicit versus implicit memory overlooks important distinctions among different types of implicit phenomena that have been pooled by virtue of their lack of conscious accessibility. By providing an alternative account of the findings that have been used to support the consciousness dichotomy, this article describes an alternative framework regarding human memory that resonates with an escalating rejection of the view that memory systems in the mind and brain can be divided on the basis of conscious accessibility (e.g., Berry et al., 2008; Bower, 1996; Chun & Phelps, 1999; Ryan, Althoff, Whitlow, & Cohen, 2000; Turk-Browne, Yi, & Chun, 2006).

### Organization of Article

This article reviews the phenomena that have been put forward as arguments for separate implicit and explicit memory systems.

The phenomena are grouped into three categories: behavioral dissociations, neuropsychological dissociations, and neuroimaging dissociations. We also review the evidence that illustrates that these dissociations are not robust and describe how a simple computational model of memory can explain why the purported dissociations frequently occur. In addition we illustrate that the conventional wisdom is challenged by some of the findings from our lab.

In the course of unpacking our arguments, we formalize our explanations by using an extant computational model called SAC. SAC stands for *source of activation confusion* to reflect the idea that a mind responds on the basis of the activation level of a concept but that the attributed cause of that activation may be erroneous. This model has accounted for a number of phenomena such as how rapid feeling of knowing and spurious feeling of knowing occur (Reder & Ritter, 1992; Reder & Schunn, 1996; Schunn, Reder, Nhouyvanisvong, Richards, & Stroffolino, 1997), perceptual contexts effects in recognition (Diana, Peterson, & Reder, 2004; Reder, Donavos, & Erickson, 2002), cued recall interference effects for amnesic and normal performance (Reder, Oates, et al., 2007), aging data (Buchler & Reder, 2007) and mirror effects for word frequency (Reder et al., 2000; Reder, Angstadt, Cary, Erickson, & Ayers, 2002), list length and list strength (Cary & Reder, 2003; Diana & Reder, 2005) and remember–know judgments. Computational details of SAC can be found elsewhere (e.g., Reder et al., 2000; Reder, Paynter, Diana, Ngiam, & Dickison, 2007). Although SAC has been shown to account for a wide variety of phenomena in isolation, this is the first article in which the more general architectural assumptions of SAC have been used to support arguments against the view that performance on implicit and explicit memory tasks derives from separate systems.<sup>1</sup>

It is important to stress that this formal account is presented in an effort to clarify our theoretical stance of when and why the “dissociation” occurs between implicit and explicit memory tasks. Our goal is to promote theoretical transparency, not to promote the model as the only one that could account for these phenomena. That said, it is helpful to begin by reviewing the basic representational and processing assumptions of this model. In addition to describing our assumptions in qualitative terms, we include the specific equations that allow us and others to test the model. Specific aspects of SAC that relate to the research reviewed in this article are described in greater detail in the context of specific empirical phenomena.

### Theoretical Stance

#### *The Representation and How Experience Affects Memory Strength*

SAC assumes a localist (as opposed to a distributed) memory representation of nodes (such as the concept of “dog”) that are connected to other nodes via experience. In addition to contextual associations, a concept node also has associations to its semantic,

<sup>1</sup> Some new assumptions were added to SAC in Reder, Oates, et al. (2007), but none of the new assumptions are discussed here and they are unnecessary to explain the results that have given rise to the view that memory systems divide on consciousness. Those assumptions are not inconsistent with the models we present here, however.

perceptual, lexical, phonemic, and other features that comprise its meaning and physical properties. The strength of a node and the strength of bindings between nodes are based on their history of use. The more often a concept is experienced, the stronger it becomes. Conversely, a concept loses strength over the time since it was last experienced. This strength or baseline activation ( $B$ ) of a node both increases and decays according to a power function:

$$B = B_w + cN \sum t_i^{-d_N}, \quad (1)$$

in which  $B_w$  is the base-level activation of the node,  $cN$  and  $d_N$  are constants ( $d_N$  represents the decay of activation of the node), and  $t_i$  is the time since the  $i$ th presentation. Likewise associations among nodes (bindings) strengthen with repeated exposure and decay over time with disuse according to a power function:

$$S_{s,r} = cL \sum t_i^{-d_L}. \quad (2)$$

In this equation,  $S_{s,r}$  is the strength of the link from node  $s$  to node  $r$ ,  $t_i$  is the time since the  $i$ th association between the two nodes, and  $cL$  and  $d_L$  are constants for the links ( $d_L$  represents the decay of link strength).

The amount of activation that can spread from one node to another is affected by the strength of that connection in relation to the number of competing associations. The amount of activation that any node  $r$  receives is calculated according to the following equation:

$$\Delta A_r = \sum (A_s \times S_{s,r} / \sum S_{s,i}), \quad (3)$$

in which  $\Delta A_r$  is the change in activation of the receiving node,  $A_s$  is the activation of each source node  $s$ ,  $S_{s,r}$  is the strength of the link between nodes  $s$  and  $r$ , and  $\sum S_{s,i}$  is the sum of the strengths of all links emanating from node  $s$ . The number of competing links from a node is referred to as the *fan* of that node.

### Episodic Versus Semantic Memory

In SAC, episodic events are also represented as nodes that bind concepts to the context in which they are experienced. This schematic representation does not enumerate all the qualities and features that can be bound into a given context. Although there is likely some contextual drift in these features over time, this general experimental context is treated as a single node (e.g., *general context*) in the interest of model simplicity. Those features that comprise the situational context that are common to all stimuli experienced within a given experimental task are represented as a single context node. Additional aspects of the context that are idiosyncratic to a particular stimulus presentation are represented by individual (e.g., *specific context*) nodes that are bound separately to the corresponding episode node. These episode nodes are important for recollection, and the nature of the contextual cues can vary from emotional responses, to internal states of hunger, to physical features of the stimulus or the room, to the elaborations that the participant generates in response to the stimulus. Likewise the features associated with the general experimental context can vary in the richness of the features that are encoded or retained. For example, consider a nonlaboratory setting such as an episode in which a person interacts with a close friend or family member. An episode node would be created that binds the concept that repre-

sents the friend, mother, or whomever with specific details of the situation, including the person's own reaction to the event.

We assume that there are two ways to recognize something, either by *recollecting the experience* of when it was encountered or by judging that the stimulus seems so *familiar* that it must have been encountered recently (Diana, Reder, Arndt, & Park, 2006; Reder et al., 2000; Reder, Angstadt, et al., 2002). Recollection depends on the availability of an episode node, which is a function of its activation. Like other nodes, the activation of an episode node depends on its resting level (which depends on how many times it has been repeated and how long it has been since it was last experienced—see Equation 1) and the amount of activation it receives from associated concepts that have been activated from environmental stimulation (e.g., by being presented on a computer screen in an experiment), including reinstated contextual features. The amount it receives from each source will depend on the strength of the association relative to the competing associations (see Equation 3).

### Two Ways to Recognize a Stimulus

If activation of the episode node is not sufficient for recollection (or an episode node was never formed in the first place), then recognition can be based on the less accurate process of assessing the familiarity of the concept. Note that the familiarity process is based on the activation of the concept node, which we claim is affected by the same variables as the episode node. A word or concept node has a higher resting level of activation than an episode node does because it has been experienced over a person's lifetime. Although we assume the nodes for the episodes do not exist before the experiment, we estimated the base-level activation and the preexperimental contextual fan for each word using its normative word frequency from the Kučera and Francis (1967) frequency counts. Specifically, we computed each word node's initial baseline strength ( $B_w$ ) by raising each word's Kučera and Francis frequency count to an exponent of 0.4. Similarly, we computed the fan (number of associations to each word) using an exponent of 0.7.

### Representational Differences and Similarities Between Implicit and Explicit Tasks

A simple schematic of how SAC represents studying a word in an experiment is shown in Figure 1. It also illustrates how implicit and explicit memory tasks share the same representation. We postulate that explicit memory tasks such as recognition memory are affected by the activation levels of both the episode and word nodes. In contrast, we postulate that performance on implicit memory tasks such as lexical decision or fragment completion depends only on the activation level of the word node. Note that binding of the word to its experimental context (i.e., the episode node) is critical for recollection but irrelevant for familiarity-based judgments or implicit memory tasks.

### Nature of the Current Controversy

A controversial assumption, but one that is at the heart of the present arguments (and the SAC model), is the claim that the

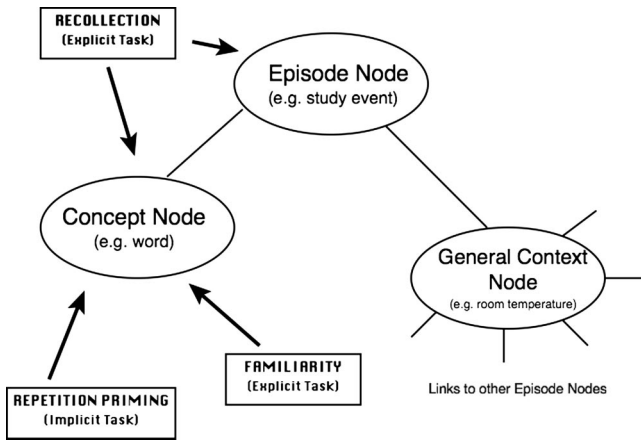


Figure 1. A schematic illustration of how the source of activation confusion model represents studying a word in an experiment. The figure also illustrates the aspect of the representation that is shared by implicit and explicit memory tasks.

representation that is evaluated for familiarity judgments in recognition (i.e., an explicit memory task) is the same representation that supports repetition priming effects (i.e., an implicit memory task). Although the processes that give rise to familiarity (“know”) judgments in tasks like Tulving’s (1985) remember–know paradigm differ from those processes involved in an implicit priming task (e.g., lexical decision or fragment completion), we claim that both judgments are affected by the (elevated) base-level activation of the same representation of the words or concepts.<sup>2</sup> The current or resting level of activation of such a node affects a familiarity judgment such that the higher the activation level of the word node, the more likely the concept is to be judged as familiar; similarly, the higher the level of activation of the node, the more available it is and hence the easier it comes to mind, increasing the likelihood of a successful fragment completion or faster access in a lexical decision task. Factors such as previous experience with a word will heighten its current level of activation, making it more available for implicit memory tasks such as fragment completion and for explicit memory tasks such as recognition.

In the remainder of this article we examine the arguments for memory systems that divide on consciousness. We examine the arguments for three classes of data: behavioral, neuropsychological, and neuroimaging. After reviewing the evidence that has been put forward for the dissociations, we review the counterevidence and then offer a mechanistic explanation for why there was the appearance of this dissociation. In several cases we also provide evidence that challenges the assumptions of the purported implicit versus explicit memory system dichotomy. The general nature of our theoretical arguments is that the pattern of results observed in the various dissociations derives from the activity of two principled memory processes: (a) the strengthening of existing structures and associations and (b) the establishment of new structures that bind or associate preexisting structures to each other or to context. Some explicit memory tasks do not require that new associations be formed and some implicit tasks do. Furthermore, some explicit memory tasks and some implicit memory tasks employ processes that operate on the same memory representation.

It is important to emphasize that the position we advance, namely, that dissociations in performance between implicit and explicit memory tasks result from different requirements for the two tasks, is shared by many other theorists. A number of articles have been written that make some of the points that we review (including some of our own). However, no other article, to our knowledge, attempts to review all the types of arguments that have been advanced for separate implicit and explicit memory systems, nor does any provide a computational model that illustrates how all these phenomena can be explained without positing separate implicit and explicit memory systems. Our claim that implicit and explicit memory tasks access a common memory representation is perhaps the most salient point of departure of the present thesis from the distinct implicit and explicit memory systems account.

### Behavioral Dissociations

Most of the arguments for separate implicit and explicit memory systems that are based on behavioral tasks involve findings that variables affecting explicit memory tasks, such as recall or recognition, do not affect implicit memory tasks, such as lexical decision or fragment completion. Examples of variables that have been claimed to dissociate these purported systems are manipulations of levels of processing, generation effects, delays, and repetitions beyond the first one. All of these variables are thought to affect only explicit task performance and to have no effect on implicit task performance.

One problem with an argument in which all of the aforementioned variables affect explicit memory tasks and not implicit memory tasks is that the conclusion is vulnerable to claims that the implicit task is just not as sensitive to these manipulations as is explicit memory. In order to demonstrate that the dissociation is not merely one of measurement, it has been viewed as crucial to find a variable that affects only implicit memory tasks and not explicit memory tasks. Finding such a variable supports the claim of a *double dissociation* between implicit and explicit memory tasks, a finding critical to the position of independent systems. *Perceptual match* is the one variable that has been thought to affect only implicit memory tasks (e.g., Jacoby & Hayman, 1987; Madigan, McDowd, & Murphy, 1991; Roediger & Blaxton, 1987) and not explicit memory tests such as recall and recognition (e.g., Murdock & Walker, 1969; for reviews see Richardson-Klavehn & Bjork, 1988; Roediger & McDermott, 1993).

### *Perceptual Match*

#### *Evidence for the Dissociation*

The *perceptual match effect* refers to the finding that priming effects are largest when the perceptual qualities of the stimulus (e.g., modality of the stimulus, and if typed, the font of the stimulus) are the same at encoding and test. The different pattern of results for implicit versus explicit memory tests was extensively

<sup>2</sup> Although the terms *concept* and *word* are used interchangeably, concepts can be things other than words and there can be multiple words for the same concept. Later in the article we discuss how the physical properties of a concept, such as font of the lexical entry, are encoded and accessed as part of the memory representation.

studied by Jacoby (1983a, 1983b). He found that repetition priming was largest when the primed word (e.g., *cold*) had been read in isolation, smallest when the word was generated in an antonym task (e.g., *hot-c\_\_\_*), and intermediate when the word was read with a context word (e.g., *hot-cold*). In contrast, measures of explicit memory for the target word showed the opposite pattern. Words were most likely to be recalled if generated and least likely to be recalled if read passively in isolation.

More work investigating the value added of reading the word for an implicit task revealed that the degree of perceptual match (modality, type font, type case, size) is strongly correlated with the degree of priming but is unrelated to recall accuracy and other measures of explicit memory (Jacoby & Hayman, 1987; Jacoby & Witherspoon, 1982; Kirsner, Milech, & Stumpfel, 1986; Madigan et al., 1991; Roediger & Blaxton, 1987). For example, study–test changes in speaker’s voice, intonation, and sound frequency have been found to significantly reduce priming in auditory word identification and stem completion but not in recall, recognition, or conceptual explicit memory tests (Church & Schacter, 1994; Pilotti, Bergman, Gallo, Sommers, & Roediger, 2000; Sommers, 1999).

### Evidence Against Claimed Dissociation

A number of findings, however, promote skepticism regarding the notion that dissociations of implicit and explicit task results should be attributed to distinct representational systems. For example, Graf and Ryan (1990) showed that reinstating the encoding font (i.e., perceptual match) could enhance recognition test performance, although they argued that this effect occurred only if participants were asked to encode the words by judging legibility. In their view, the value of reinstating the font was due to the repeated processes that were engaged in both study and test and was not due to separate systems. Further they asserted that it was judging legibility that engaged the perceptual processes that would otherwise not play a role in an explicit task such as recognition.

Reder, Donavos, and Erickson (2002) also found that matching the font from study to test affected recognition such that performance was enhanced when the font matched (participants were told that font was not relevant to the old–new decision). However, unlike Graf and Ryan (1990), the levels of processing manipulation (judging pleasantness vs. legibility) affected only absolute level of recognition: The value of level of processing did not interact with whether the font matched or not.

More important, Reder, Donavos, and Erickson (2002, Experiment 3) found that the value added of reinstating the font did interact with the number of other words that had been studied with that particular font. That is, some words were studied with a font that had been presented only with that particular word (low font fan), whereas other words were studied with fonts that were used to encode 12 words (high font fan). The benefit of perceptual match was reduced when the matching font was associated with a dozen words, as shown in Figure 2. This modulation of perceptual match as a function of font fan was something not found before. The mechanistic explanation for this pattern and other results is described below.

Other research also challenges the notion that implicit memory tasks show priming only when there is a perceptual match. Clarke and Morton (1983) presented participants with words for study in

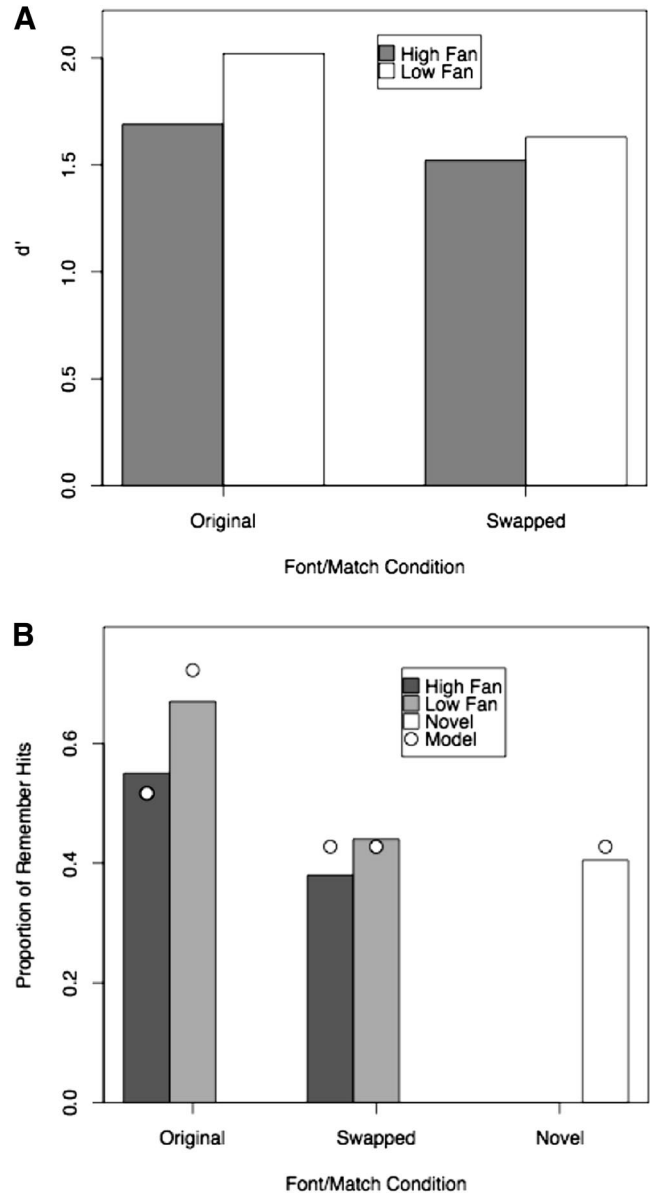


Figure 2. A: An illustration of recognition memory performance (measured in  $d'$  units) as a function of whether the encoding font was reinstated (original vs. swapped) and as a function of whether the font was encoded with only one word (low fan) or studied with a dozen words (high fan). The data in this figure are from “Perceptual Match Effects in Direct Tests of Memory: The Role of Contextual Fan,” by L. M. Reder, D. K. Donavos, & M. A. Erickson, 2002, *Memory & Cognition*, 30, p. 321. Copyright 2002 by the Psychonomic Society. Adapted with permission. B: An illustration of the proportion of remember hits as a function of whether the test font matched the encoding font (original), mismatched but was used with a different word (swapped), or was a novel font not used during encoding (novel). The model predictions are represented as open circles on each bar. The data in this figure are from “Perceptual Match Effects in Direct Tests of Memory: The Role of Contextual Fan,” by L. M. Reder, D. K. Donavos, & M. A. Erickson, 2002, *Memory & Cognition*, 30, p. 321. Copyright 2002 by the Psychonomic Society. Adapted with permission. Model fit from “Modeling the Role of Perceptual Features in Word Recognition and Fragment Completion,” by M. Cary & L. M. Reder, 2000, paper presented at the 41st annual meeting of the Psychonomic Society, New Orleans, LA.

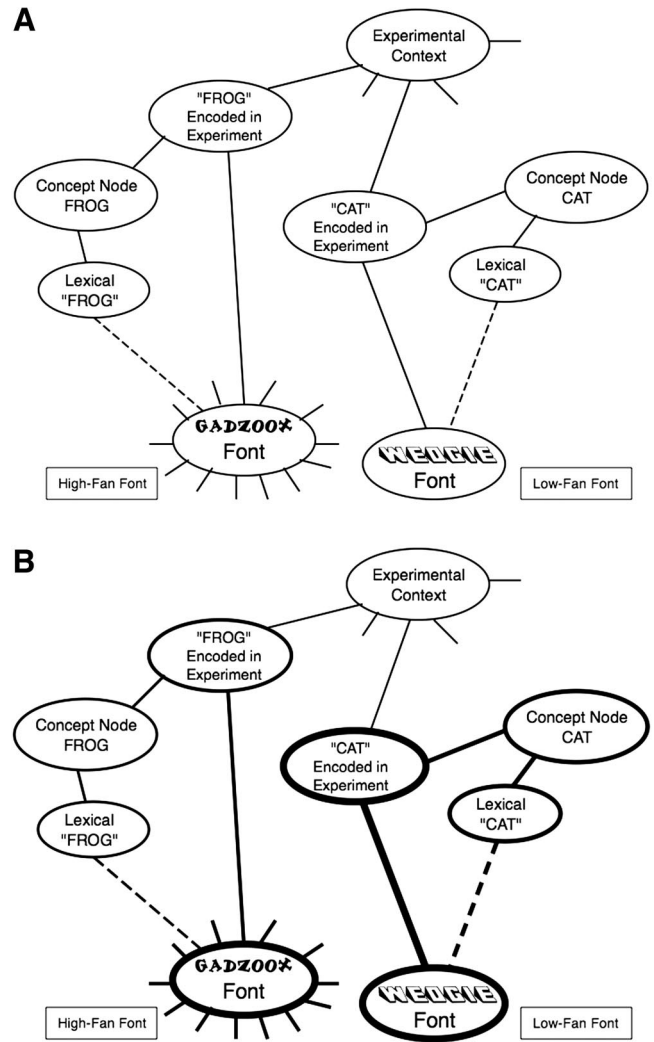
handwritten form and in printed form at test. Despite a perceptual mismatch, handwritten words produced large priming effects in a word identification test, suggesting that the effects of repetition priming are not dependent upon the match of perceptual features between encoding and retrieval. Likewise, Graf and Ryan (1990) found that under certain encoding conditions, priming in word identification was unaffected by whether the previously studied item was presented in a matched or mismatched font at test. Rajaram and Roediger (1993) also reported that priming in a matching typeface condition was equivalent to priming in a mismatching typeface condition for word fragment, word stem, anagram solution, and word identification tasks. As we explain below, we believe that the size of these priming effects is affected by the fan of the perceptual qualities. It may be that the value added of stimulus match was minimal in the studies cited above because the fan was too high.

Finally, using midazolam, a benzodiazepine known to cause transient anterograde amnesia, Hirshman, Passannante, and Arndt (1999) demonstrated that some aspects of implicit memory performance were spared while other aspects were affected by the drug. Specifically, they found a priming effect under both the drug and saline; however, the priming effect was reduced for the within-modality conditions under the drug. Given that midazolam is thought to selectively impair explicit memory tasks, the result that it also reduced the perceptual match effect for implicit memory tasks raises further doubts about the validity of the claim that the memories are supported by independent memory systems.

#### *Theoretical Account of When and How Perceptual Match Affects Implicit and Explicit Memory Tasks*

Figure 3A provides an embellished illustration of Figure 1, depicting how words read in different distinctive fonts are represented in memory. If the same font was used for all words in an experiment, the font node would be part of the general context node (if it was interesting enough to encode at all). At test, activation spreads from all sources in the probe: word, general experimental context, and specific context (such as font). If the font is the same one used to encode the word during study, more activation can reach the episode node, making recollection more likely. Figure 3B provides a crude illustration of how the amount of activation that is sent from a source node down any particular link is affected by the number of competing links from that source. Note that the amount spread from the font with high fan (studied with many words) sends less activation to the relevant episode node than does a matching font that is studied with only one word (see Equation 3). If the font is swapped (i.e., the font had been studied with a different word), the activation that spreads from the swapped font will not arrive at the appropriate episode node.

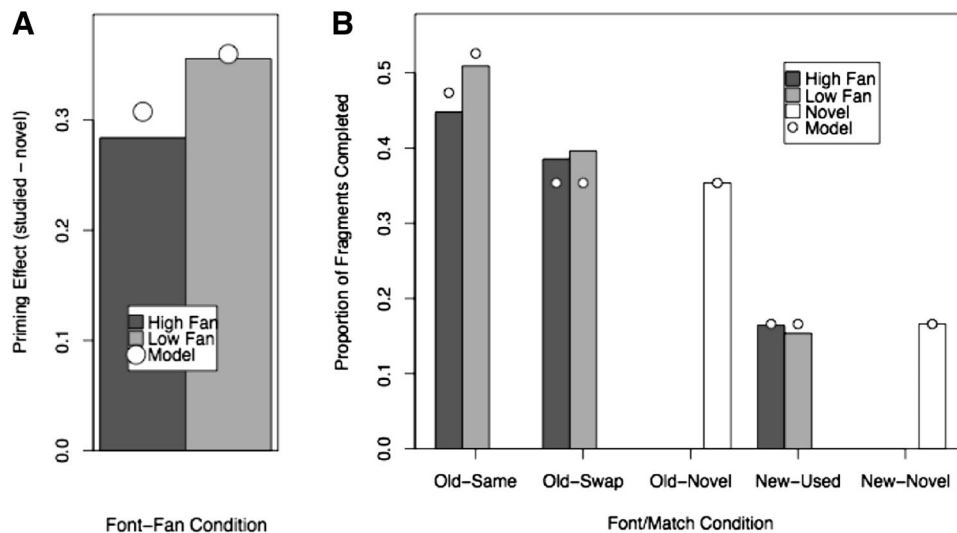
According to SAC (e.g., Diana et al., 2006; Reder et al., 2000), participants first attempt recollection and then the link between the font and the episode node will send additional activation to the episode node. SAC therefore predicts that the advantage of more hits with a matching font will be manifest in the recollection component of recognition. Further, and most important, SAC predicts that this effect will be greater if the font has less contextual fan. Recollection can be estimated from the “remember” responses given by participants in a recognition judgment. A fit of the SAC model (Cary & Reder, 2000) to the Reder et al. (2000)



*Figure 3.* A: An illustration of a schematic illustration of source of activation confusion's memory representation of words studied in various unusual fonts. The different number of links fanning out of the font nodes represent the different number of words (and hence encoding contexts) associated with the different fonts. B: A schematic illustration of how the amount of activation sent to the relevant episode and word node is modulated by font fan, when the same font is reinstated at test.

data for remember responses is shown in Figure 2B. The model provided a good fit to the data ( $SSE = .03$ ,  $R^2 = .94$ ).

An obvious prediction based on the assumption that conceptual and perceptual information are part of a common representational memory system is the claim that the aforementioned fan effects will also be reflected in performance on an implicit memory test. This prediction was supported in a study using a fragment completion task (Cary & Reder, 2000). In terms of encoding manipulations, the Cary and Reder (2000) experiment was very similar to that by Reder, Donavos, and Erickson (2002). Specifically, Cary and Reder varied the number of words associated with an unusual font during the study phase and then varied whether the same font was used at test to reinstate the word, or in this case, the word fragment. That is, fragments of primed words and new words were



*Figure 4.* Empirical data (vertical bars) and source of activation confusion model predictions (circles) from Cary and Reder (2000). A: The priming effect when the studied font is reinstated at test (difference in proportion of fragments completed for studied vs. unstudied words) as a function of whether the test font was high or low fan (studied with many words or only one). B: Plot of the proportion of fragments completed for old and new words as a function of whether the font at test matched the font during encoding (for old words) and whether the font was high or low fan or a novel font. The model fit was first reported in “Modeling the Role of Perceptual Features in Word Recognition and Fragment Completion,” by M. Cary & L. M. Reder, 2000, paper presented at the 41st annual meeting of the Psychonomic Society, New Orleans, LA.

presented in fonts that had been seen many times or only once, and some of the primed words were shown in the original encoding font, whereas other fragments were presented in a font that had been used with a different word.

Repetition priming (better completion for words experienced earlier) occurred regardless of whether the same font was reinstated. The conventional finding that the priming effect was enhanced when the font was reinstated between encoding and test also emerged. However, as shown in Figure 4A, Cary and Reder (2000) also demonstrated that the advantage of reinstating the same font was modulated by the fan of the font; the benefit of a matching font was reliably greater for words that had been studied in a low-fan font rather than a high-fan font, analogous to the findings of the explicit memory task. Specifically, the advantage of perceptual match decreased as the number of words that shared an unusual font increased. It is important to note that Cary and Reder modeled these priming effects using the same parameter values used to model the explicit memory data. Figure 4B plots the empirical and theoretical points for probability of completing a fragment for old and new words as a function of whether the font used for the fragment was high or low fan or novel and, for studied words, whether the font used was the same one used during encoding. Here too, the model provided a good fit to the data ( $SSE = .005$ ,  $R^2 = .97$ ).

As a rule, implicit tasks tend to be more sensitive to manipulations of physical similarity (e.g., Craik, Moscovitch, & McDowd, 1994; Wagner, Gabrieli, & Verfaellie, 1997) because performance depends on whether the word node is available at all. In fragment completion or stem completion, only part of the word is represented, so the letters must serve as cues to activate the word node. A reinstated font at test will have more links that were recently

activated that can send additional activation to get the node over threshold than will a probe in a different modality that shares no physical features.

#### *Repetition Priming and Familiarity Judgments Operate on the Same Memory Representation*

We contend that the familiarity process that is sometimes the basis of a recognition judgment operates on the same representation that is used for implicit memory tasks. Repetition priming tends to be less critical for recognition because the word is presented as the target and thus is already available. Priming will have more impact for tasks that require the participant to access the word than for tasks where the word is presented. In order to access the word node in implicit tasks, the node must become sufficiently active. If a word has been experienced recently, it is more active and needs less activation than if it has not; however, the word node gets an extra boost if the probe reinstates features (e.g., font) that were activated during encoding (see Figure 3) that can send additional activation to the word node.

When recognition performance is influenced by the perceptual match of the font from study to test, this influence is more likely to be manifested at the episode node. This is because recollection is the preferred (and less error-prone) process for recognition. Whether the matching font affects performance in an explicit task will depend on whether the activation that is sent from the font node makes a big enough difference in the probability of the episode node getting over threshold. That will depend, in part, on the fan from the font node, as that affects how much activation is sent along any one link (e.g., Park, Arndt, & Reder, 2006).

### *Other Behavioral Dissociations*

The other purported behavioral dissociations all share the property that the manipulation is thought to affect only explicit memory tasks and not implicit memory tasks. Recall that the importance of perceptual match was that it was the manipulation thought to affect only implicit tasks but not explicit memory tasks. As we noted earlier, failure to find an effect in an implicit memory task may just reflect lack of statistical power. Nonetheless, we review these dissociations here, showing that these manipulations sometimes affect implicit memory tasks and do not always affect explicit memory tasks. We also offer a mechanistic explanation, using SAC, to explain why the manipulations tend to affect explicit memory tasks rather than implicit memory tasks.

### *Encoding Manipulations*

#### *Evidence Supporting Purported Dissociation*

Two encoding manipulations, popular for decades, have been shown to affect explicit memory performance: the *generation effect* (Greenwald & Johnson, 1989; Slamecka & Graf, 1978) and manipulations of *levels of processing* (LOP: Craik & Lockhart, 1972; Craik & Tulving, 1975). More recently, memory researchers have investigated whether these encoding manipulations also affect performance on implicit memory tasks. A number of studies suggested that manipulations of processes engaged at encoding do not impact implicit memory performance (e.g., Brooks, Gardiner, Kaminska, & Beavis, 2001; Chiu, 2000; Chiu & Schacter, 1995; Graf & Mandler, 1984; Graf, Mandler, & Haden, 1982; Richardson-Klavehn & Bjork, 1988; Roediger, Weldon, Stadler, & Riegler, 1992) or have the opposite effects than those found for explicit memory (Jacoby, 1983b).

The generation effect refers to the finding that, when a participant is required to generate a target word (e.g., in an antonym task, *good-b\_\_\_\_\_*) rather than passively process the word (e.g., *good-bad*), retention is improved for both recall and recognition tests. As discussed in the previous section, Jacoby (1983b) found the opposite effect of generation on explicit and implicit tasks: Recognition was best for words that were generated and worst for words read in isolation, whereas the implicit task of word identification was fastest for words read in isolation and slowest for words that had previously been generated.

LOP refers to the phenomenon wherein the manipulation of the encoding task affects later memory performance of the encoded material. Encoding operations that encourage semantic processing (a “deep” level) tend to produce better performance on explicit memory tests, such as free or cued recall, compared with “shallow” processing tasks that focus on surface features, such as counting the number of vowels in a word, and that do not require processing the semantics of the stimulus (e.g., Craik & Lockhart, 1972; Craik & Tulving, 1975; Lockhart & Craik, 1990). The apparent selectivity for explicit memory of both the generation effect and LOP manipulations has been cited as evidence in support of a perceptual representation system (PRS; Schacter, 1990, 1992, 1994; Schacter, Wagner, & Buckner, 1999) wherein conceptual, elaborative, and contextual information are stored as part of an explicit memory system while physical and graphemic characteristics of task stimuli are stored as part of a separate, implicit memory system.

### *Evidence Against Claimed Dissociation*

The selectivity of these encoding manipulations with respect to performance on tests of explicit memory has been called into question by numerous demonstrations of these variables affecting implicit memory performance. LOP has been shown to affect both implicit and explicit memory performance (e.g., Blaxton, 1989, 1999; Challis & Brodbeck, 1992; Challis, Velichovsky, & Craik, 1996; Hamann, 1990; Horton, Wilson, & Evans, 2001; Srinivas & Roediger, 1990), and generation manipulations have been shown to affect the degree of priming in word identification (Masson & MacLeod, 1992) and, in another implicit task, picture fragment completion (Hirshman, Snodgrass, Mindes, & Feenan, 1990). McBride and Doshier (1997) also showed that levels of processing had an impact on both explicit and implicit tests with an advantage for semantic processing, although the degree of advantage differed depending on the test (see also McBride & Shoudel, 2003).

The point to take from these studies is that there are effects of the manipulations in both types of test even though there may be differences in the size of the effects. One reason the size of the effect might vary from one type of test to the other is that one test may be less sensitive to manipulations due to ceiling or floor effects. Indeed, Challis and Brodbeck (1992) and A. S. Brown and Mitchell (1994) examined studies that had reported null effects of LOP on implicit tests and found problems with the conclusion of a dissociation. Both articles reported a meta-analysis of prior evidence and, contrary to the claims, their analyses revealed that semantic encoding consistently produced greater priming than did nonsemantic encoding in perceptual implicit tests. That is, their analyses showed that there are significant LOP effects in implicit memory.

The claim of a dissociation for the generation effect has also been questioned by a number of studies (see Blaxton, 1989). Toth and Hunt (1990), for example, required participants to study words either in their complete form or as fragments and later tested these stimuli in their complete or fragmented form. In the study, they also sometimes included a context cue during encoding or at test (e.g., *hot—c\_l\_*). In word identification tests, performance was better when the target had been generated during encoding if the test stimulus was also a fragment. Even word identification was facilitated by an item generation task (compared to reading) if the same contextual cue that had been used as a cue during encoding was presented as a prime at test. Masson and MacLeod (1992) likewise showed that generating a word from a sentence, rather than merely reading a word, produced more priming on a word identification task. The performance advantage of generation has also been shown for picture fragment completion (Hirshman et al., 1990). Those results are inconsistent with the dissociation view in that these contextual effects and generation effects are not supposed to facilitate performance on implicit memory tests. Further evidence for this position is presented in the section concerned with amnesia.

### *Theoretical Account of When and How LOP and Generation Manipulations Affect Implicit and Explicit Memory Tasks*

Craik (e.g., Craik & Lockhart, 1972; Craik et al., 1994) has theorized that the depth of processing manipulation affects the type



of information that is processed during encoding, and we concur. Specifically, we believe that the processes engaged during encoding affect the content of the traces formed or whether any new traces are generated at all. For example, Craik et al. (1994) asked participants to judge whether a *pagoda* is found in China. We assume that deep processing fosters the generation of elaborations (Anderson & Reder, 1979), the most generic of which is “in this experiment I studied this word,” which in turn should influence the likelihood that an episode (node) is formed to represent this study event. Elaborations, which are presumably bound to the episodic node as well as the stimulus term, can also provide additional retrieval cues for reconstruction of the to-be-recalled item (see Reder, Paynter, et al., 2007, for further discussion).

At test, if presented with the word *pagoda*, the word could send activation to the episode node, making a recollection more probable. A participant is much less likely to be able to retrieve the episode/elaboration unless given the probe *pagoda* that is associated with it; therefore, the value added of conceptual processing on fragment completion should be limited.

In contrast, a shallow type of processing focuses on the perceptual qualities of the stimulus itself and therefore increases the activation of the concept node and the perceptual features that had activated it in the first place. As we discussed earlier in this article, implicit task performance does not benefit from the establishment of an episode node; implicit memory tasks require access only to the concept/word node. Therefore, we predict that LOP effects will have a smaller influence over performance on tests of implicit memory. To the extent that deep processing also influences the degree of priming/strengthening of the concept node, it may affect implicit task performance.

The generation effect can be explained similarly. Consider the antonym generation task used in Jacoby’s (1983b) seminal article. In order to generate the antonym, the link between *hot* and *cold* is strengthened along with a boost in activation for the two words. For a cued recall task, that strengthened link facilitates later retrieval from the cue to the target. Toth and Hunt (1990) found that a generation task helped more than did reading in word identification when the cue was re-presented as part of the test because activation could spread from the cue along the recently strengthened link to the concept node, making it still more available at test.

### *Practice and Study Duration*

#### *Evidence Supporting Purported Dissociation*

Another manipulation thought to differentially affect implicit and explicit memory performance is the extent of stimulus exposure. Ebbinghaus (1885/1964) clearly established that repeated exposure to a stimulus improves later (explicit) memory for that item. Manipulations of the number of repetitions or exposure duration have also been cited in support of the notion that implicit and explicit memory tasks operate on distinct memory representations that are part of different memory systems with different properties (Challis & Sidhu, 1993; Parkin, Reid, & Russo, 1990). This dissociation was first noted by Jacoby and Dallas (1981), who reported that an advantage in explicit memory performance due to prolonged stimulus exposure was not observed in implicit performance as reflected in a priming task. Since then, similar dissoci-

ations have been reported by others (e.g., Hirshman & Mulligan, 1991; Neill, Beck, Bottalico, & Molloy, 1990). For example, Challis and Sidhu (1993) reported a selective advantage of stimulus repetition in explicit memory performance, and Parkin et al. (1990) demonstrated that, unlike for explicit memory tasks, repetition of a stimulus beyond the first presentation did not improve implicit memory performance for that item.

#### *Evidence Against Claimed Dissociation*

A number of studies have found enhanced performance on implicit memory tasks when the stimulus is presented multiple times (e.g., Erickson & Reder, 1998; Feustel, Shiffrin, & Salasoo, 1983; Grant & Logan, 1993; Salasoo, Shiffrin, & Feustel, 1985). For example, Erickson and Reder (1998) contrasted few stimulus repetitions (0, 1, or 2) with many repetitions (8 or 11). They found that the degree of priming of fragment completion varied with the amount of repeated exposure, not just whether there had been any repetition priming. That benefit was assessed at delays (between study and test) as long as 18 months. In the experiments with delays of approximately 12 or 18 months, questionnaires administered at the end of the session indicated that participants were unaware of the connection between the fragment completion test (conducted in groups with experimenters unfamiliar to participants) and the earlier study in which the words had been studied (individually on a computer screen with different experimenters). Therefore, the benefit of multiple repetitions cannot be attributed to explicit memory contamination.

#### *Theoretical Explanation of When and Why Presentations Beyond the First Do Not Provide Greater Priming*

According to SAC, every node is strengthened with each exposure (repetition) and loses strength over time since the last exposure. Thus, recent exposure to a word elevates the activation level of the concept and its constituent features, leading to the prediction of repetition priming effects for that stimulus. However, there are two reasons why successive stimulus repetitions may not always yield appreciable benefits. First, strength accrues according to a power law (diminishing returns with additional presentations). Second, and more important, additional boosts in strength will matter only if they increase the availability of the node. If one presentation is sufficient to get the node over threshold, additional presentations will not help further. Note that in fragment completion, the word is not presented and so activation of the word node depends on sufficient activation arriving at the word node. Therefore, strengthening and reinstating paths into the lexical entry by representing the same encoding cues will help get sufficient activation to the correct word node.

Ostergaard (1998) offered a similar explanation, suggesting that the priming effect is constrained by baseline task performance. He proposed that repetition priming effects in implicit memory would be larger if the baseline level of performance was low and that priming effects would be constrained when baseline performance was high. Erickson and Reder (1998) provided evidence that is consistent with these accounts. They showed that the benefits of stimulus repetition were larger for words of normative low frequency than high frequency in terms of priming of both word identification and word fragment completion tasks. This finding is

consistent with SAC predictions: Because low-frequency words have lower levels of baseline activation, they should receive greater benefit from repeated exposures.

The reason why multiple repetitions are typically more important for explicit memory tests such as recall is that the episode node and the link from the word node to it have no preexperimental base-level activation. They need a lot more strengthening to facilitate retention and retrieval of the episodic information.

### *Forgetting Rates and Effects of Interference*

#### *Evidence Supporting Purported Dissociation*

Decay and interference have been the two dominant, and often opposing, explanations of forgetting. Ebbinghaus (1885/1964) mapped out the forgetting functions for nonsense syllables as a function of time and the number of prior repetitions before the final test. Given the “law-like” functions of forgetting and interference (e.g., J. Brown, 1958; Murdock, 1961; Peterson & Peterson, 1959) that have been ascribed for explicit knowledge, it is only logical to investigate whether these same forgetting and interference functions apply to performance in implicit memory tasks.

Among the first to report that implicit and explicit memory traces might decay at different rates, Jacoby and Dallas (1981) stated that the benefits of stimulus priming in a word identification test persisted over a 24-hr delay period despite appreciable forgetting in recognition memory performance. Likewise, Graf, Squire, and Mandler (1984) found that priming on a word stem completion task was resistant to decay over a 15-min delay condition, and Tulving et al. (1982) reported that priming of word fragment completion showed no evidence for substantial decay over a week-long delay. Picture priming effects were suggested to be long lasting and stable from the changes of environmental contexts (Cave, 1997; Mitchell, 2006). For example, Mitchell (2006) claimed that priming effects found on picture identification tasks lasted for 17 years. The apparent stability of performance on tasks of implicit memory contrasts with sharp declines in performance on tasks of explicit memory and has led some researchers to conclude that performance in the two types of tasks is based on traces from distinct memory systems with a distinct set of functional mechanisms that govern their decay over time (e.g., Mitchell, 2006).

As with the effects of delay between study and test, it has been argued that there are differential effects of interference on implicit and explicit memory tasks, also providing support for the position of qualitatively different memory systems (e.g., Graf & Schacter, 1987; Sloman, Hayman, Ohta, Law, & Tulving, 1988). For example, Graf and Schacter (1987) presented participants with two lists of word paired-associates (e.g., *shirt–window*). In one condition, some of the words from the first list also appeared in the second list but were paired with a new word (e.g., *shirt–finger*). Comparisons were made between letter-cued recall and word-completion performance for target words (the second word in the pair) as a function of whether the stimulus word (the first word in the pair) had only one or multiple target words associated with it during the study period. Their results showed that when memory was tested using a cued recall task, performance was significantly impaired by interference. However, when memory was measured using a fragment completion task, performance was unaffected by the

interference manipulation. These results led to the conclusion that implicit memory was less prone to interference than explicit memory, which was advanced as additional support for the reality of distinct implicit and explicit memory systems.

#### *Evidence Against Claimed Dissociation*

The dissociation between implicit and explicit memory tests in terms of their resistance to decay and interference found in the studies reviewed above is far from ubiquitous. For example, Jacoby (1983a) reported parallel effects in performance on tests of perceptual enhancement (thought to be operating in an implicit memory system) and recognition (explicit) memory following manipulations of both delay (thought to affect amount of decay) and interference. Casting further doubt on the consistency of the decay/interference-based dissociation between implicit and explicit memory, Squire and colleagues (see Chen & Squire, 1990; Squire, Shimamura, & Graf, 1987) reported findings that performance on a fragment completion task declined to chance levels within 2 hr for amnesic participants but was above chance for normal participants for days.

In order to address these conflicting findings, McBride and Doshier (1997) carefully controlled forgetting rates in tasks of implicit and explicit memory using word stem completion as a measure of implicit memory performance and cued recall as a measure of explicit memory performance for the same test items over the equivalent retention intervals. McBride and Doshier (1997) reported that memory performance was significantly above chance at both short and long delays in both explicit and implicit tasks. Importantly, the decay rate for performance on the two tasks over time was best fit by the same power function, showing an initial rapid decay rate that slowed and leveled out over long delays. Subsequent research using Jacoby’s (1991) process dissociation procedure provided converging evidence that forgetting rates do not seem different for implicit and explicit memory tasks (McBride & Doshier, 1999; McBride, Doshier, & Gage, 2001).

The purported dissociation between implicit and explicit memory on the basis of interference effects is also in doubt. Nelson, Keelean, and Negrao (1989) found retroactive interference in a word fragment completion test regardless of whether implicit or explicit instructions were given at test. Interestingly, interference was greater when the intervening study list contained items that were lexically similar (e.g., *fear* and *near*) than when the intervening list contained semantically similar words (e.g., *fear* and *afraid*), supporting the view that the properties ascribed to the PRS are also vulnerable to interference. This general finding that implicit memory is also susceptible to the effects of interference has since been replicated on a number of occasions (e.g., Lustig & Hasher, 2001; Martens & Wolters, 2002; Ratcliff & McKoon, 1997). Taken together, these data suggest that, contrary to the claimed dissociation, performance on both implicit and explicit memory tasks is vulnerable to the effects of forgetting over time and interference, supporting the view that these judgments are based on a shared memory representation. Some have argued that the inconsistencies in the literature on the differential effects of decay and interference for implicit and explicit tasks can be attributed to subtle characteristics of the materials used to measure implicit and explicit memory (e.g., Schacter, Chiu, & Ochsner, 1993). We agree that properties of the stimuli and task will affect

forgetting and interference rates; however, a straightforward explanation for these effects does not require positing two systems.

### *Theoretical Account of When and Why Forgetting Rates and Interference Effects Differ for Implicit and Explicit Tasks*

Familiarity-based recognition judgments and implicit tasks such as fragment completion or lexical decision operate on the same representation. During encoding the boost that the word node receives cannot “know” whether the subsequent test will be an implicit or explicit one. Therefore, the forgetting rate and vulnerability to interference should not differ. On the other hand, if the test requires retrieval of an episodic trace, then there are aspects of the representation that are not shared. Episode nodes are necessarily weaker than word nodes, as the former were created during the experiment. The links from the word node to the episode node are also weak and will be lost if the delay is long enough and the link is not strengthened through repetition. Therefore, if an explicit task such as recognition depends on retrieval of an episode node, performance that is based on recollection will go to chance relatively quickly unless there is rehearsal of the new node and binding. In other words, if the implicit and explicit tasks are both based on the word/concept node, the forgetting rate should be equivalent. If the explicit task requires access to an episodic trace, a structure that is not used in most implicit memory tasks, that structure is more vulnerable to forgetting.

Interference effects observed in explicit memory tasks are well explained by SAC (e.g., Reder, Paynter, et al., 2007) and are central to accounting for phenomena such as the low-frequency hit rate advantage in recognition (Reder et al., 2000; Reder, Angstadt, et al., 2002). Less activation will spread down any link (path) to an associated node the more competitive links there are that fan out from the node sending this activation. If less activation arrives at an associated memory, it is less accessible/available for any task. Interference can affect implicit tasks to the extent that the boost in current activation of the critical word node depends on the activation it receives from a source node whose number of associations (links) can vary. In a preceding section on the generation effect, we reviewed evidence that even implicit tasks benefit from reinstating context cues. If those cues have greater fan (e.g., Cary & Reder, 2003), then the priming effect is diminished.

### *Aging*

#### *Evidence Supporting Purported Dissociation*

The conventional wisdom is that memory declines with age. Not only do older adults generate more complaints about their memory, they also perform less well on both laboratory (e.g., free and cued recall, recognition) and real-life tasks (e.g., remembering an appointment) than do young adults (Craik & Jennings, 1992; Einstein & McDaniel, 1990). Yet there have been a number of studies suggesting that memory decline in older adults does not extend to tests of implicit memory performance (e.g., Java & Gardiner, 1991; Light & Singh, 1987; Light, Singh, & Capps, 1986; Russo & Parkin, 1993).

The neuropsychological literature has also supported this dissociation. Prull, Gabrieli, and Bunge (2000) concluded that only

recall and recognition, thought to be mediated by medial temporal and frontal lobes, significantly declined with age. Daselaar, Rombouts, Veltman, Raaijmakers, and Jonker (2003) demonstrated that priming effects in younger and older adults were accompanied by activations in similar areas including bilateral parietal and frontal regions as well as the sensory motor area and basal ganglia. Fleischman, Wilson, Gabrieli, Bienias, and Bennett (2004) concluded that performance of younger and older adults was roughly equivalent in measures of priming despite significant impairments in the older adults with respect to tests of explicit memory.

#### *Evidence Against Claimed Dissociation*

A broader consideration of the literature suggests that the evidence for this proposed neuropsychological dissociation is both complex and inconsistent (e.g., Chiarello & Hoyer, 1988; Hashtroudi, Chrosniak, & Schwartz, 1991). For example, some tests of implicit memory are impaired for older adults (e.g., Maki, Zonderman, & Weingartner, 1999; Pilotti, Meade, & Gallo, 2002). Specifically, Pilotti et al. (2002) found that cross-modality priming was comparable between younger and older adults but reduced in older adults for modality-specific priming. This finding is especially notable because proponents of the PRS argue that the consistency in the perceptual qualities of the stimulus at encoding and test should improve implicit memory. Friedman, Snodgrass, and Ritter (1994) found that younger and older adults performed equally well on tests of both implicit and explicit memory. They also found that older adults produce healthy memory-related brain responses as measured by event-related potentials recorded during a word stem completion and a cued recall test (Friedman, Ritter, & Snodgrass, 1996).

#### *Theoretical Account of When and Why Explicit Versus Implicit Memory Tasks Are Affected by Age*

It has been argued elsewhere that the ability to form a binding between a concept and an episode node (or other contextual details) depends on both sufficient working memory (Blumenfeld & Ranganath, 2006; Reder, Paynter, et al., 2007) and an intact *hippocampal system* (Aggleton & Brown, 1999; Davachi, Mitchell, & Wagner, 2003; Diana, Yonelinas, & Ranganath, 2007; Eichenbaum, Yonelinas, & Ranganath, 2007). There is ample reason to believe that working memory declines with age (e.g., Craik & Jennings, 1992; Hartman, Bolton, & Fehnel, 2001) and that the hippocampus also atrophies with age (Hedden & Gabrieli, 2004; Jack et al., 1989, 1998). In other words, we posit that with age it is more difficult to form new associations, including episodic associations, because of a reduction in working memory capacity and because of a volumetric reduction of the hippocampus. Chalfonte and Johnson (1996) and Naveh-Benjamin (2000) have been major proponents of the view that the memory deficit in older adults is related to their increased difficulty in binding the information rather than loss of the item information.

Whether an explicit or an implicit memory task is differentially affected by age depends in part on whether new associations are required to perform the task. With a lower probability of forming an episodic trace, explicit memory will necessarily suffer; however, the absence of an episodic trace should not affect familiarity-based judgments or priming tasks that depend on the concept node

that was primed from the stimulus exposure. Consistent with this view, several studies have shown that older adults are especially impaired in terms of memory for specific contextual information such as the details of an experimental context and the source of the studied items, even when older and younger adults are matched with respect to their overall memory performance (e.g., Hashtroudi, Johnson, & Chrosniak, 1990; McIntyre & Craik, 1987; Schacter, Kaszniak, Kihlstrom, & Valdiserri, 1991).

Besides the reduced probability of forming new associations in the elderly, our theoretical position also allows for another problem for the elderly that occurs at retrieval rather than at encoding. Older adults have more experience with concepts, which means that their concept nodes have been linked to more episode nodes, leading to increased contextual fan or interference. In other words, they are doubly hurt: It is more difficult for older adults to form these bindings, and it is also more difficult to retrieve them, once formed, because the amount of activation that is spread to an episode node from the concept node is reduced as a function of the number of competing links that also send out activation. In previous work we have shown that ability to recollect is affected by the amount of preexperimental contextual fan (Reder et al., 2000; Reder, Donavos, & Erickson, 2002) and that aging effects could be explained by postulating greater preexperimental fan and greater familiarity of concept nodes, also due to more exposure (Buchler & Reder, 2007). Examples of these model fits are shown in Figures 5A and 5B.

Older adults are more likely to false alarm to nonstudied items than younger adults (Balota, Burgess, Cortese, & Adams, 2002), a finding consistent with this explanation; however, their recognition memory is just as good as younger adults' for novel, abstract stimuli (Koutstaal et al., 2003). Typically older adults false alarm more often because they must rely on familiarity more often than do younger adults, who can use the less error-prone recollection process. There are several reasons why older adults are less able to use recollection. First, an episode is less likely to have been formed because of a reduction in working memory processing capability (e.g., Dobbs & Rule, 1989; Salthouse & Babcock, 1991) or frontal lobe functioning (Glisky, Rubin, & Davidson, 2001). Second, even if the episodic trace was formed, older adults would have more trouble retrieving it. They rely on familiarity to a greater extent than do young adults because with added experience comes greater preexperimental fan, meaning less activation arriving at any particular episode node (Buchler & Reder, 2007). Finally, older adults are more vulnerable to the familiarity process because the added experience with concepts means that their base-level activation is higher, making the concepts more familiar and more vulnerable to spurious familiarity judgments. On the other hand, individuals can have no prior experience with novel stimuli, so the base-level activation should not differ by group. Furthermore, neither group can easily form episode nodes to link a novel, abstract stimulus to the study context (Reder et al., 2006; Reder, Oates, et al., 2007), and therefore older adults are not at a disadvantage on the recollection process or the familiarity-based process for this stimulus class.

It is relatively straightforward to explain why performance on many implicit memory tasks is spared. To the extent that implicit memory performance depends only on the availability of the

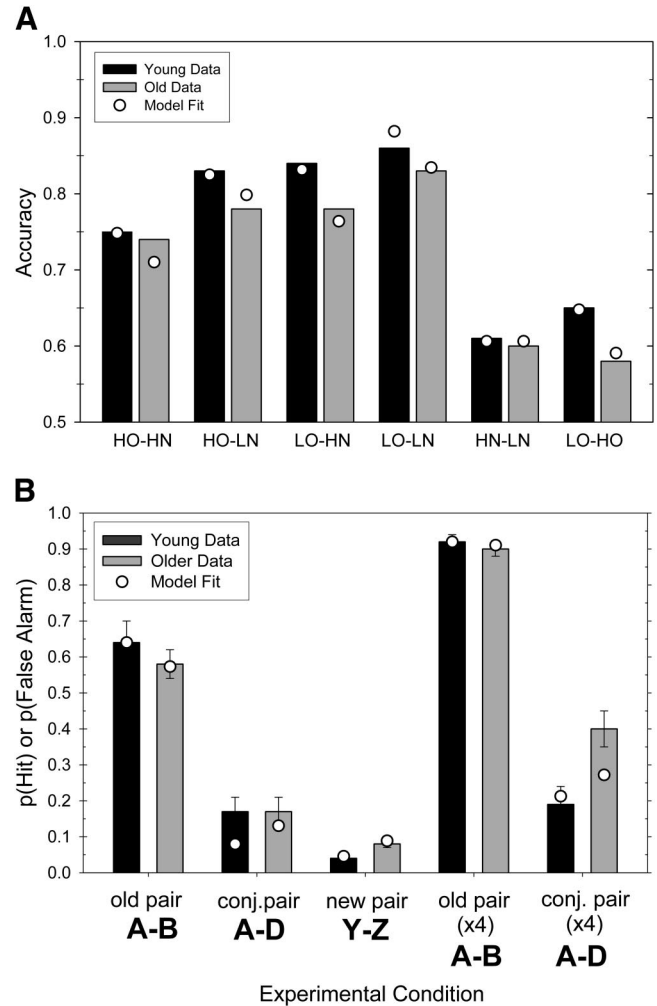


Figure 5. Source of activation confusion model fit (open circles) to the young and older adult recognition memory data of (A) Bowles and Poon (1982) and (B) Light, Patterson, Chung, and Healy (2004). Two parameters were estimated for each data set, and  $R^2 = .98$  for each fit. From "Modeling Age-Related Memory Deficits: A Two-Parameter Solution," by N. E. G. Buchler & L. M. Reder, 2007, *Psychology & Aging*, 22, pp. 108 & 114. Copyright 2007 by the American Psychological Association. Reprinted with permission. In Figure 5A, HO = high-frequency old word; HN = high-frequency new word; LO = low-frequency old word; LN = low-frequency new word. In Figure 5B, A-B and A-D are study word pairs, and X, Y, and Z are new words. The error bars represent standard errors of the mean. Conj. = conjunction.

word/concept node, all the deficits due to a reduction in working memory capacity or the efficacy of the hippocampus are irrelevant. On the other hand, when implicit memory tasks can be affected by priming from recently formed links, such as from a particular font or voice, then the older adults are less likely to benefit because the links are less likely to be formed.

#### Conclusions Concerning Behavioral Dissociations

We have reviewed a broad variety of purported behavioral dissociations that have been advanced in support of the claim that

memory systems divide on consciousness, that there exist separate implicit and explicit memory systems. For each of the claimed dissociations, we have reviewed not only the evidence in support of the contention but also the evidence that challenges such a dissociation. More importantly, we have provided a mechanistic explanation for why the various manipulations or factors tend to produce patterns of performance that differ for the two types of tasks.

The central idea in our account is that although most explicit memory tasks rely on a binding between a concept and a context, priming tasks do not. The variables that affect the probability of forming a binding (encoding task, age of the participant) or retrieving a node associated with a binding (delay, interference) will affect tasks that depend on retrieval of this binding, typically explicit memory tasks. Variables that affect access to the concept node, such as reinstatement of the perceptual cues that were bound to the concept/word node during encoding, will affect performance on implicit memory tasks.

Although the evidence reviewed above provides a serious challenge to the notion of separate implicit and explicit memory systems, there are a number of other phenomena that also have been put forward that are considered especially important to the argument for separate systems. One of these concerns the performance of amnesic patients and the other concerns neuroimaging data. We discuss each of these arguments in turn.

## Amnesia

### *Evidence Supporting Purported Dissociation*

One of the most renowned and compelling arguments for distinct implicit and explicit memory systems is the finding that people with anterograde amnesia exhibit selective deficits in memory performance (e.g., Corkin, 1965; Gabrieli, Milberg, Keane, & Corkin, 1990; Milner, Corkin, & Teuber, 1968; Shimamura & Squire, 1984; Squire et al., 1987; Warrington & Weiskrantz, 1974). Whereas amnesic patients tend to perform poorly on explicit memory tests (e.g., recall and recognition) they often perform at levels that are comparable to healthy control participants on tests of implicit memory such as repetition priming on a word stem completion task (Graf & Schacter, 1985; Schacter & Buckner, 1998; Schacter & Graf, 1986). Amnesic patients also show normal priming effects on both verbal and nonverbal perceptual identification tasks (Cave & Squire, 1992; McAndrews, Glisky, & Schacter, 1987). In the Knowlton and Squire (1993, 1995) studies, the amnesic group demonstrated comparable performance to the control group on a classification task, but their performance was disproportionately impaired on a recognition task. In the McAndrews et al. (1987) study, severely amnesic patients were unable to recognize previously seen test items (or even recollect that they had performed the task) but showed evidence of priming in a sentence–puzzle test following a 1-week delay.

Despite the intriguing findings that have emerged from the study of clinical populations with amnesia subsequent to brain injuries, it is important to acknowledge the limitations inherent in this research such as compensation and reconstitution (Kolb & Whishaw, 1990). Although the study of people with organic amnesia is useful for inferring links between cognitive and brain functions, this mapping may be distorted by compensatory mech-

anisms and by the recruitment of other brain regions to accomplish task goals (Helmstaedter & Elger, 1998; Nudo, Plautz, & Frost, 2001). There is also an inherent problem of variability with respect to the nature and specificity of brain lesions that are encountered in clinical populations. In many cases, this variability is likely to give rise to significant variability in the behavioral performance of people with amnesia, making the correspondence between brain structure and function difficult to interpret (e.g., Spiers, Maguire, & Burgess, 2001).

Notwithstanding these inherent difficulties, the observed dissociation in amnesic patients has been the crux of many arguments supporting the notion that there exist distinct implicit and explicit memory systems. These dissociations are taken as evidence that there exist independent neural systems that can be distinguished on the basis of conscious reportability. One of the most prominent claims to emerge from this literature regarding an anatomical distinction between explicit and implicit memory representations is that structures of the medial temporal lobe uniquely support functions related to the storage and retrieval of explicit, but not implicit, memory (see Gabrieli et al., 1990; Scoville & Milner, 1957; Squire, 1987, 1992b).

### *Evidence Challenging the Purported Dissociation*

Contrary to the evidence supporting this dissociation, there are studies that have demonstrated conditions under which performance on explicit memory tasks is spared for amnesic patients and other studies that have demonstrated conditions under which performance on implicit memory tasks is impaired for amnesic patients. We discuss each set of studies in turn.

*Evidence that explicit tasks are not always affected by amnesia.* Huppert and Piercy (1976, 1978) asked amnesic patients to study pictures and words of low and high frequency. They tested recognition memory for these items at delays of 10 min, 1 week, and 7 weeks. Performance was quite good both for pictures and for low-frequency words (significantly above chance even at the longest retention interval) but not for high-frequency words. Furthermore, the forgetting rate for patients was no faster than that for healthy control participants.

In a second experiment of Huppert and Piercy (1976), they presented familiar and unfamiliar pictures on two different days. After the presentation at the second session, participants were asked to discriminate studied from novel pictures. Performance was again well above chance on a simple studied–nonstudied discrimination. However, when asked to discriminate whether the picture was seen a day ago or 10 min prior, patient performance was at chance. In other words, Huppert and Piercy found that for some stimuli, recognition was spared in amnesic patients that but their ability to discriminate temporal context was heavily impaired. The authors concluded that “the primary defect in amnesia may concern contextual memory rather than memory for items as such” (Huppert & Piercy, 1976, p. 3). Later in this section, we explain why some stimuli are more vulnerable to item recognition failure with anterograde amnesia.

*Evidence that implicit memory tasks are not always spared with amnesia.* Chun and Phelps (1999) compared the patterns of results from hippocampal anterograde amnesic patients performing the same task given to a control group. The task involved a visual search for a target embedded in a field of distractors. Over the

course of the experiment, half of the displays were repeated across blocks while the other half of the displays were seen only one time. Both groups of participants improved at the task with practice (over the blocks of trials) in terms of faster reaction times and more accurate performance. The healthy control participants demonstrated a specific improvement for the repeated displays: The difference in reaction time and accuracy between new and repeated displays increased over blocks such that the more practice with a specific display, the greater the performance advantage. The amnesic participants showed a general speed-up in performance with practice; however, they showed no specific improvement for the repeated displays compared with the novel displays.

What makes this result interesting is that improvement on repeated displays was an implicit facilitation: Although normal participants were significantly faster at the repeated displays in terms of the time to locate the target in the display, they were at chance at discriminating repeated from novel displays (i.e., the improvement was unconscious or implicit) on an explicit posttest. In other words, amnesics showed a normal speed-up on the skill (motor) portion of the task but were significantly impaired on the other aspect of the task that involved implicit acquisition of the displays.

Chun and Phelps (1999) argued that the failure of amnesic participants to benefit from repeated displays was due to an inability to bind contextual cues (i.e., the configuration of distractors) to the position of the target in a given display and that this deficit of relational processing could be attributed to the impaired functioning of the hippocampus. The notion that the hippocampus is responsible for relational processing rather than declarative memory, per se, is elaborated later in this section.

In another study, Ryan et al. (2000) explored the notion of relational processing deficits in amnesic patients by studying the acquisition of interitem associations in real-world visual scenes. Ryan et al. measured the information sampling (i.e., visual fixations) in various visual scenes by recording the eye movements of amnesic and control participants while viewing novel scenes, repeated scenes, and modified scenes after study. A modified scene was a studied scene that had been altered in one region from initial study to subsequent exposure. Importantly, components of the scene were kept the same; it was the relation among the components that was modified in the altered region of the picture. Reduced sampling of repeated visual scenes by both amnesic and control participants was interpreted to reflect intact memory for these scenes. However, when modified scenes were presented, only the control group showed an increased number of fixations in the region of the modification. Additionally, only the control group showed an increased number of transitions into and out of the modified region of the modified displays. The amnesic group's number of fixations and transitions in and out of the critical region was unaffected by the change.

Most interesting, and analogous to the finding of the Chun studies (e.g., Chun & Jiang, 1998; Chun & Phelps, 1999), the altered information sampling for modified repeated displays occurred despite the fact that control participants reported that they were unaware of the modification. Moreover, while others have demonstrated a small degree of conscious awareness in contextual cuing tasks (e.g., Preston & Gabrieli, 2008; Smyth & Shanks, 2008), the contextual cuing effect was obtained regardless of whether participants demonstrated any awareness, and

the size of the effect was not predicted by whether a specific display was available to awareness. Although amnesic patients demonstrated the expected facilitation for repeated scenes just like control participants did, the amnesics did not seem to detect the altered relation of information in modified scenes. Thus, Ryan et al. (2000) concluded that the memory impairment in amnesia is specific to the processing of interitem associations, a conclusion similar to that of Chun and Phelps (1999).

The conclusions of Chun and Phelps (1999) and Ryan et al. (2000) were challenged by studies using different amnesic groups (e.g., Manns & Squire, 1999, 2001; Smith, Hopkins, & Squire, 2006). An inherent problem with research involving clinical populations is the heterogeneity of the participants. There are differences in etiology and variability with respect to the nature and specificity of brain lesions that are encountered, making it difficult to interpret the correspondence between brain structure and function (Spiers et al., 2001). This issue motivated us to replicate the Chun and Phelps study using synthetic amnesia (Park, Quinlan, Thornton, & Reder, 2004).

As noted earlier, midazolam mimics anterograde amnesia, impairing performance on explicit memory tasks but leaving implicit tasks such as repetition priming unaffected (e.g., Arndt, Passannante, & Hirshman, 2004; Curran, DeBuse, Woroch, & Hirshman, 2006; Polster, McCarthy, O'Sullivan, Gray, & Park, 1993; Thomas-Anterion, Koenig, Navez, & Laurent, 1999). Therefore, we wanted to determine whether drug-induced amnesia would also be vulnerable in this implicit memory task. We used a double-blind, cross-over, within-participants design and created two versions of the visual search task, counterbalancing which version was given during the first session and which drug condition was tested first. When performing under saline, participants showed both a general speed-up and a specific speed-up for the repeated displays; however, under midazolam, participants still showed a general speed-up with practice at the task, not the specific speed-up for repeated displays (i.e., they did not show the contextual cuing effect). As in the previous studies, the facilitation for repeated displays was implicit (i.e., participants performed at chance at discriminating old from novel displays even in the saline condition). Figure 6 compares the Park et al. (2004) data to that of Chun and Phelps (1999). Our midazolam versus saline pattern is very similar to their comparison of amnesic patients versus healthy control participants.

The Park et al. (2004) study produced the expected impairment on explicit (cued recall) performance but also replicated the Chun and Phelps (1999) finding of impairment on some implicit aspects of the task, specifically no facilitation on repeated displays. On the other hand, as with organic amnesia, the impairment on implicit learning of the repeated displays did not extend to skill learning of the task. That is, there was a general improvement in task performance indexed by faster reaction times in both the midazolam and saline conditions. Like the organic amnesics, the impairment was limited to situations in which forming a contextual association was required. There was no support for the view that impairments were specifically conscious or unconscious in nature.

*Additional evidence that implicit memory tasks can be affected by encoding manipulations.* In a previous section, we reviewed evidence that levels of processing manipulations previously thought to affect only explicit memory tasks also affect implicit

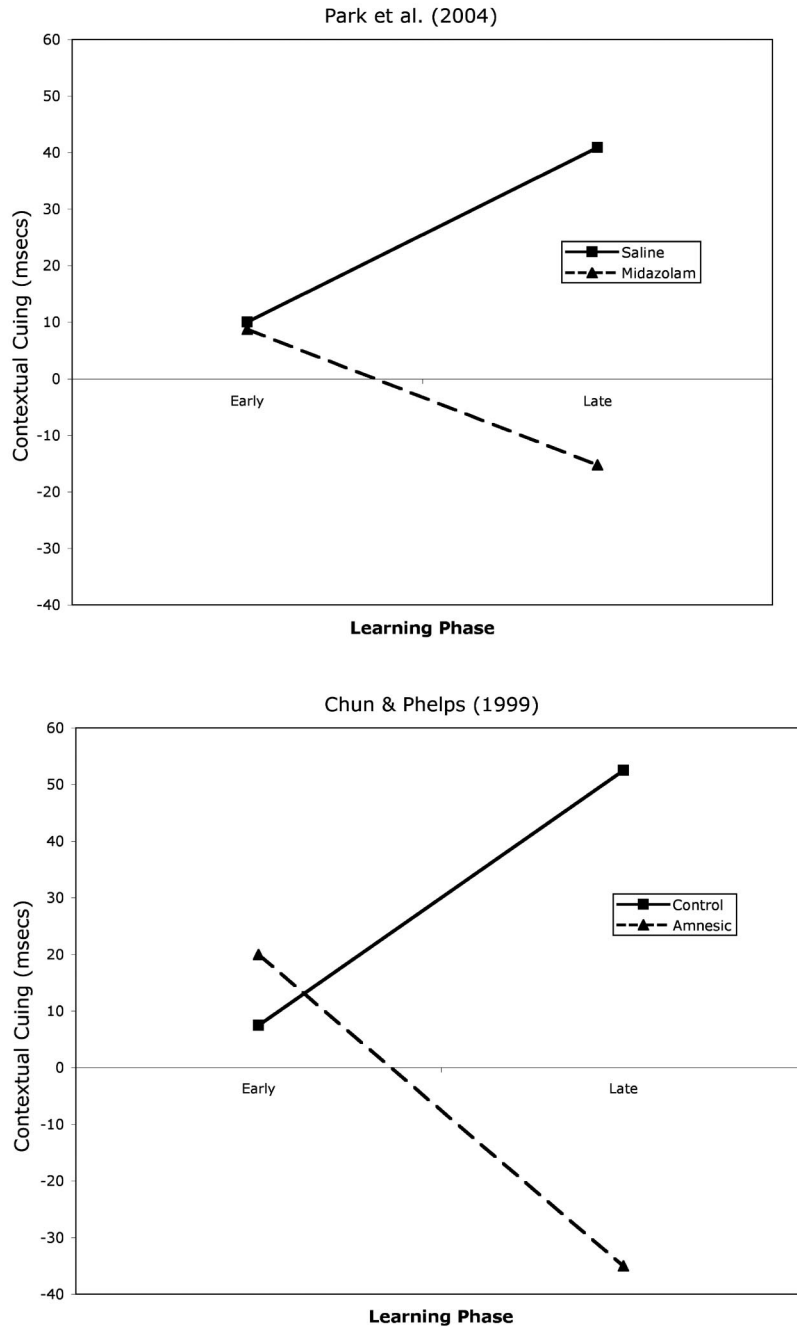


Figure 6. Contextual cuing effect (in ms) in a visual search task (repeated novel displays) early and late in the experiment. Top panel: Normal participants' performance under saline and midazolam, a drug that simulates amnesia (Park et al., 2004). The data in this figure are from "The Effect of Midazolam on Visual Search: Implications for Understanding Amnesia," by H. Park, J. J. Quinlan, E. Thornton, & L. M. Reder, 2004, *Proceedings of the National Academy of Sciences, USA*, 101, p. 17882. Copyright 2004 by the National Academy of Sciences. Adapted with permission. Bottom panel: Hippocampal patients compared with normal control participants (Chun & Phelps, 1999). The data in this figure are from "Memory Deficits for Implicit Contextual Information in Amnesic Participants with Hippocampal Damage," by M. M. Chun & E. A. Phelps, 1999, *Nature Neuroscience*, 2, p. 845. Copyright 1999 by Nature America.

memory tasks. However, Hamann and Squire (1996) argued that the results with normal participants were contaminated from explicit memory. In support of this argument, Hamann and Squire showed that amnesic patients did not show an LOP effect on word fragment or word stem completion tests, whereas the control participants did. Given that patients, who could not use explicit memory, showed no effect of an encoding manipulation on implicit task performance, Hamann and Squire concluded that implicit memory tasks are not affected by encoding manipulations unless there is contamination from explicit memory.

This conclusion was challenged by Hirshman, Passannante, and Arndt (2001) in a synthetic amnesia study involving the drug midazolam. Hirshman et al. demonstrated that participants showed a generation benefit in recall performance only in the saline condition but not while under the influence of midazolam. That finding is to be expected, given the claim that midazolam impairs explicit memory and the conventional wisdom that generation effects are revealed in explicit memory performance. The surprise finding was that participants benefitted from word generation over reading for implicit memory tasks in both drug conditions (saline or midazolam). In other words, the study demonstrated that implicit memory is also susceptible to encoding manipulations in a situation in which the findings cannot be attributed to contamination by explicit memory.

#### *Theoretical Account of When and Why Anterograde Amnesia Affects Explicit Versus Implicit Memory Tasks*

According to SAC, recognition judgments can be made on the basis of recollection or familiarity. In order to make a recognition judgment that is based on a recollection, an episode node would have had to be formed that binds the concept to the experimental context. We postulate that people suffering from anterograde amnesia are impaired in creating new bindings. We believe that this binding of the concept node to the context depends on sufficient attentional (working memory) resources and a functioning hippocampus. The critical role of the hippocampus in the binding process has been established for at least a decade (e.g., Chalfonte, Verfaellie, Johnson, & Reiss, 1996; Chun & Phelps, 1999; Cohen, Poldrack, & Eichenbaum, 1997; Düzel et al., 2003; Henke, Weber, Kneifel, Wieser, & Buck, 1999; Eichenbaum, 1997; Eichenbaum & Bunsey, 1995; Johnson & Chalfonte, 1994; Norman & O'Reilly, 2003; Ryan et al., 2000; Sperling et al., 2001, 2003; Wallenstein, Eichenbaum, & Hasselmo, 1998; Yonelinas, Hopfinger, Buonocore, Kroll, & Baynes, 2001). Patients with organic amnesia due to a damaged hippocampal system are unable to create new bindings and therefore cannot form new episodic memories because that involves binding the concept(s) to a context. They are also more likely to falsely recognize foils that are combinations of studied components, suggesting that they suffered from a *cohesion failure* (Kroll, Knight, Metcalfe, Wolf, & Tulving, 1996).

Although amnesia deters the formation of a new episode node, it does not affect increases in activation of a concept or link when stimulated (e.g., presented during an experiment). Repetition priming is due to an increase in the base-level activation of a concept. That is why performance on implicit tasks such as repetition priming is unaffected by amnesia.

According to SAC, the representation and process that produces repetition priming also underlies the familiarity process in recog-

nition. Note that this is not to say that priming and recognition rely on the same mechanism at test. Rather, we claim that priming and familiarity-based recognition share the same representation and are affected by the same processes at encoding: If a representation gets a boost in strength from a recent exposure, both the implicit test processes and familiarity-based process will benefit from that boost.

The reason why the patients studied by Huppert and Piercy (1978) could perform above chance on recognition tests of low-frequency items is that those stimuli were not familiar preexperimentally. High-frequency items are already too familiar, which means that the false alarms will be almost as numerous as the hits. The boost in activation value does not matter if the concept is already very familiar. Although healthy control participants also demonstrate more false alarms to familiar stimuli, they can set their familiarity threshold higher for saying "old" because they can also use recollection, which is a more reliable process. Recollection is not available if the binding process does not work.

*More evidence that amnesia affects binding but not familiarity.* In a recent study using midazolam (Reder et al., 2006), participants were presented with three different classes of stimuli to encode: words, photographs, and abstract pictures. After rating each item on pleasantness, participants were given a recognition task and had to discriminate studied stimuli from other stimuli that had not been selected for study.

In the saline condition, performance was best for words and worst for abstract pictures. Words had the highest hit rate because it was easiest to create a unique episode node for words so there was a recollection as well as familiarity component. Episode nodes could be created for photographs, but because they were unfamiliar pictures (unknown people or locations) the labels were generic (e.g., river scene, male Asian face) and many other photographs (both targets and foils) would match those descriptions. Abstract pictures are difficult to label and therefore difficult to bind to an episode node (see Reder, Oates, et al., 2007, for more).

Under midazolam, performance was most impacted for words and least impacted for abstract pictures. In our view, participants could not bind abstract pictures to episode nodes under saline, and therefore the loss of the ability to create a binding did not affect that stimulus class. Photographs could be labeled under saline but the label often would not discriminate between targets and foils, rendering it of little advantage over familiarity-based responding on the image itself. Figure 7 presents the hit rate and false alarm rate for each type of stimulus as a function of drug condition.

*Computational model to test theoretical ideas.* We tested our explanation that anterograde amnesia results from an inability to form new bindings in a paired-association cued recall experiment involving midazolam in one session and saline in the other (Reder, Oates, et al., 2007). On each day participants attempted to learn 45 paired associates on each of three lists. They studied the paired associates and then had two cued recall test/study phases per list. Lists 2 and 3 contained 15 pairs that were identical to those on List 1 (practice pairs), 15 pairs that involved interchanging the response terms with the stimulus cues (interference pairs), and 15 pairs that were not studied in either of the other two lists (control pairs). Midazolam or saline was injected after the completion of study of List 1 and before beginning study of List 2. After List 3 was completed, there was a final cued recall test in which participants were given a stimulus word and the list number (for the practice



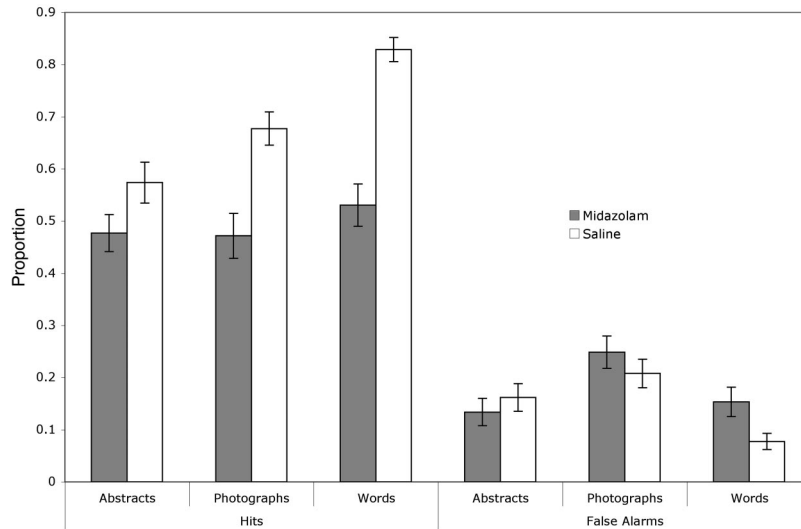


Figure 7. Proportion of hits and false alarms for each type of stimulus as a function of drug condition. From “Drug Induced Amnesia Hurts Recognition, But Only for Memories That Can Be Unitized,” by L. M. Reder et al., 2006, *Psychological Science*, 17, p. 565. Copyright 2006 by Blackwell. Reprinted with permission. Error bars represent standard errors of the mean.

pairs, the list number was randomly selected from the three lists). The dependent measures included learning rates (accuracy on the first test study cycle and second test study cycle for each list), forgetting rates (final test performance after all three lists), errors (tendency to give the response from the wrong list), and reaction times to respond. Figure 8 plots the test accuracy as a function of

drug condition and list. The predicted performance is superimposed above each empirical bar.

The key to fitting these data was to assume that midazolam blocked the formation of links with a certain probability (1.0 right after injection, with the probability going down as time passed; we estimated the recovery rate from midazolam and its immediate

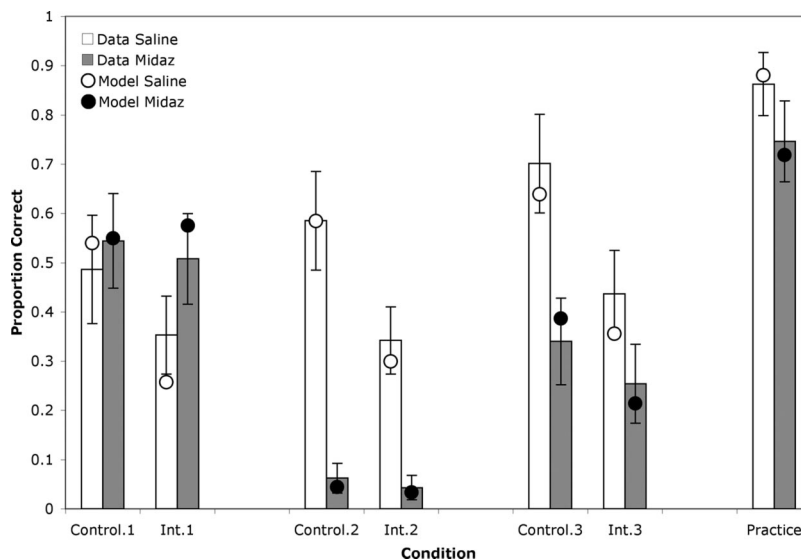


Figure 8. Proportion correct on final test as a function of test list, pair condition, and drug condition. The empirical data are presented in bar graphs and source of activation confusion model predictions are superimposed dots on top of the respective conditions. From “Retrograde Facilitation Under Midazolam: The Role of General and Specific Interference,” by L. M. Reder, J. M. Oates, et al., 2007, *Psychonomic Bulletin & Review*, 14, p. 264. Copyright 2007 by the Psychonomic Society. Reprinted with permission. Error bars represent standard errors of the mean. Midaz = midazolam; Int = interference.

postinjection effect on binding). That meant that the drug affected the probability of forming the link from the stimulus term to the response term and the link to the list node and the general experimental context. The test accuracy data contained 14 data points that were fit with five parameters previously estimated to fit the pattern of acquisition responses (correct or error) that contained 42 data points. No new parameters were estimated to fit these data for a root-mean-square deviation of .061 and an  $R^2$  of .94. In other words, with these same assumptions and parameters, we were also able to fit the latency data, acquisition data, and specific error pattern with few free parameters. The quality of this fit with so few parameters is strong support that the effect of midazolam is to block the formation of new associations. The model also provides a plausible mechanistic account of anterograde amnesia more generally.

### Neuroimaging

Neuroimaging data have been used to suggest that a dissociation exists in the regions involved in implicit versus explicit tasks (Paller, Hutson, Miller, & Boehm, 2003; Rugg, Schloerscheidt, & Mark, 1998; Schott, Richardson-Klavehn, Heinze, & Düzel, 2002). Implicit and explicit tasks must engage different processes, and therefore the different activation patterns may reflect only the differences in the required processes between the two tasks and not rule out the conclusion that the two tasks share the same representation and the same mechanisms for strengthening during encoding. Recently, new neuroimaging evidence has emerged that supports the view that brain regions are not dedicated to implicit or explicit memory tasks. First, we review the counterargument.

#### *Evidence Supporting Separate Brain Regions/Systems for Implicit and Explicit Memory*

Neuroimaging studies involving event-related potentials (ERPs) and fMRI techniques have been used to support the reality of the implicit–explicit memory system distinction. Studies using ERPs have reported different spatiotemporal components for implicit and explicit tasks (e.g., Paller et al., 2003; Rugg et al., 1998; Schott et al., 2002), and studies employing fMRI have reported neuro-anatomical differences between the tasks in terms of patterns of activation (Cabeza & Nyberg, 2000; Donaldson, Petersen, & Buckner, 2001; Henson, 2003; Schacter & Buckner, 1998; Wiggs & Martin, 1998). Priming of visual stimuli is associated with reduced activation in the extrastriate cortex and the inferior prefrontal cortex (e.g., Buckner et al., 1998; Schnyer, Ryan, Trouard, & Forster, 2002; Wagner, Desmond, Demb, Glover, & Gabrieli, 1997; Wagner, Koutstaal, Maril, Schacter, & Buckner, 2000). Similarly, Schott et al. (2005) found performance on an implicit task was associated with hemodynamic decreases in the fusiform and bilateral frontal and extrastriate regions, whereas performance on an explicit task was associated with increases in regions of the posterior cingulate, precuneus, and inferior parietal lobe.

#### *Evidence Challenging the Purported Dissociation*

Recently a number of fMRI studies (e.g., Buckner, Koutstaal, Schacter, & Rosen, 2000; Orfanidou, Marslen-Wilson, & Davis, 2006; Schacter, Wig, & Stevens, 2007) have found that patterns of

brain deactivation (associated with priming) that occur within frontal regions regardless of the modality of the cues and whether the perceptual qualities of the stimulus were repeated. These findings call into question the notion that priming is necessarily perceptual in nature and have led Schacter et al. (2007) to postulate two different types of priming mechanisms.

A recent study by Turk-Browne et al. (2006) is especially challenging for the notion of separate implicit and explicit memory systems in which priming is part of an implicit nondeclarative system (e.g., Squire, 1992a, 1992b). Turk-Browne et al. demonstrated that, for subsequently remembered items, the two indices of implicit memory (behavioral repetition priming and neural attenuation) measured during encoding were strongly correlated with brain activity in a number of regions such as the fusiform, parahippocampal place area, and the right inferior prefrontal cortex. Participants viewed photographs in a magnetic resonance scanner and had to classify the pictures as indoor or outdoor scenes. Each photograph was presented twice for classification and the reduction in response time for the classification on the second appearance of a picture was taken as an index of priming. After the rating task in the scanner, participants were presented with previously viewed and new photographs in a surprise recognition test that asked them to rate which photographs had been classified earlier and, if they judged the picture as old, to indicate whether they were confident in their decision.

Turk-Browne et al. (2006) partitioned the scan trials into those for which the subsequent recognition test produced a high confident hit or a miss (failure to recognize the picture). For those pictures that were subsequently recognized with high confidence, there was (a) a large behavioral priming effect (reduction in response time from the first to second presentation), (b) a large reduction in the blood-oxygenation level-dependent (BOLD) signal (neural attenuation), and (c) a strong correlation between amount of priming and the extent of neural attenuation. In contrast, for items that were not recognized this pattern of results was not observed. These findings suggest that implicit and explicit tasks can share processes and representations during encoding. Previous researchers had found smaller correlations between reduction in the BOLD function and behavioral priming (e.g., Maccotta & Buckner, 2004), presumably because they had not partitioned the stimuli in terms of whether they were subsequently recognized.

### General Discussion

The overarching goal of this article was to review the hypothesis that performance on implicit and explicit memory tasks reflects the functioning of two distinct memory systems. In particular, this review addressed Squire's (1992a, 1992b) popular dichotomy that proposes that memory should be divided into declarative (i.e., explicit) and nondeclarative (i.e., implicit) memory and holds that the division should be based on whether the process driving the behavior is reportable. Observed dissociations between implicit and explicit memory task performance led researchers to posit separate memory systems based on conscious awareness. Recent, accumulating evidence, however, suggests that this approach to understanding the nature of human memory is not viable.

We reviewed evidence for an alternative perspective in which the terms *implicit* and *explicit* refer to different types of tasks that operate on the same representation that is necessarily strengthened

(or weakened) by recent experience (or lack of it) with the corresponding information. We argued for the view that the same memory representation can be used whether information is tested explicitly or implicitly and that perceptual information is represented within the same system, processed in the same way, and affected by the same laws of memory (strengthening and interference affect perceptual and conceptual information in the same way). The nature of the argument involved both a review of the literature and also an illustration of how the effects could be explained within a simple memory model. We predicted that implicit tasks such as fragment completion would also show that the advantage of reinstatement of perceptual features (font) was modulated by fan (number of other words studied in that font). We were able to provide an excellent quantitative fit to those data using the same memory representation, process assumptions, and parameter values that we have used to model explicit memory tasks such as recognition.

The key assumption of SAC is that recollection and recall require the binding of concepts to the context within which they are experienced during encoding and the ability to access these traces when needed later. This binding process can be affected by variables such as available working memory or degree of attention allocated (see Reder, Paynter, et al., 2007, for more details). Implicit tasks such as repetition priming require only that existing structures be given a boost in activation. Sometimes explicit tasks such as recognition can use (with a limited degree of success) familiarity as a basis for judgment, obviating the need to retrieve a contextual association of the memory probe.

#### *Other Theoretical Accounts for the Perceived Dissociations*

We noted in the introduction that although we find it useful to use the SAC theory to provide an explanation for the observed dissociations between tasks and how these phenomena can be understood without assuming separate memory systems, the explanation presented here meshes with ideas presented in a number of other articles, as implied in the various studies we cited. Although these other articles have provided cogent arguments to explain a number of the phenomena that we discussed, generally the articles have not attempted a general review of all the classes of phenomena that have been marshaled for separate implicit and explicit memory systems. In this section, we compare some of the alternative theories that have been proposed to account for many of the phenomena that were analyzed in this article.

*Perceptual representation system.* Perhaps the mostly frequently cited theoretical account is the perceptual representation system (PRS) developed by Schacter (Schacter, 1990, 1992, 1994; Schacter et al., 1999). PRS was proposed as a representational system, separate from explicit memory, that stores perceptual information. The introduction of the PRS reflected the belief that the dissociation between implicit and explicit memory in the perceptual match effect is due to a separation of sensory-perceptual and semantic memory systems (e.g., Jacoby & Dallas, 1981). The PRS proposal involved three perceptual subsystems dedicated to the representation of (a) visual word form, (b) structural description, and (c) auditory word form. Because it is argued that these subsystems represent only the perceptual attributes and not the semantic meaning of stimuli, PRS endorses the position

that perceptual and semantic information are represented in qualitatively different ways.

Some of the results reviewed in this article challenge the assumptions of the PRS. These include the findings that (a) reinstating perceptual features as contextual cues (e.g., font or voice) are subject to the same principles (interference/cue overload) as semantic/conceptual cues (e.g., Park et al., 2006) and (b) the size of the implicit effect (behavioral priming and reduced BOLD activity) are modulated by explicit task performance, specifically whether the item is subsequently recognized (Turk-Browne et al., 2006).

Some of the findings from Schacter's own lab also provide evidence that challenge some of the original assumptions of the PRS. As mentioned in the previous section, Schacter et al. (2007) showed that neither behavioral nor neural priming (reduction in reaction time or the BOLD response, respectively) necessarily require perceptual similarity of the features between presentations. In particular, they found that both prefrontal regions and regions of the lateral temporal cortex demonstrate repetition priming that is amodal in nature. In a recent address at the 2006 meeting of the Cognitive Science Society, Schacter reviewed a number of imaging studies from his lab and others that indicate that the same regions that support repetition priming (demonstrated by a reduction in the BOLD response on the second presentation) such as the fusiform also predict subsequent recognition (e.g., Garoff, Slotnick, & Schacter, 2005; Schacter, Dobbins, & Schnyer, 2004; Simons, Koutstaal, Prince, Wagner, & Schacter, 2003; Wagner et al., 1998).

*Transfer-appropriate processing.* Challenges to the notion that purported dissociations are the result of separate implicit and explicit memory systems have been advanced for decades. The most salient of these challenges comes from the advocates of the transfer-appropriate processing (TAP) framework (e.g., Blaxton, 1989; Bransford, Franks, Morris, & Stein, 1979; Kolers & Roediger, 1984; Roediger, 1990; Roediger, Weldon, & Challis, 1989; Srinivas, 1993). Proponents of this view argue that the terms *implicit* and *explicit* provide a taxonomy of memory tasks but do not connote different systems. They believe that different patterns of performance observed in different types of tasks are best understood by considering the relationship between the processes engaged during encoding and at test. Specifically, this framework can explain a large number of dissociations by postulating that performance at test will be strongly influenced by whether the encoding operations emphasized the same features of the stimulus that are relevant/required to perform the task at test. A stimulus has a large variety of features associated with it, not all of which come to mind in all contexts. If the encoding task requires the processing of a particular subset of features and the subsequent task requires a substantial overlap of the same features for processing, performance is likely to be much higher.

An illustration of this point is the study by Graf and Ryan (1990) described earlier, which demonstrated that perceptual match of font (at study and test) affected explicit memory performance when the encoding operations emphasized judging the legibility of the font but not when the encoding task emphasized the semantic aspects of the word (judging pleasantness). On the other hand, we found an effect of font matching for both types of encoding tasks, and the size of the effect did not vary with the encoding task (Diana et al., 2004; Reder, Donavos, & Erickson, 2002).

The result that is more challenging for TAP is that we also found that the advantage of matching fonts was modulated by the number of other words encoded or tested in the same font such that the advantage of matching fonts was greater when fewer words shared the same font. Moreover, the size of the effect of font fan was not affected by the encoding task. SAC predicts that the effect of matching font will be manifested in the recollection component and that the effect of fan, when the fonts match, will also affect the recollection component. These predictions were confirmed, and we fit the data using very few free parameters.

One possible modification to TAP that might account for the fan manipulation described above would be to assume that the processing of the perceptual information during encoding is modulated by how distinctive it is. That is, if the font has been seen many times before, it becomes less distinctive and is less likely to draw attention to later words presented in that font. In one study (Park et al., 2006) we attempted to answer this question by keeping the average fan of the features associated with the words constant at study but varying the fan of the features presented at test. At study, words were simultaneously heard and read, using different voices and fonts. Any given word was presented either with a high-fan voice (voice used to present many words) and low-fan font or vice versa. At test, the study words (and foils) were presented with just one feature (either heard or read) and the feature could be a high-fan or low-fan voice or font. We found that the fan of the reinstated contextual feature predicted latency and accuracy. This indicates it is not distinctiveness at study that is critical but the fan at test.

Overall, the position of the proponents of TAP is consistent with our position that repetition priming and familiarity-based recognition share similar encoding processes; however, they do not discuss memory representations and thus are silent about the claim that the processes at test operate on the same representation.

*Jacoby's position.* Jacoby's research has been seminal in illustrating that the type task used during encoding affects performance depending on the type of task required later (e.g., Jacoby, 1983a; Jacoby & Witherspoon, 1982). Jacoby and his collaborators have provided evidence for the notion that perception and memory are closely intertwined (e.g., Jacoby & Kelley, 1991; Jacoby, Kelley, & Dywan, 1989; Kelley & Jacoby, 1996, 1998; Whittlesea, Jacoby, & Girard, 1990). They have demonstrated that memory affects perception and that perception affects memory. Their explanation involved postulating the construct of *perceptual fluency* and that this perceptual fluency could be misinterpreted. For example, names experienced recently become more familiar, and if the source of that feeling of familiarity is not recollected, the person becomes "famous overnight" (Jacoby, Woloshyn, & Kelley, 1989). Sentences that were recently experienced would be easier to discern in white noise than unfamiliar sentences, and therefore the "primed" sentences would be judged as louder even though they were not (Jacoby & Witherspoon, 1982); likewise, words that were subliminally primed were more likely to be judged as having been studied earlier. We believe that this is because the brief exposure elevated the base-level activation of the word node making the word seem more familiar, which participants misattributed to having studied the word (Jacoby & Whitehouse, 1989).

Rather than adopting the notion of implicit and explicit memory systems, Jacoby and colleagues (Jacoby, Begg, & Toth, 1997; Jacoby & Kelley, 1991; Jacoby, Toth, & Yonelinas, 1993) have

posited two independent sets of processes, an automatic and an intentional or controlled process. The automatic process demonstrates the influence of what others call implicit memory effects, whereas the intentional processes rely on explicit memories, those for which contextual information can be retrieved. Jacoby (1991) has developed a process-dissociation procedure to estimate the influence of the automatic, familiarity-based process and the controlled, recollective process, and he would argue that these two processes are independent.

Like TAP, the framework and demonstrations of Jacoby and colleagues (Jacoby et al., 1993, 1997; Jacoby & Kelley, 1991) are consistent with the view that memory does not divide on consciousness. It is difficult to know whether they would agree with our position that the same representation underlies priming effects and familiarity-based processes because they do not postulate a memory representation upon which the processes operate. Likewise it is difficult to know whether the contextual fan manipulations reviewed earlier are consistent with their point of view because the theory has no way to represent high versus low fan contextual features.

*Bower's account.* Bower (1996) proposed an account of the relationship between implicit and explicit memory effects that shares a number of ideas with the ones proposed here. The representational assumptions are similar; however, there are two important differences between Bower's proposal and the one we advanced. Bower proposed that there are different types of links, called Type 1 and Type 2, such that the Type 1 associations "include all old associations plus those encoding novel, integrated perceptual units" (p. 31). Type 2 associations involve the recording of a novel pairing of previously unassociated elements or events. SAC does not posit qualitatively different types of associations. Indeed, we argue that perceptual information such as font and voice influence memory in the same way as conceptual information. We have modeled both perceptual and conceptual fan effects, using the same sets of assumptions and parameter values, and found no reason to treat them differently.

The second difference is that Bower's (1996) theory postulated that explicit memory effects are based solely on retrieval of contextual information (Type 2 associations) and does not propose the existence of a familiarity-based recognition process that operates on the same representation used for implicit tasks. Our article reviews the evidence from amnesic patients and participants with drug-induced anterograde amnesia that support the claim that recognition can be based on "priming" of the concept even when a binding to context cannot be built.

### *Additional Arguments Against Implicit and Explicit Memory Systems*

A number of formal models have been developed that take issue with the behavioral patterns that have been taken as evidence for memory systems that divide on consciousness (e.g., Berry, Henson, & Shanks, 2006; Berry et al., 2008; Kinder & Shanks, 2001, 2003; Nosofsky & Zaki, 1998; Taatgen, 1999; Zaki, Nosofsky, Jessup, & Unverzagt, 2003). Their analyses are consistent with our point of view; however, these formal proposals tend to include neither a specification about the nature of the memory representation nor a mechanistic account of the processes that underlie these tasks. Other proposals (e.g., Ryan & Cohen, 2003) have

likewise suggested that the distinction between an implicit and explicit memory system is problematic on the basis of neuropsychological evidence and suggest that it is more appropriate to describe memory systems in terms of whether performance depends on the ability to form new bindings.

Critically, these proposals tend to accept the view that repetition priming is a separate, independent memory system from the one responsible for familiarity-based recognition judgments. For example, Cohen et al. (1997) suggested that repetition priming and skill learning “are two implicit memory phenomena [that] can be mediated by a single incremental learning mechanism in accord with claims of procedural-declarative theory” (p. 131). The Cohen and Eichenbaum (1993) model provides more componential structure of memory on the basis of amnesic data and animal models. Different memory systems, components of memory, are assumed to correspond to distinct brain regions with different operating characteristics and representations. They argued that the hippocampus plays the critical role in declarative memory, which supports relational processing between items and items with context. Their insight about the critical role of the hippocampus in relational processing is extremely important. The proposal advanced in this article is a modification of their position in that we do not posit separate brain systems for implicit versus explicit tasks. Specifically, our proposal stipulates that repetition priming phenomena result from the same “declarative” memory representation responsible for familiarity-based recognition and that the hippocampus can be responsible for relational binding even in implicit learning tasks.

Norman and O’Reilly (2003) have extended the complementary learning systems framework to account for a variety of familiarity- and recollection-based memory phenomena. They proposed that the hippocampus is responsible for recollection of studied details whereas the medial temporal lobe cortex is responsible for familiarity-based judgments based on the match between study and test items. The model they present accounts for phenomena that have also been (quantitatively) modeled using SAC (e.g., Cary & Reder, 2003; Diana & Reder, 2005; Reder et al., 2000), but the exercise seems less natural in their framework. That is, the predictions from SAC do not require additional assumptions to fit the data. It is not obvious, for example, that their model of the list strength effect would predict that recollection is modulated by the fan of the reinstated contextual cues (Diana & Reder, 2005) or the pattern of fan-modulated perceptual match effects found for both implicit and explicit memory tasks described earlier.

### Conclusion

We reviewed representative dissociations that have been put forward to argue for the plausibility of positing independent implicit and explicit memory systems. For each one, we have shown that there exist compelling counterexamples that challenge the validity of separate systems. Moreover, we provided a theoretical account, implemented in a computational model, that can explain when and why these dissociations occur across tasks without postulating independent memory systems based on consciousness. We also reviewed evidence that challenged the purported dissociations for amnesics and provided converging evidence for our alternative explanation using a drug that produces temporary amnesia and modeled these data as well.

Empirical arguments showing that these purported dissociations are not robust have been advanced previously (e.g., McBride & Doshier, 1997, 1999; Reder, 1999; Reder, Donavos, & Erickson, 2002; Roediger, Weldon, & Challis, 1989). Nonetheless, the usage of the terms *implicit* and *explicit* as separate memory systems or mechanisms can be found in numerous publications including recent articles and textbooks. For example, Mitchell (2006) wrote “it is now accepted as fact that the neurological systems serving implicit memory are separate from those involved in conscious recollection” (p. 925). A recent introductory textbook on cognitive neuroscience (Baars & Gage, 2007) laid out a framework for learning and memory that is divided on consciousness such that there are “different types of long-term memory, explicit and implicit ones” (p. 259), and described amnesia as affecting only the explicit side of the divide.

SAC is not a complete model of memory or cognition and is undoubtedly inaccurate in certain respects as well as incomplete; however, by virtue of specifying both a representation and a process that operates on the representation, it is straightforward to generate predictions for various conditions. An advantage of an implemented theory is that it makes salient those aspects of the conventional wisdom that violate assumptions of the theory that should be carefully tested (e.g., Reder et al., 2000).

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Received September 28, 2007

Revision received June 13, 2008

Accepted June 23, 2008 ■